Supply of Critical Drinking Water and Wastewater Treatment Chemicals—A White Paper for Understanding Recent Chemical Price Increases and Shortages
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About the Water Research Foundation

The Water Research Foundation (formerly Awwa Research Foundation or AwwaRF) is a member-supported, international, 501(c)3 nonprofit organization that sponsors research to enable water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.

The Foundation’s mission is to advance the science of water to improve the quality of life. To achieve this mission, the Foundation sponsors studies on all aspects of drinking water, including resources, treatment, distribution, and health effects. Funding for research is provided primarily by subscription payments from close to 1,000 water utilities, consulting firms, and manufacturers in North America and abroad. Additional funding comes from collaborative partnerships with other national and international organizations and the U.S. federal government, allowing for resources to be leveraged, expertise to be shared, and broad-based knowledge to be developed and disseminated.

From its headquarters in Denver, Colorado, the Foundation’s staff directs and supports the efforts of more than 800 volunteers who serve on the board of trustees and various committees. These volunteers represent many facets of the water industry, and contribute their expertise to select and monitor research studies that benefit the entire drinking water community.

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Supply of Critical Drinking Water and Wastewater Treatment Chemicals—A White Paper for Understanding Recent Chemical Price Increases and Shortages

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Acronyms and Abbreviations

ACH  aluminum chlorohydrate
AM  acrylamide monomer
AMWA  Association of Metropolitan Water Agencies
ANSI  American National Standards Institute
AWWA  American Water Works Association
BOD  biochemical oxygen demand
CDC  Centers for Disease Control and Prevention
CWS  Community Water Systems
DADMAC  diallyldimethyl ammonium chloride
DAP  diammonium phosphate
EDC  endocrine disrupting chemical
EPA  U.S. Environmental Protection Agency
Epi-DMA  epichlorohydrin dimethylamine
FSA  fluorosilicic acid
GDP  gross domestic product
HAA5  haloacetic acid
HF  hydrogen fluoride
µg/L  micrograms per liter
mg/L  milligrams per liter
NDMA  N-nitrosodimethyamine
NP  nonylphenol
NPDES  National Pollutant Discharge Elimination System
NPE  nonylphenol ethoxylates
NSF  National Sanitation Foundation
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAC</td>
<td>project advisory committee</td>
</tr>
<tr>
<td>PACl</td>
<td>polyaluminum chloride</td>
</tr>
<tr>
<td>PAM</td>
<td>polyacrylamide</td>
</tr>
<tr>
<td>PPI</td>
<td>producer price index</td>
</tr>
<tr>
<td>ppm</td>
<td>parts per million</td>
</tr>
<tr>
<td>PVC</td>
<td>polyvinyl chloride</td>
</tr>
<tr>
<td>SF</td>
<td>sodium fluoride</td>
</tr>
<tr>
<td>SFS</td>
<td>sodium fluorosilicate</td>
</tr>
<tr>
<td>THM</td>
<td>trihalomethane</td>
</tr>
<tr>
<td>TOC</td>
<td>total organic carbon</td>
</tr>
<tr>
<td>UKWIR</td>
<td>U.K. Water Industry Research</td>
</tr>
<tr>
<td>UV</td>
<td>ultraviolet</td>
</tr>
<tr>
<td>WEF</td>
<td>Water Environment Foundation</td>
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</table>
FOREWORD

The Water Research Foundation (Foundation) is a nonprofit corporation that is dedicated to the implementation of a research effort to help utilities respond to regulatory requirements and traditional high-priority concerns of the industry. The research agenda is developed through a process of consultation with subscribers and drinking water professionals. Under the umbrella of a Strategic Research Plan, the Research Advisory Council prioritizes the suggested projects based upon current and future needs, applicability, and past work; the recommendations are forwarded to the Board of Trustees for final selection. The Foundation also sponsors research projects through the unsolicited proposal process; the Collaborative Research, Research Applications, and Tailored Collaboration programs; and various joint research efforts with organizations such as the U.S. Environmental Protection Agency, the U.S. Bureau of Reclamation, and the Association of California Water Agencies.

This publication is a result of one of these sponsored studies, and it is hoped that its findings will be applied in communities throughout the world. The following report serves not only as a means of communicating the results of the water industry’s centralized research program but also as a tool to enlist the further support of the nonmember utilities and individuals.

Projects are managed closely from their inception to the final report by the Foundation’s staff and large cadre of volunteers who willingly contribute their time and expertise. The Foundation serves a planning and management function and awards contracts to other institutions such as water utilities, universities, and engineering firms. The funding for this research effort comes primarily from the Subscription Program, through which water utilities subscribe to the research program and make an annual payment proportionate to the volume of water they deliver and consultants and manufacturers subscribe based on their annual billings. The program offers a cost-effective and fair method for funding research in the public interest.

A broad spectrum of water supply issues is addressed by the Foundation’s research agenda: resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide the highest possible quality of water economically and reliably. The true benefits are realized when the results are implemented at the utility level. The Foundation’s trustees are pleased to offer this publication as a contribution toward that end.

David E. Rager  
Chair, Board of Trustees  
Water Research Foundation

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Executive Director  
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Mike Hotaling (Newport News Dept. of Public Utilities)
Mike Turrell (South Staffordshire Water)

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The researchers also wish to thank the many individuals who helped execute the technical tasks and produce this report, especially Diane Callow, Tsasha Facteau, and Erin Miles of Stratus Consulting, and Christina Thomas of Sage TechEdit Inc. for her editing services.

Thank you all very much.

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Boulder, Colo. (April 2009)
Executive Summary

Water treatment chemicals play a critical role in providing clean water to protect public health and the environment. Water and wastewater utilities have been experiencing significant water treatment chemical price increases and chemical shortages in the last several years. This issue has significant implications for utility finance, regulatory compliance, public and environmental health, security, and long-term utility sustainability.

The water community lacks current and readily available information regarding the markets for water treatment chemicals. This white paper is designed to identify what is known about the issue and the driving forces behind the recent price and chemical availability concerns. The paper identifies critical knowledge gaps and potential research needs, identifies important stakeholders and potential sources of information that can help clarify the issue, and develops recommendations for next steps toward effectively managing the issue.


From 2003 to 2008, the world experienced the largest commodity price boom compared to any experienced in the 20th century (World Bank, 2009). This boom, and subsequent bust in mid-2008, are directly linked to the behavior of the water treatment chemical market over the same period. Many of the same factors driving commodity markets are the ones that have driven the water treatment chemical market. Those factors include:

- Strong, sustained international economic growth, led by developing countries
- Excess commodity production capacity, which deterred investment in new capacity
- A significant increase in biofuels production, including corn production, which is very fertilizer intensive (and thus competes with the water sector for several key commodities).

Limited supply relative to demand in commodity markets translated into increasing prices and shortages for water treatment chemicals. The financial crisis that started in the United States and spread worldwide starting in mid-2008 accelerated the recession that had already began in many countries. The recession has caused commodity prices to fall worldwide. This has especially affected production of chemicals that are a by-product of other production processes. So while shortages for water treatment chemicals before the bust were led by competing demands for the same input, such as competing demands for phosphorus, shortages after the bust were led by a lack of production in some processes that generate by-products used for water treatment, such as fluoride and caustic soda.
Water Treatment Chemical Prices and Availability in 2008

The project was fortunate to be conducted at the same time that the Association of Metropolitan Water Agencies (AMWA) conducted a survey of U.S. drinking water utilities to understand specifics about chemical price changes and delivery shortages in the past year. AMWA shared the survey results for use in this white paper.

The U.S. survey was administered in January 2009, and asked utilities to compare current unit cost for treatment chemicals with unit cost one year ago. U.S. utility respondents reported significant price increases for many of the chemicals in the survey. A few of the chemicals with the greatest price increase include the following:

- Phosphoric acid showed the largest average percent increase of any chemical in the survey, at 223%, based on responses from 12 utilities reporting phosphoric acid use. The largest reported increase was 586%, and the lowest was 0%. The lowest non-zero increase was 95% (a zero percent increase may indicate that a long-term contract was in place).

- Caustic soda showed an 80% average percent increase, from 25 utilities reporting caustic soda use.

- Forty-one utilities reported using fluoride, the greatest number of utilities reporting use of one chemical. All reported fluoride use for which the specific type was reported was fluorosilicic acid. The average reported price increase was 44%.

One month after the U.S. survey, U.K. water and wastewater utilities were invited to respond to the same survey, with slight revisions. Seven out of 26 utilities responded to the U.K. survey, resulting in a 27% response rate. Similar to their U.S. counterparts, U.K. utilities also reported significant price increases for many chemicals. The two chemicals with the greatest price increase are as follows:

- Phosphoric acid showed the largest average percent increase at 175%, based on responses from five utilities reporting phosphoric acid use. The largest reported increase was 350%, and the lowest was -40%.

- Caustic soda showed a 52% average increase over the last year, from six utilities reporting caustic soda use. The largest reported increase was 100%, and the smallest reported increase was 25%. One utility reported no increase in price.

U.K. utilities also reported through the Water U.K. Chemicals Committee that as of late February 2009, there was a high current and projected price increase risk for ferric sulfate and caustic soda.
Utilities in the United States and in the United Kingdom also reported some water treatment chemical shortages or delivery restrictions in 2008. The surveys asked utilities to respond with a “yes” or “no” regarding whether they had experienced chemical shortages or delivery restrictions in the past year. It should be noted that although the responses do indicate the presence of some level of supply restriction, they do not indicate the number of shortage events in 2008 or their duration.

The U.S. respondents reported adequate supply for most chemicals. Of the chemicals with at least three “yes” responses, fluoride and to some extent caustic soda, phosphoric acid, and gaseous chlorine were unavailable in some way. Because the most commonly used form of fluoride in the United States is a by-product of fertilizer production, decreased fertilizer demand starting in mid-2008 adversely affected fluoride availability. More than 65% of U.S. utilities responding to the AMWA survey indicated fluoride supply problems in 2008. Caustic soda is directly related to chlorine production, and recent decreases in demand for chlorine for polyvinyl chloride (PVC) production affected caustic soda availability. Force majeure1 was implemented for caustic soda in the United States following two hurricanes in 2008. Phosphoric acid shortages also were reported by 3 of the 11 utilities that use it (27%), and gaseous chlorine shortages were reported by 3 of 33 utilities reporting its use (9%).

U.K. utilities have concerns regarding short- and long-term chemical availability. Despite the small number of respondents to the U.K. survey, responses to this question seem to indicate that there have been supply problems with some chemicals over the past year, including phosphoric acid, ferric chloride, and ferric sulfate. A separate ranking by Water U.K. Chemicals Committee members from the same time as the survey in February 2009 reported existing supply restrictions for ferrous chloride, and possible supply difficulties for ferric chloride, ferric sulfate, ferrous sulfate, chlorine, caustic soda, and sodium hypochlorite. Results from the risk register reported by the Water U.K. Chemicals Committee provides a snapshot of current and near future chemical availability that is changing monthly, and differences between the backward-looking survey results and the forward-looking risk register underline the rapidly changing nature of the treatment chemical market (Mike Turrell, Water U.K. Chemicals Committee, personal communication, 4/1/2009).

U.K. utilities have significant concerns regarding water treatment chemicals when only one manufacturer serves the U.K. market. In particular, U.K. utilities have significant concerns because it is believed that one bulk chlorine producer currently supplies the U.K. market for water treatment. Other chemicals for which only one supplier has been identified as serving the U.K. market are caustic soda, sulfuric acid, and sulfur dioxide.

1. Force majeure clauses exclude a party from contract liability because of forces beyond control of parties in the contract, such as natural disasters or other unavoidable catastrophes. Force majeure literally means “greater force.”
General Outlook for Water Treatment Chemical Price and Availability

The recent increases in water treatment chemical prices were tied to the commodity price boom from 2003 to 2008. With decreasing worldwide demand for commodities and decreasing energy prices, prices for chemicals are generally expected to decrease in 2009. Water treatment commodity chemical prices have declined in the United States since mid-2008. Price increases for specialty chemicals are also generally expected to cease because of declining prices for inputs.

Water treatment chemical price declines have not yet been reported in the United Kingdom. It possible that U.K. utilities will see some relief from chemical price increases over 2009, especially for chemicals for which there are multiple U.K. suppliers. However, price declines for water treatment chemicals in the United Kingdom appear less likely than in the United States.

When worldwide economic growth returns after the current recession, worldwide commodity demand is expected to increase as well. The World Bank forecasts that the price of oil will stabilize in several years at about $75 a barrel, 30% less than the peak during the recent commodity price boom, but greater than the price before the boom (World Bank, 2009). As a result, it seems likely that water treatment chemical prices will show a longer term increase at moderate rates. A more precise prediction for short-term and long-term prices, and with respect to individual chemicals, is beyond the capabilities of this study.

With regard to chemical shortages, until production of fertilizer picks up again, intermittent and often regionalized shortages of fluorosilicic acid in the United States appear likely to persist. Another chemical that is a by-product of other production processes is caustic soda. It is produced in the conjunction with chlorine. When demand for chlorine decreases and production drops, so does production of caustic. Reduced supply of caustic soda appears likely to continue in the United States and the United Kingdom until demand for PVC picks up as economies worldwide rebound. Production of biofuels and associated use of fertilizer are expected to continue into the future. However, the recession should depress general fertilizer demand in the near term. With a decrease in demand for fertilizer, more phosphoric acid should be available for other uses in the short term, provided that regional production capacity keeps pace with demand.

Planning and Purchasing Strategies

Through responses to surveys or through industry experts or the literature, several planning and purchasing strategies have been identified to help utilities minimize the impact of future price increases or chemical supply shortages. Some of those strategies include:
Contracting. Utilities that have long-term purchasing contracts were most insulated to volatility of the chemical market in 2008. However, during 2008, chemical suppliers resisted establishing new long-term agreements. A useful contracting approach suggested by utilities was to tie chemical prices in the contract to a price index. The exact approach has varied, but the general idea is to use independently published indices such as the producer price index (PPI) to justify price increases and indicate when decreases are needed.

Dual sourcing. Although a utility can get better prices from large volume purchases, it may be advantageous in some cases to use two sources of supply. When considering dual sources for reliability of supply, utilities should be sure that the chemicals are coming from two distinct sources (i.e., different sources of raw materials, different manufacturing processes).

Joint purchasing. When possible, utilities should consider regional purchasing solutions to take advantage of potential economies of scale (i.e., share the cost of storage or shipping). In the United Kingdom, anti-collusion laws often limit utilities’ ability to join together to negotiate with manufacturers. However, in the United States, several examples exist of regional purchasing for multiple utilities by one designated party.

Storage. Keeping within recommended storage times, a utility should evaluate increasing storage for chemicals with known supply issues. For example, because fluoride is tied to fertilizer production, a system should plan for times when fertilizer production slows.

Contingency planning. For good reason, water utilities are hesitant to try alternative treatment chemicals. Wastewater utilities have had a little more flexibility. The unpredictability of the market the last few years has made it clear that utilities should at least evaluate options for sources of supply and alternative chemicals. Recognizing that any change is a big deal, these options can be part of a utility’s emergency plan, to be used only if the current option becomes unfeasible.

Policy. Utilities and policy makers need to discuss water and wastewater system security and continuity of service. Utilities should initiate the conversation on the local level with their regulatory agency and local emergency management officials to develop contingencies for chemical supply issues. These discussions should also be conducted on the national level between the water and wastewater community and regulatory authorities.

New system design. When designing a new water treatment plant or upgrading an existing facility, a utility should consider the price and reliability of chemical supply. For example, if using an alternative chemical is possible (e.g., lime instead of caustic, alum instead of ferric), chemicals handling and delivery systems should be designed to allow for either chemical. A utility might also consider a treatment technology that requires little or no chemical addition, yet
recognize that most often the trade-off requires more energy (which has its own price volatility and reliability issues).

**Recommendations**

Two of the most helpful steps that utilities can take to understand how to control costs and protect public health and the environment are to: (1) track chemical markets over time and, (2) to invest in planning that can help them manage the risk associated with future water treatment market volatility, as discussed in the preceding section. Utilities could benefit from systematic tracking of information on chemical prices and availability over time, and sharing of the latest information. This concept is included as a suggestion for future research to develop an ongoing chemical market information service that facilitates chemical information sharing between utilities and provides timely chemical market updates to the water supply and wastewater community.

**Reference**

1. Introduction

Use of water treatment chemicals by water and wastewater utilities is critical to protect public health and the environment. Using these chemicals is becoming even more important as population increases put growing pressure on the highest quality sources, use of lesser quality sources becomes more important, and recently detected contaminants in waters raise concern.

Water and wastewater utilities in the United States and the United Kingdom have been experiencing significant water treatment chemical price increases and short-term supply shortages for some of those chemicals. Chemical suppliers have been reporting to utilities that the shortages and price increases have been caused by worldwide increases in other uses for these chemicals. In addition, utilities have concerns about the long-term sustainability of supply for some chemicals, especially when there is only one supplier or a few suppliers for a market. In most cases, demand for water treatment chemicals is a small share of the overall market demand for those chemicals. And, because of the dispersed nature of water treatment, each facility accounts for a small share of the water treatment market, further minimizing buying power.

The water community currently lacks readily available information about the markets for critical water treatment chemicals. Better understanding of the variables that govern the cost and availability of these chemicals will help managers make better decisions to minimize impacts from changes in the price or availability of chemicals.

Regulators, policy makers, public health officials, and the general public are generally unaware of the short-term and long-term implications of chemical cost and availability problems for the water community. Lack of availability and long-term increases in cost of critical chemicals challenges the water community’s ability to sustain essential processes such as wastewater treatment, drinking water treatment, and corrosion control. If unchecked, the problems have serious implications for utility finance, regulatory compliance, public and environmental health, and utility business continuity.

1.1 Project Objectives

The goal of this project was to develop a white paper that describes the nature of the recent treatment chemical supply issue for drinking water and wastewater utilities. This white paper describes what is known about factors driving the issue, identifies critical knowledge gaps and potential research needs, identifies important stakeholders and potential sources of information that can help inform and clarify the issue, and develops recommendations for next steps toward resolving or effectively managing the issue. The white paper is designed to help the water community develop strategies for addressing the issue. The results could also be used to engage
important stakeholders outside the water community who can contribute to developing a coordinated approach to the problem.

1.2 Project Approach

Approximately 30 water treatment chemicals are used in water and wastewater treatment processes, as identified in a recent survey of drinking water utilities (MacPhee et al., 2002). This is similar to the number of chemicals identified by the Water U.K. Chemicals Committee for water and wastewater treatment, as is detailed in the section of this paper on findings. To manage the scope of this project, 11 water treatment chemicals (or groups of chemicals) were selected as the focus of this study. Table 1 lists the 11 chemicals investigated in this study, and their uses.

<table>
<thead>
<tr>
<th>Name</th>
<th>Uses</th>
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<tr>
<td>Aluminum sulfate (alum)</td>
<td>Coagulation</td>
</tr>
<tr>
<td>Chlorine gas</td>
<td>Disinfection</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>Coagulation</td>
</tr>
<tr>
<td>Ferric sulfate</td>
<td>Coagulation</td>
</tr>
<tr>
<td>Phosphate-based corrosion inhibitors</td>
<td>Corrosion and scale control</td>
</tr>
<tr>
<td>Polyaluminum chloride</td>
<td>Coagulation</td>
</tr>
<tr>
<td>Fluoride</td>
<td>Additive to improve dental condition</td>
</tr>
<tr>
<td>Polymers</td>
<td>Coagulation, flocculation</td>
</tr>
<tr>
<td>Sodium hydroxide (caustic soda)</td>
<td>pH and alkalinity adjustment, regeneration of ion exchange resins, precipitate softening</td>
</tr>
<tr>
<td>Sodium hypochlorite</td>
<td>Disinfection</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>pH adjustment</td>
</tr>
</tbody>
</table>

The main approach was to gather available information on key water treatment chemicals from water and chemical industry experts and from a review of available literature. This information was organized in a common format and summarized by chemical in Appendix A of this study.

The project also was fortunate to be conducted at the same time that the Association of Metropolitan Water Agencies (AMWA) conducted a survey of U.S. drinking water utilities to understand specifics about chemical price changes and delivery shortages in the past year. To complement the U.S. survey, the AMWA survey with slight modifications was sent to water utilities in the United Kingdom. Results of these AMWA surveys are used in the analysis.
presented this paper. The responses from the U.S. and U.K. surveys are summarized in Appendix B.¹

### 2. Findings

#### 2.1 Link between Worldwide Commodity Markets and Water Treatment Chemical Markets

Supply and demand for chemicals used in water treatment are closely related to the worldwide market for commodities such as oil, metals and minerals, and food. Oil and energy costs can be a significant portion of the cost of producing water treatment chemicals. Also, production of most water treatment chemicals depends on metals and minerals availability, whether as a direct input or as a by-product of the production process. For instance, alum production depends directly on aluminum as an input. Production of some water treatment chemicals is related to food production through fertilizer production. Fertilizer production has a significant effect on the supply and demand of phosphoric acid, sulfuric acid, and fluoride. Also, production processes that use commodities can be a significant competing use for chemicals used in water treatment. Appendix A details the specific factors influencing supply and demand for water treatment chemicals by chemical or chemical group.

#### 2.2 The Worldwide Commodity Price Boom of 2003–2008²

The story of recent water treatment chemical price increases and shortages is directly related to the recent boom in prices for oil and other commodities. From 2003 to 2008, the world experienced the largest commodity price boom compared to any experienced in the 20th century. The real (inflation-adjusted) U.S. dollar price of all commodities more than doubled, increasing approximately 110%, from 2003 to 2008. The increase in earlier commodity booms was never higher than 60%. By mid-2008, oil prices were 230% higher than in January 2003, and metals and minerals prices were 296% higher. The increase in commodity prices accelerated through 2007 and early 2008. Energy prices were 80% higher in 2008 than a year earlier, and non-energy commodity prices were 35% higher than a year earlier. The boom ended in mid-2008, and oil

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¹ AMWA survey administrator Ray Yep, of the Santa Clara Valley Water District, shared results of the U.S. survey for use in this paper. The U.K. survey was administered as a separate new effort for this project.

² The information in this section is summarized from *Global Economic Prospects: Commodities at the Crossroads*, a report published in early 2009 by the World Bank, on the subject of the worldwide commodity boom and bust.
prices fell more than 60% by December, with prices for other commodities falling rapidly as well. Almost all commodity prices peaked in early or mid-2008, and have declined sharply since then (World Bank, 2009).

The world had experienced other commodity booms in the 20th century. Those booms were generally caused by strong demand combined with short-term supply disruptions. Oil crises in the early 1970s and again in the late 1970s were caused by short-term supply restrictions, resulting in rapidly increased oil prices. In each of these events, demand for oil and other commodities dropped quickly in response to rapidly increasing prices. As a result, the effect of these disruptions on other commodity prices varied: the early 1970s oil crisis significantly increased non-energy related commodity prices and the crisis of the late 1970s did not.

In fact, commodity prices, including oil prices, declined over the 1980s and 1990s, in real terms (i.e., after adjusting for inflation). This decline in commodity prices generally led to idle production capacity as producers cut their production following declining demand. Excess capacity deterred investment in new supply capacity and depressed activity in exploration and exploitation services, which made expanding new capacity quickly more difficult.

The most recent commodity boom had a somewhat different pattern than the disruptions in the 1970s. This recent boom was led primarily by strong international demand instead of a supply disruption. Excess production capacity in oil and minerals was absorbed in the early 1990s, and after the remaining excess production capacity was reached, demand continued to rise while investment in new capacity could not keep up. And, international demand for commodities did not adjust to price increases as quickly as it had in response to previous rapid price increases. Rapid international economic growth, especially in rapidly expanding developing economies such as China and India, continued throughout this period. Much of the strength and duration of the boom was fueled by persistent developing-country growth, which continued longer than during previous commodity price booms. Developing countries were surprisingly able to absorb higher commodity prices, and the supply response for commodities was slow in coming.

Increases in commodity prices led to an investment boom in oil, metals and minerals markets. The ability to create the needed capacity had atrophied during the years of excess capacity, and the costs to add capacity now increased dramatically. Capacity is being added, but it will not be in place for several years. This means supply will continue to be relatively scarce.

High oil prices also sparked a boom in biofuel production in the United States and Europe that boosted demand for grains and oilseeds, contributing to their rapid price rise in 2007 and early 2008. More than two-thirds of the increase in world corn production since 2004 has been used to meet increased biofuel demand in the United States. Corn production is relatively fertilizer intensive, increasing demand for fertilizer and necessary production inputs, including phosphoric acid.
The end of the commodity boom in mid-2008 was precipitated by slowing of gross domestic product (GDP) growth worldwide, and accelerated and deepened by the financial crisis that started in the United States and spread worldwide. Since then, growth slowed significantly worldwide, and some economies have contracted.

Whether upward pressure on commodity prices will resume again depends on future growth in relation to production capacity. In China, growth is expected to moderate over time as high investment rates and expansion of manufacturing capacity slow.

The World Bank projects energy prices to decline 25% in 2009 from their peak in 2008 and remain flat in 2010. Non-energy commodity prices are expected to decrease 23% in 2009 and decrease 4% in 2010. Long-term oil prices are expected to stabilize at $75 a barrel in nominal terms during 2008–2009, a 30% real decline from the peak during the recent boom. Similarly, the index of metals and minerals prices is expected to fall 25% in 2009 and another 5% in 2010.

Worldwide GDP growth in 2009 is expected to average about 0.9%, with uncertainty about that estimate ranging from a high of 1.4% to a low of 0.4%. The confidence interval around the 2010 estimate is even wider. The World Bank notes that whatever the actual growth rate, economic activity over the next two years will be radically different from that which was expected as of mid-2008, and policies will need to adapt.

### 2.3 Recent Price Increases for Water Treatment Chemicals

#### 2.3.1 Price increases reported by U.S. utilities

The market for water treatment chemicals has been relatively steady over the last 20 years or more. Figure 1 shows the U.S. producer price index (PPI) for water treating compounds, which shows trends in prices received by domestic chemical producers over time for an unspecified mix of water treatment chemicals.³ The index for water-treating compounds shows an increasing trend of price increases until more significant price increases starting in 2004. The PPI for commodity chemicals clearly shows the effect of the commodity price boom of 2003–2008. Figure 2 shows the U.S. PPI over time for industrial chemicals in general, and for aluminum compounds, sulfuric acid, and phosphates.

---

³ Information regarding which chemicals are included in the water-treating compounds item in the U.S. PPI is confidential data from manufacturers and not available to the public. Also, the mix of chemicals used in water treatment changes over time, and so the mix of chemicals included in the PPI for the water-treating compound item adjusts over time to reflect this change. That is, from one year to the next, the water-treating compounds included in the PPI may shift based on changes in industry practices, or advancements in technology.
Mirroring the commodity price boom of 2003–2008, there were dramatic price increases for water treatment chemicals. Table 2 shows average price increases reported by 47 utilities responding to the AMWA survey of U.S. drinking water utilities. The survey response rate was approximately 24%, which is typical for this type of survey. Responses are shown here for the 11 chemicals on which this paper concentrates.

The survey asked utilities to compare current unit cost for the chemical (in January 2009) with unit cost one year ago (in January 2008). The survey asked about a longer list of chemicals than is the focus of this study, and Appendix B lists the price increases for all chemicals in the AMWA survey.

Figure 1. U.S. PPI for water-treating compounds (1986–2008).

Figure 2. U.S. PPI for (a) industrial chemicals (1926–2008), (b) aluminum compounds (1996–2008), (c) sulfuric acid (1988–2008), and (d) phosphates (1947–2008).

Table 2. Price increases from January 2008 to January 2009 for selected chemicals in the AMWA survey of U.S. water utilities (based on responses from 47 utilities)

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Number of utilities indicating use</th>
<th>Average increase (%)</th>
<th>Minimum increase (%)</th>
<th>Non-zero minimum increase&lt;sup&gt;a&lt;/sup&gt; (%)</th>
<th>Maximum increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alum</td>
<td>25</td>
<td>53</td>
<td>0</td>
<td>15</td>
<td>168</td>
</tr>
<tr>
<td>Caustic soda</td>
<td>25</td>
<td>80</td>
<td>0</td>
<td>6</td>
<td>209</td>
</tr>
<tr>
<td>Chlorine (gaseous)</td>
<td>30</td>
<td>-1</td>
<td>-40</td>
<td>-40</td>
<td>42</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>11</td>
<td>23</td>
<td>0</td>
<td>1</td>
<td>54</td>
</tr>
<tr>
<td>Ferric sulfate&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6</td>
<td>52</td>
<td>0</td>
<td>25</td>
<td>125</td>
</tr>
<tr>
<td>Fluoride</td>
<td>41</td>
<td>44</td>
<td>0</td>
<td>1</td>
<td>145</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>12</td>
<td>233</td>
<td>0</td>
<td>95</td>
<td>586</td>
</tr>
<tr>
<td>Polyaluminum chloride</td>
<td>10</td>
<td>14</td>
<td>-1</td>
<td>-1</td>
<td>72</td>
</tr>
<tr>
<td>Polymer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anionic polymer</td>
<td>8</td>
<td>6</td>
<td>-14</td>
<td>-14</td>
<td>45</td>
</tr>
<tr>
<td>Cationic polymer</td>
<td>20</td>
<td>15</td>
<td>-7</td>
<td>-7</td>
<td>81</td>
</tr>
<tr>
<td>Non-ionic polymer</td>
<td>10</td>
<td>9</td>
<td>-1</td>
<td>-1</td>
<td>20</td>
</tr>
<tr>
<td>Sodium hypochlorite (15% solution)</td>
<td>16</td>
<td>19</td>
<td>-3</td>
<td>-3</td>
<td>81</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>7</td>
<td>82</td>
<td>30</td>
<td>30</td>
<td>129</td>
</tr>
</tbody>
</table>

<sup>a</sup> Zero percent price changes often result from long-term contracts that span the time period in question. Non-zero minimum price change is included in the table to show the minimum price change that was likely not associated with a long-term contract.

<sup>b</sup> Ferric sulfate was not listed on the survey as originally distributed, but was inserted by six utilities.

Utility respondents reported significant price increases for each of the chemicals listed in Table 2, except gaseous chlorine. A few of the chemicals with the greatest price increase include the following:

- Phosphoric acid showed the largest average percent increase of any chemical in the survey at 233%, from 12 utilities reporting phosphoric acid use. The largest reported increase was 586%, and the lowest was 0%. The lowest non-zero increase was 95%.

- Caustic soda showed an 80% average percent increase, from 25 utilities reporting caustic soda use.

- Forty-one utilities reported using fluoride, the greatest number of utilities reporting use of one chemical. All reported fluoride use for which the specific type was reported was fluorosilicic acid (FSA). The average reported price increase was 44%.
The survey also asked utilities to identify reasons given to them by suppliers for price increases. Utilities identified the same price drivers that have generally been identified as the reasons for the commodity price boom of 2003–2008:

- Rising cost of energy, including fuel costs
- Increased foreign demand (India, China, and worldwide)
- Manufacturing capacity limitations
- Increased cost of inputs and raw materials (for example, metals, sulfuric acid, phosphates)
- Increased ethanol production and resulting demand for fertilizer for corn, domestic and abroad.
- Increased consumption of finished chemical product by other, non-water treatment industries.

Utilities also identified some of the drivers that are specific to the United States or are regional supply issues:

- Increased transportation costs in addition to fuel (rail surcharges for increased safety regulations)
- Extreme weather events (spring 2008 Mississippi floods, hurricanes, ice storms)
- Falling value of Canadian dollar (for Canadian supplier)
- Lack of availability of product that meets National Sanitation Foundation (NSF) standards.

In addition to the price of inputs for making water treatment chemicals, prices faced by utilities are also greatly increased by competition with other industries that use the chemicals. In most cases, demand for water treatment chemicals is a small share of the overall market demand for those chemicals. And, with the dispersed nature of water treatment, each facility accounts for a small share of the water treatment market, further minimizing buying power. Transportation often adds significant cost, especially to utilities located some distance from chemical producers. In some instances, local chemical producers shutting down has caused significant price increases to local water utilities.
2.3.2 Price increases reported by U.K. utilities

U.K. utilities were invited to respond to the same survey, with slight revisions. The response was somewhat limited, in part because U.K. utilities were hesitant to take any action that could be seen as conflicting with U.K. anti-collusion laws and make it appear that they were acting in concert to affect water prices. Nonetheless, 7 utilities out of 26 responded to the survey (a 27% response rate).

Table 3 shows responses from U.K. utilities for chemicals for which four or more responses were received.

Table 3. Price increases from January 2008 to January 2009 for selected chemicals in the survey of U.K. utilities (based on responses from 7 utilities)

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Number of utilities indicating use</th>
<th>Average increase (%)</th>
<th>Minimum increase (%)</th>
<th>Non-zero minimum increase (%)</th>
<th>Maximum increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alum</td>
<td>4</td>
<td>18</td>
<td>0</td>
<td>5</td>
<td>33</td>
</tr>
<tr>
<td>Caustic soda</td>
<td>6</td>
<td>52</td>
<td>0</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>Chlorine (gaseous)</td>
<td>5</td>
<td>9</td>
<td>0</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Ferric sulfate</td>
<td>4</td>
<td>13</td>
<td>0</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>5</td>
<td>175</td>
<td>-40</td>
<td>-40</td>
<td>350</td>
</tr>
<tr>
<td>Polyaluminum chloride</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>10</td>
</tr>
</tbody>
</table>

a. Zero percent price changes often result from long-term contracts that span the time period in question. Non-zero minimum price change is included in the table to show the minimum price change that was likely not associated with a long-term contract.

The two chemicals with the greatest price increase are as follows:

- Phosphoric acid showed the largest average percent increase at 175% from five utilities reporting phosphoric acid use. The largest reported increase was 350%, and the lowest was -40%.

- Caustic soda showed a 52% average increase over the last year, from six utilities reporting caustic soda use. The largest reported increase was 100%, and the smallest reported increase was 25%. One utility reported no increase in price.
The survey also asked U.K. utilities to identify reasons given to them by suppliers for price increases. Those responses mirrored the responses for the U.S. survey and the drivers for the 2003–2008 commodity boom:

- Increased energy costs (oil, gas, and transport costs)
- Increased raw materials costs (especially those linked to fertilizer markets)
- Demand for raw materials from other sectors
- Variance in exchange rates (U.S. dollar, Euro, Pound Sterling)
- Closing of production facilities, slowdown of production in some sectors
- State of the global economy.

U.K. utilities, through a meeting of the Water U.K. Chemicals Committee, identified their perceived level of risk of price increases as of late February 2009 and in the near future, and assigned three ranking levels for risk of price increase. Table 4 shows their rankings. Lower price risk ratings indicate greater price risk.4 Of the 11 chemicals identified for study in this paper, those assigned the “very likely” risk of price increases are ferric sulfate and caustic soda. Those with “probable” risk of price increase included ferric chloride, chlorine, sodium silicofluoride, sulfuric acid, polyaluminum chloride, aluminum sulfate, and sodium hypochlorite.

### 2.3.3 General outlook regarding chemical prices

With decreasing demand and decreasing fuel prices, prices for chemicals are generally expected to decrease in 2009. Water treatment commodity chemical prices have declined in the United States since mid-2008. Price increases for specialty chemicals are also generally expected to cease because of declining prices for inputs.

Water treatment chemical price declines have not yet been reported in the United Kingdom. It is possible that U.K. utilities will see some relief from chemical price increases over 2009, especially for chemicals for which there are multiple U.K. suppliers. However, U.K. suppliers are served by one manufacturer for several important chemicals, including chlorine, caustic soda, sulfuric acid, and sulfur dioxide. Therefore price declines for water treatment chemicals in the United Kingdom appear less likely than in the United States.

---

4. These risk rankings provide a snapshot of conditions as of the end of February 2009. The rankings have been shown to change quickly over time as supply and demand conditions change.
Table 4. Treatment chemical price risk ratings by U.K. water and wastewater utilities, February 2009

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Price risk (lower number means higher risk)</th>
<th>Number of utilities</th>
<th>Metric tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferric sulfate / ferrous sulfate</td>
<td>1.3</td>
<td>9</td>
<td>145,488</td>
</tr>
<tr>
<td>Sodium carbonate</td>
<td>1.5</td>
<td>2</td>
<td>1,140</td>
</tr>
<tr>
<td>Caustic soda (sodium hydroxide)</td>
<td>1.5</td>
<td>11</td>
<td>32,116</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>1.6</td>
<td>5</td>
<td>4,380</td>
</tr>
<tr>
<td>Chlorine</td>
<td>1.8</td>
<td>10</td>
<td>8,067</td>
</tr>
<tr>
<td>Aluminum chloride</td>
<td>2.0</td>
<td>1</td>
<td>183</td>
</tr>
<tr>
<td>Sodium silicofluoride</td>
<td>2.0</td>
<td>1</td>
<td>240</td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td>2.0</td>
<td>6</td>
<td>294</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>2.0</td>
<td>9</td>
<td>13,710</td>
</tr>
<tr>
<td>Polyaluminum chloride</td>
<td>2.1</td>
<td>9</td>
<td>23,182</td>
</tr>
<tr>
<td>Aluminium sulphate</td>
<td>2.1</td>
<td>8</td>
<td>114,705</td>
</tr>
<tr>
<td>Hexafluorasilicic acid</td>
<td>2.2</td>
<td>6</td>
<td>2,390</td>
</tr>
<tr>
<td>Carbon (GAC)</td>
<td>2.2</td>
<td>5</td>
<td>2,703</td>
</tr>
<tr>
<td>Oxygen</td>
<td>2.3</td>
<td>4</td>
<td>11,933</td>
</tr>
<tr>
<td>Packaged chemicals</td>
<td>2.3</td>
<td>4</td>
<td>2,208</td>
</tr>
<tr>
<td>Ferrous chloride</td>
<td>2.3</td>
<td>3</td>
<td>31,915</td>
</tr>
<tr>
<td>Sodium hypochlorite</td>
<td>2.3</td>
<td>9</td>
<td>11,981</td>
</tr>
<tr>
<td>Sodium bisulphite</td>
<td>2.4</td>
<td>10</td>
<td>2,660</td>
</tr>
<tr>
<td>Lime</td>
<td>2.4</td>
<td>9</td>
<td>81,310</td>
</tr>
<tr>
<td>Calcium nitrate</td>
<td>2.5</td>
<td>6</td>
<td>7,209</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>2.5</td>
<td>6</td>
<td>1,736</td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>2.5</td>
<td>2</td>
<td>891</td>
</tr>
<tr>
<td>Sodium dihydrogenorthophosphate (MSP)</td>
<td>2.5</td>
<td>4</td>
<td>11,509</td>
</tr>
<tr>
<td>Polyelectrolytes</td>
<td>2.6</td>
<td>10</td>
<td>11,141</td>
</tr>
<tr>
<td>Salt</td>
<td>2.6</td>
<td>8</td>
<td>11,606</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>2.8</td>
<td>10</td>
<td>11,246</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>3.0</td>
<td>1</td>
<td>1,250</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>3.0</td>
<td>2</td>
<td>36</td>
</tr>
<tr>
<td>Liquid urea</td>
<td>3.0</td>
<td>1</td>
<td>105</td>
</tr>
<tr>
<td>Micronutrients</td>
<td>3.0</td>
<td>1</td>
<td>6,185</td>
</tr>
<tr>
<td>Potassium permanganate</td>
<td>3.0</td>
<td>1</td>
<td>32</td>
</tr>
</tbody>
</table>

**Total metric tons** 553,552

Price risk scale:
Very likely: 1.0–1.5; probable: 1.6–2.4; unlikely: 2.5–3.0.
When worldwide economic growth returns after the current recession, worldwide commodity demand is expected to increase as well. The World Bank projects that the price of oil will stabilize in several years at about $75 a barrel, 30% less than the peak during the recent commodity price boom, but greater than the price before the boom (World Bank, 2009). As a result, it seems likely that water treatment chemical prices will show a longer term increase at moderate rates. A more precise prediction for short-term and long-term prices, and with respect to individual chemicals, is beyond the capabilities of this study.

2.4 Recent Supply Shortages for Water Treatment Chemicals

2.4.1 Supply shortages reported by U.S. utilities

The decrease in demand for commodities during the recession has led some production facilities to close. Especially hard hit are the water treatment chemicals that are a by-product of other processes.

Table 5 shows the AMWA survey results of U.S. utilities on chemical availability restrictions in 2008. The survey asked utilities to respond with a “yes” or “no” regarding whether they had experienced chemical shortages or delivery restrictions in the past year (during 2008). It should be noted that although the responses do indicate the presence of some level of supply restriction, they do not indicate the number of shortage events in 2008 or their duration.

The respondents reported adequate supply for most chemicals. Of the chemicals with at least three “yes” responses – fluoride and to some extent caustic soda, phosphoric acid, and gaseous chlorine – were unavailable in some way. Because fluoride is a by-product of fertilizer production, decreased fertilizer demand starting in mid-2008 adversely affected fluoride availability. More than 65% of 47 U.S. utilities responding to the AMWA survey indicated fluoride supply problems in 2008. Caustic soda is directly related to chlorine production, and recent decreases in demand for chlorine for polyvinyl chloride (PVC) production affected caustic soda availability. Force majeure was implemented for caustic soda in the United States following two hurricanes in 2008. Phosphoric acid shortages also were indicated by 3 of the 11 utilities that reported using it (27%), and gaseous chlorine shortages were reported by 3 of 33 utilities reporting its use (9%).

---

5. Force majeure clauses exclude a party from contract liability because of forces beyond control of parties in the contract, such as natural disasters or other unavoidable catastrophes. Force majeure literally means “greater force.”
Table 5. U.S. utilities in AMWA survey indicating chemical shortages or delivery issues in 2008 (based on responses from 47 utilities)\textsuperscript{a}

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Number of utilities indicating use\textsuperscript{b}</th>
<th>Number indicating shortages</th>
<th>Percent indicating shortages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alum</td>
<td>23</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Caustic soda</td>
<td>27</td>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td>Chlorine (gaseous)</td>
<td>33</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ferric sulfate\textsuperscript{c}</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fluoride</td>
<td>41</td>
<td>27</td>
<td>66</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>11</td>
<td>3</td>
<td>27</td>
</tr>
<tr>
<td>Polyaluminum chloride</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Polymer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anionic polymer</td>
<td>9</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Cationic polymer</td>
<td>20</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Non-ionic polymer</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sodium hypochlorite (15% solution)</td>
<td>20</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>6</td>
<td>1</td>
<td>17</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Only chemicals that are the focus of this paper are shown.
\textsuperscript{b} Shows the number of utilities that responded with either a “yes” or a “no” to the question of whether there had been a shortage in the past year.
\textsuperscript{c} Ferric sulfate was not listed on the survey as originally distributed, but was inserted by six utilities.

Reasons reported by utilities for treatment chemical shortages included:

- Force majeure (extraordinary events beyond control of contract parties)
- Short supply, increased demands
- Manufacturing capacity constraints, other manufacturing issues (off-line, maintenance of facilities)
- Some manufacturers no longer making specific chemical (fluoride)
- Rail and trucking issues (rail car shortages, unsafe conditions, equipment failures)
- Supplier back ordered on shipments, so some delayed deliveries.
2.4.2 Supply shortages reported by U.K. utilities

U.K. utilities have concerns regarding short- and long-term chemical availability. Table 6 shows the response to the survey question asking if utilities had experienced chemical shortages or other restrictions in the past year. Despite the small number of respondents to the U.K. survey (seven), responses to this question seem to indicate that there may be supply problems with some chemicals, including ferric chloride, ferric sulfate, and phosphoric acid.

Table 6. U.K. utilities indicating chemical shortages or delivery issues in 2008 (based on responses from 7 utilities)

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Number of utilities indicating use(^{a})</th>
<th>Number indicating shortages</th>
<th>Percent indicating shortages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alum</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Caustic soda</td>
<td>7</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>Chlorine (gaseous)</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>3</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>Ferric sulfate</td>
<td>5</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>Fluoride</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>7</td>
<td>3</td>
<td>43</td>
</tr>
<tr>
<td>Polyaluminum chloride</td>
<td>7</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>Polymer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anionic polymer</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cationic polymer</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Non-ionic polymer</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sodium hypochlorite</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^{a}\) Shows the number of utilities that responded with either a “yes” or a “no” to the question of whether there had been shortage in 2008.

Respondents to the U.K. survey gave the following reasons from their suppliers for treatment chemical shortages:

- Availability of raw materials (ferrous sulfate, phosphate, issues related to steel manufacturing leading to shortage of ferric chloride)
- Weather conditions
- Manufacturing capacities
- Global demands
- Closing of production facilities, slowdown of production in some sectors.
U.K. water and wastewater utilities, through the Water U.K. Chemicals Committee, identified their perceived level of risk of supply shortages as of late February 2009 and in the near future, and assigned three ranking levels for risk of supply shortages. Table 7 shows their rankings. Lower supply risk rankings indicate greater levels of risk. The chemical assigned the highest level of risk of supply difficulties was ferrous chloride. Of the 11 chemicals identified for study in this paper, those assigned the second highest risk of supply difficulties, indicating “possible” supply difficulties, were ferric chloride, ferric sulfate, chlorine, caustic soda, and sodium hypochlorite.

U.K. utilities have significant concerns regarding water treatment chemicals when one manufacturer serves the U.K. market. For instance, although no shortages have yet been reported, U.K. utilities have significant concerns because it is believed that one bulk chlorine producer currently supplies the U.K. market for water treatment. Other chemicals for which only one supplier has been identified as serving the U.K. market are caustic soda, sulfuric acid, and sulfur dioxide.

### 2.4.3 General outlook regarding chemical supply restrictions

Until production of fertilizer picks up again, intermittent and often regionalized shortages of FSA in the United States appear likely to persist. One supplier in the United States stated that farmers who normally buy fertilizer and other material before the next planting season on extended credit plans were not able to get credit in the winter of 2008–2009. Production capacity for FSA has been idled until fertilizer demand returns, meaning that no FSA was available from those manufacturers in January and February 2009. The distributor recommended that utilities consider adding storage capacity for this chemical, if possible, when considering plant upgrades. By March, more fertilizer demand was expected, and thus supplies of FSA were expected to return.

Another chemical that is a by-product of other production processes is caustic soda. It is produced in the conjunction with chlorine. When demand for chlorine decreases and production drops, so does production of caustic. Reduced supply of caustic soda appears likely to continue until demand for PVC picks up as economies worldwide rebound.

Production of biofuels and associated use of fertilizer are expected to continue into the future. However, the recession should depress general fertilizer demand in the near term. With a decrease in demand for fertilizer, more phosphoric acid should be available for other uses in the short term.
Table 7. Treatment chemical supply risk ratings by U.K. water and wastewater utilities, February 2009

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Supply risk (lower number means higher risk)</th>
<th>Number of users</th>
<th>Metric tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrous chloride</td>
<td>1.3</td>
<td>8</td>
<td>31,915</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>1.8</td>
<td>9</td>
<td>4,380</td>
</tr>
<tr>
<td>Ferric sulfate / ferrous sulfate</td>
<td>1.9</td>
<td>9</td>
<td>145,488</td>
</tr>
<tr>
<td>Chlorine</td>
<td>2.1</td>
<td>6</td>
<td>8,067</td>
</tr>
<tr>
<td>Caustic soda (sodium hydroxide)</td>
<td>2.3</td>
<td>1</td>
<td>32,116</td>
</tr>
<tr>
<td>Sodium hypochlorite</td>
<td>2.4</td>
<td>2</td>
<td>11,981</td>
</tr>
<tr>
<td>Sodium carbonate</td>
<td>2.5</td>
<td>10</td>
<td>1,140</td>
</tr>
<tr>
<td>Carbon (GAC)</td>
<td>2.6</td>
<td>10</td>
<td>2,703</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>2.6</td>
<td>6</td>
<td>11,246</td>
</tr>
<tr>
<td>Aluminium sulphate</td>
<td>2.6</td>
<td>2</td>
<td>114,705</td>
</tr>
<tr>
<td>Polyaluminum chloride</td>
<td>2.7</td>
<td>10</td>
<td>23,182</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>2.7</td>
<td>1</td>
<td>13,710</td>
</tr>
<tr>
<td>Calcium nitrate</td>
<td>2.8</td>
<td>5</td>
<td>7,209</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>2.8</td>
<td>5</td>
<td>1,736</td>
</tr>
<tr>
<td>Polyelectrolytes</td>
<td>2.9</td>
<td>6</td>
<td>11,141</td>
</tr>
<tr>
<td>Sodium bisulphite</td>
<td>2.9</td>
<td>8</td>
<td>2,660</td>
</tr>
<tr>
<td>Aluminium chloride</td>
<td>3.0</td>
<td>9</td>
<td>183</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>3.0</td>
<td>11</td>
<td>1,250</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>3.0</td>
<td>1</td>
<td>36</td>
</tr>
<tr>
<td>Hexafluorsilic acid</td>
<td>3.0</td>
<td>6</td>
<td>2,390</td>
</tr>
<tr>
<td>Lime</td>
<td>3.0</td>
<td>4</td>
<td>81,310</td>
</tr>
<tr>
<td>Liquid urea</td>
<td>3.0</td>
<td>4</td>
<td>105</td>
</tr>
<tr>
<td>Micronutrients</td>
<td>3.0</td>
<td>3</td>
<td>6,185</td>
</tr>
<tr>
<td>Oxygen</td>
<td>3.0</td>
<td>9</td>
<td>11,933</td>
</tr>
<tr>
<td>Packaged chemicals</td>
<td>3.0</td>
<td>9</td>
<td>2,208</td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>3.0</td>
<td>2</td>
<td>891</td>
</tr>
<tr>
<td>Potassium permanganate</td>
<td>3.0</td>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td>Salt</td>
<td>3.0</td>
<td>10</td>
<td>11,606</td>
</tr>
<tr>
<td>Sodium dihydrogenorthophosphate (MSP)</td>
<td>3.0</td>
<td>1</td>
<td>11,509</td>
</tr>
<tr>
<td>Sodium silicofluoride</td>
<td>3.0</td>
<td>1</td>
<td>240</td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td>3.0</td>
<td>1</td>
<td>294</td>
</tr>
<tr>
<td><strong>Total metric tons</strong></td>
<td><strong>553,552</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Supply risk scale:
Supply difficulties: < 1.8; possible supply difficulties: 1.8–2.4; unlikely to have supply difficulties: 2.5–3.0.
2.5 Planning and Purchasing Strategies

Water utilities can minimize the cost of water treatment chemicals and plan for a more secure supply. Several planning and purchasing strategies have been identified through responses to surveys or through industry experts or the literature.

**Contracting.** Utilities that have long-term purchasing contracts were most insulated to the volatility of the chemical market in 2008. However, these long-term agreements may be a thing of the past. Several utilities that had long-term agreements come up for renewal in the spring and summer of 2008 found getting additional long-term contracts difficult, with manufacturers willing to agree only to short-term contracts. Sometimes one to two month agreements with very short price guarantees are the best offered. And, even with a long-term contract in place, some utilities have been forced to renegotiate their contracts because suppliers could not supply them at the prices negotiated. Some utilities have wording in their contracts that allow price increases based on published market conditions when they may cause a hardship to the supplier.

A useful contracting approach suggested by utilities was to tie chemical prices in the contract to a price index. The exact approach has varied, but the general idea is to use independently published indices such as the PPI to justify price increases and indicate when decreases are needed. When using the PPI, the general index for chemical prices could be used or the index for specific commodity chemicals could be used if they address the chemical in question directly. Commodity chemical indexes currently included as a subcategory under chemicals in the PPI are sulfuric acid, aluminum compounds, chorine, sodium hydroxide, phosphates, nitrogenates, and phosphoric acid.

To get even more precise using indices, utilities have suggested identifying inputs to producing a chemical and their share of total cost of production, and then using the index for each input to adjust that share of total cost. For example, if energy were 40% of the cost of production and a metal were the other 60%, then 40% of the allowed price would be adjusted using an energy price index and the other 60% would be adjusted using a price index for the metal.

**Dual sourcing.** Although a utility can get better prices from large volume purchases, it may be advantageous in some cases to use two sources of supply. When considering dual sources for reliability of supply, utilities should be sure that the chemicals are coming from two distinct sources (i.e., different sources of raw materials, different manufacturing processes). When considering price issues, utilities need to balance the advantage of spreading risk by having multiple suppliers versus the advantage of large volume purchases resulting in lower prices.

**Joint purchasing.** When possible, utilities should consider regional purchasing solutions to take advantage of potential economies of scale (i.e., share the cost of storage or shipping). A recent request for proposals from the International Procurement Association is an example of utilities...
using their combined buying power to attempt to influence manufacturers. In the United Kingdom, anti-collusion laws often limit utilities’ ability to join together to negotiate with manufacturers. However, in the United States, several examples exist of regional purchasing for multiple utilities by one designated party. More research is needed to understand institutional and regulatory obstacles to creating joint purchasing relationships.

Storage. Keeping within recommended storage times, a utility should evaluate increasing storage for chemicals with known supply issues. For example, because fluoride is tied to fertilizer production, a system should plan for times when fertilizer production slows.

Contingency planning. For good reason, water utilities are hesitant to try alternative treatment chemicals. Wastewater utilities have had a little more flexibility. The unpredictability of the market the last few years has made it clear that utilities should at least evaluate options for sources of supply and alternative chemicals. Recognizing that any change is a big deal, these options can be part of a utility’s emergency plan, to be used only if the current option becomes unfeasible.

Policy. Utilities and policy makers need to discuss water and wastewater system security and continuity of service. Utilities should initiate the conversation on the local level with their regulatory agency and local emergency management officials to develop contingencies for chemical supply issues. These discussions should also be conducted on the national level between the water and wastewater community [American Water Works Association (AWWA) Water Environment Foundation (WEF), AMWA, U.K. Water Industry Research (UKWIR)] and regulatory authorities [U.S. Environmental Protection Agency (EPA), U.S. Homeland Security, U.K. Drinking Water Inspectorate].

New system design. When designing a new water treatment plant or upgrading an existing facility, a utility should consider the price and reliability of chemical supply. For example, if using an alternative chemical is possible (e.g., lime instead of caustic, alum instead of ferric), chemicals handling and delivery systems should be designed to allow for either chemical. A utility might also consider a treatment technology that requires little or no chemical addition, yet recognize that most often the trade-off requires more energy (which has its own price volatility and reliability issues).

Other strategies. Encouraging new manufacturers to enter the marketplace could be a potential option for water utilities acting collectively, especially if the chemical in question is a waste product of another process, and thus would require minimal investment by the manufacturer.
2.6 Knowledge Gaps

The preceding discussion is a start toward fully describing water treatment chemical markets and recent water and wastewater utility experience with chemical prices and availability. However, filling in existing knowledge gaps would help complete the picture. Those gaps include but are not limited to the following:

- Information regarding shares the water treatment market holds of the total market for each chemical would allow utilities to gain a more detailed view of their collective market power. The most likely source of this information is market analyses available for purchase from market research firms. Reports for one chemical or chemical group are often very expensive and were not purchased as part of this project.

- Greater detail on the relative share of each input needed to manufacture a chemical in total costs for the manufacturing processes may help utilities gauge to what extent price changes in one input should affect the overall price. Appendix A identifies major cost drivers for each chemical or chemical group, but detail on the relative share of total cost coming from each input was not generally available.

- The share of supply in the United States and the United Kingdom that is imported was not identified. Understanding the detail on the share of supply that is imported can shed light on issues such as the relative importance of changes in exchange rates between countries involved in trade of a chemical.

- The supply chain, including manufacturers, distributors, resellers, and reformulators, changes quickly in the chemical industry. Mergers and acquisitions of chemical companies or production units, and entry and exit of firms from the marketplace, can make it difficult to stay current with the supply chain over time. Information gathered for Appendix A is an incomplete snapshot of manufacturers and gives incomplete information regarding suppliers. More complete identification of suppliers for each critical chemical is needed to help utilities understand their chemical supply options, along with tracking of the supply chain over time to keep up with changes.

- Future prices and availability of treatment chemicals are closely tied to the global market for commodities. The commodity market in turn is closely tied to worldwide growth rates. The most recent commodity price boom and subsequent bust show the difficulty in predicting future economic activity. Predicting short-term activity is not easy, and predicting long-term activity is especially difficult. Continuous tracking and forecasting of economic growth prospects, especially as they relate to commodity production, can help the water industry understand the potential direction of change in water treatment
chemical prices. However, in-depth market research updated frequently over time is needed to produce reliable forecasts of water treatment chemical prices and availability.

3. Recommendations

Two of the most helpful steps that utilities can take to understand how to control costs and protect public health and the environment are to track chemical markets over time and to invest in planning that can help them manage the risk associated with future water treatment market volatility. These steps help shape a list of potential research topics that follow.

3.1 Market Tracking

Water and wastewater utilities can increase their ability to minimize the effect of water treatment chemical price changes by closely tracking the market for treatment chemicals. Appendix A has summary information for each chemical examined in this study. The reference lists for each summary have various websites that have useful information for that chemical. A few of these sites can be used to track information for these chemicals.

However, utilities could benefit from systematic tracking of information on chemical prices and availability over time, and sharing of the latest information. One option may be to use local or regional meetings for professional associations to share information on chemical price and availability regionally. Applying this concept at a national or multinational level to create a treatment chemical market information service is included as a suggestion for future research in the section on future research topics below.

3.2 Taking Steps within the Utility to Manage Market Volatility

Investing in planning also can help utilities be prepared for treatment chemical market changes. Utilities should periodically evaluate potential options for treatment processes. This could include evaluating alternative treatment chemicals or alternative treatment processes. This evaluation should keep up with the latest alternatives and incorporate the latest market information that may indicate which chemicals or processes are projected to have long-term increases or decreases in cost. Emergency and contingency planning also can help utilities ensure that their reactions to sudden water treatment chemical supply disruptions is efficient in protecting public health and minimizing cost.
3.3 Future Research Topics

This project has identified a range of potential future research topics and suggests potential projects on those topics:

1. Evaluating options for alternatives to water treatment chemicals

Water utilities need options in the event of key water treatment chemical supply shortages or large-scale price increases such as those observed over the last several years. Because of the significant challenges associated with changing chemicals, utilities need to have advance planning, piloting, and permitting of their options before they experience an emergency situation.

This suggested project would look at potential treatment options such as alternative chemicals that may have a more stable price history or projection, and other treatment processes that do not require chemicals. An effective evaluation would consider items such as chemical feed properties, impact on water quality, cost factors, and regulatory requirements and impediments. This information would assist in long-range planning and be especially useful when designing new treatment facilities or considering major modifications to existing facilities.

2. Strengthening of the water industry’s buying power for chemicals

As individual utilities, each water utility is in essence a small market for the chemicals they purchase. As a small part of the overall market for a chemical, each utility has limited power to shape the chemical marketplace and negotiate lower rates or to have a say in the manufacturing process. Examples have emerged of utilities combining their buying power on energy and recently on purchasing chemicals.

Research is needed to develop strategies for the water industry to increase their buying power. This research would include examining examples within and outside the water industry, regulatory and institutional barriers, as well as purchasing and delivery opportunities and barriers.

3. Emergency and contingency planning for water treatment chemicals

Shortages for key water treatment chemicals have occurred over the last few years in conjunction with the commodity price boom, and have been observed from time to time due to weather events such as hurricanes or ice storms. The possibility of political unrest, war, or terrorism can also affect chemical production and supply. Since delivery of safe water is a national security priority, a dialogue on chemical supply among federal and local officials and water systems needs to be initiated.
Water and wastewater utilities need to be able to control chemical costs and ensure that treatment processes can continue to function no matter what the future brings. Time invested in emergency planning and contingency planning can help utilities know what steps can be taken to lessen the impact of water treatment chemical supply disruptions.

This planning would identify and prioritize the vulnerabilities associated with chemical supply. Dialogue would be started with agencies such as Homeland Security and EPA in the United States (and comparable agencies in the United Kingdom), and with elected officials and policy makers, to begin to develop contingency plans in the event of such an occurrence.

4. **Short-term and long-term forecasting of chemical prices**

As identified in this paper, forecasting chemical prices is challenging at best. Although chemical price forecasting is essential for utilities in developing short- and long-term budgets, only limited guidance is currently available. This project would look at methods for forecasting chemical prices and identify strategies for utilities to use in making their own forecasts.

5. **Developing an ongoing chemical market information service for the water supply and wastewater community**

Utilities are challenged with making decisions about chemical purchases with limited and sometimes outdated information. Chemical purchase contracts in most cases are negotiated infrequently, and therefore each utility needs to get up to speed with what is happening in the marketplace. There are also occasions to renegotiate agreement when significant prices changes occur.

The water and wastewater industry could benefit from sharing information on treatment chemical purchasing approaches and from systematically tracking information on treatment chemical markets. Such a service could keep current on changes in the market for each chemical and make the information available to utilities in a timely manner. This project would develop a repository, communication mechanism, and means of updating chemical supply (price and market outlook) information. Examples could include routine reporting on utility bid prices, market indicator performance, and alerts on supply issues. The communication mechanism might include a website or a newsletter.

Since this project needs to be ongoing, it could be approached in two stages. The first stage would involve a contractor developing the service, defining the information to be included, and developing the communication mechanism and update process. The second stage would be maintenance, and could be a service offered by a water industry organization such as AWWA, WEF, or AMWA, or maintained by a contractor as a fee for service system.
References


A. Information Gathered for Critical Water Treatment Chemicals, by Chemical or Chemical Group

A.1 Aluminum Coagulants

1. Uses in water and wastewater treatment

   a. Uses for the chemical
      Aluminum coagulants are used to destabilize and aggregate particles into larger masses to improve the extent and rate of their separation. The water and wastewater treatment separation processes aluminum coagulants are used in include clarification, thickening, flotation, and filtration. Aluminum compounds are also used to remove total organic carbon (TOC) and organics in drinking water plants and biochemical oxygen demand (BOD), phosphate, and sulfide odors in wastewater systems.

   b. Different formulations
      Aluminum coagulants include alum, aluminum chloride, and the family of PACl, which includes aluminum chlorohydrate (ACH). Alum is an acidic solution of aluminum sulfate in which the aluminum ions are unhydrolyzed. Aluminum chloride is the same as alum except the counter ion is chloride instead of sulfate. PACl is a diverse family of aluminum coagulants that contain partially hydrolyzed aluminum ions. The degree of hydrolysis is described as the PACl’s basicity. PACl typically ranges from 10% to 85% basicity, and the 70% to 80% products are most often used for raw water clarification. Most PACl are made from aluminum trihydrate and acid. Some contain some sulfate ions, which can enhance performance but decrease stability at the highest basicities. The highest basicity PACl (85%) is called ACH because it is made by an entirely different process that starts with aluminum metal and is more concentrated than most PACl. Because ACH requires a different manufacturing process, manufacturers of PACl from aluminum trihydrate do not usually also manufacture ACH. The amount of aluminum, the active ingredient, in PACl products expressed in terms of Al₂O₃ (alumina) content varies from about 10% to 24% (ACH). Other variations include the presence of calcium, phosphate, silicate, and as previously mentioned, sulfate. These constituents give rise to product descriptions such as PACl, chlorohydrate, chlorosulfate, hydroxychlorosulfate, and silicate-sulfate.

The shelf-life of PACl and ACH products varies significantly. Some should be used within one to three months. Generally, but not always, the stability decreases as the basicity and aluminum content increase. This is because as the basicity is increased, the
chemistry is being pushed closer and closer to the formation of aluminum hydroxide, which is an insoluble gel. The supplier’s product technical sheet should delineate the shelf-life and proper storage conditions.

ACH-polymer, PACl-polymer, and alum-polymer blends are sometimes offered, with the most common polymer used being epichlorohydrin dimethylamine (Epi-DMA) polyamines.

c. **Share of total chemical production used in the water market**

Based on sales, aluminum coagulants constitute about 20%–25% of the North American market for coagulants and flocculants for municipal and industrial water and wastewater treatment.

d. **Classification as commodity or specialty chemical**

i. **Alum** is a commodity chemical.

ii. **PACl**, including ACH products, are considered specialty chemicals. They have a wide variety of compositions, aluminum strengths, and basicities and exhibit different shelf-lives. Although one can often find more than one supplier with PACl products that perform similarly, this cannot be determined without laboratory testing and extended plant trials over a range of conditions.

2. **Distribution**

a. **Manufacturers**

i. **Alum**, General Chemical is the largest alum manufacturer. Geo Specialty Chemicals and Southern Ionics have several facilities, which are primarily located in the U.S. Gulf Coast and Southeast regions. There are a number of smaller (local) manufacturers. There are about 50 to 60 alum manufacturing plants in the United States and Canada. At least 56 firms in the United States and Canada market alum products that are certified under the American National Standards Institute (ANSI)/AWWA Standard 60 for potable water treatment.

ii. **PACl**, There are several manufacturers of PACl products in the United States and Canada that, collectively, operate 10 to 12 production facilities. Thus, there are about five alum plants for each PACl plant. There are at least 107 firms in the United States and Canada with PACl products that are certified under ANSI/AWWA Standard 60 for potable water treatment. The larger of these firms maintain their own drum storage or bulk shipping locations.

iii. **ACH**, Several manufacturers of ACH products in the United States and Canada collectively operate six to eight production plants. Thus, there are about eight alum plants for each ACH plant. There are at least 50 firms in the United States and Canada with ACH products that are certified under ANSI/AWWA Standard 60 for potable water treatment.
b. Distributors
   i. Alum is usually ordered in bulk from a manufacturer with a nearby manufacturing location. Drums are available from the manufacturers or chemical distributors.
   ii. PACl, PACl is usually ordered in bulk from a manufacturer. However, the differences between PACl product performances and compositions necessitate that the product with the best cost performance be determined by laboratory testing followed by plant trials. Thus, the nearest PACl manufacturer may not be the selected supplier.
   iii. ACH. There are fewer ACH manufacturing sites. The likely greater freight cost is offset by the product’s greater aluminum concentration, which is about double that of some PACl products. Some PACl manufacturers do not manufacture ACH. Therefore, it is up to the purchaser to make sure that ACH is evaluated if the preferred PACl supplier does not offer it. ACH products have a basicity of 80% to 85%, and PACl products do not usually reach 80% basicity. Do not assume a 75% basicity PACl is close enough to an 83% ACH to perform identically. Their manufacturing processes are different and produce different aluminum species. Some water plants find that simultaneous addition of a PACl and ACH gives better TOC removal, but ACH can sometimes lose effectiveness in cold water and is often more expensive. There are exceptions to all these statements. This is why PACl and ACH are considered specialty chemicals and why it is up to the purchaser to make sure they are all evaluated.
   iv. ACH-polymer blends. The higher concentration of ACH better allows ACH/polymer blends to be marketed. Typically, Epi-DMA polyamines or PolyDADMAC [Poly(diallyldimethylammonium chloride)] polymers are added. Blends can sometimes perform advantageously but are not usually economical except in small applications where separate storage and feeding of ACH and a polymer is not possible or practical.

3. Factors that influence supply and demand
   a. Aluminum coagulants are manufactured from
      i. Alum
         1. Aluminum sources
            a. Bauxite (chemical grade)
            b. High Al₂O₃ clay
            c. Aluminum trihydrate (a.k.a. aluminum hydroxide, hydrated Al₂O₃) from processed ore (bauxite)
            d. Aluminum hydroxide recovered from aluminum-containing industrial process streams
         2. Sulfuric acid
            a. Sulfur
ii. **Aluminum chloride**
   1. **Aluminum sources**
      a. Aluminum trihydrate (a.k.a. aluminum hydroxide, hydrated Al$_2$O$_3$) from processed ore (bauxite)
      b. Aluminum hydroxide recovered from aluminum-containing industrial process streams
   2. **Hydrochloric acid**
      a. Chlorine

iii. **PACI (PACI except ACH)**
    1. **Aluminum sources**
       a. Aluminum trihydrate (a.k.a. aluminum hydroxide, hydrated Al$_2$O$_3$) from processed ore (bauxite)
       b. Aluminum trihydrate recovered from aluminum-containing industrial process streams
       c. Aluminum chloride
       d. Sodium aluminate
          i. Aluminum source
          ii. Caustic soda (sodium hydroxide)
       e. Alum
    2. **Acids**
       a. Hydrochloric acid (see above)
       b. Sulfuric acid (see above)
       c. Phosphoric acid
    3. **Alkaline agents used to neutralize**
       a. Hydrated lime
       b. Calcium hydroxide
       c. Soda ash (sodium carbonate)
       d. Caustic soda (sodium hydroxide)
       e. Sodium aluminate
       f. Calcium chloride
       g. Calcium carbonate
       h. Calcium sulfate (CaSO$_4$) dehydrate

iv. **ACH**
   1. **Aluminum metal, which is made from**
      a. Al$_2$O$_3$
         i. Bauxite by the Bayer process
         ii. Caustic soda
      b. Electricity
      c. Cryolite
   2. **Hydrochloric acid (see above) and or aluminum chloride (see above)**
b. Key raw materials
   i. Alum
      1. Bauxite and other aluminum sources
      2. Sulfuric acid
   ii. PACl and aluminum chloride
      1. Aluminum trihydrate and other aluminum sources
      2. Hydrochloric acid
      3. Various alkaline agents
   iii. ACH
      1. Aluminum metal
      2. Hydrochloric acid
      3. Aluminum chloride

c. Cost drivers
   i. Gasoline. The low price per pound for most aluminum coagulants makes the freight
to deliver them a significant portion of the delivered price.
   ii. Bauxite is the major but not the only aluminum source for alum.
   iii. Sulfuric acid is a major raw material for alum.
   iv. Aluminum trihydrate is a major but not the only source of aluminum for aluminum
chloride and PACl.
   v. Hydrochloric acid is a major raw material for PACl and aluminum chloride.
   vi. Alkaline agents are major raw materials for PACl. The proprietary nature and
diversity of manufacturing formulas used by the manufacturers make it impossible to
identify any one alkaline agent as being representative of this raw material’s cost.
   vii. Aluminum metal is usually the major aluminum source for ACH. Aluminum has been
estimated to be about 2.5 to 4 times more expensive than the aluminum sources used
to make PACl and alum. However, this greater cost is partially offset by the reduced
product freight cost per pound of aluminum because of ACH’s higher concentration
and ACH manufacture’s reduced consumption of alkaline agents.

d. Impurities
   i. Alum
      1. Certification for drinking water application. Many suppliers provide alum that is
certified under ANSI/NSF Standard 60 for drinking water treatment up to a
specific maximum use level. The maximum use level specified for each alum
product, which for most liquid products was 150 milligrams per liter (mg/L) in
January 2009, varies because of differences in the product strengths (aluminum
content) and concentrations of impurities or other chemicals.
      2. AWWA standard. Check AWWA Standard B403 (latest version), Aluminum
Sulfate – Liquid, Granular, Lump, for impurity limits and other requirements and
guidelines.
ii. PACl
   1. Certification for drinking water application. Many suppliers provide PACl that are certified under ANSI/NSF Standard 60 for drinking water treatment up to a specific maximum use level. The maximum use level specified for each liquid PACl product, which for most products was 150 mg/L as of January 2009, varies because of differences in the product’s strength (aluminum content) and concentrations of impurities or other chemicals.
   2. AWWA standard. Check AWWA Standard B408 (latest version), Liquid PACl, for impurity limits and other requirements and guidelines.

iii. ACH
   1. Certification for drinking water application. Many suppliers provide ACH that are certified under ANSI/NSF Standard 60 for drinking water treatment up to a specific maximum use level. The maximum use level specified for each liquid ACH product, which for most products was 250 mg/L as of January 2009, varies because of differences in the product’s strength (aluminum content) and concentrations of impurities or other chemicals.
   2. AWWA standard. Check AWWA Standard B408 (latest version), Liquid PACl, which includes ACH, for impurity limits and other requirements and guidelines.

iv. Aluminum chloride
   1. Certification for drinking water application. Many suppliers provide aluminum chloride that is certified under ANSI/NSF Standard 60 for drinking water treatment up to a specific maximum use level. The maximum use level specified for each liquid aluminum chloride product, which ranged from 70 to 450 mg/L in January 2009, varies because of differences in the product’s strength (aluminum content) and concentrations of impurities.
   2. No AWWA standard. There is no AWWA standard for aluminum chloride because it is almost never used as an inorganic coagulant for municipal potable water treatment. It is occasionally used in industrial water or wastewater treatment. Its primary drinking water use is as a raw material for the manufacture of PACl and ACH.

c. Regulatory drivers of demand
   i. New and ongoing regulatory requirements that are being phased in tend to increase the number of substances removed or the extent of removal required. In some cases the best approach to meeting these water and wastewater quality requirements is to increase the dosages of existing coagulants or to use multiple coagulants. Many water and wastewater treatment facilities designed for the less stringent regulations of the past have been able to meet the new requirements by using inorganic coagulants and polymers. In wastewater treatment, using inorganic coagulants in the secondary clarification process can increase removals of some pollutants, including phosphorous, halogenated carbon precursors, and suspended solids. It is possible that
they will also increase the removal of some endocrine disruptor chemicals, a diverse group of emerging contaminants.

f. **Trends**
   i. **Prices.** The 2008 recession and subsequent drop in oil and natural gas prices should cascade through the raw material chain and cause a decrease in prices of aluminum coagulants in 2009.
   ii. **Consumption:** Short-term decrease. The recession of 2008 has reduced industrial production and, therefore, the demand for aluminum coagulants for industrial applications. Municipal applications should not be affected.
   iii. **Supply.** Supply is adequate. Because of industry consolidation, particularly with respect to alum, there are fewer manufacturers in some areas of the United States. Production capacity is adequate to meet demand.

4. **Purchasing alternatives and operational approaches to minimize cost**

   a. **Consider alum suppliers that use different aluminum sources**
      Ask the supplier for the aluminum source of the alum. Seek suppliers that use different aluminum sources. Put them all on your bid or quote list. Most alum manufacturers use bauxite. However, some use other aluminum sources. For example, Geo Specialty Chemicals has several facilities that use high Al₂O₃ clay. Aluminum hydroxide recovered from industrial waste streams is another source that is independent of bauxite.

   b. **Consider other aluminum coagulants**
      Whichever of the aluminum coagulants you are using, alum, PACl, or ACH, try the other two. If sulfuric acid prices have increased much more than bauxite, aluminum trihydrate, and aluminum metal, then PACl and ACH prices should increase less than alum prices. Both laboratory tests and a plant trial should be undertaken to determine which, if any, of the other aluminum coagulants will work. This is best done before the prices start to increase. Be aware that the nature of the sludge may and probably will change such that a different polymer may be needed for effective sludge dewatering.

   c. **Consider iron coagulants**
      Ferric chloride and ferric sulfate may be effective substitutes for an aluminum coagulant. You will need storage and feeding systems that are compatible with these coagulants. Ferric sulfate has less demanding requirements than ferric chloride. You may need to add alkalinity (caustic soda, lime, soda ash) to neutralize these highly acidic coagulants. If sulfuric acid has increased significantly in comparison to hydrochloric acid, ferric chloride could be less expensive, assuming there is adequate supply. Both laboratory tests and a plant trial should be undertaken to determine which, if either, of the iron coagulants will work. This is best done before prices start to increase. Be aware that the nature of the sludge may and probably will change such that a different polymer may be needed for effective sludge dewatering.
d. **Consider also adding a coagulant polymer**
Adding low doses [0.3 to 2 parts per million (ppm)] of an Epi-DMA polyamine or PolyDADMAC polymer has been shown to economically replace a portion (30%) of the inorganic coagulant, sometimes with better removal of color or other substances. Three to five different molecular weights of each of these polymer types are available. Use laboratory testing to determine which is best. Set the maximum polymer dose tested to be less than one third of the cost of the current inorganic coagulant’s cost. Conduct a plant trial to verify the polymer’s efficacy and its effect on any other treatment plant operations. This is best done before prices start to increase.

e. **Consider adding a coagulant aid polymer**
Adding low doses (0.05 to 0.1 ppm) of a high molecular weight polyacrylamide (PAM) polymer to build floc size may allow the inorganic coagulant’s dosage to be decreased. Laboratory tests should be used to select the best PAM product, which may be anionic, nonionic, or cationic in charge. Conduct a plant trial on the selected coagulant aid PAM. This is best done before prices start to increase. Be aware that carryover overdosed polymer can negatively affect downstream filters over an extended period of time. The dosages recommended here are generally believed to be low enough to avoid such effects.

f. **Cost indices**
A purchasing agent might track the following aluminum coagulant cost indices through appropriate trade magazines/services:

i. Gasoline (relative to delivery freight costs)
ii. Bauxite (alum)
iii. Sulfuric acid (alum)
iv. Aluminum trihydrate (PACl)
v. Hydrochloric acid (PACl, ACH)
vi. Aluminum metal (ACH)

A.1.1 **Bibliography**

This section lists the key documents that provided information for the treatment chemical summary above.


Kemira Water. Undated. PAX-XL1900 Product Information Sheet. Available: 


Niknam Chemicals. Undated. Aluminum Trihydrate. Available: 

NSF International. Undated. NSF Certified Drinking Water Treatment Chemicals. Available: 


A.2 Caustic Soda, Chlorine, Sodium Hypochlorite

1. Uses in water and wastewater treatment

   a. Uses for the chemical
      i. Sodium hypochlorite. Sodium hypochlorite is an important water treatment chemical used to generate aqueous chlorine for disinfection.
      ii. Caustic soda. Sodium hydroxide is used for pH and alkalinity adjustment of drinking water, for regeneration of ion exchange resins, and in precipitate softening.
      iii. Chlorine. Chlorine gas, which is commonly called a liquid because that is how it is sold in pressurized cylinders, is used as a disinfectant. Chlorine gas is sometimes used as an oxidant to facilitate manganese removal on filters or to remove organic substances. Although chlorine gas is less expensive than sodium hypochlorite, does not contain some of the impurities (chlorate, chlorite, perchlorate) present in sodium hypochlorite, and does not degrade in time as sodium hypochlorite does, its accidental (or deliberate) release is a major health and security concern. Use and storage of chlorine gas are subject to much greater regulatory reporting, fees, safety precautions, safety training, hazardous release training, and regulatory inspection than sodium hypochlorite. Consequently, many utilities, particularly smaller ones and those with facilities located in highly populated areas, have switched to sodium hypochlorite.

   b. Different formulations
      i. Sodium hypochlorite. Aqueous solutions of sodium hypochlorite contain 5%–15% available chlorine. The commercial sodium hypochlorite used for water treatment is usually 15%. Sodium hypochlorite may also be generated on-site.
      ii. Caustic soda. None.
      iii. Chlorine. Chlorine gas (liquid) is typically sold in either 150 pound or 1 ton cylinders. The weight refers to the amount of chlorine in the cylinder.

   c. Share of total chemical production used in the water market
      i. Caustic soda. Water treatment use constitutes 5% of total caustic soda use (Dow Chemical, 2006).
      ii. Chlorine and sodium hypochlorite. Drinking water and wastewater treatment represents approximately 2% of the total market for chlorine gas.

   d. Classification as commodity or specialty chemical
      i. Sodium hypochlorite. This is a commodity chemical in that it will initially perform the same from any responsible supplier from the perspective of providing hypochlorite ions. However, its impurities can vary significantly with the method of manufacture and raw materials used. The impurities can affect the rate of degradation as well as the amounts of bromate, a regulated contaminant, and chlorate, a contaminant anticipated to be regulated, introduced by the product’s use.
ii. **Caustic soda.** This is a commodity chemical in that it will perform the same from any responsible supplier.

iii. **Chlorine.** This is a commodity chemical in that it will perform the same from any responsible supplier. Because of the hazardous nature of this chemical, the supplier’s safety and security provisions and support can be an important purchasing consideration.

2. **Distribution**

   a. **Multiple suppliers exist for each of the three chemicals**

      i. **Sodium hypochlorite.** ANSI/NSF 60 certifications by approved certification companies include at least 56 firms and 136 production or shipping sites in the United States.

      ii. **Caustic soda.** ANSI/NSF 60 certifications by approved certification companies include at least 49 firms and many production or shipping sites in the United States.

      iii. **Chlorine.** ANSI/NSF 60 certifications by approved certification companies include at least 22 firms and 62 production or shipping sites in the United States.

   b. **Chemical distributors**

      A list of the top 100 chemical distributors in 2005 can be obtained by typing same into a Google.com search. A search of ICIS.com produced a list of 270 distributors of sodium hypochlorite.

   c. **Chlor-alkali plants**

      One source estimates that there are about 39 chlor-alkali plants in the United States, 7 of which use the mercury cell process in 2009.

3. **Factors that influence supply and demand**

   a. **Key raw materials**

      i. **Caustic soda (sodium hydroxide) and chlorine** are primarily manufactured by the chlor-alkali process, which entails the electrolysis of brine. The raw materials are:

         1. Sodium chloride
         2. Electricity

         Caustic soda is occasionally made by adding lime to soda ash at locations where soda ash is plentiful.

      ii. **Sodium hypochlorite** is primarily manufactured by adding chlorine gas to chilled caustic soda. The raw materials are:

         1. Chlorine
         2. Caustic soda
iii. Sodium hypochlorite is occasionally manufactured at the point of use for safety or other reasons by the electrolysis of brine under controlled conditions. The raw materials are:
1. Sodium chloride
2. Electricity
This process produces hypochlorite solutions that contain significant quantities of sodium chloride.

b. Cost drivers
i. Electricity. The simultaneous manufacture of chlorine and caustic soda requires significant quantities of electricity, which may constitute 40%–50% of production costs.

ii. Salt brine, rock salt (sodium chloride). The two largest uses of salt are in the chlor-alkali process for production of chlorine, caustic soda, and other chemicals and for the de-icing of roads in the winter. Road salt consumption, which usually uses only rock salt, is strongly dependent on the weather and takes place in the northern United States and Canada, yet many, but not all, of the salt deposits are in the southern United States. Some chlor-alkali plants use only salt brine solution. Raw materials represent 15% of the cost of production of chlorine and caustic.

iii. Chlorine and caustic soda. For each 2.25 tons of 50% caustic soda, the chlor-alkali process produces 1 ton of chlorine gas and consumes 1.72 tons of salt. Chlorine production is driven not only by chlorine demand but also by the demand for caustic soda. Because caustic soda can be much more easily stored than chlorine, chlorine prices can drop significantly if production exceeds demand. For example, supply snags combined with increased demand drove the price of diaphragm-grade caustic soda from $390 a ton in January 2008 to more than $600 a ton in July 2008 while chlorine prices remains flat or decreased. The largest use of chlorine is to make the precursors for PVC. PVC consumption, like many of the uses of caustic soda, tracks the GDP. Chlorine demand for pulp and paper manufacture has been greatly reduced because of environmental concerns of its generation of dioxin during the bleaching process. Consequently, some bleaching processes have been converted to using hydrogen peroxide, whose production uses caustic soda. The net result is increasing demand for caustic soda and decreasing demand for chlorine.

iv. Sodium hypochlorite. Most sodium hypochlorite is commercially manufactured by adding chlorine to caustic soda. Occasionally, consumers generate their own sodium hypochlorite on-site from salt to avoid having to purchase or store sodium hypochlorite or chlorine. However, on-site production of sodium hypochlorite is complex to operate and maintain, capital intensive, and often more expensive than purchasing the commercially available product, and can create unwanted impurities that are difficult to measure if the salt quality is not controlled or the process is not optimized.
c. **Impurities**  
   
   i. **Sodium hypochlorite**  
   
   1. *Certification for drinking water application.* Many suppliers provide sodium hypochlorite that is certified under ANSI/NSF Standard 60 for drinking water treatment up to a specific maximum use level. The maximum use level specified for each product varies because of differences in the strength of the sodium hypochlorite and the amount of contaminants present.  
   
   2. *AWWA standard.* Check AWWA Standard B300 (latest version), Hypochlorite, for impurity limits and other requirements and guidelines.  
   
   3. **Bromate.** One important contaminant is bromate, which is a regulated drinking water contaminant because it is considered a cancer risk and may pose risks to the liver and nervous system. According to The Chlorine Institute, Inc.’s November 19, 2004, article, “Bromate in Sodium Hypochlorite: Potable Water Treatment,” “Bromide ions are found in the salt used to make both chlorine and sodium hydroxide, the two raw materials for sodium hypochlorite.” “Virtually all of the bromine in chlorine and the bromide in sodium hydroxide quickly becomes bromated at the pH of NaOCl [sodium hypochlorite].” “The concentration of bromide varies tremendously in different salt sources.” Although some chlor-alkali plants can change their salt source, others cannot. “Current technology cannot easily or economically remove bromate or its precursor from either the initial salt, the two reactants [chlorine and caustic soda] or the final sodium hypochlorite solution.”  

   Three different chlor-alkali processes are used: the diaphragm cell process is widely used, the membrane cell process is growing in use, and the mercury cell process is being phased out in the United States because of mercury pollution. The “mercury cell and membrane cell plants tend to partition virtually all of the bromide from the salt into the chlorine while the diaphragm cell plants place most (70% to 80%) of the bromide into the sodium hydroxide.” “This information allows sodium hypochlorite manufacturers to select raw materials from processes and production sites that are lower in bromate precursors.” As of January 2009, most suppliers had their 12.5% strength sodium hypochlorite products certified under ANSI/NSF Standard 60 for maximum use levels of at least 45 mg/L, with many about twice this level and a few even higher. These levels are based on the assumption that no more than a certain chosen percentage of EPA Maximum Contaminant Level for bromate can come from the sodium hypochlorite. The intent is to decrease this chosen percentage over time, thereby reducing the maximum use levels.  

   4. **Bromate – water plants using ozonation.** Drinking water plants that both ozonate the water and add sodium hypochlorite must take special precautions to ensure that the bromate formed by ozonation of bromide in the treatment plant’s water is
Appendix A

not so great that the addition of bromate from sodium hypochlorite will cause them to exceed the Maximum Contaminant Level for bromate regardless of the sodium hypochlorite’s ANSI/NSF Standard 60 certified maximum use level.

5. Chlorate – water plants using chlorine dioxide. There is limited chronic toxicity data on chlorate. EPA has not established a maximum limit for chlorate in drinking water. Under the Disinfectants/Disinfection Byproducts Rule, EPA expressed its intention to set chlorate limits. Health Canada recommends that hypochlorite solutions “contain less than 1500 mg chlorate/L” (Environmental and Workplace Health, Chlorite and Chlorate in Drinking Water,” May 2005). Sodium hypochlorite manufactured by a continuous process often contains significantly less chlorate than that manufactured by a batch process. Drinking water plants that add chlorine dioxide and sodium hypochlorite should pay attention to the additive concentration of chlorate from chlorine dioxide, sodium hypochlorite, and other chemicals.

6. Perchlorate. Perchlorate is an emerging contaminant that one study found in 90% of sodium hypochlorite samples. Its concentration in the sodium hypochlorite increased with time.

7. Degradation – impurities and concentration. Sodium hypochlorite solutions degrade over time. The rate of degradation increases with increasing concentration, temperature, ultraviolet (UV) radiation (sunlight), and contaminants. The pH of sodium hypochlorite, best defined as the minimum and maximum amount of excess caustic soda present, is an important variable for minimizing degradation rates. Impurities of concern include the metals nickel, copper, and iron. All three accelerate the degradation processes. Iron also causes maintenance problems. Because these metals are usually present in particulate form, they can be substantially removed through filtration. The source of the metal can be the salt or the specific equipment used. For example, some methods of caustic soda production generate higher levels of nickel.

ii. Caustic soda (sodium hydroxide)

1. Certification for drinking water application. Many suppliers provide caustic soda that is certified under ANSI/NSF Standard 60 for drinking water treatment up to a specific maximum use level. The maximum use level specified for each product varies because of differences in the strength of the sodium hydroxide and the amount of contaminants present. As of January 2009, suppliers had their 50% strength sodium hydroxide products certified for maximum use levels of 100 to 200 mg/L.

2. AWWA standard. Check AWWA Standard B501 (latest version), Sodium Hydroxide, for impurity limits and other requirements and guidelines.

3. Bromide – water plants using ozonation. Bromide, which comes from the salt used in the chlor-alkali process, gets oxidized to bromate in water plants that practice ozonation downstream of where the caustic soda is added. Bromate is a
regulated drinking water contaminant. Sodium hydroxide manufactured in mercury cell and membrane cell chlor-alkali plants has lower bromide levels than caustic soda manufactured in diaphragm cell plants.

4. Chlorate – water plants using chlorine dioxide. EPA has not established a maximum legal limit for chlorate in drinking water but intends to. Drinking water plants that add chlorine dioxide and sodium hydroxide should pay attention to the additive concentration of chlorate introduced by chlorine dioxide, sodium hydroxide, and other chemicals.

5. Other impurities. The more common impurities in caustic soda – sodium chloride, sodium carbonate, sodium sulfate, potassium and low levels of iron, nickel and other metals – are not usually a concern in water or wastewater treatment.

iii. Chlorine
   1. Certification for drinking water application. Many suppliers provide chlorine that is certified under ANSI/NSF Standard 60 for drinking water treatment up to a specific maximum use level. The maximum use level specified for each product may vary because of differences in the strength of the chlorine sodium hydroxide and the amount of contaminants present. As of January 2009, most suppliers had their chlorine certified for a maximum use level of 30 mg/L.
   2. AWWA standard. Check AWWA Standard B301 (latest version), Liquid Chlorine, for impurity limits and other requirements and guidelines.
   3. Impurities. Chlorine needs to be free of organic substances that might form halogenated compounds with the chlorine. Check the AWWA standard for limits on impurities. The user should determine whether it desires any additional requirements with respect to impurity levels.

d. Trends
   i. Prices. The 2008 recession and subsequent drop in oil and natural gas prices and demand for sodium hydroxide and chlorine are resulting in decreasing prices of all three chemicals after substantial increases in caustic soda in 2007–2008.
   ii. Consumption
      1. Short-term decrease. The recession of 2008 reduced industrial production and, therefore, the demand for chlorine and sodium hydroxide for industrial applications. Municipal applications should be less affected
      2. Long-term increase. Consumption of sodium hydroxide and chlorine correlates to GDP growth. Hypochlorite bleaches were projected by one consulting firm to grow by about 2.2% to 3.3% a year, depending on the use, through 2010 (SRI Consulting, “Hypochlorite Bleaches,” James Glauser, August 2006).
iii. Supply
   1. Capacity (chlor-alkali process) is adequate. Supply depends on the demand for caustic soda and the demand for chlorine for PVC. Both tend to track the GDP. Because water and wastewater treatment usage of chlorine is not the largest usage, supply can be tight when there is a recession and GDP growth slows.
   2. Force majeures were declared by several major manufacturers in 2008 for caustic because of storms in the South and Northeast that knocked out power supplies. This happened in February as well as September (hurricanes). Companies supplied reduced volumes and the price increased. Storms combined with reduced operating rates because of reduced PVC demand have led to caustic shortages.
   3. The September 29, 2008, issue of Chemical Week stated, “The market, overall, is ‘shell-shocked’ by the disruptions and the full impact is not yet clear, sources say. Meanwhile, several scheduled outages are due at chlor-alkali plants in October. ‘Producers that have declared force majeure are going to have a hard time building inventory’ to accommodate outages, one source says. ‘Without a rebound for PVC in sight, the ability to increase operating rates will be limited for some.’”

4. Purchasing alternatives and approaches to minimize cost
   a. Sodium hypochlorite and chlorine
      Switching from one disinfectant to another generally requires far more important considerations than the cost of the chemicals. Disinfection byproducts and safety are some of those considerations. Although it is moderately capital intensive to switch from chlorine to sodium hypochlorite, it is highly capital intensive to install chlorine, ozone, or UV disinfection.
   b. Caustic soda
      Two widely used chemical alternatives to caustic are lime and soda ash. However, both require significant capital investment and are more work for the operations and maintenance staffs, particularly lime. That said, lime and soda ash can improve corrosion control compared to caustic soda in some circumstances. Changing to lime or soda ash should be considered only if there is such a benefit or a compelling reason other than short-term cost changes.
   c. Cost indices
      i. Sodium hydroxide (caustic soda), liquid 50%
      ii. Chlorine (liquid), one-ton cylinders
A.2.1 Bibliography

This section lists the key documents that provided information for the treatment chemical summary above.


Appendix A


A.3 Ferric Chloride

1. Uses in water and wastewater treatment
   
   a. Uses for the chemical
      Ferric chloride is used to destabilize and aggregate particles into larger masses to improve the extent and rate of their separation. The water and wastewater treatment separation processes ferric chloride is used in include clarification, thickening, flotation, filtration, and sludge dewatering. Ferric chloride is also used to remove TOC and organics in drinking water plants, and BOD, phosphate, and sulfide odors in wastewater systems.
   
   b. Different formulations
      None.
   
   c. Share of total market for the chemical
      Based on sales, iron salts (ferric chloride, ferric sulfate, and ferrous chloride and sulfate) constitute about 10%–15% of the North American market for coagulants and flocculants for municipal and industrial water and wastewater treatment.
   
   d. Classification as commodity or specialty chemical
      Ferric chloride is a commodity chemical. The active ingredient is consistent for each formulation, but the impurities may vary to an extent that may pose a concern.

2. Distribution
   
   a. Manufacturers
      Acquisition of smaller manufacturers has resulted in two major manufacturers in the United States and Canada, Kemira and PVS Chemicals, Inc. Kemira is the largest producer. Kemira and PVS have, collectively, at least eight major production locations in the United States and Canada as well as other manufacturing locations and bulk shipping terminals. Competition is expected to be greatest where both have nearby manufacturing locations, which includes the U.S. Midwest, Texas, and Georgia.
   
   b. Distributors
      Ferric chloride is usually purchased from a manufacturer but might be purchased from some chemical distributors. A list of the top 100 chemical distributors in 2005 can be obtained by typing same into a Google.com search.

3. Factors that influence supply and demand
   
   a. Ferric chloride is manufactured from
      i. Scrap steel and hydrochloric acid
      ii. Higher grade scrap steel and hydrochloric acid
      iii. Oxidation of waste pickle liquor ferrous chloride from steel processing
iv. Titanium oxide processing when hydrochloric acid is used
v. Iron ore and hydrochloric acid (not believed to be widely used)

b. Key raw materials
i. Scrap steel
ii. Hydrochloric acid
iii. Waste pickle liquor from steel processing

c. Cost drivers
i. Energy. Energy is cost driver in two ways:
   1. Freight. Ferric chloride’s relatively low price per pound and smaller number of
      manufacturing sites compared to alum make the freight cost to deliver the product
      to the user a significant cost driver.
   2. Hydrochloric acid. About 50% of the cost to produce chlorine, which is used to
      make hydrochloric acid, is electricity consumption. However, because chlorine
      prices can vary for reasons other than electricity (see below) and hydrochloric
      acid is less of a cost factor than the iron source, ferric chloride can be considered
      to not be highly dependent on energy costs.

ii. Oil. Oil and oil related products are not consumed in the manufacture of ferric
     chloride, but gasoline prices are a significant factor in the freight cost to deliver the
     product to the user.

iii. Raw materials. Raw materials are major cost drivers, but forecasting their costs can
     be difficult.
   1. Scrap steel. Scrap steel prices vary widely for many reasons, including supply,
      demand (including China), quality, and market forces. Prices increased from
      about $100 per ton to as much as $1,000 a ton in 2008 and then decreased by 35%
      to 70% by early 2009.
   2. Chlorine. Chlorine, which is used to manufacture hydrochloric acid, is produced
      by the chlor-alkali process in which electricity flows through a sodium chloride
      solution. The process produces equal molar amounts of chlorine and sodium
      hydroxide (caustic soda). Sodium hydroxide can be stored in significant
      quantities, but chlorine cannot. Thus, chlorine prices can vary widely depending
      on sodium hydroxide demand.

d. Impurities
Although ferric chloride is a commodity chemical in that it will perform the same from
different manufacturers subject to differences in their iron concentration, the different
manufacturing methods used to make ferric chloride employ byproduct streams or scrap
steel. These can introduce significant differences in the levels and types of impurities
present. This is particularly important for potable water treatment.

i. Both Kemira and PVS sell ferric chloride that is approved for potable use by the NSF
   and meets the requirements of ANSI/AWWA Standard B407 (latest version), Liquid
   Ferric Chloride.
ii. The user should check the AWWA standard for recommended limits on impurity levels.

iii. The user should determine whether it desires any additional requirements with respect to impurity levels.

iv. Ferric chloride produced from titanium dioxide can contain high concentrations of manganese, and other metals.

v. Scrap steel can contain chrome, nickel, and other metals if stainless steel is present and lead and copper if electrical cable or components are present. Oil or hydrocarbons on the scrap steel can cause the formation of halogenated organic compounds. Number one bundles of scrap steel are supposed to be free of cable, stainless steel, and oil.

vi. One possible source of contamination is residual material from previous shipments of other, possibly harmful, substances that have not been adequately cleaned from the bulk truck used to deliver the ferric chloride.

vii. The user should establish a program of immediate sampling of delivered product, sample retention, quality control testing at the time of delivery even if only visible inspection and smell (and possibly density/specific gravity), and periodic quality control testing by an outside laboratory for the heavy metals, organic compounds, and other contaminants listed in the AWWA standard.

e. Regulatory drivers of demand

i. The EPA Disinfectants/Disinfection Byproducts Rule, which initiated mandatory removals of TOC in 2002–2003, has caused water treatment plants to use greater concentrations of inorganic coagulants. Sometimes, ferric coagulants perform better than aluminum coagulants in this regard. Use of ferric salts has increased and continues to grow from both drivers.

ii. The EPA Stage 2 Disinfectants/Disinfection Byproducts Rule, which went into effect in 2006, effectively decreased the maximum allowable levels of trihalomethanes (THMs) and haloacetic acids (HAA5s). This will cause some water treatment plants to have to further reduce TOC levels by adding greater concentrations of inorganic coagulants or exploring the use of iron coagulants if they have not already done so.

iii. Future regulation of endocrine disrupting chemicals (EDCs) in the United States and further regulation in Canada is likely to be approached from two directions – reduction of the use of such chemicals in household and industrial products and increased removal of EDCs in wastewater treatment plants. Iron salts may prove a cost-effective means of increasing removal.

iv. Increased phosphorus control regulations for wastewater and expected regulations for emerging pollutants of concern may expand the use of inorganic coagulants. Sometimes ferric coagulants may perform better than aluminum coagulants in this regard.
f. Trends
i. Recession. The recession of 2008 reduced the production of steel that makes waste pickle liquor (ferrous chloride) available, thereby limiting ferric chloride production at manufacturing locations that use pickle liquor. Although prices should decrease in 2009 as a result of decreasing scrap steel prices, the decreased supply of ferric chloride could support higher prices.

ii. Consumption
1. Short-term decrease. See Recession, above. If prices stay relatively higher than aluminum coagulants and supplies remain tight, ferric chloride users may be able to or have to switch to ferric sulfate or an aluminum coagulant.
2. Long-term increase. The ratio of sulfate to chloride is recognized as one factor in managing the corrosivity of drinking water toward lead containing metals. This could cause a switch to ferric sulfate in water plants experiencing lead corrosion problems that have not been controlled by other approaches.
3. Increasing emphasis in wastewater treatment on phosphorous removal is increasing demand for ferric chloride.

iii. Supply
1. Short term, the limited availability of waste pickle liquor will decrease supply until more manufacturing capacity using scrap steel is installed or steel production increases in the United States.

4. Purchasing alternatives and approaches to minimize costs

a. Chemical-specific approaches
i. Ferric sulfate. Ferric chloride’s costs are driven by different factors than ferric sulfate, although both products are freight intensive, so proximity to a manufacturing site is a major cost driver. If the user has conducted laboratory and plant testing to verify that both products work satisfactorily and has storage and feeding facilities suitable for both chemicals (ferric chloride cannot be exposed to stainless steel, ferric chloride and ferric sulfate cannot be mixed), the user can switch from ferric chloride to ferric sulfate based on price swings. For example, in 2008, huge increases in sulfuric acid prices drove the price of ferric sulfate up more than ferric chloride. The composition of the particular water can determine whether ferric chloride or ferric sulfate works on an equivalent iron dosage basis.

ii. Aluminum coagulants. The use of ferric chloride may be able to be replaced by an aluminum coagulant such as alum or one of the PACI including ACH. Laboratory and plant testing is needed, including consideration of the effects of cold water temperatures, when ACH is sometimes known to be less effective. Aluminum and iron coagulants should not be mixed. Ferric chloride is highly corrosive and requires appropriate storage and feeding facilities that do not contain stainless steel components.
b. Cost indices
   A purchasing agent might track the following cost indices through appropriate trade
   magazines/services:
   i. Chlorine (liquid, 1 ton cylinder or larger)
   ii. Scrap steel (no. 1 bundle)
   iii. Gasoline (relative to delivery freight costs)

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PVS Chemicals. Undated (b). PVS Product Literature. Available:
A.4 Ferric Sulfate

1. Uses in water and wastewater treatment

   a. Uses for the chemical
      Ferric sulfate is used to destabilize and aggregate particles into larger masses to improve
      the extent and rate of their separation. The water and wastewater treatment separation
      processes ferric sulfate is used in include clarification, thickening, flotation, filtration,
      and sludge dewatering. Ferric chloride is also used to remove TOC and organics in
      drinking water plants, and BOD, phosphate, and sulfide odors in wastewater systems.

   b. Different formulations
      None.

   c. Share total chemical production used in the water market
      Based on sales, iron salts (ferric chloride, ferric sulfate, and ferrous chloride and sulfate)
      constitute about 10%–15% of the North American market for coagulants and flocculants
      for municipal and industrial water and wastewater treatment.

   d. Classification as commodity or specialty chemical
      Ferric sulfate can be classified as a commodity chemical. The active ingredient is
      consistent for each formulation but the impurities may vary to an extent that may pose a
      concern.

2. Distribution

   a. Manufacturers
      Acquisition of smaller manufacturers has resulted in two major manufacturers in the
      United States and Canada, Kemira and General Chemical. Kemira is the larger producer.
      Kemira and General Chemical have, collectively, at least five or six major manufacturing
      sites and a number of other bulk shipping terminals in the United States and Canada.
      Competition is expected to be greatest where both have nearby major manufacturing
      locations, which includes the Texas area.

   b. Distributors
      Ferric sulfate is usually purchased from a manufacturer but might be purchased from
      some chemical distributors. A list of the top 100 chemical distributors in 2005 can be
      obtained by typing same into a Google.com search.

3. Factors that influence supply and demand

   a. Ferric sulfate is manufactured from iron ore and sulfuric acid
      Different iron ores are used and each has its advantages and disadvantages
b. Key raw materials
   i. Iron ore (magnetite, hematite)
   ii. Sulfuric acid

c. Cost drivers
   i. Energy is a cost driver in two ways
      2. Freight. Ferric sulfate’s relatively low price per pound and fewer manufacturing
         sites compared to alum make the freight cost to deliver the product to the user a
         significant cost driver.
      3. Production. Manufacture requires heating the ore and sulfuric acid, and the heat
         can be partially recovered. Because the costs of iron ore and sulfuric acid are
         more significant cost drivers, ferric sulfate can be considered to not be highly
         dependent on energy costs.
   ii. Oil and oil related products are not consumed in the manufacture of ferric sulfate, but
       gasoline prices are a significant factor in the freight cost to deliver the product to the
       user.
   iii. Raw materials are the major cost drivers, but forecasting their costs can be difficult:
       1. Iron ore. Almost 80% of the world supply of iron ore is produced by three firms,
          Vale of Brazil with 38% of the market, Rio Tinto, and BHP Billiton. Because of
          this concentration of supply, the three firms have previously been able to set the
          price for most iron ore annually. The 2008 price, for example, was about 85%
          greater than 2007. However, the spot prices dropped 30% in early 2009 as a result
          of the recession, and the existence of a spot market has increased. When the 2008
          prices expire in April 2009, iron ore prices are expected to decrease significantly
          because of decreased steel product, as evidenced by the fact that 17 of the 24 blast
          furnaces in the United States were shut down in November 2008 and have not
          been restarted as of February 2009.
       2. Sulfuric acid. The raw material, sulfur, is a byproduct of oil refining and some
          metals smelting. The deindustrialization of the United States has resulted in
          decreased supply. Canadian smelters are a major source. Consumption has
          increased because of the growth of ethanol production for two reasons. First,
          sulfuric acid is used to generate phosphoric acid for fertilizer from phosphate
          rocks, and half of the U.S. phosphate fertilizer production is used for growing
          corn. Second, sulfuric acid is used in the ethanol production process. In 2008, spot
          prices for sulfuric acid reached $400 per ton after some sulfuric acid was sold for
          as low as $50 a ton a year or two earlier. By January 2009, the recession had
          caused prices to decrease to the $200–$300 per ton range.

d. Impurities
   Although ferric sulfate is a commodity chemical in that it will perform the same from
   different manufacturers subject to differences in their iron concentration, the different
   iron ores used to manufacture ferric sulfate can introduce some differences in the levels
   and types of impurities or the amount of free acid present.
i. Both major suppliers provide products that are approved for potable water use by NSF and that meet the requirements of ANSI/AWWA Standard B406 (latest version), Liquid Ferric Sulfate.

ii. The user should check the AWWA Standard for limits on impurity levels.

iii. The user should determine whether it desires any additional requirements with respect to impurity levels.

iv. One possible source of contamination is residual material from previous shipments of other, possibly harmful, substances that have not been adequately cleaned from the bulk truck used to deliver the ferric sulfate.

v. The user should establish a program of immediate sampling of delivered product, sample retention, quality control testing at the time of delivery even if only visible inspection and smell (and possibly density/specific gravity), and periodic quality control testing by an outside laboratory for the heavy metals and other contaminants listed the AWWA standard.

e. Regulatory drivers of demand

i. The EPA Disinfectants/Disinfection Byproducts Rule, which initiated mandatory removals of TOC in 2002–2003, has caused water treatment plants to use greater concentrations of inorganic coagulants. Sometimes, ferric coagulants perform better than aluminum coagulants in this regard. Use of ferric salts has increased and continues to grow from both drivers.

ii. The EPA Stage 2 Disinfectants/Disinfection Byproducts Rule, which went into effect in 2006, effectively decreased the maximum allowable levels of THMs and HAA5s. This will cause some water treatment plants to further reduce TOC levels by adding greater concentrations of inorganic coagulants or exploring the use of iron coagulants if they have not already done so.

iii. Future regulation of EDCs in the United States and further regulation in Canada is likely to be approached from two directions – reduction of the use of such chemicals in household and industrial products and increased removal of EDCs in wastewater treatment plants. Iron salts may prove a cost-effective means of increasing removal.

f. Trends

i. Recession. The recession of 2008 reduced steel production and, therefore, the demand for iron ore, causing iron ore prices to decrease. Similarly, sulfuric acid prices have plummeted, although a deepening recession could shut down some metal smelters that produce much of the sulfuric acid. Ferric sulfate prices should decrease in 2009 as a result.

ii. Consumption

1. Short-term decrease. In 2008, significant price increases for both major raw materials increased ferric sulfate prices significantly. Ferric sulfate thus became less competitive with some other inorganic coagulants. Normally, this would decrease demand because some users would switch to other, relatively less expensive coagulants. For example, ferric sulfate users with storage and feed
systems that can handle ferric chloride would switch to that coagulant. However, the decline in steel production in 2008–2009 caused a shortage in one of ferric chloride’s raw materials, waste pickle liquor, reducing the supply of that coagulant. This has had the opposite effect, causing some ferric chloride users to switch to ferric sulfate regardless of price. On the other hand, some ferric sulfate users may be able to switch to an aluminum coagulant such as one of the family of PACl coagulants.

2. Long-term increase. The ratio of sulfate to chloride is recognized as one factor in managing the corrosivity of drinking water toward lead containing metals. This could cause a switch to ferric sulfate in water plants experiencing lead corrosion problems that have not been controlled by other approaches.

iii. Supply. Supply is adequate. If manufacturers see sustained demand increases or believe areas of the country not now locally served present opportunities for growth, they will increase capacity at existing production sites or construct new production sites or new bulk terminals.

4. Purchasing alternatives and approaches to minimize cost

a. Aluminum coagulants
The use of ferric sulfate may be able to be replaced by an aluminum coagulant such as alum or one of the PACl, including ACH. Laboratory and plant testing is needed, including consideration of the effects of cold water temperatures, when ACH is sometimes known to be less effective. Aluminum and iron coagulants should not be mixed. Ferric sulfate storage and feeding facilities may be suitable for alum, but the presence of chloride ions in PACl products necessitates the absence of stainless steel.

b. Ferric chloride
Ferric chloride’s costs are driven by different factors than ferric sulfate, although both products are freight intensive, so proximity to a manufacturing site is a major cost driver. If the user has conducted laboratory and plant testing to verify that both products work satisfactorily and has storage and feeding facilities suitable for both chemicals (ferric chloride cannot be exposed to stainless steel, ferric chloride and ferric sulfate cannot be mixed), the user can switch from ferric sulfate to ferric chloride based on price swings. The composition of the particular water can determine whether ferric chloride or ferric sulfate works on an equivalent iron dosage basis. This purchasing alternative is currently not viable until the supply of ferric chloride increases. This could occur from an increase in steel production in the United States or from conversion of ferric chloride production to the use of scrap steel from the use of waste pickle liquor.
c. **Cost indices**
   A purchasing agent might track the following ferric sulfate cost indices through appropriate trade magazines/services:
   i. Sulfuric acid (bulk)
   ii. Hematite ore and magnetite ore (delivered to New Orleans or some other southern port)
   iii. Gasoline prices (relative to delivery freight costs)

A.4.1 **Bibliography**
This section lists the key documents that provided information for the treatment chemical summary above.


A.5 Fluoride

1. Uses in Water and Wastewater Treatment
   
a. Uses for the chemical
   Fluoride chemicals are used as an additive to improve dental condition. In many source settings, fluoride exists in raw water and in some cases at levels that require removal rather than addition. Adding fluoridation chemicals to drinking water dates back to 1945 in the United States. Current fluoridation practice is approximately 69%–70% of the U.S. population served by Community Water Systems (CWS) based on 2006 data from Centers for Disease Control and Prevention (CDC). Fluoridation use varies significantly within and across states, from a high of 100% (District of Columbia) to a low of 8.4% (Hawaii) (CDC, 2006). The Healthy People 2010 (www.healthypeople.gov) initiative includes a fluoridation goal of 75% of CWS population served. Although not yet available, CDC’s 2008 data are expected to show an increase over 2006 data.

b. Different formulations
   Three different chemicals are used in fluoridating drinking water:
   i. Fluorosilicic acid (FSA). A water-based solution used by most water fluoridation programs in the United States. FSA is also referred to as hydrofluorosilicic acid or hydrofluorosilicate. FSA is available at 20% to 40% aqueous solution H₂SiF₆. The most common concentration used in water treatment is 23%–25% (AWWA, 2004).
   ii. Sodium fluorosilicate (SFS). A dry additive that comes largely from FSA, dissolved into a solution before being added to water.
   iii. Sodium fluoride (SF). A dry additive that comes mainly from FSA, typically used in small water systems, dissolved into a solution before being added to water.
   FSA is by far the most used because it is relatively easy to use; it is thought to constitute more than 80% of total water treatment use. The two dry forms make up the remainder. SFS in particular offers opportunity for use in the future as an available, lower cost, quality product, but its use will require educational, equipment, and operating changes to convert from liquid product use.

c. Share of total chemical production used in the water market
   There are competing uses for FSA: for example, photovoltaic panel production, computer chip manufacture, aluminum manufacture, glass flux processing. In 2007, sale of FSA for water treatment in the United States was approximately 80% of total FSA use (derived from USGS, 2008).

d. Classification as commodity or specialty chemical
   Fluoride formulations are a commodity chemical. The active ingredient is consistent for each formulation, but the impurities may vary to an extent that may pose a concern.
2. Distribution

   a. Manufacturers

   Fluoride additives are produced by several manufacturers, and it is not common for all the suppliers to be negatively affected equally when production problems occur.

   Major producers of FSA include but are not limited to Spectrum Chemical Mfg Co., Solvay Chemicals, JR Simplot Company, and Mosaic Company, although further investigation is warranted. Production also occurs as a byproduct of other mining operations on a market basis. More investigation is suggested to more firmly establish manufacturing and distributor involvement with fluoridation chemicals.

   All FSA is produced in North America. Approximately half of SFS is produced in the United States and is dependent on FSA production, though good quality SFS can be produced from lesser quality FSA than is normally desired for direct use in treatment. The remaining SFS is produced outside the United States. Virtually all SF comes from Asian producers.

   b. Distributors

   LCI and Univar are large distributors. A list of 15 suppliers of FSA in the United States is available from www.icis.com:


3. Factors that influence supply and demand

   a. Key raw materials

   In the United States, most fluoridating agents are produced from phosphorite rock. Phosphorite is a mixture of apatite (a mineral high in phosphate and fluoride), calcium phosphate, and limestone minerals (calcium carbonates). When phosphorite rock is heated with sulfuric acid, it produces a slurry of phosphoric acid and gypsum (CaSO₄).

   The heating releases hydrogen fluoride (HF) and silicon tetrafluoride (SiF₄) gases. The gases are then captured and condensed into a water based solution comprising 23% FSA.

   This heating process produces 95% of the FSA used in water treatment. The other 5% comes as a byproduct from two sources: HF manufacturing and HF application during the manufacture of solar panels.

   FSA has been the main fluoridating additive in the United States since the early 1950s, largely because of the high purity and low cost. Other dry fluoridating additives are derived from FSA, including SFS and SF.
FSA can be neutralized by applying sodium chloride or caustic soda to produce SFS. And if the SFS is entirely neutralized, SF will be formed. In the United States, about 90% of the SF is derived from FSA [CDC, Undated (a)].

b. Common impurities, contamination sources

Along with testing for compliance with NSF/ANSI standard 60, fluoridating agents are tested for impurities, including radionuclides, lead, and arsenic.

The presence of arsenic in fluoride additives is the most common concern regarding water fluoridation. However, quality testing conducted by NSF rarely detects any arsenic. Samples that test positive for arsenic contain only about 1.2% of EPA’s permissible level of arsenic (EPA allows 10 parts per billion of arsenic in drinking water).

Testing for other impurities such as metals shows even lower levels: 1% to 3% of fluoridating agents contained detectable levels of metals, resulting in an estimated exposure less than 0.1% of EPA’s allowable exposure [CDC, Undated (b)].

c. Competing uses

i. General. Though demand for fluoride products has shifted over the past 20 years or so, the supply has remained relatively constant. Glass flux processors and aluminum manufacturers used to make up a large part of the market for fluoride products in the United States. Since the 1980s, many glass flux processors have switched to fluxes not requiring fluoride products, and aluminum manufacturers have closed down. This decrease in demand left the fluoride industry with little incentive to increase production capacity. In the past decade, however, new applications for FSA developed, such as the manufacture of solar panels and computer chips. These new uses have increased demand to the extent that a market surplus no long exists. It is thought that it will take at least one to three years for production capacity to increase to levels able to sustain current demands [CDC, Undated (b)].

ii. FSA. As a 1–2% solution, FSA is used widely for sterilizing equipment in brewing and bottling. Other concentrations of FSA solutions are used in electrolytic refining of lead, in electroplating, for hardening cement, for crumbling lime or brick work, for removal of lime from hides during the tanning process, for removal of molds, and as a preservative for timber (ATSDR, 2003).

iii. SFS. This chemical is also used in enamels for china and porcelain, in the manufacturing of opal glass, as an insecticide, as a rodenticide, and for mothproofing of wool. It is also an intermediate in the production of synthetic cryolite (ATSDR, 2003).

iv. SF. SF is also used as a flux for deoxidizing rimmed steel, as a component of laundry sours (removal of iron stains), and in the resmelting of aluminum, manufacture of vitreous enamels, pickling of stainless steel, wood preservative compounds, casein glues, manufacture of coated papers, and heat treating salts (ATSDR, 2003).
d. **Supply trends**

i. **Shortages.** In the United States, there are more shortages of liquid FSA than dry fluoride additives such as SFS and SF. This trend, it seems, has little to do with logistical complications. Half of the supply of SFS comes from a single American producer and the other half from imported Asian sources. If the single domestic supplier cannot produce at expected capacity for whatever reason (maintenance, process inefficiencies) or a sudden increase in demand occurs, it may take several weeks to procure an increase in imports to meet demands. The majority of SF used in America is imported from Asia and is also vulnerable to shortages because of the lag time between demand increases and receipts of shipments. In contrast, 100% of the liquid FSA used in drinking water is produced North America, offering much broader facility conditions and less complex logistical issues.

The production of fluoride additives occurs in only a few areas of the United States, and supplies are normally transported via railways. Plant maintenance (taking production off-line) and variations in raw materials (decrease in process efficiency) can also reduce productivity, causing shortages. Shipments can be delayed during inclement weather, either at points of production or at delivery, causing short-term regional shortages. Particularly in Florida, the largest producer of fluoride additives, intense storms and hurricanes can cause shipment delays and thus shortages. Changes in the market for fertilizer such as global demand for fertilizer, exchange rates, and prices for raw materials can also shift the production of fluoride additives [CDC, Undated (b)].

ii. **Color.** The AWWA Standards Committee researched the color requirements in the AWWA B703 standard. Some producers recommended the color limit be increased above 100 units. The committee concurred and increased the color limit to 200 units; it then produced an addendum reflecting this change. It is hoped this change will allow more supply from geological settings with higher natural color constituents. It may provide future benefit of increased supply (Kip Duchon, Centers for Disease Control and Prevention, personal communication, January 30, 2009).

4. **Purchasing Alternatives and Approaches to Minimize Costs**

a. **Chemical-specific approaches**

i. **Storage.** Shortages of fluoride additives occur most often in the summer. Utilities can see water demand increase 50% during the summer, and without proper storage, can be running out of fluoride additives before the end of the season. It is recommended to plan ahead by scheduling an additional delivery in the summer months or by storing maximum inventory at the beginning of summer. Holding inventories over six months is not ideal and should be avoided, particularly for dry additives [CDC, Undated (b)].
A.5.1 Bibliography

This section lists the key documents that provided information for the treatment chemical summary above.


A.6 Phosphate-Based Corrosion and Scale Inhibitors

1. Uses in water and wastewater treatment
   
   a. Uses for the chemical
   Phosphates are used in water treatment to control corrosion and scale.
   
   b. Different formulations
   Phosphate based scale control and corrosion inhibitors, hereafter referred to only as corrosion inhibitors, include a diversity of products from many companies. One of the reasons for the diversity of products is the diversity of phosphates available. A brief summary of the types and phosphate compound names used for many of the products certified under ANSI/NSF Standard 60 for use for potable water treatment as well as by the applicable ANSI/AWWA standards follows:
   
   i. Phosphates containing one phosphorous atom
   1. Phosphoric acid (trihydrogen phosphate)
   2. Monosodium orthophosphate [AWWA Standard B504 (latest version), Monosodium Phosphate, Anhydrous]
   3. Dipotassium orthophosphate
   4. Trisodium orthophosphate
   5. Disodium orthophosphate [AWWA Standard B505 (latest version), Disodium Phosphate, Anhydrous]
   6. Monopotassium orthophosphate
   7. Tripotassium orthophosphate
   
   ii. Phosphates containing two phosphorous atoms
   1. Tetrapotassium pyrophosphate
   2. Tetrasodium pyrophosphate
   3. Sodium acid pyrophosphate
   
   iii. Phosphates containing three phosphorous atoms
   1. Sodium tripolyphosphate [AWWA Standard B503 (latest version), Sodium Tripolyphosphate]
   2. Sodium trimetaphosphate
   3. Potassium tripolyphosphate
   
   iv. Phosphates primarily containing more than three phosphorous atoms
   1. Sodium polyphosphates, glassy (sodium hexametaphosphate) [AWWA Standard B502 (latest version), Sodium Polyphosphates, Glassy (sodium hexametaphosphate)]
   
   v. Phosphates containing multiple phosphorous atoms
   1. Polyphosphoric acids (at least three different products)
   
   vi. Zinc-phosphate/polyphosphate blends
   1. Zinc orthophosphate [AWWA Standard B506 (latest version), Zinc Orthophosphate]
2. Zinc polyphosphate.
The underlined compounds directly above are those most widely certified for potable water treatment as corrosion and scale inhibitors. The use of potassium rather than sodium salts is most likely driven by price and availability. Their primary uses are for fertilizer and food additives where potassium salts are often desirable. One exception where a water system may desire a potassium salt is when the raw water contains high sodium levels, requiring them to avoid adding more sodium when they add treatment chemicals.

c. Share of total chemical production used in the water market
   Water treatment uses of phosphates comprise less than 3% of phosphate production (World Phosphate Institute, 2006).

d. Classification as commodity or specialty chemical
   i. Blends. Although one can often find more than one supplier with corrosion products that contain the same or similar contents of orthophosphate and polyphosphate, zinc and ortho- or polyphosphates, or other blends, using these products involves considering multiple variables such that the experience and expertise of the supplier’s technical representative can be and often are important. Thus, these products are considered to be specialty chemicals.
   ii. Phosphoric acid. Phosphoric acid, which comes in different concentrations, is a commodity chemical.
   iii. Phosphate products. The various phosphate-containing corrosion inhibitors and scale control agent products are typically purchased from specialty chemical firms.

2. Distribution

a. Manufacturers
   i. Orthophosphates. At least 20 firms in the United States and Canada supply corrosion inhibitor products certified for drinking water use under ANSI/NSF Standard 60 as containing monosodium orthophosphate. These 20 firms represent an estimated 11 bulk shipping locations.¹
   ii. Sodium polyphosphates, glassy (sodium hexametaphosphate). At least 49 firms in the United States and Canada supply corrosion inhibitor products that are certified for drinking water use under ANSI/NSF Standard 60 as containing sodium hexametaphosphate. These 49 firms represent an estimated 24 bulk shipping locations.
   iii. Tetrapotassium pyrophosphates. At least 41 firms in the United States and Canada supply corrosion inhibitor products that are certified for drinking water use under ANSI/NSF Standard 60 as containing tetrapotassium pyrophosphate. These 41 firms

¹. Multiple firms ship from the same shipping location.
represent an estimated 16 bulk shipping locations. There are three primary manufacturers of this phosphate in the United States.

iv. Zinc orthophosphates. At least 46 firms in the United States and Canada supply corrosion inhibitor products containing zinc orthophosphate that are certified for drinking water use under ANSI/NSF Standard 60. These 46 firms represent an estimated 16 bulk shipping locations. These products differ in their ratios of zinc to phosphate as well as whether they use zinc chloride or zinc sulfate. The chloride products are more soluble but also more corrosive and hazardous to handle. The sulfate products are less corrosive and hazardous to handle but less soluble and stable.

v. Other phosphates. Of the 17 different phosphates certified for potable water use listed in the beginning of Section A.6 under “different formulations,” 5 are sold by at least 20 firms, 2 are sold by at least 10 firms, and the remaining 10 are sold by a small number of firms. Competition for these 10 phosphates is, therefore, limited. On the other hand, there may not be definitive data to demonstrate that these less-frequently offered phosphates perform differently than the more frequently sold ones.

b. Distributors
   i. Phosphoric acid. As a commodity chemical, phosphoric acid can be purchased from any chemical distributor. A list of the top 100 chemical distributors in 2005 can be obtained by typing same into a Google.com search.
   ii. Phosphate products. The various phosphate-containing corrosion inhibitors and scale control agent products are typically purchased from specialty chemical firms.

3. Factors that influence supply and demand

a. Phosphate corrosion inhibitors are manufactured from
   i. Phosphates and phosphoric acids, which are manufactured from:
      1. Phosphate rock (ore)
      2. Sulfuric acid, which is made from sulfur
      3. Sodium sulfates (sodium salts) or potassium sulfates (potassium salts)
   ii. Zinc chloride or sulfate, which is made from:
      1. Zinc
      2. Hydrochloric or sulfuric acid

b. Key raw materials
   i. Phosphate rock
   ii. Sulfuric acid
   iii. Zinc

c. Cost drivers
   i. Agricultural fertilizer supply and demand. Worldwide, about 80% of the use of phosphates is for agricultural fertilizers. Food and detergents comprise another 17% of phosphate production. Water treatment corrosion inhibitors account for a small percentage of the remaining 3% of production. Consequently, phosphate prices are
driven by agricultural fertilizer demand. From 2007 to September 2008, phosphate prices increased 120% because worldwide grain production increased 10% since 2006. In the United States, increased corn production, which requires substantial amounts of fertilizer, also contributed to increasing prices.

There also has been a consolidation of phosphate producers. Morocco has 75% of the world’s phosphate rock reserves. Phosphate prices started to decrease in September 2008 and have rapidly decreased back to the level they were a few years ago. Phosphoric acid production was stopped in late 2008 until February 2009 because of the glut of unsold phosphate. This could cause shortages of polyphosphates. The forecast for phosphate prices is uncertain because production has decreased along with the falling prices.


iii. Zinc supply and demand. Zinc prices escalated with the rapid increase in demand resulting from growth of the world economy, particularly China and India. The metal’s price increased fourfold from 2005 to 2007, after which it steadily decreased until November 2008, when it fell back to the 2005 level.

d. Impurities

i. Phosphate products

1. Certiﬁcation for drinking water application. Many suppliers provide phosphate based corrosion inhibitors that are certiﬁed under ANSI/NSF Standard 60 for drinking water treatment up to a speciﬁc maximum use level. The maximum use level speciﬁed for each alum product varies with differences in the products’ strengths (phosphate content) and the speciﬁc phosphate used.

2. AWWA standard. Check any AWWA Standards (latest version) for the speciﬁc phosphate used. The table in the beginning of the white paper lists many of the phosphate chemicals approved under Standard 60 as well as those that happen to have AWWA standards. Of the 17 phosphate chemicals, 5 have AWWA Standards. If your corrosion inhibitor contains a phosphate compound that does not have an AWWA standard, consider using the AWWA standard with the phosphate compound closest to the one you are using for reference.

ii. Zinc ortho/polyphosphate products

1. Wastewater treatment. Most drinking water ends up at a wastewater treatment plant. Although zinc is not highly toxic to humans and is used in some medications, it does adhere to the gills of fish, causing their asphyxiation. Therefore, the concentration of zinc in wastewater treatment plant efﬂuents is often limited, sometimes to less than 1 mg/L; EPA Secondary Standards permit up to 5 mg/L in drinking water.
2. *AWWA standard.* Check AWWA Standard B506 (latest version), Zinc Orthophosphate for impurity limits and other requirements and guidelines. A review of 1,200 products submitted for drinking water certification to NSF International, one of the approved ANSI/NSF Standard 60 certifying agencies, from 1991 to 1999 revealed that those few product submittals that failed were due to the presence of excessive levels of one of the following metals: lead, mercury, cadmium, or zinc (see Health Canada website).

A.6.1 Bibliography

This section lists the key documents that provided information for the treatment chemical summary above.


Appendix A


A.7 Polymers (Polyelectrolytes)

1. Uses in water and wastewater treatment

   a. Uses for the chemical
      Polymers are used as coagulants and flocculants to destabilize and aggregate particles into larger masses to improve the extent and rate of their separation. The separation processes polymers are used in include clarification, thickening, flotation, filtration, and sludge dewatering. Polymers are used to a limited extent in wastewater mainstream treatment but are often critical in sidestream treatment of biosolids in thickening and dewatering processes.

   b. Different formulations
      Three classes of polymers are used in drinking water treatment:
      - Epi-DMA polyamines
      - PolyDADMACs
      - PAMs

      Five classes of polymers are used in wastewater treatment:
      - Epi-DMA polyamines
      - PolyDADMACs
      - PAMs
      - Mannich polymers
      - Acid colloids

      PAMs come in both liquid emulsion/dispersion form and powder form (powder/granular/bead). PAMs are made with varying molecular weights, different charge types (anionic, nonionic, cationic), and varying charge densities (frequency of charges). All of these variables result in a great diversity of PAM products, particularly in the wastewater treatment market.

      In drinking water treatment where anionic and nonionic PAMs are most frequently used, fewer PAM products are available because of the relatively small size of this market and the requirements and cost of obtaining ANSI/NSF Standard 60 approval. The largest PAM market is wastewater sludge dewatering and thickening where a wide range of cationic PAMs are usually used. Although five different cationic monomers are used to prepare cationic PAMs, one of them is used most of the time.
PAM polymers are manufactured in the following charge types and densities:
- Anionic charge density (3%–10%, 20%, 30%, and, in wastewater treatment, 40% on a weight basis)
- Nonionic
- Cationic charge density (5%, 10%, 20%, 30%, 40%, 50%, 60%, and, in wastewater treatment, 80% on a molar basis)

Another type of PAM used for wastewater treatment sludge dewatering is Mannich polymers. Mannich polymers, which are made by aminomethylation of nonionic PAM, are sold as highly viscous aqueous solutions that have the strong fish-like odor of dimethylamine unless a masking agent has been added. Because Mannich polymers typically contain only 3%–6% polymer, the freight cost of delivery is a major cost component.

Several other types of polyamines are sold for wastewater treatment applications. Because their compositions (raw materials) vary significantly and their use is relatively small compared to the other polymers discussed here, they are not further considered here.

c. Share of total chemical production used in the water market
   Based on sales, polymers constitute about 60%–65% of the North American market for coagulants and flocculants for municipal and industrial water and wastewater treatment.

d. Classification as commodity or specialty chemical
   Polymers are specialty chemicals. They require the specialized expertise of the seller to select or apply the product. They require laboratory testing or plant testing to determine the products cost-effectiveness and performance. And, they perform in a unique manner such that the product with the same composition from another manufacturer may perform differently.

2. Distribution

a. Manufacturers
   Consolidation of the industry through acquisitions has resulted in fewer manufacturers. Following are an estimate of the major manufactures of each polymer type in the United States and Canada:
   i. Epi-DMA polyamines: Ciba (BASF), SNF, Nalco, Kemira
   ii. PolyDADMACs: SNF, Ciba (BASF), Nalco, Kemira.
   iii. PAMs (powder/granule/bead form): SNF
   iv. PAMS (emulsion/dispersion form): SNF, Nalco, Ciba (BASF), Kemira, Ashland Hercules
   v. Mannich polymers: SNF, Kemira, Nalco, Delta Chemical, Atlantic Coast Polymers.
b. **Manufacturing/shipping sites**

   Generally, bulk liquid products are shipped directly from a manufacturing site. Drums and bags are often shipped from more locations. Some major manufacturers have more than one manufacturing location for a polymer type. Generally, the more capital intensive the polymer type is to manufacture, the fewer the manufacturing sites. Thus, a firm would not have more than one powder PAM facility in the United States and Canada but it might have two Epi-DMA polyamine sites and multiple Mannich polymer sites. The dilute nature of Mannich polymers renders them highly freight intensive such that a firm would need five or more manufacturing sites to compete in most of the United States.

c. **Supply chain**

   There may be more than 100 firms in the United States and Canada that sell some of the polymers discussed here. Besides the major manufacturers, there are firms that are:
   
   i. **Distributors.** They sell products of the major manufacturer under the major manufacturer’s name. Often, these will be niche markets such as for industrial or agricultural applications.
   
   ii. **Major resellers.** These firms have the polymers rebranded under their own name by the major manufacturer. Some are national in scope. Some are specialty chemical firms that offer hundreds of products for industrial and other applications. Sometimes they will try to add value to the product by blending multiple products for niche applications. They may do the blending themselves, have a third party do it, or have the manufacturer do it under an exclusive arrangement.
   
   iii. **Regional and smaller resellers.** Some small resellers are former salespersons from a major reseller or manufacturer who has started up his or her own firm. Some grow to become regional firms. Often the regional firms specialize in one or more markets such as municipal water and wastewater.

3. **Factors that influence supply and demand**

   a. **Polymers are manufactured from**

      i. **Nonionic PAM**
         
         1. Acrylamide monomer (AM)

      ii. **Anionic PAM**
         
         1. AM
         2. Either acrylic acid or sodium acrylate monomers

      iii. **Cationic PAM (except Mannich polymers)**
         
         1. AM
         2. Either an acrylate based cationic quaternary monomer or a methacrylate based quaternary monomer
a. The acrylate based cationic monomer, which is often referred to as AETAC or N,N-dimethylaminoethyl acrylate methyl chloride quaternary, is most frequently used.

b. The methacrylate based cationic monomer is often referred to as METAC or N,N-dimethylaminoethyl methacrylate methyl chloride quaternary.

iv. PAMs manufactured in emulsion/dispersion form also contain
1. Hydrocarbon oil/solvent (25%–50% by weight).
2. Multiple surfactants (3%–6% by weight). The surfactants keep the emulsion/dispersion stable and allow the PAM polymer to go into solution when mixed with water in the proper ratio and manner.

v. Epi-DMA polyamine
1. Epichlorohydrin
2. Dimethyl amine
3. Small amounts of a branching agent such as ethylene diamine or ammonia are added to manufacture the relatively higher molecular weight Epi-DMA polyamines

vi. PolyDADMAC
1. DADMAC monomer
   a. DADMAC monomer is manufactured from
      i. Allyl chloride
      ii. Dimethyl amine

vii. Mannich polymers
1. AM
2. Dimethyl amine
3. Formaldehyde

b. Key raw materials
i. Acrylamide is made from acrylonitrile
   1. Acrylonitrile is made from propylene
      a. Propylene is primarily made as a byproduct of ethylene production or gasoline production from petroleum feedstocks

ii. Acrylic acid is made from propylene

iii. Epichlorohydrin is made from allyl chloride

iv. Allyl chloride is made from propylene and chlorine

v. Dimethyl amine is made from methanol and ammonia.
   1. Methanol is primarily made from natural gas
   2. Ammonia is made from natural gas (and air)

vi. Formaldehyde is made from methanol

vii. Hydrocarbon oils/solvents are derived from petroleum
c. **Cost drivers**

i. **Energy.** Energy is a cost driver in two ways:
   1. Freight.
   2. Production. Manufacture requires heating, from which heat can be partially recovered. Because the costs of the raw materials are more significant cost drivers, polymers can be considered to not be highly dependent on energy costs.

ii. **Oil.** Oil is the base raw material for:
   1. PAM, especially those made in the emulsion/dispersion form
   2. Two of the three major raw materials for Mannich polymers
   3. One of the two major raw materials for Epi-DMA polyamines
   4. One of the two major raw materials for PolyDADMAC polymers

iii. **Natural gas.** Natural gas is the base raw material for:
   1. One of the two major raw materials for Epi-DMA polyamines
   2. One of the two major raw materials for PolyDADMAC polymers
   3. One of the three major raw materials for Mannich Polymers

d. **Impurities**

i. **For drinking water applications,** the major suppliers provide Epi-DMA polyamines, PolyDADMAC polymers, and a limited number of PAM polymers in powder or emulsion/dispersion forms that are approved for potable water use by NSF and that meet the requirements of the applicable AWWA standard

ii. **For PAM polymers,** check ANSI/AWWA Standard B453 (latest version), Polyacrylamide

iii. **For Epi-DMA polyamines,** check ANSI/AWWA Standard B452 (latest version), EPI-DMA Polyamines

iv. **For PolyDADMAC polymers,** check ANSI/AWWA Standard B451 (latest version), PolyDADMAC

v. Check the AWWA Standard for limits on impurity levels and additive requirements

vi. **Determine whether you desire any additional requirements with respect to impurity levels**

   1. **N-nitrosodimethlyamine (NDMA) formation potential.** The Province of Ontario and State of California have maximum contaminant levels for NDMA. Epi-DMA polyamines and PolyDADMAC polymers have been found to contribute to NDMA formation in some circumstances, probably through their allowed levels of residual dimethylamine. NDMA and five other nitrosamines are being sampled from 2008 through 2010 at selected water systems in the United States under the EPA Unregulated Contaminant Monitoring Rule 2.

   2. **Acrylamide monomer (AM).** The current EPA treatment technique limit for AM is 0.05% dosed at 1 mg/L (or equivalent). Most powdered PAM are approved by NSF for use up to 1 ppm, making the effective AM limit 0.05%. EPA is currently reviewing AM toxicity and limits. In 2007, the European Union instituted AM
limit of 0.1 micrograms per liter (µg/L), which equates to 0.01% when dosed at 1 ppm.

3. **Nonyl phenols ethoxylates (NPE).** NPEs have often been used in emulsion form PAM products to ensure that the polymer goes into solution. NPEs are widely used in many personal care and cleaning products. Nonyl phenol (NP) is a weak estrogen-type endocrine disruptor in fish and laboratory animals. NPEs break down in the environment to NP. Therefore, the European Union decided to classify NP and NPE as “reproductive hazards” and restrict their use in cosmetics and other products, including polymers used for water treatment to 0.1% by weight. In 2002, Canada issued guidelines that limit NP and NPEs in freshwater and marine water. In 2006, EPA issued National Pollutant Discharge Elimination System (NPDES) ambient water quality chronic criteria for NP (but not NPEs) of 6.6 µg/L (freshwater) and 1.7 µg/L (saltwater). Some U.S. manufacturers of emulsion/dispersion form PAM have voluntarily removed or partially removed NPEs from their products.

vii. **One possible source** of contamination is residual material from previous shipments of other, possibly harmful, substances that have not been adequately cleaned from the bulk truck used to deliver the ferric sulfate.

viii. **Establish a program** of immediate sampling of delivered product, sample retention, quality control testing at the time of delivery even if only visible inspection and smell (also possibly Brookfield viscosity of the product), and periodic quality control testing of total solids and the Brookfield viscosity and pH of a solution of the product.

ix. **Consider requiring the manufacturer or supplier** to provide an affidavit attesting that the polymer product provided with each shipment complies with applicable requirements of NSF and AWWA standards.

e. **Guidelines for the ease of substituting one manufacturer’s polymer for another manufacturer’s polymer of the same composition**

In some but not all applications, there are Epi-DMA polyamines and PolyDADMACs from multiple manufacturers that, once selected with laboratory testing and plant trials, perform equivalently. In some but not all applications, the 30% anionic PAM polymers from multiple manufacturers often perform similarly. Generally, the following applications or polymer compositions usually require laboratory testing or plant trials or both to demonstrate cost performance:

i. **Sludge dewatering** and other high-solids applications

ii. **PAMs**, especially cationic PAMs

iii. **Mannich polymers**

iv. **Comparing** powder form PAMs and emulsion/dispersion form PAMs

v. **The highest molecular weight versions** of PolyDADMAC and Epi-DMA polyamines.

f. **Regulatory drivers of demand**

i. **Long-term increase.** New and ongoing regulatory requirements tend to increase the number of substances removed or the extent of removal required, such that using
more chemicals such as polymers is needed. Many water and wastewater treatment facilities designed for the less stringent regulations of the past have been able to meet the new requirements by using inorganic coagulants and polymers. In wastewater treatment, using polymers for secondary clarification is one such growing application.

g. Trends
i. Prices. The 2008 recession and subsequent drop in oil and natural gas prices should cascade through the raw material chain and lower polymer prices.

ii. Consumption
1. Short-term decrease. The recession of 2008 reduced industrial production and, therefore, the demand for polymers for industrial applications. Municipal applications should be less affected but are likely to also show some decrease.
2. Long-term decrease. Although manufacturers have decreased the levels of impurities in many polymers in response to growing awareness of their effects, global regulatory requirements, and the development of more accurate and sensitive analytical tests, water treatment plants are likely to increasingly scrutinize the use of polymers. In wastewater treatment, the same scrutiny has not yet become prevalent but may increase with concerns about EDCs, the impurities in Mannich polymers, and the fate of the oil and surfactants in emulsion polymers.

iii. Supply. There has been considerable consolidation of polymer manufacturers through acquisition and consolidation of manufacturing locations. The largest PAM manufacturers have become more backward integrated. This smaller number of large manufacturers supplies the many firms who sell direct to the industrial and municipal water and wastewater markets. Supply is adequate.

4. Purchasing alternatives and approaches to minimize cost

a. Inorganic coagulants
In clarification and other low solids applications, aluminum or iron coagulants can often but not always be substituted for some or all of the Epi-DMA polyamine or PolyDADMAC polymers.

b. Cost indices
A purchasing agent might track the following ferric sulfate cost indices through appropriate trade magazines/services:

i. Oil
ii. Natural gas
iii. Gasoline (relative to delivery freight costs, particularly for Mannich polymers)
A.7.1 General information sources

Frank Mangravite’s 17 years experience working for polymer and inorganic coagulant companies in the capacities of product management, research and development, purchasing polymers from other firms, sales support, wholesale sales to other firms, and business management. Also, the knowledge he gained from being chairman of the AWWA Polyelectrolytes Standards Comm.

Internet research on the following companies including their websites, 10K reports, news articles, and patents. Vulcan Chemicals, Kemira, Callaway Chemicals, General Chemical, Stockhuasen, Ciba, Ashland Chemicals.

A.7.2 Bibliography

This section lists the key documents that provided information for the treatment chemical summary above.


A.8 Sulfuric Acid

1. Uses in water and wastewater treatment

   a. Uses for the chemical
   Sulfuric acid is one of the highest volume chemicals manufactured in the world. It is a basic building block or essential ingredient in numerous chemical processes in many industries, including metals production, petroleum refining, industrial chemicals production, rubber and plastics production, ethanol production, and pulp and paper production. However, the most significant use of sulfuric acid is for fertilizer production, which accounts for about 60% of its use.

   The primary use of sulfuric acid in the water and wastewater treatment markets is as a raw material to manufacture alum, ferric sulfate, PACl, and phosphate. In rare instances, it may be used as a neutralizing agent to reduce pH levels.

   b. Different formulations
   Sulfuric acid that is certified under ANSI/NSF Standard 60 is most commonly sold as 98% or 93%, which is also called “66 Baume,” but is sometimes sold in lower concentrations, including 50% and 38%.

   c. Share of total chemical production used in the water market
   Water and wastewater uses of sulfuric acid constitute less than 2% of its production.

   d. Classification as commodity or specialty chemical
   Sulfuric acid is a commodity chemical. It is the world’s largest commodity chemical and historically has been one of the most stable resources in the global market.

2. Distribution

   a. Manufacturers
   There were 38 virgin sulfuric acid production facilities in the United States in 2002, with the greatest production located in Florida for the processing phosphate rock into fertilizer. In addition, there are several smelter production plants, particularly in Canada. Chemical Register’s website, chemicalregister.com, lists 58 U.S. sulfuric acid suppliers. In February 2009, NSF International certified about 27 independent sulfuric acid suppliers with 39 production facilities in the United States under ANSI/NSF Standard 60 for drinking water treatment. In addition, Underwriters Laboratories, Inc. also certifies products under Standard 60.

   Large primary producers in North America include Akzo Nobel, Cargill, Chemtrade Logistics, East Penn Manufacturing Co., El Dorado Chemical Co., Grupo Mexico, Irving Oil, NorFalco (Xstrata), and Rhone-Poulenc.
b. **Distributors**
As a commodity chemical, sulfuric acid can be purchased from any chemical distributor. A list of the top 100 chemical distributors in 2005 can be obtained by typing same into a Google.com search.

3. **Factors that influence supply and demand**

   a. **Key raw materials**
   Sulfuric acid is manufactured from sulfur:
   1. Natural underground deposits (83%)
   2. Some metal smelters that process sulfide ores (8%)
   3. Byproduct recovery and other sources (9%)  
   
   b. **Common impurities, contamination sources**
   Certification for drinking water application. Many suppliers provide sulfuric acid that is certified under ANSI/NSF Standard 60 for drinking water treatment up to a specific maximum use level. The maximum use level specified for each sulfuric acid product, which for most products of 93% to 98% concentration was 50 mg/L in January 2009, varies because of differences in the product’s strength (sulfuric acid content) and the concentrations of impurities.  
   Sulfuric acid used to manufacture inorganic coagulants. There is no AWWA standard for sulfuric acid because drinking water treatment rarely requires acidification. However, sulfuric acid is a primary raw material in the production of alum, ferric sulfate, and some PACl used for drinking water treatment. The manufacturers of these certified products must use only sulfuric acid certified to meet ANSI/NSF Standard 60. Waste (spent) sulfuric acid from alkylation or other chemical processes, which usually contain high levels of impurities, should never be used.
   
   c. **Price trends**
   Before the recession and collapse of commodity prices in 2008, there was an imbalance between supply and demand in the global market, resulting in extraordinary market conditions.

   The 2008 recession and subsequent drop in fertilizer demand and sulfur prices are expected to continue to cause sulfuric acid prices to decrease, although prices may decrease less where regional supply shortages exist.

   Decreased fertilizer consumption and industrial production should reduce consumption in the short term.

   In the long term, demand is expected to increase. Worldwide GDP growth is expected to increase the usage of fertilizer and industrial chemicals, which will consume more sulfuric acid.


d. **Raw material cost drivers**  
i. **Oil prices.** Use of sulfuric acid in gasoline production and petrochemical processing has increased along with general increases in GDP.  

Oil refineries make 60% of sulfur supply through refining. Unplanned production plant shutdowns in 2007 and 2008 further constricted sulfur production.  

ii. **Increased demand from China and India.** China and India became net importers of acid because of rapid economic growth and industrialization. China and India previously produced more than enough sulfuric acid for themselves But their needs have outstripped their production capacity, so they are increasingly importing sulfuric acid. As countries raise their standard of living, more food is consumed (using more fertilizer, which is a competing use for sulfuric acid).  

China is normally the biggest purchaser of DAP (diammonium phosphate) fertilizer exported from the United States, and the production of DAP and other phosphate fertilizers is the biggest single use for sulfuric acid. Less global demand for fertilizer in late 2008 and 2009 means lower sulfuric acid prices.  

iii. **Competing uses**  
1. Manufacture of phosphate fertilizers and phosphoric acid: Roughly 60% of sulfuric acid produced goes into agriculture, primarily in the manufacture of phosphate fertilizers  
2. Extraction of metal from ore  
3. Petroleum refining  
4. Aluminum and ferric sulfate production  
5. Automobile lead-acid battery production  
6. Iron and steelmaking industries to remove oxidation, rust, and scale  
7. Catalyst in nylon production  
iv. **Ethanol production.** The rapid increase in demand for corn for ethanol production boosted corn prices starting in September 2006. Farmers planned record corn plantings plus additional fertilizer applications to boost yields. Phosphate fertilizer production increased to meet demand as prices soared. As a result, less sulfuric acid was for sale to the merchant market.  

Increased ethanol production had a “double effect” on the demand for sulfuric acid. First, more fertilizer is needed to grow corn, which is the ultimate source of most fermentation ethanol. And corn is a relatively fertilizer-intensive crop. In addition, ethanol plants consume sulfuric acid in their own processing operations. Each new ethanol plant requires anywhere from 2,000 to 4,000 tons of sulfuric each year (Graff, 2007).
v. **Boom in metals (copper, nickel).** The global construction boom increased prices of such metals as copper and nickel, which use sulfuric acid in ore leaching processes. Smelting of nonferrous metals yields sulfuric acid as a byproduct, but metals producers needed more sulfuric acid during the boom than they could produce internally. With high prices for metals, metals companies were able to absorb high prices for sulfuric acid much more easily than in recent years (Graff, 2007).

High metals prices essentially collapsed at the end of 2008, with copper and nickel trading at less than one-half and one-third, respectively, what they were at their peak in 2007 (Graff, 2008).

vi. **Supply conditions.** Before the commodity boom, the market for sulfuric acid was oversupplied, resulting in a significant decrease in production facilities making sulfuric acid over the past five to seven years. Despite the recent increase in demand, little or no new capacity for sulfuric acid is planned in the United States.

Imports of sulfuric acid into the United States declined in 2007–2008. In the past, U.S. buyers of sulfuric acid would have turned to foreign suppliers when there wasn’t enough domestic product to go around. But foreign suppliers are bypassing the United States because sulfuric acid markets in other countries were more attractive (Graff, 2007).

vii. **Regional market effects.** Influences such as strikes at a major sulfuric acid supplier and at metals smelting plant, an explosion at a sulfuric acid production plant, and plant outages had regionalized effects on U.S. sulfuric acid supply in 2007 and 2008. Regional supply tightness was expected to keep the price of sulfuric acid from declining dramatically in late 2008. By December 2008, global demand for the acid was slowing in its key markets – metals and fertilizers. Even though the overall trend of sulfuric acid prices was a peak in September 2008 and a decline from the peak by half by the end of 2008, some areas of North America, particularly the northeastern United States, did not see prices drop as much because of local supply limitations. Prices were expected to generally trend downward as some production capacity re-enters the market (Hannon, 2008; Graff, 2008).

viii. **Regulatory effect on supply.** Increasing regulatory requirements to reduce sulfur dioxide emissions are forcing sulfuric acid plants to invest in scrubbers and other emissions-reducing technologies or go out of business. On January 12, 2009, EPA announced a settlement with three sulfuric acid producers, the third such settlement. Collectively, the settlements will cause 20 sulfuric acid plants in the United States to reduce sulfur dioxide emissions by 35,000 tons per year.
4. Purchasing alternatives and approaches to minimize costs

   a. Chemical-specific approaches
      Consider using carbon dioxide. Treatment plants can sometimes use carbon dioxide to acidify water. Because carbon dioxide (carbonic acid in water) is a much milder acid than sulfuric acid, this will not always be possible or practical. However, using carbon dioxide has the added benefits of avoiding the addition of sulfate ions, avoiding handling a hazardous chemical, and increasing the water’s buffering capacity.

      Consider removing the need to use sulfuric acid. Water and wastewater treatment rarely requires the need to add acid. When it does, the need to acidify is often the result of overly alkaline conditions that are the result of a specific water treatment process or a particular industrial process. It may be possible to use a different water treatment process (or chemicals) or to alter the industrial process to reduce or eliminate the source of alkalinity.

   b. Cost indicators to monitor
      Sulfuric acid: 98%

      Sulfur: Domestic sulfur price is typically tied to the published Tampa Index (Green Market).

      Not all commercial grades of sulfuric acid use sulfur as a starting material, but the prices of sulfur and sulfuric acid have always been linked to some extent. With the decline in sulfur prices, a decoupling of sulfur and sulfuric acid prices has been observed in the United States, with sulfuric producers resisting steep price-cutting. The decline of sulfur prices was reported to contribute to sulfuric acid price weakness, but sulfuric acid price were not declining as fast as prices for sulfur (Graff, 2008).

A.8.1 Bibliography

This section lists the key documents that provided information for the treatment chemical summary above.


B. Survey Results for the United States and the United Kingdom

B.1 Results Summary of the AMWA Water Treatment Chemical Supply Survey for the United States

AMWA conducted a survey of 195 public water systems in the United States in January 2009 regarding water treatment chemical pricing and availability, and ideas for chemical cost management. The survey inquired about 19 common water treatment chemicals. A few respondents added their own chemicals if not covered in the original list. Forty-seven utilities responded to the survey, which meant a response rate of approximately 24%. Figure B.1 shows that responding utilities are fairly well geographically dispersed across the United States.

The survey asked for information by chemical on the chemicals used, units in which they are purchased (e.g., tons or gallons), concentration of the chemical, annual usage, current unit cost, cost change from the previous year, and existence of shortages or other delivery issues in the past year.

The survey also asked for open-ended input on five questions:

1. What reasons are you getting from your suppliers for the chemical prices increases?
2. What reasons are you getting from your suppliers for the delivery constraints?
3. How many chemicals must be purchased from a single supplier?
4. Are there any cost containment provisions in your chemical supply contracts that have proven effective?
5. Other useful information not requested.

Only the answers to the questions regarding cost change from current year, shortages or other delivery issues in the last year, and the five open-ended questions are summarized here.
B.1.1 Price increases

The survey asked for price increases by chemical over the last year. The survey was administered in January 2009, and so the comparison requested was the current unit cost in January 2009 with the unit cost in January 2008. As a result, this comparison is a “snapshot” of chemical price changes spanning a year’s time that may not capture some of the price adjustments on contracts with duration of less than a year.

Table B.1 shows a summary of price increases for chemicals along with the number of utilities reporting use of that chemical. Response is shown for all chemicals listed by utilities.
Table B.1. Price increases for selected chemicals in the AMWA survey of the United States

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Number of utilities indicating use</th>
<th>Average price increase (%)</th>
<th>Minimum (%)</th>
<th>Non-zero minimum (%)</th>
<th>Maximum (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alum</td>
<td>25</td>
<td>53</td>
<td>0</td>
<td>15</td>
<td>168</td>
</tr>
<tr>
<td>Alum Polymer Blend, Delta DF613</td>
<td>1</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
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<tr>
<td>Anhydrous ammonia</td>
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<td>84</td>
<td>46</td>
<td>46</td>
<td>150</td>
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<td>-3</td>
<td>184</td>
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<td>37</td>
<td>37</td>
<td>37</td>
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<td>Carbon dioxide</td>
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<td>10</td>
<td>38</td>
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<td>25</td>
<td>80</td>
<td>0</td>
<td>6</td>
<td>209</td>
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<tr>
<td>Chlorine (gaseous)</td>
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<td>-1</td>
<td>-40</td>
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<td>23</td>
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<td>1</td>
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<td>Ferric sulfate(^a)</td>
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<td>52</td>
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<td>Lime</td>
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<td>5</td>
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<td>-29</td>
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<td>Magnesium hydroxide</td>
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<td>Anionic polymer</td>
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<td>9</td>
<td>-1</td>
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<td>20</td>
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<td>Potassium permanganate</td>
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<td>22</td>
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<td>3</td>
<td>80</td>
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<td>6</td>
<td>10</td>
<td>-17</td>
<td>-17</td>
<td>36</td>
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<tr>
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<td>50</td>
<td>0</td>
<td>8</td>
<td>197</td>
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<td>Zinc-polyphosphate</td>
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<td>15</td>
<td>15</td>
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<td>15</td>
</tr>
</tbody>
</table>

\(^a\) Ferric sulfate was not listed on the survey as originally distributed, but was inserted by six utilities.
Phosphoric acid showed the largest average percent increase at 233%, from 12 utilities reporting phosphoric acid use. The largest reported increase was 586%, and the lowest was 0%. The lowest non-zero increase was 95%.

Caustic soda showed an 80% average percent increase over the last year, from 25 utilities reporting caustic soda use.

Forty-one utilities reported using fluoride – the greatest number of utilities reporting use of one chemical. All of the reported fluoride use for which the specific type was reported was FSA, but a clear indication of formulation was often not given. The average reported price increase in the last year was 44%.

B.1.2 Chemical shortages or other restrictions

The survey asked utilities to indicate by marking “yes” or “no” whether there had been chemical shortages or other restrictions in the past year. Although this question does indicate the presence of some level of supply restriction, the responses do not capture the number of shortage events in the last year or reflect their duration. Table B.2 shows a summary of chemical shortages reported by survey respondents.

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Number of utilities indicating use</th>
<th>Number indicating shortages</th>
<th>Percent with shortages, of utilities indicating use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alum</td>
<td>23</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Alum Polymer Blend, Delta DF613</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Anhydrous ammonia</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aqua ammonia</td>
<td>15</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Calcium thiosulfate</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>3</td>
<td>1</td>
<td>33</td>
</tr>
<tr>
<td>Caustic soda</td>
<td>27</td>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td>Chlorine (gaseous)</td>
<td>33</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Chlorine (liquid, bulk)</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Chlorine (liquid, 1-ton containers)</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ferrous chloride</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ferrous iron</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ferric sulfate</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table B.2. Utilities in AMWA survey indicating chemical shortages or other supply restrictions in 2008 in the United States (cont.)

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Number of utilities indicating use&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Number indicating shortages</th>
<th>Percent with shortages, of utilities indicating use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluoride</td>
<td>41</td>
<td>27</td>
<td>66</td>
</tr>
<tr>
<td>Lime</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Liquid oxygen</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Magnesium hydroxide</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Phosphate</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>11</td>
<td>3</td>
<td>27</td>
</tr>
<tr>
<td>Polyaluminum chloride</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Polymer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anionic polymer</td>
<td>9</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Cationic polymer</td>
<td>20</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Non-ionic polymer</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Potassium permanganate</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Powdered activated carbon</td>
<td>5</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>Sodium bisulfite</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sodium hypochlorite (15% solution)</td>
<td>20</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>6</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td>Zinc-polyphosphate</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

a. Only chemicals that are the focus of this paper are shown.
b. Shows the number of utilities that responded with either a “yes” or a “no” to the question of whether there had been shortage in the past year.
c. Ferric sulfate was not listed on the survey as originally distributed, but was inserted by six utilities.

Fluoride shortages were common in the last year, according to survey respondents. Sixty-six percent of the utilities indicating they used fluoride reported shortages (27 utilities indicating shortages of fluoride, out of 41 indicating use of fluoride). Figure B.2 shows the distribution of utilities reporting use of fluoride. The figure shows that fluoride shortages were not confined regionally.

Three or more utilities also reported chemical shortages in the last year for caustic soda (of utilities indicating use, 22% reported shortages), chlorine (gaseous; of utilities indicating use, 9% reported shortages), and phosphoric acid (of utilities indicating use, 27% reported shortages).
Figure B.2. Location of utilities reporting fluoride shortages during January 2008 to January 2009 (based on responses from 42 utilities).
B.1.3 Summary of responses to open-ended questions

1. What reasons are you getting from your suppliers for the chemical prices increases?
   - Rising costs of energy
   - Rising costs of fuel
   - Increased transportation costs in addition to fuel (rail surcharges for safety regulations)
   - Extreme weather events (spring 2008 Mississippi floods)
   - Diversion of phosphates and other materials to corn for ethanol production
   - High demand for chemicals used in water treatment, decrease in supply
   - Increased foreign demand (India, China, and worldwide)
   - Market conditions, fluctuations in economy, inflation
   - Manufacturing capacity limitations
   - Increased cost of inputs and raw materials (for example, metals, sulfuric acid, phosphates)
   - Carbon surcharge (charged by Canadian lime supplier)
   - Falling value of Canadian dollar (for Canadian lime supplier)
   - Slowing of steel industry due to economic downturn
   - Demand for fertilizer for corn/ethanol production, domestic and abroad
   - Increased consumption of finished product by other non-water treatment industries
   - Lack of availability of product that meets NSF standards.

2. What reasons are you getting from your suppliers for the delivery constraints?
   - Force majeure (extraordinary events beyond control of contract parties)
   - Short supply, increased demands
   - Manufacturing capacity constraints, other manufacturing issues (off-line, maintenance of facilities)
   - Some manufacturers stopped making specific chemical (fluoride)
   - Rail and trucking issues (car shortages, unsafe conditions, equipment failures)
   - Supplier is back ordered on shipments, so some deliveries are delayed.

3. Are there any cost containment provisions in your chemical supply contracts that have proven effective?
   - Require price increases to be justified/explained
   - Price increases can happen only during renewal of contract
   - Price increases can be negotiated quarterly
   - Set a maximum allowable price increase
   - Allow price increases when force majeure is declared
Shorter-term contracts (agencies switching from multi-year to single-year deals, or from single-year deals to six-month deals)

Fix the price over length of contract (commonly one year, though even one year catches much resistance from suppliers)

Require the price be adjusted for changes in the actual percentage of product delivered, or for the specific gravity of delivered product

Entering purchasing alliances with other agencies, benchmarking with other agencies

Tying prices to various indices (PPI, Bureau of Labor Statistics industrial chemical index, third party/independent indices)

Do not limit the amount of chemical that can be purchased

Bid on price for the chemical as its delivered

Receive bids only for the chemical, with no other costs included

Only accept bids which take into account fluctuations in raw materials and fuel costs

Bid specifications include highest percentage concentrations available to ensure highest yield per dose.

4. Other useful information not requested.

Potassium hydroxide cost was so prohibitive, respondent switched to caustic (soda).

Employed reverse bidding process (where suppliers compete to bid the lowest to win the supply contract) for four of our large quantity chemicals. Powdered activated carbon, sodium chlorite, lime, and ferric sulfate. Respondent did not see any cost reduction.

After having problems with fluoride and liquid oxygen deliveries two years ago, respondent started awarding primary and secondary vendors for all chemical contracts. Now, when the primary vendor cannot deliver in a timely manner or asks for a price escalation, the respondent can rely on the secondary vendor instead of having to take spot bids.

Respondent bids contracts based on the markets for each chemical. If chemical costs are down, longer-term contracts are secured; if chemical costs are up, shorter one-year contracts are arranged.

In September 2008, respondent switched to a liquid ortho-phosphate, expecting to save about 20% versus using zinc poly.

Fluoride is the dominant chemical of concern; other chemicals have increased significantly in unit price over inflation, but within budgetary predictions (overall cost based on usage is not nearly as high as for fluoride).

Respondent is in transition from chlorine gas to sodium hypochlorite and chlorine dioxide.
B.2 Summary of Results of the Water Treatment Chemical Supply Survey of the United Kingdom

To gather data for the United Kingdom similar to U.S. data collected with the AMWA survey, a very similar survey was sent for this project to 26 water and wastewater utilities in the United Kingdom. Additions to the survey compared to the AMWA survey of the United States included adding ferric sulfate to the list of chemicals and adding a box for entering chemical cost as a percentage of total budget or operating budget.

B.2.1 Price increases

The survey asked for price increases by chemical over the last year. The survey was administered in February 2009, and the comparison requested was the current unit cost compared to the unit cost a year ago. This price comparison captures the price change over a year and does not reveal other price changes or fluctuations that may have occurred throughout the year.

Table B.3 shows price changes for water treatment chemicals with the greatest number of utilities reporting use of that chemical.

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Number of utilities indicating use</th>
<th>Average price increase (%)</th>
<th>Minimum (%)</th>
<th>Non-zero minimum (%)</th>
<th>Maximum (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alum</td>
<td>4</td>
<td>18</td>
<td>0</td>
<td>5</td>
<td>33</td>
</tr>
<tr>
<td>Caustic soda</td>
<td>6</td>
<td>52</td>
<td>0</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>Chlorine (gaseous)</td>
<td>5</td>
<td>9</td>
<td>0</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Ferric sulfate</td>
<td>4</td>
<td>13</td>
<td>0</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>5</td>
<td>175</td>
<td>-40</td>
<td>-40</td>
<td>350</td>
</tr>
<tr>
<td>Polyaluminum chloride</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Sodium bisulfite</td>
<td>6</td>
<td>10</td>
<td>0</td>
<td>5</td>
<td>30</td>
</tr>
</tbody>
</table>

Because of the small number of responses, this summary includes only chemicals used by at least four of the seven respondents.

Phosphoric acid showed the largest average percent increase at 175%, from five utilities reporting phosphoric acid use. The reported price changes ranged from a 350% increase to a 40% decrease.
Caustic soda showed an 52% average percent increase over the last year, from six utilities reporting caustic soda use. The largest reported increase was 100%, with the smallest reported increase being 25%. One utility reported no increase in price.

Fluoride was listed as used by three agencies, with only one responding they had experienced any price change over the past year, and that was a change of 5%.

**B.2.2 Chemical shortages or other restrictions**

The survey asked utilities to indicate by marking “yes” or “no” whether there had been chemical shortages or other restrictions in the past year. This question does not capture the number of shortage events in the last year or reflect their duration. Table B.4 shows a summary of chemical shortages reported by survey respondents. Because of the limited number of responses, chemicals are listed only if at least three utilities reported using that chemical.

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Number of utilities indicating use</th>
<th>Number indicating shortages</th>
<th>Percent with shortages, of utilities indicating use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alum</td>
<td>5</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Anionic polymer</td>
<td>3</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Cationic polymer</td>
<td>4</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Caustic soda</td>
<td>7</td>
<td>1</td>
<td>14%</td>
</tr>
<tr>
<td>Chlorine (gaseous)</td>
<td>5</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>3</td>
<td>3</td>
<td>100%</td>
</tr>
<tr>
<td>Ferric sulfate</td>
<td>5</td>
<td>2</td>
<td>40%</td>
</tr>
<tr>
<td>Fluoride</td>
<td>4</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Liquid oxygen</td>
<td>4</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>7</td>
<td>3</td>
<td>43%</td>
</tr>
<tr>
<td>Polyaluminum chloride</td>
<td>7</td>
<td>1</td>
<td>14%</td>
</tr>
<tr>
<td>Sodium bisulfite</td>
<td>6</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Sodium hypochlorite</td>
<td>7</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>7</td>
<td>0</td>
<td>0%</td>
</tr>
</tbody>
</table>

a. Shows the number of utilities that responded with either a “yes” or a “no” to the question of whether there had been shortage in the past year.

In general, respondents did not report many chemical supply shortages or restrictions, however, all three agencies indicating they used ferric chloride reported shortages. Other shortages existed for caustic soda, ferric sulfate, phosphoric acid, and PACI.
B.2.3 Summary of responses to open-ended questions

1. What reasons are you getting from your suppliers for the chemical price increases?
   - Increased energy costs (oil, gas, and transport costs)
   - Increased raw materials costs (especially those linked to fertilizer markets)
   - Demand for raw materials from other sectors
   - Variance in exchange rates (U.S. dollar, Euro, Pound Sterling)
   - Closing of production facilities, slowdown of production in some sectors
   - State of the global economy.

2. What reasons are you getting from your suppliers for the delivery constraints?
   - Availability of raw materials (ferrous sulphate, phosphate, issues around steel manufacturing leading to shortage of ferric chloride)
   - Weather conditions
   - Manufacturing capacities
   - Global demands
   - Closing of production facilities, slowdown of production in some sectors.

3. Are there any cost containment provisions in your chemical supply contracts that have proven effective?
   - Prices linked to indices
   - Successful at sticking to price as listed on contract
   - Only review possible price increases during extreme market events.

4. Other useful information not requested.
   - Respondent has concerns about the diminishing number of suppliers for a range of chemicals, unsure if single sourcing will be successful.