**Technology
Status Report**

TS-01-01

GWRTAC S SERIES

Technology Status Report
Perchlorate Treatment Technologies
First Edition

Prepared By:

Diane S. Roote, P.G.

Ground-Water Remediation
Technologies Analysis Center
Pittsburgh, PA

May 2001

Prepared For:

GWRTAC *Ground-Water Remediation
Technologies Analysis Center*

Operated by Concurrent Technologies Corporation
425 6th Avenue • 28th Floor - Regional Enterprise Tower • (412) 577-2646 • (800) 373-1973
Fax: (412) 577-2660 • www.gwrtac.org • gwrtac@gwrtac.org

Ground-Water Remediation Technologies Analysis Center (GWRTAC)

Technology Status Report: Perchlorate Treatment Technologies, First Edition

May 15, 2001

Contract No. DAAE30-98-C-1050

Prepared by
National Defense Center for Environmental Excellence (NDCEE)

Operated by Concurrent Technologies Corporation

Ground-Water Remediation Technologies Analysis Center (GWRTAC)

Technology Status Report: Perchlorate Treatment Technologies, First Edition

May 15, 2001

Contract No. DAAE30-98-C-1050

Submitted by

Concurrent Technologies Corporation
100 *CTC* Drive
Johnstown, PA 15904

FOREWORD

About GWRTAC

The Ground-Water Remediation Technologies Analysis Center (GWRTAC) is a national environmental technology transfer center that provides information on the use of innovative technologies for the remediation of contaminated groundwater.

Established in 1995, GWRTAC is operated by Concurrent Technologies Corporation (*CTC*) in association with the University of Pittsburgh's Environmental Engineering Program through funding provided by the U.S. Environmental Protection Agency's (EPA) Technology Innovation Office (TIO), the U.S. Department of Defense (DoD) National Defense Center for Environmental Excellence (NDCEE), and the U.S. Department of Energy (DOE).

About "S" Series Reports

This report is one of the GWRTAC "S" Series of reports developed to provide a snapshot of the status of a given groundwater remediation technology or topic, based on information compiled for GWRTAC's case study database. These reports are based on readily available information from literature or from personal communications with involved parties. These reports are not intended as in-depth technical analyses and are not peer-reviewed.

Acknowledgements

GWRTAC would like to thank all those who assisted in this compilation of current project summaries that will aid our stakeholders seeking perchlorate treatment information, especially representatives of American Waterworks Association Research Foundation (AWWARF), Applied Research Associates (ARA), Inc., Envirogen, Inc, EnSafe, Inc., Calgon Carbon Corporation, NASA, NAVFAC, and U.S. DOE Los Alamos National Laboratory. GWRTAC gratefully acknowledges the National Defense Center for Environmental Excellence (NDCEE) for providing the funding to complete this work. It is our hope to provide periodic updates and refinements to this report over the next several years, due to the fast pace of new developments in perchlorate treatment technologies. Thanks to Mr. Brian Bosilovich, *CTC*, who created all figures and charts in the report from database queries, to Ronnie Britto of EnSafe, Inc. for his review comments, and to Mr. Terry Jennings, *CTC*, for his overall review.

Disclaimer

GWRTAC makes no warranties, express or implied, including without limitation, warranty for completeness, accuracy, or usefulness of the information, warranties as to the merchantability, or fitness for a particular purpose. Moreover, the listing of any technology, corporation, company, person, or facility in this report does not constitute endorsement, approval, or recommendation by GWRTAC, *CTC*, the University of Pittsburgh, U.S. EPA, U.S. DoD, or U.S. DOE.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX

1.0 INTRODUCTION / PURPOSE OF STATUS REPORTS

The Ground-Water Remediation Technologies Analysis Center (GWRTAC) continually compiles laboratory-, pilot- and full-scale case study information for a variety of innovative technologies for groundwater and soil remediation. At this time, GWRTAC's case study database contains approximately 670 case studies. Periodically, GWRTAC provides "S" Series Status reports based on information contained in the GWRTAC case study database for a selected technology.

GWRTAC's case study database is not represented as being comprehensive, nor are the case studies included screened to verify their validity, quality, or "success" in remediation. Rather the case study database and resultant status reports are intended to provide members of the ground-water remediation community with basic information on completed, in-progress, or planned activity in laboratory research, field demonstration, or full-scale application of innovative technologies in both the public and private sectors. The GWRTAC database was designed in a manner that allows analysis of the use of each innovative technology monitored by GWRTAC, which is accomplished by the preparation of various tables and charts to reveal trends in technology application. This analysis, presented in the "S" Series Status reports, is performed by GWRTAC, and is based solely on the information in the GWRTAC database. The status reports are provided as a "snapshot" of the contents of GWRTAC's "living" case study database. As such, status reports for a given technology may be repeated in the future to reflect additional case study information compiled, and/or updates/revisions/additions to the database.

Submission of innovative technology case study summary and project contact information to GWRTAC via email to gwrtac@gwrtac.org, will allow GWRTAC to continue updating the database. Such notifications are appreciated, and may be followed with a request for additional information when GWRTAC focuses on the technology prior to preparation of an "S" Series report.

In addition to this Section 1.0, Introduction / Purpose of Status Reports, the remainder of this report is organized as follows. Section 2.0, Summary of Perchlorate Treatment Technologies, reviews and illustrates trends related to general information such as the scale and status of the perchlorate treatment project summaries in the database, project objectives, target media, and project locations. Section 3.0, Analysis of Perchlorate Treatment Technologies, provides GWRTAC's analysis of trends in technology type, contaminant ranges treated, and appropriate specific information for ex situ water, ex situ soil, and *in situ* technologies, including results-oriented information where available. It is important to note, that in this report, approximately half of the reported projects are in in-progress or planned, so that results information is not yet available. Section 4.0, Summary, provides a final overview of the perchlorate treatment technologies, and Section 5.0, References, provides references used in preparation of the text of this report, as distinguished from references for individual project summaries, which are included in the Appendix.

The Appendix contains the detailed project summaries for each of the perchlorate treatment projects currently contained in the GWRTAC database. Each summary includes GWRTAC's source(s) of information and other external references, such as journal articles, pertaining to the project. The length and amount of detail in the project summaries varies greatly, depending upon the source material used by GWRTAC, and the status of the project. The information presented was obtained from proceedings, including the August 2000 Perchlorate Remediation Workshop at the Joint Services Pollution Prevention Convention, and through information available on the Internet or provided to GWRTAC by individuals involved with perchlorate treatment technologies and/or R&D efforts. For enforcement sites, GWRTAC has not obtained copies of multiple documents submitted to regulatory agencies that provide a full and detailed picture of the project. For research sites where published papers or reports are readily available to summarize the project, executive summaries or project summaries were often provided to GWRTAC electronically for direct incorporation into the database. In other cases, information found in the project summaries was provided by abstracts, or from vendors.

2.0 SUMMARY OF PERCHLORATE TREATMENT TECHNOLOGIES

2.1 Overview / General Internet-Based Information Availability

Perchlorate (ClO_4^-) is the soluble anion associated with the solid salts of ammonium, potassium, and sodium perchlorate. Ammonium perchlorate is used as an energetics booster or oxidant in solid propellant for rockets and missiles. It is, therefore, a national technical asset integral to the Nation's strategic defense system and space exploration. Ammonium perchlorate is also used in certain fireworks, the manufacture of matches, as a component of air bag inflators, and in analytical chemistry to preserve ionic strength. Large-scale production of ammonium perchlorate began in the United States in the mid-1940's. Ammonium perchlorate has a limited shelf life, and must be periodically replaced in munitions and rockets, or in inventory. This has lead to the disposal of large volumes of the compound since the 1940's in Nevada, California, Utah, and likely other states. In addition, the Military Departments have jointly identified a need for an environmentally responsible method to dispose of rocket propellant that complies with arms control treaties (Cooperative Threat Reduction Program, START I and START II) and requirements of the Clean Air Act (CAA). Disposal and demilitarization of solid rocket motors from large propulsion systems is a major task facing DoD.

Potassium perchlorate until recently was used to treat hyperthyroidism resulting from Grave's disease, and is still used diagnostically to test thyroid hormone production in some clinical settings. In addition, potassium perchlorate is used in protective breathing equipment on Air National Guard (ANG) aircraft for use in the event of depressurization, and in naval emergency escape breathing devices. Other uses of perchlorate salts include in nuclear reactors and electronic tubes, as additives in lubricating oils, in tanning and finishing leather, as a fixer for fabrics and dyes, and in electoplating, aluminum refining, rubber manufacture, and production of paints and enamels. Areas of natural occurrence of perchlorate are rare; however, one natural source of solid perchlorate is found in potassium nitrate from Chile (Chile saltpeter), which may be used in chemical fertilizers originating from Chile. Additional areas of natural occurrence of perchlorate have not been identified, but are speculated to exist, based on the confirmed existence of several genera of perchlorate-reducing organisms.

The toxicity of perchlorate is an active area of research, with most activity focused on the potential of perchlorate to hinder the synthesis of thyroid hormones and/or subsequent consequences resulting from decreases in thyroid hormones. Based on an EPA reference dose (RfD) range of 0.0001 to 0.0005 mg/kg-day revised in 1995, and applying standard default body weights and water consumption levels, provisional cleanup or action levels would range from 4 to 18 parts per billion (ppb). In April 1997 the California Department of Health Services developed an ion chromatography analytical method capable of detecting perchlorate in water at the 4 ppb detection limit; prior to this, analytical techniques were reliable only to a 100 ppb detection limit. Since April 1997, perchlorate has been found in the drinking water supplies of over 15 million people in California, Nevada, and Arizona, and in surface or groundwater throughout the U.S., including Arizona, Iowa, Indiana, Kansas, Maryland, New Mexico, New York, Pennsylvania, Texas, Utah, and West Virginia. Several ongoing projects are now being conducted by various federal and state agencies and research institutions to fully determine the extent of perchlorate occurrence in the environment.

The EPA is continuing the process to more completely and accurately characterize human and ecotoxicological risks associated with perchlorate contamination, which will likely result in a change to the human and ecotoxicology benchmarks. A revised oral risk benchmark of 0.0009 mg/kg-day that combines noncancer and cancer approaches has been proposed in an external review document prepared by the EPA Office of Research and Development (ORD) and National Center for Environmental Assessment (NCEA). Applying standard default body weights and water consumption levels to this revised benchmark would yield a drinking water equivalent level (assuming all perchlorate comes from drinking water) of 31.5 ppb.

At this time, EPA Office of Research and Development (ORD) recommends that the 1995 provisional RfD continue to be used by risk assessors as the more conservative estimate. The state of California has established 18 ppb as an action level, resulting in water suppliers without perchlorate treatment capabilities having to shut down wells or blend water in order to meet this 18 ppb action level. Water utilities in California and Nevada have expressed interest in treating perchlorate to non-detectable levels, and some environmentalist organizations believe treated potable water should have zero ppb perchlorate. The majority of the work being conducted in perchlorate treatability research, testing, and application uses 4 to 18 ppb as benchmark treatment goals.

Treatment of perchlorate contamination in water is complicated because the perchlorate anion does not respond to typical water treatment techniques due to its fundamental physical and chemical nature. The perchlorate tetrahedron itself is structured such that the four oxygen atoms surround the central chlorine atom, effectively blocking reductants from directly attacking the chlorine. The perchlorate anion is soluble and very mobile in aqueous systems. It can persist in the environment for many decades under typical groundwater and surface water conditions because of its resistance to react with other available constituents. While perchlorate is thermodynamically a strong oxidizing agent, with chlorine in the +7 oxidation state, it is a kinetically sluggish species, such that its reduction is generally very slow, rendering common reductants ineffective.

Perchlorate treatment technologies may be generally classified into categories of destruction or removal technologies. Destructive processes include biological reduction, chemical reduction, and electrochemical reduction. Physical removal processes include anion exchange, membrane filtration (including reverse osmosis and nanofiltration), and electrodialysis, which all require subsequent disposal of removed perchlorate. This report contains project summaries on all of these technologies except electrochemical reduction and electrodialysis.

The optimum treatment technology for a given perchlorate occurrence may depend on several factors, including perchlorate concentration, the presence and concentration of co-contaminants, other water quality parameters (pH, alkalinity, natural organic matter (NOM), total dissolved solids (TDS), metals, etc.), and geochemical parameters (nitrate, sulfate, chloride, dissolved oxygen, redox potential, etc.). The presence of indigenous perchlorate-reducing microbes (PRM), and substances inhibitory to PRM activity will also influence perchlorate treatment technology effectiveness. For *in situ* treatment of perchlorate contamination, variables related to the site hydrogeological setting, such as depth to and distribution of contaminants, soil permeability, groundwater flow velocity, etc. are also additionally important. As stated previously, this document does not evaluate the effectiveness of different treatment technologies, but rather seeks to provide basic information on the compiled case studies involving perchlorate treatment, pertinent data on some of the above factors that create complexity, and where available, results-oriented data.

Some additional on-line information sources on perchlorate use, occurrence in the environment, and health, environmental, and treatability issues may be found at the following locations on the Internet.

U.S. Environmental Protection Agency (EPA) Perchlorate Home Page – EPA Office of Water – Ground Water and Drinking Water – http://www.epa.gov/ogwdw000/ccl/perchlor/perchlo.html

U.S. Environmental Protection Agency (EPA), Region IX Fact Sheet on Perchlorate - http://www.epa.gov/safewater/ccl/perchlor/r9699fac.pdf

U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD) National Center for Environmental Assessment (NCEA) The Effects of Ammonium Perchlorate on Thyroids Pathology Working Group Report http://www.epa.gov/ncea/perch.htm

Federal Remediation Technologies Roundtable (FRTR) Interagency Information on Perchlorate – http://www.frtr.gov/perchlorate/index.html

Defense Environmental Information EXchange (DENIX) - http://www.denix.osd.mil/denix/Public/Library/Water/Perchlorate/perchlorate.html

The EPA Perchlorate Home Page also contains information on the activities of the Interagency Perchlorate Steering Committee (IPSC), formed in January 1998, to coordinate a cooperative effort between 24 federal, state, and/or tribal government agencies to address all aspects of perchlorate in the environment. The IPSC contains the following committees: Executive, Analytical, Human Health Risk / Toxicity, Ecological Risk, Treatment Technologies, Communications, and Peer Review. The IPSC has held several public meetings for stakeholders in areas of the U.S. most impacted by perchlorate, including meetings in Henderson, Nevada, Salt Lake City, Utah, and Phoenix, Arizona. The IPSC continues its efforts to ensure an integrated approach to address perchlorate issues and inform and involve stakeholders about technical and regulatory developments. Further information on the IPSC is available at http://www.epa.gov/safewater/ccl/perchlor/ipsc.html

2.2 GWRTAC Database / Scale and Status of Projects

Currently, GWRTAC's case study database contains a total of 65 perchlorate treatment technology (perchlorate) projects. Table 1 provides a summary of pertinent information for the perchlorate case studies that are currently part of the GWRTAC database. The case studies are listed in alphabetical order by project name (which often indicates project location and/or site owner). Also listed for each site is a unique identification number assigned by GWRTAC; for reasons involved in development of the database, the GWRTAC ID numbers are not in consecutive order; consequently, there may be gaps in the sequence. It should be noted that where individual but unique pilot-scale demonstrations are planned or have occurred at the same location (ie., Edwards Air Force Base, California, and others), these individual efforts are counted as separate pilot-scale case studies. Table 1 lists not only the GWRTAC ID and project name and location, but also lists selected primary organization points of contact for the categories of 1) Potentially Responsible Party (PRP)/Site Owner; 2) Funding Source/Sponsor; 3) Regulatory Agency; and 4) Technical Team Member. Where available, GWRTAC's actual database contains additional contacts for each category, including names, addresses and phone numbers for points of contact. This information is available upon request from GWRTAC. Table 1 also includes information on the project scale, technology type, and the project status. It may be useful for the reader to refer to Table 1 while reviewing the remainder of this report.

As Table 1 depicts, there are many different organizations involved in researching and applying a variety of perchlorate treatment technologies. A few of the principle projects are highlighted below. Three organizations involved in funding and/or managing much of the research currently underway, include the American Waterworks Association Research Foundation (AWWARF), the Strategic Environmental Research and Development Program (SERDP), and the National Science Foundation (NSF). AWWARF is managing congressionally appropriated funds to address low level (< 1,000 ppb) concentrations of perchlorate in water for drinking water utilities. These projects are being conducted by a variety of academic and public institutions including Northwestern University, the Pennsylvania State University, Clarkson University, the University of Illinois and the Metropolitan Water District of Southern California, the University of Colorado, National Institute of Standards and Technology, University of Houston, Montgomery Watson, and Johns Hopkins University. SERDP is funding research related to development of *in situ* bioremediation methods to address perchlorate. The SERDP research is being collaboratively conducted by Envirogen, Inc., Southern Illinois University, and Geosyntec, Inc. NSF has funded research in chemical reduction by Iowa State University and the University of California at Los Angeles, and in biodegradation mechanisms by the Pennsylvania State University. Much of the research and pilot- to full-scale work has been individually sponsored directly by water utilities, companies that have manufactured or used perchlorate, by U.S. DoD entities including the Army, Air Force, and Navy, and by the National Aeronautics and Space Administration (NASA).

The U.S. Air Force has worked with Applied Research Associates, Inc. (ARA) of Panama City, Florida, to develop a bioreactor to remediate high concentrations of perchlorate in wastewaters from washout of booster motors, and has sponsored pilot-scale groundwater treatability studies at Edwards Air Force Base, California. The Navy has contracted EnSafe, Inc. of Memphis, Tennessee, to implement full-scale remediation of perchlorate-contaminated soil and groundwater at the Naval Weapons Industrial Reserve Plant (NWIRP) in McGregor, Texas. The Army is currently involved in sponsoring laboratory- and pilot-scale research and demonstrations by the University of Georgia for perchlorate-contaminated soil and groundwater at the Longhorn Army Ammunition Plant in Karnack, Texas. NASA is assisted by the Naval Facilities Engineering Service Center (NFESC) in managing various pilot-scale groundwater treatment projects being conducted at their Jet Propulsion Laboratory (JPL) in Pasadena, California. Aerojet and Kerr-McGee Chemical LLC are two of the private sector companies that have sponsored much of the work on treatment of perchlorate. Aerojet is currently operating a full-scale perchlorate treatment plant at its Rancho Cordova facility that is based on four fluidized bed reactors designed and installed by Envirogen, Inc. of Lawrenceville, New Jersey. In addition, Aerojet has sponsored numerous pilot projects. Kerr-McGee contracted ARA, Inc. to design and install a full-scale treatment plant at their former facilities in Henderson, Nevada that utilizes ARA's continuously stirred tank reactor. The Main San Gabriel Watermaster undertook a fast-track effort to select a perchlorate treatment technology that resulted in Calgon Carbon Corporation of Pittsburgh, Pennsylvania conducting a pilot-scale test of their ISEP TM anion exchange technology system at Big Dalton Well, Baldwin Park, California. This successful pilot led to the design and installation of the current full-scale ISEP TM system for the La Puente Valley County Water District. These are just some of the projects summarized in the Appendix to this report.

As illustrated by the pie chart in Figure 1, of the 65 perchlorate case studies listed in the GWRTAC database, 31 (47%) are laboratory studies, 26 (40%) are pilot-scale studies, and 7 (11%) are full-scale site remediation projects. In some cases, separate projects are listed for laboratory-scale research efforts and for subsequent pilot-scale tests that arose from the initial laboratory efforts. Figure 2 illustrates the status of the projects contained in the GWRTAC database. As seen from the figure, 35 (53%) of the projects have been completed, 27 (42%) projects are in-progress, and 3 (5 %) projects are in the planning stages. Results information is not yet readily available for many projects, since they are ongoing or planned. Table 1 lists individual scale and status information for each project illustrated in Figures 1 and 2.

2.3 Project Objectives / Target Media

Figure 3 depicts the project objectives typically inferred from GWRTAC's sources of information. More than one project objective may be included per project. In Figure 5 and subsequent figures where more than one chart category is applicable, the chart indicates the total number of selections, or "responses", and thus the number upon which the chart's percentage labels are based, as well as the number of case studies containing the information charted. The full-scale/commercial projects are intended for site remediation. Several of the pilot/field demonstrations are undertaken as feasibility studies for collection of economic/design data, or to evaluate performance, and may have either a research or a remediation aspect to them. Laboratory-scale projects are identified as having a research or proof-of-concept objective. Approximately 8 projects (8% of 104) were identified as being conducted as part of full or partial site remediation efforts, 33 projects (32% of 104) were identified as having research as an objective, and 14 projects (13% of 104) were identified as proof-of-concept. Approximately 22 (21% of 104) projects were inferred to have a feasibility aspect (collection of economic or design data), with 27 projects (26% of 104) conducted to evaluate performance of a technology.

Figure 4 displays, for case studies of all scales, the environmental media targeted by the projects, identified from GWRTAC's sources of information. More than one target medium may be indicated for an individual project. Perchlorate-contaminated water or wastewater streams was targeted in approximately 30 (44% of 69) projects, approximately 25 responses (36% of 69), targeted groundwater contamination, approximately 9 (13% of 69) responses targeted soil contamination only (where soil contamination is limited to the vadose zone), and an additional 4 (6% of 69) projects targeted both soil and groundwater.

Figure 5 illustrates the general technology type being applied for each of the perchlorate case studies currently contained in the GWRTAC database. Of 65 projects for which this information is currently entered, 29 projects (45%) utilize or study some type of ex situ biological technology, and 14 projects (22%) address an ex situ physical technology. An additional 12 projects (18%) utilize or study an *in situ* biological technology. Four projects (6 %) include ex situ chemical technology, and four projects (6 %) are indicated as addressing a general biological technology. This last category was created to reflect projects where biological research might easily benefit either *in situ* or ex situ biological technology application. Two projects (3%) were listed as not specified, but are known to be some type of ex situ abiotic technologies.

2.4 Project Location

Figure 6 depicts the location distribution by EPA Region of the 33 perchlorate projects in the GWRTAC database which have advanced to pilot- or full-scale. Figure 6 depicts the locations of only 31 projects because two projects are located at confidential sites, and their locations are unknown from project summary information. EPA Region IX contains the majority (19) of the perchlorate projects. Work in this Region is significant and is due in part to the detection of perchlorate in drinking water sources derived from groundwater in Los Angeles County, California, and pilot-scale work at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, various Aerojet facilities in California, and at former Kerr-McGee facilities in Nevada.

Five projects are located in EPA Region VI, which includes pilot- to full-scale projects at the Naval Weapons Industrial Reserve Plant in McGregor, Texas, and at the Longhorn Army Ammunition Plant in Karnack, Texas. It should be noted that "pilot-scale" operations in Florida and New Jersey represent large pilot-scale facilities operated respectively by Applied Research Associates (ARA), Inc., and Envirogen, Inc., rather than reflecting any on-site source of perchlorate at these locations. These companies have the ability to accept relatively large quantities of perchlorate-impacted waters for pilot testing at their research facilities, as opposed to bench-scale testing that takes place at several additional locations not shown.

Figure 7 illustrates the project location distribution by EPA Region and the general perchlorate treatment type used for the pilot- and full-scale studies in the GWRTAC database. Figure 7 also indicates that chemical technologies (chemical reduction) have not yet been demonstrated at the pilot-scale. The most commonly applied technology at the pilot- to full-scale has been the use of ex situ bioreactors followed by other applications of biological technologies. To a lesser extent, physical technologies, primarily anion exchange, have also been applied at pilot- to full-scale.

Table 2 lists the U.S. state, Canadian province, or other country of each of the bench-, pilot-, or field-scale studies in the database. Most research activities have taken place in California, Florida, Pennsylvania, Texas, and Nevada. Included again are the bench- and pilot-scale facilities in Florida and New Jersey. Additional laboratory testing centers and their respective locations include the Pennsylvania State University, Calgon Carbon Corporation in Pennsylvania, Oak Ridge National Laboratory in Tennessee, and Geosyntec, Inc., in Ontario, Canada. Academic research is also being conducted at the University of San Diego, the University of California (at Riverside and at Los Angeles), the University of Nevada at Las Vegas, the University of Colorado, the University of Georgia, and Los Alamos National Laboratory.

3.0 ANALYSIS OF PERCHLORATE TREATMENT TECHNOLOGIES

3.1 General Technologies, Project Locations, and Contaminant Ranges Treated

Figure 8 provides a detailed break-down of the various biological treatment technologies reviewed. Similarly, Figure 9 provides a detailed break-down of the various physical /chemical technologies reviewed.

Forty-five case studies were reviewed that implemented some form of biological treatment technology. As illustrated in Figure 8, it is apparent that the most widely used and investigated biological technology for perchlorate treatment has been the use of ex situ bioreactors. The four types of bioreactors classified (fluidized bed reactor, packed bed or fixed film reactors, continuous-stirred tank or suspended growth reactors, and non-specific reactors) account for 23 of the 45 projects (50 %) reviewed where biological technologies were employed or studied. Several of the primary technical and academic entities involved in the research and application of bioreactors include ARA, Inc., Envirogen, Inc., the Pennsylvania State University, and the University of California at Riverside. In addition, the University of Georgia has conducted research into the phytoremediation of perchlorate using phytoremediation bioreactors.

Of the 11 biological treatment projects reviewed that were classified as "*in-situ*", seven were listed as "lab-directed" and four had advanced to field-scale. Four of the remaining 11 biological case studies reviewed were listed as research and development for any biological technology (either *in situ* or ex situ), and four studies were listed as ex situ soil bioremediation projects. The three remaining studies reviewed were listed as phytoremediation projects. Technical entities involved in research and application of these biological technologies include EnSafe, Inc., Geosyntec, Inc., Envirogen, Inc., and Los Alamos National Laboratory.

The most commonly investigated and used physical/chemical treatment technology was anion exchange, which accounted for 13 of the 20 (66 %) physical/chemical technology case studies reviewed. Chemical reduction research accounted for four projects (22 %) while reverse osmosis (RO) and nanofiltration accounted for two projects. Oxidation/granular activated carbon (GAC) was investigated in one project. Calgon Carbon Corporation, Oak Ridge National Laboratory, the University of Tennessee, and Los Alamos National Laboratory are involved in the research and /or application of anion exchange technology to perchlorate-containing streams. Georgetown University, Iowa State University, San Diego State University, and the University of California at Los Angeles are several of the academic institutions involved in research of chemical reduction of perchlorate.

Figure 10 illustrates the perchlorate concentration ranges treated or addressed in each of the case studies included in this report. Perchlorate concentrations were not specified in the majority of case studies reviewed; however, when provided, perchlorate concentrations ranged from <1,000 parts per billion (ppb) to >1,000,000 ppb. Research and treatment applications for drinking water sources accounted for the majority of the 15 low perchlorate concentration (<1,000 ppb) treatment projects. Projects with soil or groundwater contamination, or wastewater stream treatments (such as booster motor washout), accounted for those studies generally having higher concentrations of perchlorate.

Figure 11 depicts general perchlorate concentration ranges treated according to general technology type. Summaries for chemical reduction projects (chemical technologies) have not specified the perchlorate concentrations that were addressed. Figure 11 indicates that each perchlorate concentration range investigated has been addressed by physical technologies, ex situ bioreactors, and other biological technologies, with the exception that physical treatment technologies have not yet been applied to perchlorate concentrations greater than 1,000,000 ppb.

3.2 Ex Situ Treatment of Perchlorate-Contaminated Water

Table 3 lists pertinent data from project summaries in the GWRTAC database that involve ex situ treatment of perchlorate-contaminated water, generally from either munitions washout wastewater, or from groundwater recovered by pump and treat systems. The 39 projects summarized in this table represent the majority of case studies collected. Table 3 includes, where available, influent flow volumes treated, influent and effluent perchlorate and co-contaminant concentrations, the size of the treatment system, and the hydraulic residence time.

Most case studies attained, or were designed to evaluate attainment of treated perchlorate effluent concentrations below either the California Action Level of 18 ppb, or below the 4 ppb detection limit. In some studies, however, perchlorate effluent concentrations of <1,000 ppb were obtained when treating high concentration influent streams. In other studies, two-step processes were enlisted to treat highly contaminated influent in a first state, followed by a second stage treatment that can be enlisted if necessary. Volatile organic compounds (VOCs) were the most common co-contaminant present in influent streams, and were generally removed by other elements of the ex situ treatment train. Narratives for all projects can be found in the Appendix of this report.

3.3 Ex Situ Treatment of Perchlorate-Contaminated Soil

Table 4 lists pertinent data from project summaries in the GWRTAC database that involve ex situ treatment of perchlorate-contaminated soil. The five projects listed address a wide range of pre-treatment perchlorate concentrations (24,000 ppb to greater than 2,000,000 ppb). Four of the five projects involve anaerobic composting or treatment within an engineered treatment cell; one of which (PERC0036), is the full-scale engineered land treatment cell at NWIRP in McGregor, Texas.

A composting project at Pueblo Army Depot, Colorado (PERC0053) is underway to treat TNT and RDX. It is known that perchlorate is present at the Pueblo Army Depot site, but it has not yet been determined if the soils being composted contain perchlorate. Future activities will determine whether the soils do contain perchlorate and, if so, measurement of its biodegradation rate along with the explosives will be implemented.

Two composting pilot projects listed on Table 4 are being conducted by Geosyntec. The remaining project involves bench-scale testing of soil bioremediation at the University of Georgia. Projects classified as strictly research and development-oriented were not included in this Table. Narratives for all projects can be found in the Appendix of this report.

3.4 *In Situ* Treatment of Perchlorate-Contaminated Soil, Sediment, or Groundwater

Table 5 lists pertinent information from the seven project summaries in the GWRTAC database that involve *in situ* treatment of perchlorate-contaminated soil, sediment, or groundwater. PERC0002 represents a pilot-scale project involving phytoremediation of perchlorate-contaminated groundwater at Longhorn Army Ammunition Plant in Karnack, Texas, while PERC0004 represents an *in situ* bioremediation project at that same location. PERC0025 is a planned pilot-scale project involving remediation of perchlorate in groundwater through injection of “edible oils”. The potential for phytoremediation of perchlorate using salt cedar is discussed in PERC0045. PERC0052 provides information on planned research into the feasibility of using a permeable reactive barrier for treatment of contaminated groundwater at Los Alamos National Laboratory, New Mexico. Groundwater remediation by an *in situ* biobarrier is addressed in PERC0056; and finally, PERC0062 discusses an *in situ* bioremediation pilot-scale project conducted by GeoSyntec, Inc. at an Aerojet facility in California. Narratives for all projects can be found in the Appendix of this report.

4.0 SUMMARY

The Ground-Water Remediation Technologies Analysis Center (GWRTAC) has prepared this status (S-Series) report on perchlorate treatment technologies to assist the U.S. Department of Defense. This report summarizes information compiled from GWRTAC's case study database.

Perchlorate is the soluble anion associated with the solid salts of ammonium, potassium, and sodium perchlorate. Ammonium perchlorate is used as an energetics booster or oxidant in solid propellant for rockets and missiles. It is, therefore, a national technical asset integral to the Nation's strategic defense system and space exploration. Concerns regarding the presence of perchlorate in the environment have grown since 1997, following its detection in the drinking water of more than 15 million people in the western U.S. Research projects are underway to determine the extent of perchlorate in the environment, its toxicity (especially its potential to hinder the synthesis of thyroid hormones and subsequent consequences), and treatability.

The majority of perchlorate treatability research, testing, and application has targeted either the California Action Level of 18 ppb as the benchmark treatment goal, or the non-detectable level of 4 ppb. Information collected by GWRTAC was organized to depict trends in technology deployment and R&D efforts targeting perchlorate contamination in groundwater, water/wastewater streams, or soil. The intent is to provide the environmental community and public with information on public and private sector activity in laboratory research, and pilot- to full-scale application of innovative technologies in one convenient location.

To date, GWRTAC has identified 65 unique case studies or project summaries related to perchlorate treatment technologies or R&D projects. Thirty-one of the studies identified are laboratory studies, 26 are pilot-scale scale studies, and 7 are full-scale site remediation projects. A total of 35 of the projects have been completed, 27 projects are in progress, and 3 projects are in the planning stages. Results information is not yet readily available for many of these projects due to their on-going or planned status. The vast majority of the 33 pilot- to full-scale projects are located in EPA Region IX (19 projects) and Region VI (5 projects).

Perchlorate-contaminated water or wastewater streams were targeted in approximately 30 projects. Groundwater contamination was targeted in approximately 25 cases, while soil contamination only was targeted in 9 cases. Four projects targeted both soil and groundwater.

Of the 65 projects summarized, 29 projects utilize or study some type of ex situ biological technology, 12 projects utilize or study some type of *in situ* biological technology, and 4 projects are indicated as addressing a general biological technology (reflecting projects where biological research might easily benefit either *in situ* or ex situ biological technology application). Fourteen projects address an ex situ physical treatment technology, while four projects address ex situ chemical treatment technology. Two projects involve ex situ abiotic technologies not otherwise specified.

The most widely used and investigated biological technique for perchlorate treatment to date has been the use of ex situ bioreactors of various types, which account for 23 of the 45 projects where biological technologies are employed or studied. Seven *in situ* bioremediation projects are included which have involved laboratory work; an additional four *in situ* bioremediation projects have advanced to the field. Four projects are listed as research and development for any biological technology, being equally applicable to *in situ* or ex situ application. Finally, there are four ex situ soil bioremediation projects, and three phytoremediation projects identified in the case study summaries. The most commonly investigated and used physical/chemical technology is anion exchange, which accounts for 13 of the 20 physical/chemical technology case studies. Chemical reduction is being investigated in an additional four projects. Reverse osmosis (RO) and nanofiltration are being studied in two of the projects, and oxidation/GAC is being studied in one project.

Where known, the range of perchlorate concentrations being addressed by the projects included in this report ranged from <1,000 ppb to >1,000,000 ppb. Research and application for the treatment of drinking water sources amount to the majority of the 15 low concentration (<1,000 ppb) perchlorate treatment projects. Projects with soil or groundwater contamination, or wastewater stream treatments (such as booster motor washout), accounted for those studies generally having higher concentrations of perchlorate. Based on the information compiled for this report, each perchlorate concentration range investigated has been addressed by physical technologies, ex situ bioreactors, and other biological technologies, with the exception that physical treatment technologies have not yet been applied to perchlorate concentrations greater than 1,000,000 ppb. GWRTAC hopes to provide periodic updates and refinements to this report over the next several years, due to the extremely fast-moving developments in the perchlorate treatment area.

5.0 REFERENCES

Hurley, James., Presentation – “Ammonium Perchlorate Treatment Technology Development”; Air Force Research Laboratory, Tyndall Air Force Base, Florida

Urbansky, E.T. and M.R. Schock, 1999. “Issues in Managing the Risks Associated with Perchlorate in Drinking Water”, in Journal of Environmental Management, Vol. 56, pp. 79-95., Article No jema.1000.0274, available at http://www.idealibrary.com.

U.S. Environmental Protection Agency (EPA) Perchlorate Home Page – December 2000. EPA Office of Water – Ground Water and Drinking Water; Available at http://www.epa.gov/ogwdw000/ccl/perchlor/perchlo.html.

U.S. Environmental Protection Agency (EPA), Region IX Fact Sheet on Perchlorate - http://www.epa.gov/safewater/ccl/perchlor/r9699fac.pdf

Table 1. Perchlorate Treatment Technologies - Summary of Case Studies in the GWRTAC Database
Total Number of Case Studies = 65

GWRTAC ID	Project Name	City	State/ Prvnce	Primary PRP/Site Owner	Primary Funding Source/Sponsor	Primary Regulatory Agency	Primary Technical Team Member	Scale of Project/Target Media	Treatment Technology Classification	Status of Project
PERC0063	Aerojet Bioremediation of Soil from Former Burn Area by Anaerobic Composting	San Gabriel	CA	Gencorp Aerojet	Gencorp Aerojet	Not Specified	Geosyntec, Inc.	Pilot / Soil	Ex Situ Bioremediation (Composting)	Completed (2000)
PERC0005	Aerojet Facility, Rancho Cordova, (Sacramento) California	Rancho Cordova	CA	Gencorp Aerojet	Gencorp Aerojet	Not Specified	U.S. Filter/Envirogen, Inc.	Pilot- , Full-Scale / Groundwater	Four Anoxic Fluidized Bed Reactors, Pilot, Full-Scale Design, Startup, and Optimization	Completed (Started 1998)
PERC0008	Aerojet Facility, San Gabriel, California	San Gabriel	CA	Gencorp Aerojet	Gencorp Aerojet	Not Specified	U.S. Filter/Envirogen, Inc.	Pilot / Groundwater	Anoxic Fluidized Bed Reactor	Completed
PERC0062	Aerojet In Situ Bioremediation Field Demonstration	San Gabriel	CA	Gencorp Aerojet	Gencorp Aerojet	Not Specified	Geosyntec, Inc.	Pilot / Groundwater	In Situ Bioremediation	Completed (2000)
PERC0009	Anoxic Fluidized Bed Reactor (FBR) Optimization, Lawrenceville, NJ	Lawrenceville	NJ	Not Specified	Not Specified	Not Applicable	U.S. Filter/Envirogen, Inc.	Pilot / Groundwater	Anoxic Fluidized Bed Reactor	Completed
PERC0014	Application of Bioreactor Systems to Low-Concentration Contaminated Water (AWWARF #2530)	Chicago	IL	Not Applicable	American Water Works Association Research Foundation (AWWARF)	Not Applicable	Northwestern University	Lab / Water	Bioreactor	In-Progress (TBC 2001)
PERC0015	Application of Bioreactor Systems to Low-Concentration Contaminated Water (AWWARF #2577)	State College	PA	Not Applicable	American Water Works Association Research Foundation (AWWARF)	Not Applicable	The Pennsylvania State University	Lab-Pilot / Water	Packed Bed or Biofilm Bioreactors	In-Progress (TBC 2001)
PERC0065	Baldwin Park Operable Unit of San Gabriel Basin, CA	Los Angeles	CA	Baldwin Park Operable Unit Settling Parties (BPOUSP)	Baldwin Park Operable Unit Settling Parties (BPOUSP)	Not Specified	BPOUSP, U.S. EPA IX, Main San Gabriel Basin Watermaster	Pilot / Groundwater	Fluidized Bed Bioreactor	In-Progress (2001)
PERC0035	Bifunctional Anion Exchange Resin Development - U.S. Patent No. 6,059,975 - Regeneration Method	Oak Ridge	TN	Not Specified	Lockheed Martin	Not Applicable	Oak Ridge National Laboratory, University of Tennessee	Lab / Water	Bifunctional Anion Exchange Resin	Completed
PERC0041	Bifunctional Anion Exchange Resin Pilot	Edwards AFB	CA	U.S. Air Force	U.S. Air Force	Not Specified	Oak Ridge National Laboratory, University of Tennessee, Radian International	Pilot / Groundwater	Bifunctional Anion Exchange Resin	Completed (2000)

Table 1. Perchlorate Treatment Technologies - Summary of Case Studies in the GWRTAC Database
Total Number of Case Studies = 65

GWRTAC ID	Project Name	City	State/ Prvnce	Primary PRP/Site Owner	Primary Funding Source/Sponsor	Primary Regulatory Agency	Primary Technical Team Member	Scale of Project/Target Media	Treatment Technology Classification	Status of Project
PERC0021	Biodegradation of Subsurface Pollutants by Chlorate-Respiring Microorganisms (NSF #9714575)	State College	PA	Not Applicable	National Science Foundation	Not Applicable	The Pennsylvania State University	Lab / Soil, Water	Chlorate Reducing Microorganisms (PRMs) Physiology and Use of Chlorate as Electron Acceptor	In-Progress (TBC 2001)
PERC0046	Biological Treatment at Low Concentrations in Water - Phase 1	San Gabriel	CA	Not Applicable	Main San Gabriel Basin Watermaster	Not Applicable	Harding Lawson Associates	Bench / Water	Fluidized Bed Bioreactor	Not Specified
PERC0047	Biological Treatment at Low Concentrations in Water - Phase 2	La Puente	CA	La Puente Valley County Water District	La Puente Valley County Water District	Not Applicable	Harding Lawson Associates	Pilot / Water	Fluidized Bed Bioreactor	Not Specified
PERC0038	Bioremediation of Perchlorate in Ground Water	Riverside	CA	Not Applicable	University of California Water Research Center	Not Applicable	University of California	Lab / Water	Anaerobic Bioremediation	In-Progress (2001)
PERC0024	Calgon Carbon Corp. - ISEP(R) Continuous Ion Exchange	Los Angeles	CA	Not Applicable	Main San Gabriel Basin Watermaster	Not Applicable	Calgon Carbon Corporation	Pilot / Water	ISEP(R) Continuous Ion Exchange System	Completed
PERC0040	Calgon Carbon Corp. Ion Exchange Bed Regeneration / Umpqua Ion Exchange Bed Regeneration	Pittsburgh	PA	Not Applicable	Calgon Carbon Corporation / Marshall Space Flight Center	Not Applicable	Calgon Carbon Corporation / Umpqua Research Company	Lab / Water	Ion Exchange Bed Regeneration Optimization / Regeneration with Catalytic Oxidation System	Completed (1999)
PERC0059	Calgon Carbon Corp. Remediation of Seepage by Ion Exchange	Henderson	NV	Not Specified	Not Specified	Not Specified	Calgon Carbon Corporation	Full-Scale / Seepage Remediation	Ion Exchange	In-Progress (2000)
PERC0032	Catalytic Reduction using Oxorhenium (V) Oxazoline Complexes	Los Angeles	CA	Not Applicable	The National Science Foundation, The Beckman Foundation	Not Applicable	University of California at Los Angeles	Bench / Water	Chemical Reduction (Oxorhenium (V) Oxazoline Complexes)	Completed
PERC0053	Composting for Treatment of Explosives	Pueblo Army Depot	CO	U.S. Army	U.S. Army	Colorado Department of Public Health and Environment		Full-Scale / Soil	Ex Situ Bioremediation (Composting)	In-Progress (2001)

Table 1. Perchlorate Treatment Technologies - Summary of Case Studies in the GWRTAC Database
Total Number of Case Studies = 65

GWRTAC ID	Project Name	City	State/ Prvnce	Primary PRP/Site Owner	Primary Funding Source/Sponsor	Primary Regulatory Agency	Primary Technical Team Member	Scale of Project/Target Media	Treatment Technology Classification	Status of Project
PERC0010	Confidential Chemical Company Site, High Concentration Perchlorate/Chlorate Treatment	Not Specified	N/S	Confidential Chemical Company	Confidential Chemical Company	Not Specified	U.S. Filter/Envirogen, Inc.	Pilot / Groundwater	Anoxic Fluidized Bed Reactor	Completed
PERC0033	Demonstration of Perchlorate Reduction in Rejectate from Reverse Osmosis	Panama City	FL	Not Applicable	Not Applicable	Not Applicable	ARA & Foster Wheeler Environmental	Lab-scale Groundwater & Drinking Water	Anaerobic Biodegradation with Reverse Osmosis	Completed (2000)
PERC0013	Former Army Ammunition Plant, U.S. Army Corps of Engineers	Not Specified	N/S	U.S. Army Corps of Engineers	U.S. Army Corps of Engineers	Not Specified	U.S. Filter/Envirogen, Inc.	Pilot / Groundwater	Anoxic Fluidized Bed Reactor	Completed
PERC0031	Full-Scale Design of a 1.2 MGD Groundwater Treatment Plant	Henderson	NV	Kerr-McGee Chemical LLC	Kerr-McGee Chemical LLC	State of Nevada	ARA & Biothane Inc.	Full-scale Treatment plant Groundwater	Anaerobic Biodegradation	Completed (2000)
PERC0048	Full-Scale ISEP(R) Groundwater Treatment Plant	La Puente	CA	La Puente Valley County Water District	Main San Gabriel Basin Watermaster, the San Gabriel Basin Water Quality Authority, and the Upper San Gabriel Valley Municipal Water District	Not Specified	Calgon Carbon Corporation	Full-Scale / Water	ISEP(R) Continuous Ion Exchange	Completed
PERC0042	*In Situ* Bioreduction and Removal of Ammonium Perchlorate (SERDP #CU-1162)	Carbondale	IL	Not Applicable	Strategic Environmental Research and Development Program (SERDP)	Not Applicable	Southern Illinois University	Lab	*In Situ* Bioremediation	In-Progress (2001)
PERC0006	*In Situ* Bioremediation of Perchlorate (SERDP #CU-1163)	Lawrenceville	NJ	Not Applicable	Strategic Environmental Research and Development Program (SERDP)	Not Applicable	Envirogen, Inc.	Lab / Groundwater	*In Situ* Bioremediation	In-Progress (2001)
PERC0043	*In Situ* Bioremediation of Perchlorate-Impacted Groundwater (SERDP #CU-1164)	Guelph	ON	Not Applicable	Strategic Environmental Research and Development Program (SERDP)	Not Applicable	GeoSyntec, Inc.	Lab / Groundwater	*In Situ* Bioremediation	In-Progress (2001)
PERC0054	*In Situ* Bioremediation of Perchlorate-Impacted Groundwater (SERDP #CU-1164)	Toronto	ON	Not Applicable	Strategic Environmental Research and Development Program (SERDP)	Not Applicable	University of Toronto	Lab / Groundwater	*In Situ* Bioremediation	In-Progress (2001)

Table 1. Perchlorate Treatment Technologies - Summary of Case Studies in the GWRTAC Database
Total Number of Case Studies = 65

GWRTAC ID	Project Name	City	State/ Prvnce	Primary PRP/Site Owner	Primary Funding Source/Sponsor	Primary Regulatory Agency	Primary Technical Team Member	Scale of Project/Target Media	Treatment Technology Classification	Status of Project
PERC0023	*In Situ* Perchlorate Degradation	State College	PA	Not Applicable	Regenesis, Inc.	Not Applicable	The Pennsylvania State University, Regenesis, Inc.	Lab / Soil, Groundwater	Hydrogen Release Compound (HRC^{TM})	In-Progress
PERC0060	Influence of Humic Substances and Sulfate on Ion Exchange Resins	Las Vegas	NV	Not Specified	Not Specified	Not Specified	University of Nevada at Las Vegas	Lab / Water	Ion Exchange	Completed (2000)
PERC0025	Insoluble Organic Substrates ("Edible Oils") for Degradation of Perchlorate	Edwards AFB	CA	U.S. Air Force	Air Force Center for Environmental Excellence (AFCEE)	Not Specified	Solutions - IES	Pilot	In Situ Bioremediation	Planned (2001)
PERC0017	Investigation of Methods for Perchlorate Destruction in Aqueous Waste Stream (AWWARF #2578)	Potsdam	NY	Not Applicable	American Water Works Association Research Foundation (AWWARF)	Not Applicable	Clarkson University	Lab / Water	Various Abiotic Technologies	In-Progress (TBC 2000)
PERC0016	Investigation of Methods for Perchlorate Destruction in Aqueous Waste Stream (AWWARF#2536)	State College	PA	Not Applicable	American Water Works Association Research Foundation (AWWARF)	Not Applicable	The Pennsylvania State University	Lab / Water	Various Abiotic Technologies	In-Progress (TBC 2000)
PERC0026	Isolation of Perchlorate Reducing Bacterial Culture	Tyndall AFB	FL	Not Applicable	AFOSR, AFRL, JOCG	Not Applicable	Applied Research Associates, Inc. (ARA)	Laboratory scale Effluent from the washout of Minuteman boosters	Anaerobic Biodegradation	Completed (1990)
PERC0004	Longhorn Army Ammunition Plant, Karnack, Texas - In Situ Soil Bioremediation	Karnack	TX	Headquarters U.S. Army Operations	Headquarters U.S. Army Operations	Not Specified	University of Georgia	Pilot / Soil, Sediment	*In Situ* Bioremediation	In-Progress - (October 2000-May 2001)
PERC0002	Longhorn Army Ammunition Plant, Karnack, Texas - Phytoremediation	Karnack	TX	Headquarters U.S. Army Operations	Headquarters U.S. Army Operations, U.S. Air Force	Not Specified	University of Georgia	Pilot / Groundwater	Phytoremediation	Planned (Spring 200)
PERC0050	Low Temperature Biodegradation Studies	Panama City	FL	Not Applicable	Not Applicable	Not Applicable	Applied Research Associates, Inc.	Lab-scale Groundwater	Anaerobic Biodegradation	Completed (2000)
PERC0044	Mechanistic Chemistry of Transition Metal Oxygen and Oxo Complexes (NSF #9982004)	Ames	IA	Not Applicable	National Science Foundation	Not Applicable	Iowa State University	Lab / Soil	Chemical Reduction (Catalysis)	In-Progress (TBC 2000)
PERC0058	Multi-Cell Respirometry Unit Test of Perchlorate Destruction	Indian Head	MD	Not Applicable	Indian Head Division Naval Surface Warfare Center	Not Applicable	Indian Head Division Naval Surface Warfare Center	Lab / Water	Ex Situ Biological	In-Progress (2000)

Table 1. Perchlorate Treatment Technologies - Summary of Case Studies in the GWRTAC Database
Total Number of Case Studies = 65

GWRTAC ID	Project Name	City	State/ Prvnce	Primary PRP/Site Owner	Primary Funding Source/Sponsor	Primary Regulatory Agency	Primary Technical Team Member	Scale of Project/Target Media	Treatment Technology Classification	Status of Project
PERC0011	NASA/California Institute of Technology Jet Propulsion Laboratory, Anoxic FBR	Pasadena	CA	National Aeronautics and Space Administration (NASA) / California Institute of Technology	National Aeronautics and Space Administration (NASA) / California Institute of Technology	Not Specified	Naval Facilities Engr. Command (NAVFAC), Naval Facil. Engr. Service Center (NFESC), U.S. Filter/Envirogen, Inc.	Pilot / Groundwater	Anoxic Fluidized Bed Reactor	In-Progress
PERC0039	NASA/California Institute of Technology Jet Propulsion Laboratory, Ion Exchange Bed Regeneration	Pasadena	CA	National Aeronautics and Space Administration (NASA) / California Institute of Technology	National Aeronautics and Space Administration (NASA) / California Institute of Technology	Not Applicable	Calgon Carbon Corporation	Pilot / Water	Ion Exchange Bed Regeneration	Completed (1999)
PERC0012	NASA/California Institute of Technology Jet Propulsion Laboratory, Packed Bed Reactor	Pasadena	CA	National Aeronautics and Space Administration (NASA) / California Institute of Technology	National Aeronautics and Space Administration (NASA) / California Institute of Technology	Not Specified	Naval Facil. Engr. Service Center (NFESC), Foster Wheeler Environmental Corp., Center for Environmental Microbiology, Univ. of Calif., Riverside	Pilot / Groundwater	Packed Bed Reactor	Pending
PERC0061	Patented Hall Bioreactor	Not Specified	CA	Not Specified	U.S. DoD Installation Restoration Program	Not Specified	EcoMat, Inc., Earth Tech, Inc.	Pilot / Groundwater	Anoxic Bioreactor	Completed (2000)
PERC0027	Perchlorate Biodegradation Pilot-scale Design, Construction, and Demonstration	Tyndall AFB	FL	Not Applicable	AFRL, JOCG	Not Applicable	ARA and Case Engineering	Pilot-scale Effluent from the washout of Minuteman boosters	Anaerobic Biodegradation	Completed (1994)
PERC0052	Permeable Reactive Barrier Feasibility	Los Alamos	NM	U.S. DOE Los Alamos National Laboratory	U.S. DOE Los Alamos National Laboratory	New Mexico Environment Department	U.S. DOE Los Alamos National Laboratory	Lab-scale Groundwater	Permeable Reactive Barrier	In-Progress (2001)
PERC0001	Phytoremediation - Greenhouse Testing	Athens	GA	Not Specified	U.S. Air Force, Wright Patterson AFB	Not Applicable	University of Georgia	Lab / Soil, Groundwater	Phytoremediation (Various Plant-, Algae- and Microbial Mat-Based Bioreactors)	Completed
PERC0045	Phytoremediation By Native Saltcedar, Las Vegas, Nevada	Las Vegas	NV	Not Applicable	U.S. Environmental Protection Agency	Not Applicable	U.S. EPA National Risk Management Laboratory	Field Research	Phytoremediation	Completed (2000)

Table 1. Perchlorate Treatment Technologies - Summary of Case Studies in the GWRTAC Database
Total Number of Case Studies = 65

GWRTAC ID	Project Name	City	State/ Prvnce	Primary PRP/Site Owner	Primary Funding Source/Sponsor	Primary Regulatory Agency	Primary Technical Team Member	Scale of Project/Target Media	Treatment Technology Classification	Status of Project
PERC0028	Prototype Design, Construction, and Demonstration	Tyndall AFB	FL	Thiokol	AFRL JOCG, ESTCP, Thiokol	State of Utah	ARA, Thiokol, and Case Engineering	Prototype Effluent from the washout of Minuteman boosters	Anaerobic Biodegradation	Completed (1997)
PERC0029	Prototype Process Optimization	Brigham City	UT	Thiokol	JOCG & Thiokol	State of Utah	ARA & Thiokol	Prototype Effluent from the washout of Minuteman boosters	Anaerobic Biodegradation	Completed (2000)
PERC0018	Removal of Perchlorate and Bromate in Conventional Ozone/GAC Systems (AWWARF #2535)	Urbana	IL	Not Applicable	American Water Works Association Research Foundation (AWWARF)	Not Applicable	University of Illinois and Metropolitan Water District of Souther California (Los Angeles)	Lab / Water	Ozone/GAC	In-Progress (TBC 2001)
PERC0022	Respiratory Enzymes Used for Perchlorate Reduction by Microorganisms (NSF #0001900)	State College	PA	Not Applicable	National Science Foundation	Not Applicable	The Pennsylvania State University	Lab / Soil, Water	Perchlorate Reducing Microorganisms (PRMs) Physiology	In-Progress (TBC 2003)
PERC0064	Rocket Manufacturing Site Soil Bioremediation by Anaerobic Composting	Bay Area	CA	Not Specified	Not Specified	Not Specified	Geosyntec, Inc.	Pilot / Soil	Ex Situ Bioremediation (Composting)	Completed (2000)
PERC0003	Soil Bioremediation of Perchlorate	Athens	GA	Not Specified	Headquarters U.S. Army Operations	Not Applicable	University of Georgia	Bench / Soil	Bioremediation	Completed
PERC0049	Thermal Regeneration of Ion Exchange Brine	Panama City	FL	Not Applicable	EPA	Not Applicable	ARA	Lab-scale Groundwater & Drinking Water	Thermal Regeneration of Ion Exchange Brine	Completed (1999)
PERC0037	Titanium Ions for Perchlorate Reduction	Georgetown	VA	Not Applicable	Not Specified	Not Applicable	Georgetown University	Lab / Water	Chemical Reduction using Titanium III and Alcohol	In-Progress (2000)
PERC0034	Transformation of Perchlorate into Chloride by Newly Isolated Bacterium	Arnhem	The Nether-lands	Not Specified	Akzo Nobel Central Research	Not Applicable	Akzo Nobel Central Research	Lab / Water	Isolation of Anaerobic Culture	Completed (1996)
PERC0020	Treatability of Perchlorate in Groundwater Using Ion Exchange Technology (AWWARF #2532)	Houston	TX	Not Applicable	American Water Works Association Research Foundation (AWWARF)	Not Applicable	University of Houston, Montgomery Watson, Johns Hopkins University	Lab / Water	Ion Exchange Technology	In-Progress (TBC 2001)

Table 1. Perchlorate Treatment Technologies - Summary of Case Studies in the GWRTAC Database
Total Number of Case Studies = 65

GWRTAC ID	Project Name	City	State/ Prvnce	Primary PRP/Site Owner	Primary Funding Source/Sponsor	Primary Regulatory Agency	Primary Technical Team Member	Scale of Project/Target Media	Treatment Technology Classification	Status of Project
PERC0019	Treatability of Perchlorate-Containing Water by Reverse Osmosis and Nanofiltration (AWWARF #2531)	Boulder	CO	Not Applicable	American Water Works Association Research Foundation (AWWARF)	Not Applicable	University of Colorado, National Institute of Standards and Technology, and Metropolitan Water District of Southern California (Los Angeles)	Lab / Water	Reverse Osmosis / Nanofiltration	In-Progress (TBC 2001)
PERC0051	Treatability Studies for Perchlorate Treatment	Los Alamos	NM	U.S. DOE Los Alamos National Laboratory	U.S. DOE Los Alamos National Laboratory	New Mexico Environment Department	U.S. DOE Los Alamos National Laboratory	Lab-Scale Surface Water Outfalls	Anion Exchange	In-Progress (2001)
PERC0030	Treatability Studies on Groundwater from Henderson, NV	Panama City	FL	Kerr-McGee Chemical LLC	Kerr-McGee Chemical LLC	State of Nevada	ARA & Biothane Inc.	Laboratory scale Groundwater	Anaerobic Biodegradation	Completed (2000)
PERC0055	U.S. Navy, Southern Division, NAVFAC, Groundwater Remediation, McGregor, Texas	McGregor	TX	U.S. Navy, Naval Weapons Industrial Reserve Plant (NWIRP)	U.S. Navy, Southern Division, Naval Facilities Engineering Command	Texas Natural Resource Conservation Commission	EnSafe, Inc.	Pilot-Scale / Groundwater	Fixed Film Bioreactor	In-Progress (2001)
PERC0056	U.S. Navy, Southern Division, NAVFAC, In Situ Groundwater Remediation, McGregor, Texas	McGregor	TX	U.S. Navy, Naval Weapons Industrial Reserve Plant (NWIRP)	U.S. Navy, Southern Division, Naval Facilities Engineering Command	Texas Natural Resource Conservation Commission	EnSafe, Inc.	Full-Scale / Groundwater	Full-Scale In Situ Biobarrier	In-Progress (2001)
PERC0036	U.S. Navy, Southern Division, NAVFAC, Soil Remediation, McGregor, Texas	McGregor	TX	U.S. Navy, Naval Weapons Industrial Reserve Plant (NWIRP)	U.S. Navy, Southern Division, Naval Facilities Engineering Command	Texas Natural Resource Conservation Commission	EnSafe, Inc.	Full-Scale / Soil	Anaerobic Treatment Cell	Completed
PERC0007	U.S.-Switzerland Cooperative Research: Mobility and Interactions of Major Ions in Soils	Baton Rouge	LA	Not Applicable	National Science Foundation	Not Applicable	Louisiana State University, Swiss Federal Institute of Technology	Lab / Soil	Ion Exchange Processes in Soil	Completed
PERC0057	Zero Valent Iron Reduction or Adsorption on Fe0 and Goethite	San Diego	CA	Not Applicable		Not Applicable	San Diego State University	Bench / Water	Chemical Reduction (Fe0, Goethite)	Completed (1999)

Table 2. Perchlorate Treatment Technologies Distribution of Case Studies by U.S. State, Canadian Province, or County

Total Number of Case Studies = 65

U.S. State, Canadian Province or Country	Number of Studies
California	19
Florida	7
Pennsylvania	6
Texas	6
Nevada	4
Illinois	3
Colorado	2
Georgia	2
New Jersey	2
New Mexico	2
Ontario	2
Not Specified	2
Iowa	1
Louisiana	1
Maryland	1
New York	1
The Netherlands	1
Tennessee	1
Utah	1
Virginia	1

Table 3. Perchlorate Ex Situ Water Treatment Technologies - Average Flow Volumes and Influent/Effluent Contaminant and Co-Contaminant Concentrations
Total Number of Case Studies = 39

Note: Projects involving ex situ water treatment R&D and not tabulated include PERC0021, PERC0022, PERC0032, PERC0034, PERC0037, PERC0044, and PERC0057. See Appendix for details on all projects.

		Ex Situ Water Treatment						
GWRTAC ID	**Project Name**	**Influent Flow Volume (gpm or other spec.)**	**Influent Perchlorate Concentration (ppb)**	**Effluent Perchlorate Concentration (ppb)**	**Influent Co-Contaminants Concentration (ppb)**	**Effluent Co-Contaminants Concentration (ppb)**	**Influent/Effluent TDS Concentration (ppm)**	**Treatment Time / System Size**
PERC0001	Phytoremediation - Greenhouse Testing	Not Specified	300,000 max.	<4 to <2	TCE	TCE	Not Specified	1.2 days (half-life)
PERC0005	Aerojet Facility, Rancho Cordova, (Sacramento) California	30 gpm pilot; 4,000 gpm max. (4,000,000 gpd)	8,000	<4	VOCs (Air Stripped in Pretreatment Step)	VOCs (Air Stripped in Pretreatment Step)	Not Specified	4 FBRs 14' dia., 21' tall
PERC0008	Aerojet Facility, San Gabriel, California	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Pilot / Not Otherwise Specified
PERC0009	Anoxic Fluidized Bed Reactor (FBR) Optimization, Lawrenceville, NJ	Not Specified	6,000-8,000 25,000	Not Specified	Not Specified	Not Specified	Not Specified	Pilot / Not Otherwise Specified
PERC0010	Confidential Chemical Company Site, High Concentration Perchlorate/Chlorate Treatment	8-11.5 ml/min	First State 370,000 (400,000 ave.)	First State <5,000 <200	Not Specified	Not Specified	8,200,000 / Not Specified	2.1 HRT 3.1 HRT 4 L glass columns w/ settled sand bed vol. 1.1 L
PERC0011	NASA/California Institute of Technology Jet Propulsion Laboratory, Anoxic FBR	5-6	350-740	<4	Not Specified	Not Specified	Not Specified	20' dia., 15' tall
PERC0012	NASA/California Institute of Technology Jet Propulsion Laboratory, Packed Bed Reactor	2	<1,000	TBD	VOCs	VOCs	Not Specified	3 columns
PERC0013	Former Army Ammunition Plant, U.S. Army Corps of Engineers	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Pilot / Not Otherwise Specified
PERC0014	Application of Bioreactor Systems to Low-Concentration Contaminated Water (AWWARF #2530)	Not Specified	18-1,000	4-18 (Goal -TBD)	Nitrate, TCE, PCE, etc.	Nitrate, TCE, PCE, etc.	Not Specified	Lab-Pilot / Not Otherwise Specified
PERC0015	Application of Bioreactor Systems to Low-Concentration Contaminated Water (AWWARF #2577)	Not Specified	18-1,000	4-18 (Goal -TBD)	Nitrate, TCE, PCE, etc.	Nitrate, TCE, PCE, etc.	Not Specified	Lab-Pilot / Not Otherwise Specified
PERC0016	Investigation of Methods for Perchlorate Destruction in Aqueous Waste Stream (AWWARF#2536)	Not Specified	Not Specified	Not Specified	Nitrate, TCE, TDS, Natural Organic Matter	Nitrate, TCE, TDS, Natural Organic Matter	Not Specified	Lab-Pilot / Not Otherwise Specified
PERC0017	Investigation of Methods for Perchlorate Destruction in Aqueous Waste Stream (AWWARF #2578)	Not Specified	Not Specified	Not Specified	Nitrate, TCE, TDS, Natural Organic Matter	Nitrate, TCE, TDS, Natural Organic Matter	Not Specified	Lab-Pilot / Not Otherwise Specified
PERC0018	Removal of Perchlorate and Bromate in Conventional Ozone/GAC Systems (AWWARF #2535)	Not Specified	Not Specified	4-18 (Goal -TBD)	Not Specified	Not Specified	Not Specified	Lab-Pilot / Not Otherwise Specified
PERC0019	Treatability of Perchlorate-Containing Water by Reverse Osmosis and Nanofiltration (AWWARF #2531)	Not Specified	18-1,000	Not Specified	TDS, TOC	TDS, TOC	Not Specified	Lab-Pilot / Not Otherwise Specified
PERC0020	Treatability of Perchlorate in Groundwater Using Ion Exchange Technology (AWWARF #2532)	Not Specified	1,000 max.	18 (Goal - TBD)	Nitrate, Arsenic, VOCs	Nitrate, Arsenic, VOCs	Not Specified	Lab-Pilot / Not Otherwise Specified
PERC0024	Calgon Carbon Corp. - ISEP(R) Continuous Ion Exchange	4.28	18-76	<4	Nitrate	Nitrate	Not Specified	Pilot / Not Otherwise Specified
PERC0026	Isolation of Perchlorate Reducing Bacterial Culture	N/A	100,000-1,000,000	<1,000	Not Specified	Not Specified	2,000-4,000	Not Specified
PERC0027	Perchlorate Biodegradation Pilot-scale Design, Construction, and Demonstration	0.25 gpm	500,000-3,000,000	<1,000	Not Specified	Not Specified	2,000-6,000	Pilot / Not Otherwise Specified
PERC0028	Prototype Design, Construction, and Demonstration	1.0-2.0 gpm	500,000-6,000,000	<1,000	Salts, Corrosion Inhibitors, etc.	Salts, Corrosion Inhibitors, etc.	2,000-20,000	Prototype / Not Otherwise Specified
PERC0029	Prototype Process Optimization	1.0-2.0 gpm	500,000-6,000,000	<1,000	Salts, Corrosion Inhibitors, etc.	Salts, Corrosion Inhibitors, etc.	2,000-20,000	Prototype / Not Otherwise Specified

Table 3. Perchlorate Ex Situ Water Treatment Technologies - Average Flow Volumes and Influent/Effluent Contaminant and Co-Contaminant Concentrations
Total Number of Case Studies = 39

Note: Projects involving ex situ water treatment R&D and not tabulated include PERC0021, PERC0022, PERC0032, PERC0034, PERC0037, PERC0044, and PERC0057. See Appendix for details on all projects.

		Ex Situ Water Treatment						
GWRTAC ID	**Project Name**	**Influent Flow Volume (gpm or other spec.)**	**Influent Perchlorate Concentration (ppb)**	**Effluent Perchlorate Concentration (ppb)**	**Influent Co-Contaminants Concentration (ppb)**	**Effluent Co-Contaminants Concentration (ppb)**	**Influent/Effluent TDS Concentration (ppm)**	**Treatment Time / System Size**
PERC0030	Treatability Studies on Groundwater from Henderson, NV	N/A	100,000-1,500,000	<18	Chlorate, Sulfate, Chloride, Nitrate, 8,000-9,000 - Cr+6	200 - Cr+6	12,000 / ~13,000	1,000-2,000 lbs ClO4 reduced per day
PERC0031	Full-Scale Design of a 1.2 MGD Groundwater Treatment Plant	825 gpm	400,000	<18 (Design)	Not Specified	Not Specified	12,000 / ~13,000	Full-Scale / Not Otherwise Specified
PERC0033	Demonstration of Perchlorate Reduction in Rejectate from Reverse Osmosis	N/A	10,000-100,000	<18	80 - Cr+6	<10 - Cr+6	2,000-4,000 / 4,000	Bench-Scale / Not Otherwise Specified
PERC0035	Bifunctional Anion Exchange Resin Development - U.S. Patent No. 6,059,975 - Regeneration Method	17 Bed Vol./min (30 ml/min)	Trace	<3	Dissolved Org. Matter, Competing Anions (Cl-, SO4-2, HCO3-3, NO3-)	Dissolved Org. Matter, Competing Anions (Cl-, SO4-2, HCO3-3, NO3-)	Not Specified	Bench-Scale / 1 x 2.2 cm columns
PERC0038	Bioremediation of Perchlorate in Ground Water	Not Specified	738,000,000 738,000,000	<4 (5 hr HRT) <18 (2.5 hr HRT)	Not Specified	Not Specified	Not Specified	2.5-5 hr HRT
PERC0039	NASA/California Institute of Technology Jet Propulsion Laboratory, Ion Exchange Bed Regeneration	Not Specified	1,200	<4	TCE, DCA, CCl4	TCE, DCA, CCl4 Reduced to Non-Detectable Levels	Not Specified	Not Specified
PERC0040	Calgon Carbon Corp. Ion Exchange Bed Regeneration / Umpqua Ion Exchange Bed Regeneration	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified
PERC0041	Bifunctional Anion Exchange Resin Pilot	2 Bed Vol./min (200 ml/min)	50	<5	Dissolved Org. Matter, Competing Anions (Cl-, SO4-2, HCO3-3, NO3-)	Dissolved Org. Matter, Competing Anions (Cl-, SO4-2, HCO3-3, NO3-)	Not Specified	57.4 ml Bed Vol. Columns
PERC0046	Biological Treatment at Low Concentrations in Water - Phase 1	Not Specified	Low	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified
PERC0047	Biological Treatment at Low Concentrations in Water - Phase 2	Not Specified	Low	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified
PERC0048	Full-Scale ISEP(R) Groundwater Treatment Plant	2,500	200 (Capable 600)	5	NDMA (3,000 ppt), 1,4-dioxane	NDMA (<2 ppt)	Not Specified	Not Specified
PERC0049	Thermal Regeneration of Ion Exchange Brine	Not Applicable	50,000	<18	Not Specified	Not Specified	70,000 / 70,000	Not Specified
PERC0050	Low Temperature Biodegradation Studies	Not Applicable	300,000-650,000	<18	Not Specified	Not Specified	4,000-6,000 / 6,000	Not Specified
PERC0051	Treatability Studies for Perchlorate Treatment	1.0-2.5 lpm	100-1,600	<4	Sulfate, Nitrate, Chloride, Fluoride	Not Specified	Not Specified	2 - 0.25 cu. ft. resin vessels
PERC0055	U.S. Navy, Southern Division, NAVFAC, Groundwater Remediation, McGregor, Texas	43 (1.5 x 10-3 gpm/ft2 surf. Loading rate)	23,000	<20	Not Specified	Not Specified	Not Specified	5 ft. dia., 18 ft. tall steel tank, 40 cu. ft. of 2 3/4" bio-ring matrix
PERC0058	Multi-Cell Respirometry Unit Test of Perchlorate Destruction	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified
PERC0059	Calgon Carbon Corp. Remediation of Seepage by Ion Exchange	200-560	80,000-110,000	<2,000	Not Specified	Not Specified	Not Specified	Not Specified
PERC0061	Patented Hall Reactor	Not Specified	300-1,000	Non Detectable	Not Specified	Not Specified	Not Specified	200 L Reactor Volume
PERC0065	Baldwin Park Operating Unit	900-1,500	>18	<4	VOCs, NDMA, 1,4-dioxane, Nitrate - 10,000	Nitrate - <100	Not Specified	Not Specified

Table 4. Perchlorate Ex Situ Soil Treatment Technologies - Available Pre- and Post-Treatment Contaminant and Co-Contaminant Concentrations and System Sizes

Total Number of Case Studies = 5

**Note: Projects involving ex situ soil treatment R&D and not tabulated include PERC0044.
See Appendix for details on all projects.**

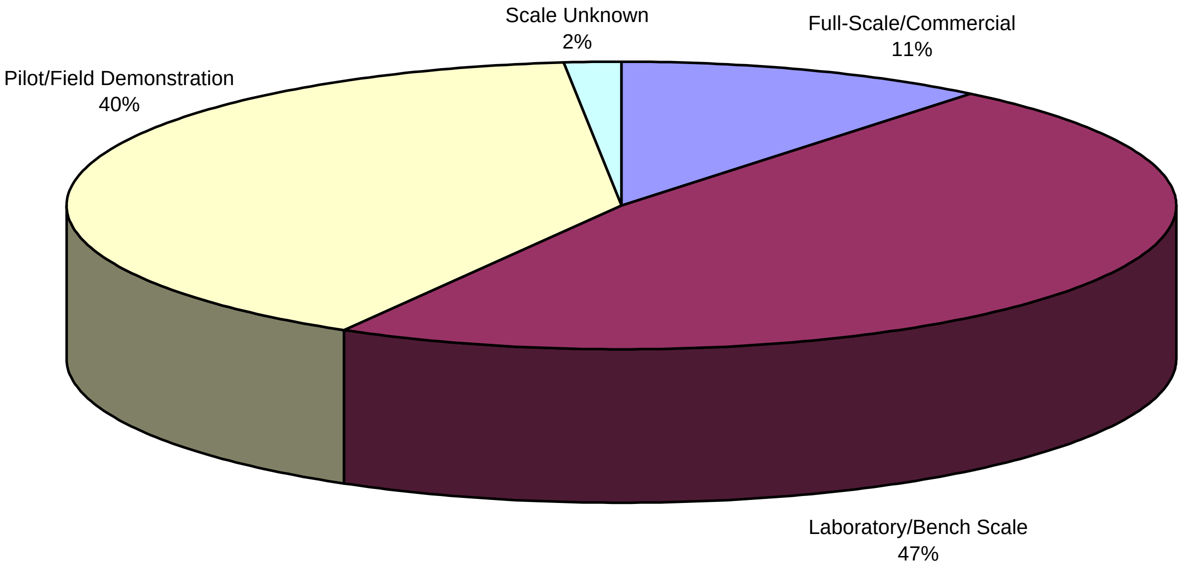
GWRTAC ID	Project Name	Ex Situ Soil Treatment				
		Pre-Treatment Perchlorate Concentration (ppb)	Post-Treatment Perchlorate Concentration (ppb)	Pre-Treatment Co-Contaminants Concentration (ppb)	Post-Treatment Co-Contaminants Concentration (ppb)	Treatment Time / System Size
PERC0003	Soil Bioremediation of Perchlorate	350,000	<4 to <2	Not Specified	Not Specified	Bench / <9 days batch
PERC0036	U.S. Navy, Southern Division, NAVFAC, Soil and Groundwater Remediation, McGregor, Texas	1,800,000 (max.) 500,000 (ave.)	<270	None Present	None Present	Full-Scale / 1,500 cu. yds. 500' x 30' at cell bottom w/ 2H:1V side slopes / 6 mos. trmt. time
PERC0053	Composting for Treatment of Explosives	Not Specified	Not Specified	TNT, RDX	TNT, RDX	Full-Scale / Soil
PERC0063	Aerojet Bioremediation of Soil from Former Burn Area by Anaerobic Composting	24,000	Approaching Non-Detectable Levels	Not Specified	Not Specified	Degradation Half-life 1 to 2 days / Pilot-Scale / Soil
PERC0064	Rocket Manufacturing Site Soil Bioremediation by Anaerobic Composting	2,100,000	<300	Not Specified	Not Specified	Degradation Half-life 2 to 4 days / Pilot-Scale / Soil

Table 5. In Situ Perchlorate Treatment Technologies - Available
Contaminant and Co-Contaminant Concentrations, Site Characterisitics, and Results
Total Number of Case Studies = 7

Note: Projects involving in situ soil and groundwater treatment R&D and not tabulated include PERC0006, PERC0023, PERC0042, PERC0043, and PERC0054. See Appendix for details on all projects.

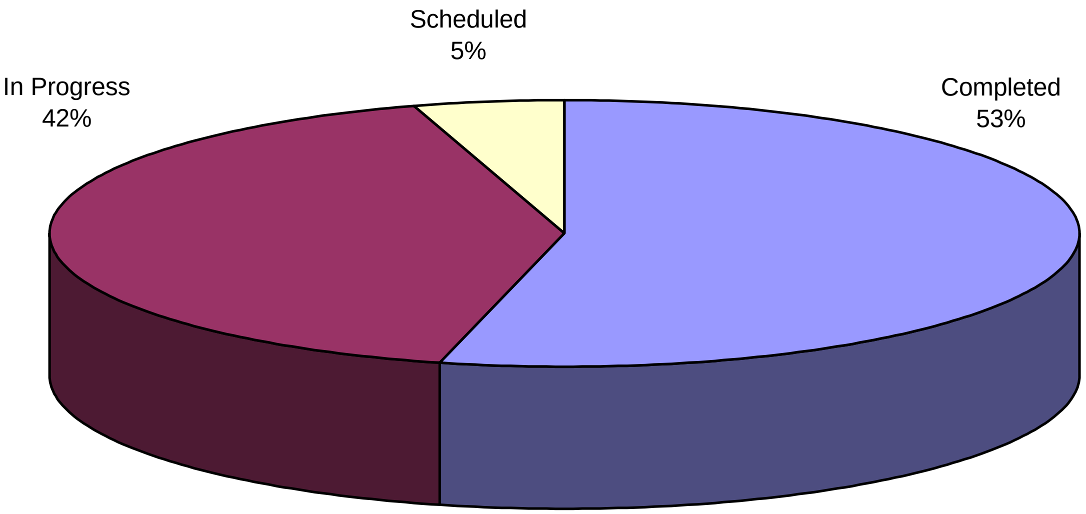
GWRTAC ID	Project Name	In Situ Soil or Groundwater Contamination									
		Perchlorate Concentration in Soil (ppb)	Co-Contaminants Concentration in Soil (ppb)	Perchlorate Concentration in Groundwater (ppb)	Co-Contaminants Concentration in Groundwater (ppb)	Targeted Treatment Zone (Vadose Soils, Groundwater, Both)	Maximum Depth of Targeted Contaminated Zone	Geology of Targeted Treatment Zone	Permeability or Groundwater Flow Velocity of Targeted Treatment Zone (Specify)	Size of Contaminated Zone (Volume of Contaminated Soil or Water - Specify)	Results Achieved
PERC0002	Longhorn Army Ammunition Plant, Karnack, Texas - Phytoremediation	Not Applicable	Not Applicable	Not Specified	Not Specified	Groundwater	Not Specified	Not Specified	Not Specified	Not Specified	Field work anticipated in spring 2001
PERC0004	Longhorn Army Ammunition Plant, Karnack, Texas - In Situ Soil Bioremediation	Not Specified	Not Specified	Not Applicable	Not Applicable	Soil	Not Specified	Not Specified	Not Specified	Not Specified	Field work in progress fall/winter 2000/2001
PERC0025	Insoluble Organic Substrates ("Edible Oils") for Degradation of Perchlorate	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Project is pending; details not yet available
PERC0045	Phytoremediation By Native Saltcedar, Las Vegas, Nevada	Not Specified	Not Specified	Not Specified	Not Specified	Water	Not Specified	Not Specified	Not Specified	Not Specified	300 ug/gm of tissue accumulated in stalks of salt cedar submerged in stream (Las Vegas wash)
PERC0052	Permeable Reactive Barrier Feasibility	Not Applicable	Not Applicable	350	actinide-contaminated colloids, actinides and metals, organic nitrogen and carbon compounds (VOCs/SVOCs)	Groundwater	Not Specified	Not Specified	Not Specified	Not Specified	Hydroxyapatite (fishbone) and pecan shell waste reduced nitrate and perchlorate to non-detectable levels in lab studies. A field-scale system will be installed in fall 2001.
PERC0056	U.S. Navy, Southern Division, NAVFAC, In Situ Groundwater Remediation, McGregor, Texas	Not Applicable	Not Applicable	27,000 (representative)	VOCs (TCE, 1,2-DCE, 1,2-DCA, 1,1,1-TCA, 1,1-DCA, 1,1-DCE, vinyl chloride, chloroethane, methylene chloride, MEK, PCE, toluene, benzene, explosives (1,3,5-TNB, TATB, HMX, RDX)	Groundwater	25 ft	Fractured Limestone	5-100 gpm, K=10-4 to 10-5 cm/s at surface and 10-7 to 10-8 cm/s at depth near confining unit	125 acre plume (est.), 150 mil. Gal. Plume vol. (est.) / 3,000 ft. long bio-barrier trench	After 3 wks., ClO4 concentrations in trench gw decreased to BDL; After 12 mos., still BDL and downgradient reduction of ClO4 and VOCs evident
PERC0062	Aerojet In Situ Bioremediation Field Demonstration	Not Applicable	Not Applicable	15,000	TCE - 3,000	Groundwater	100 ft	Interbedded silts, sands, and gravel	Closed loop (65 ft) / Recirculation 5-10 gpm	800 ft wide plume	Residence Time 21 days / Wells 15' and 35' from nutrient delivery well showed significant reductions in perchlorate concentration

Figure 1. Perchlorate Treatment Technologies - Project Scale
(Only Includes "Most Advanced" Scale for Each Project)



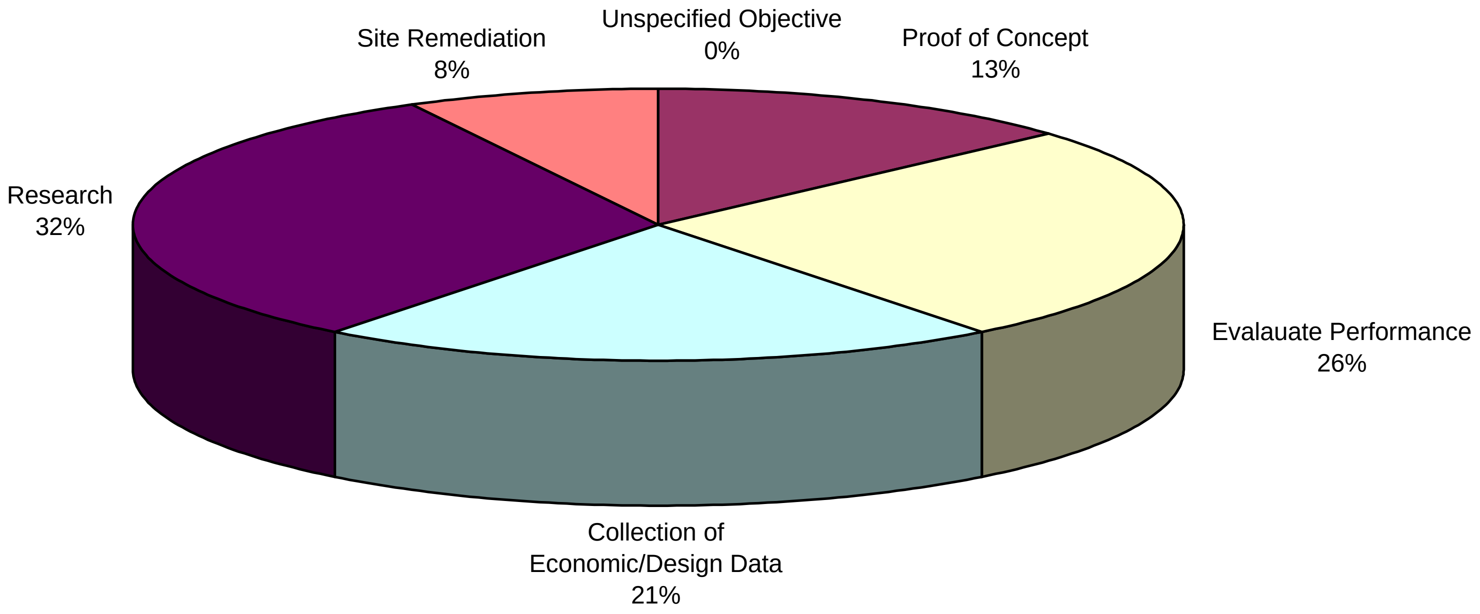
Total Number of Case Studies = 65

Figure 2. Perchlorate Treatment Technologies - Project Status



Total Number of Case Studies = 65

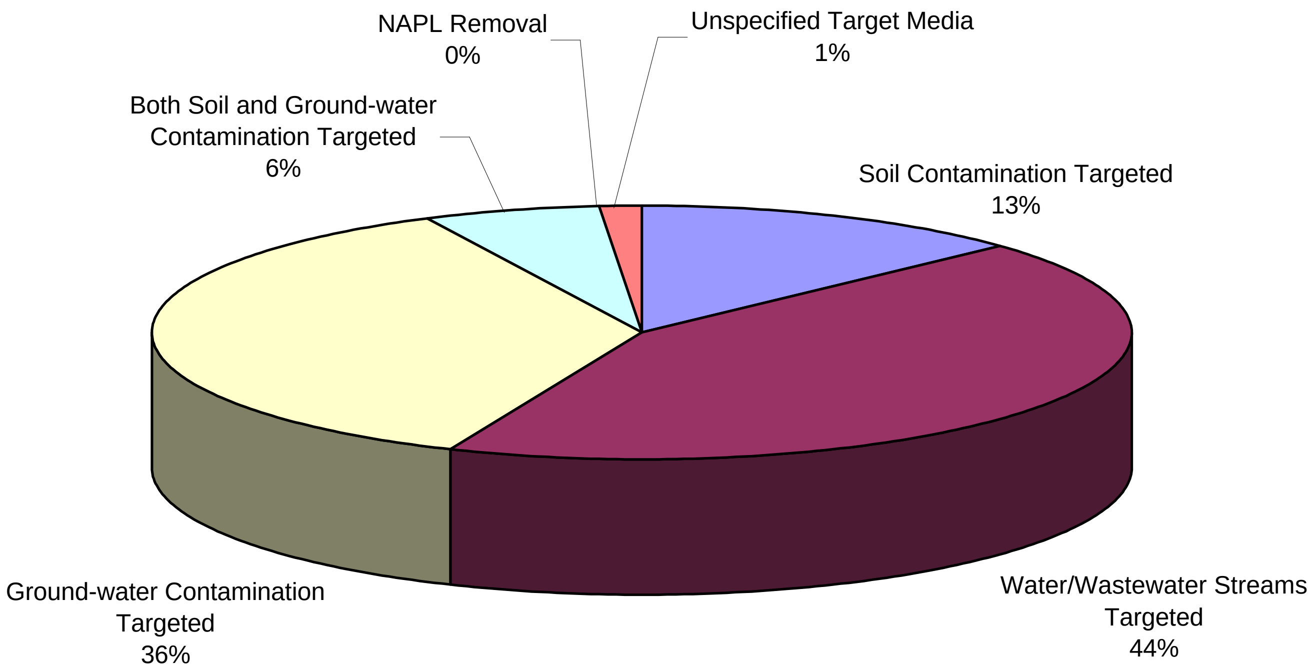
Figure 3. Perchlorate Treatment Technologies - Project Objectives
(May Include More than One Objective per Case Study)



Total Number of Case Studies = 65

Number of Responses on which Percentage Labels is Based = 104

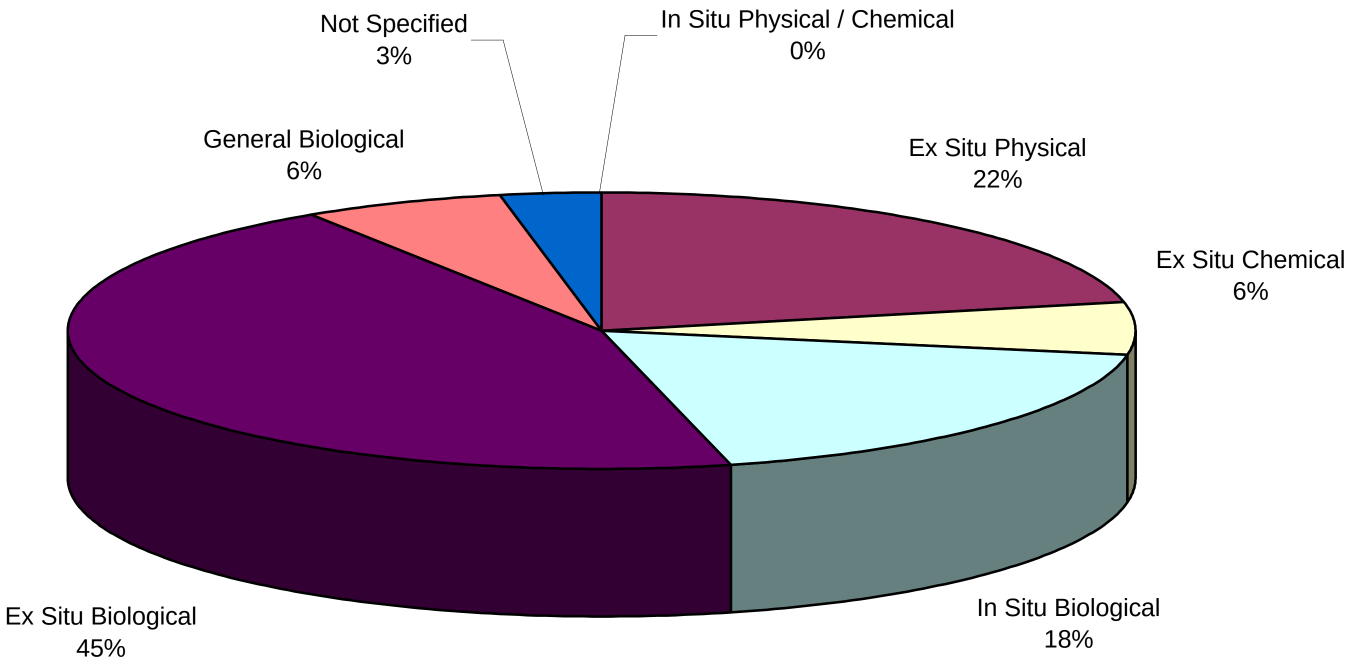
Figure 4. Perchlorate Treatment Technologies - Environmental Media Targeted
(May Include More than One Target Media per Case Study)



Total Number of Case Studies = 65

Number of Responses on which Percentage Labels is Based = 69

Figure 5. Perchlorate Treatment Technologies - General Technology Type



Total Number of Case Studies = 65

Figure 6. Perchlorate Treatment Technologies - Distribution of Case Studies By EPA Region
(EPA Region is Shown for Pilot/Field Demonstrations and Full-Scale/Commercial Projects in U.S. Only)

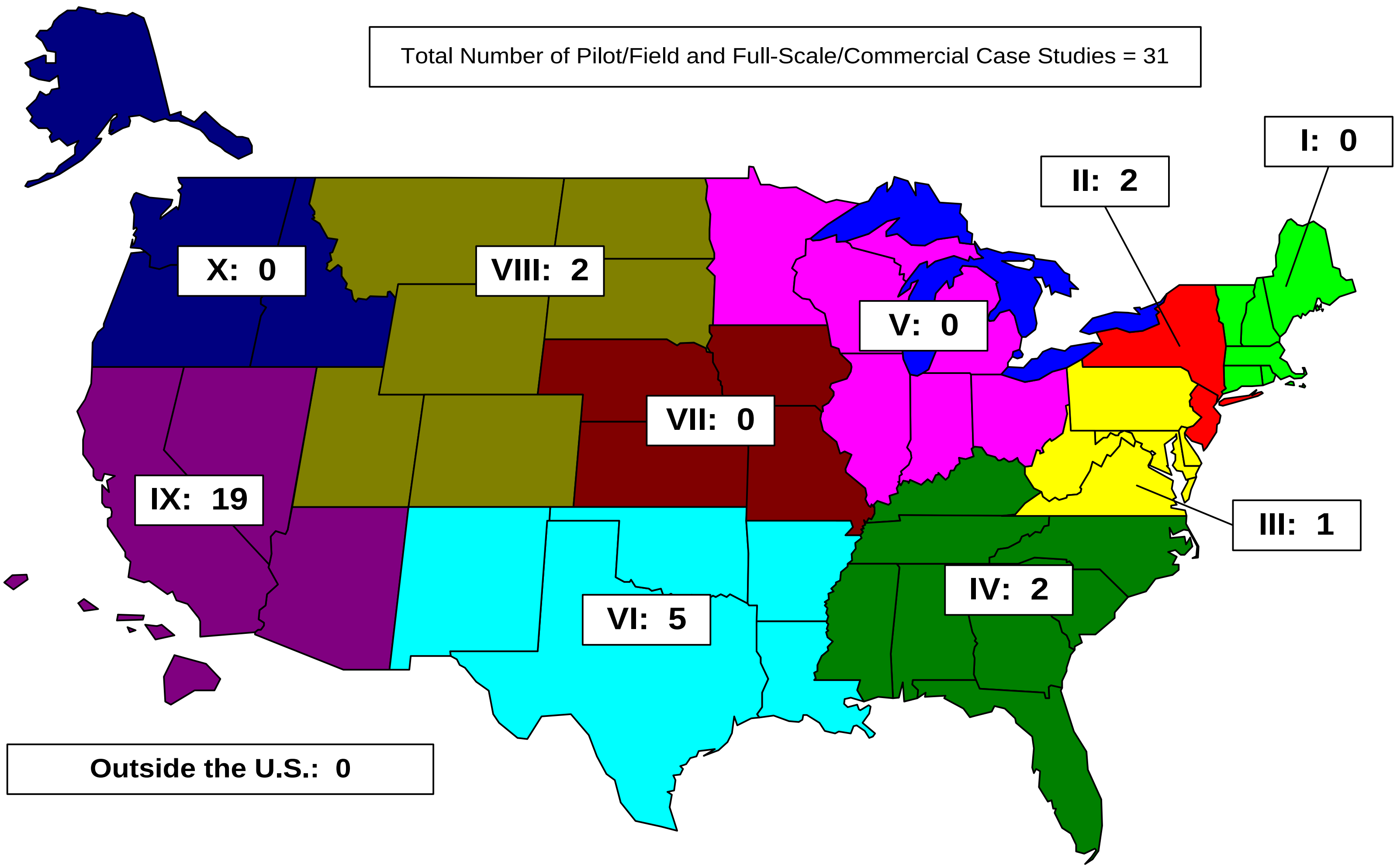
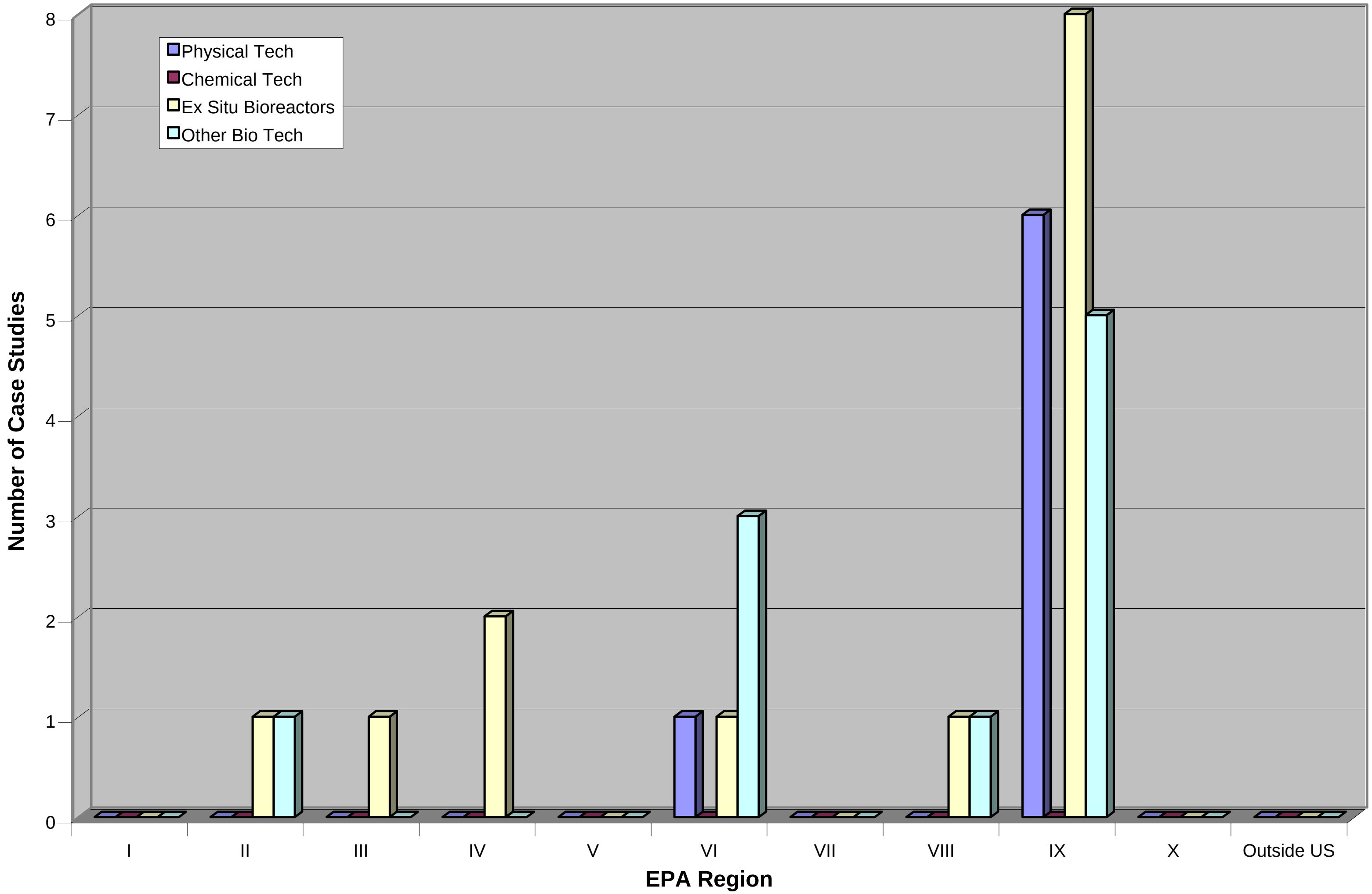


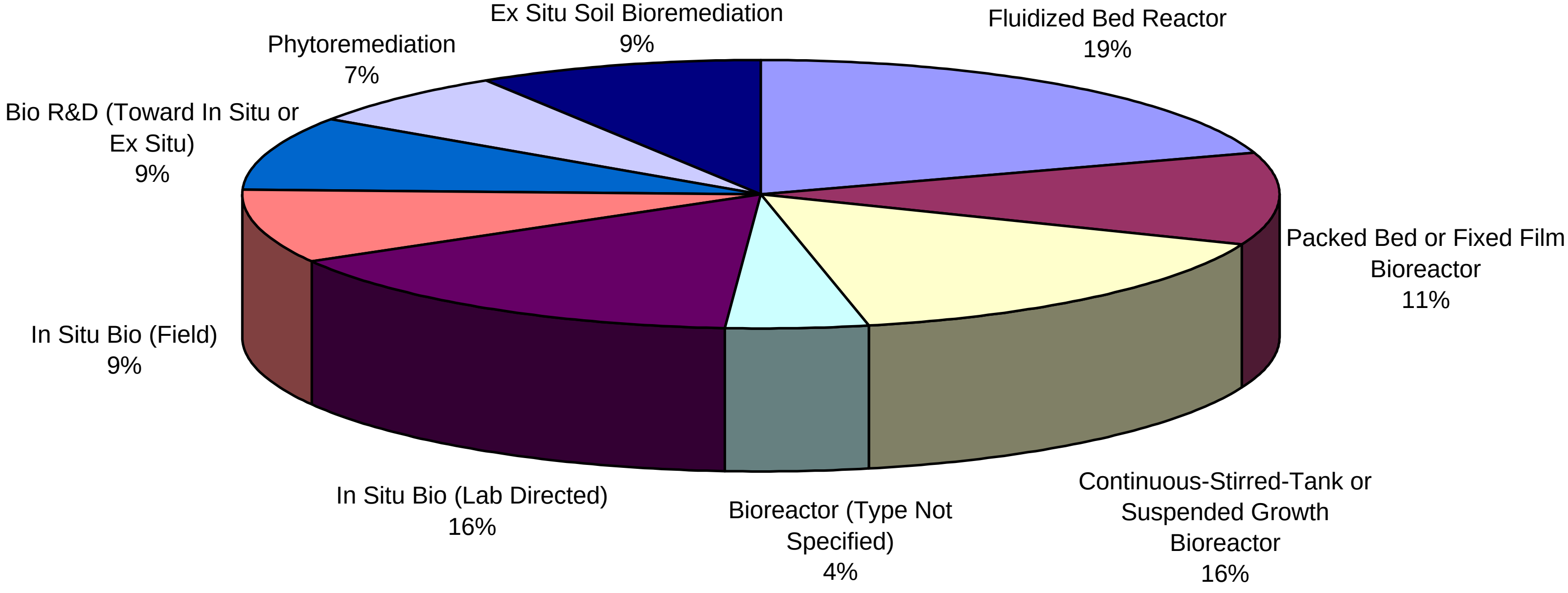
Figure 7. Perchlorate Treatment Technologies - Distribution of Case Studies by EPA Region and General Technology Type

(EPA Region is Shown for Pilot/Field and Full-Scale/Commercial Projects in U.S. Only)



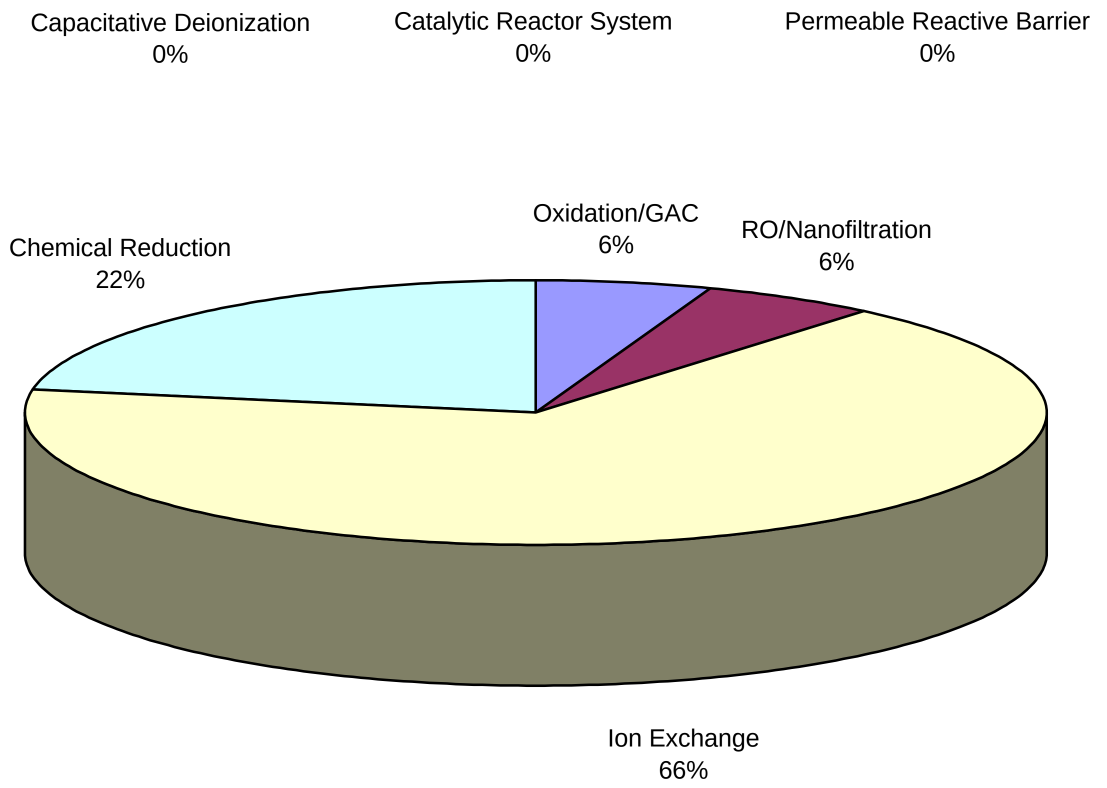
Total Number of Pilot/Field and Full-Scale Commercial Case Studies = 31

Figure 8. Perchlorate Treatment Technologies - Biological Technology Type



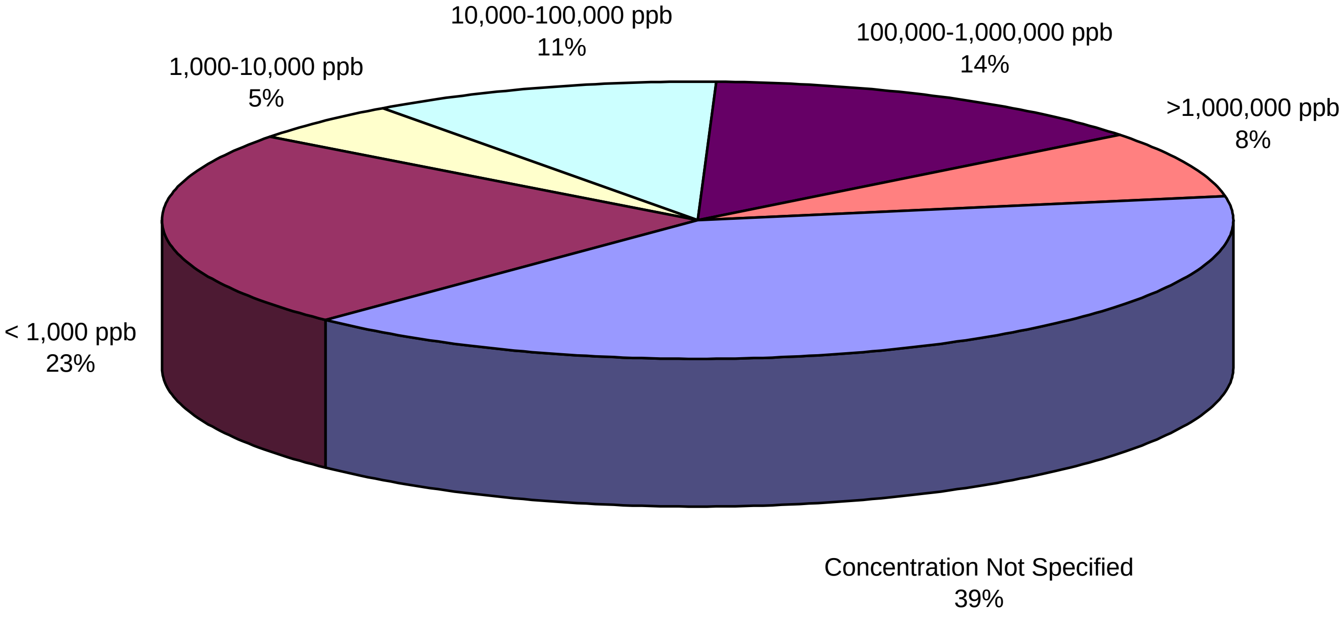
Total Number of Biological Case Studies = 45

Figure 9. Perchlorate Treatment Technologies - Physical/Chemical Technology Type



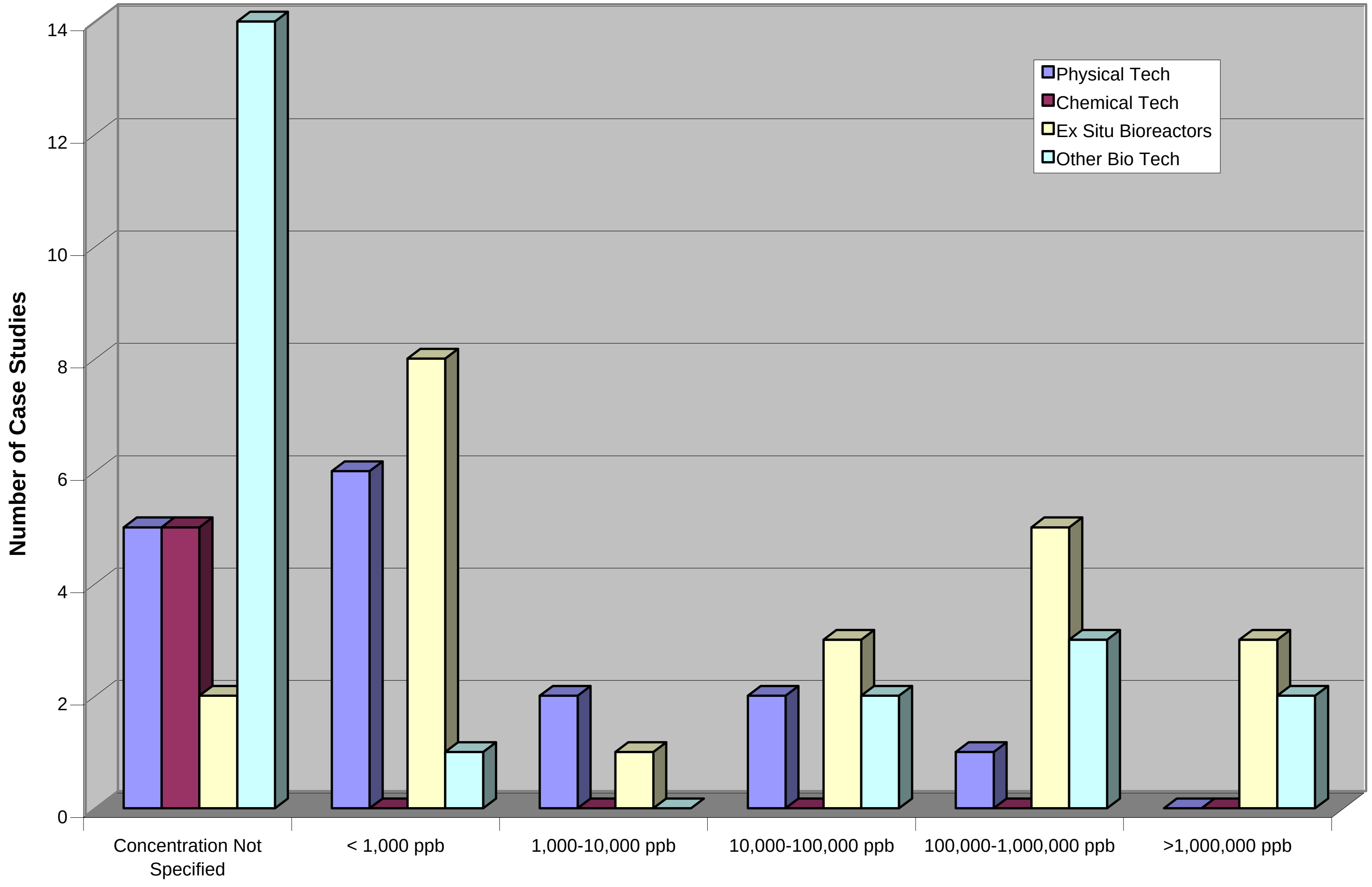
Total Number of Physical/Chemical Case Studies = 20

Figure 10. Perchlorate Treatment Technologies - Perchlorate Concentration Ranges Treated



Total Number of Case Studies = 65

Figure 11. Perchlorate Treatment Technologies - Perchlorate Concentration Ranges Treated by General Technology Type



Total Number of Case Studies = 65

Appendix

Technology Status Report: Perchlorate Treatment Technologies, First Edition

Ground-Water Remediation Technologies Analysis Center (GWRTAC)

Perchlorate Treatment Technologies
Project Summaries

GWRTAC ID:	PERC0001
Project Name:	Phytoremediation - Greenhouse Testing
City:	Athens
State/Province:	GA

Report(s)/Publication(s) (GWRTAC Source):

Valentine A. Nzengung, Ph.D., Associate Professor Department of Geology, University of Georgia, Athens, Georgia 30605, Phone: 706-542-2699, Fax: 706-542-2425, Email: vnzengun@uga.edu

Project Summary:

The following text was excerpted from project summary information provided by University of Georgia personnel, September 2000:

Green plants (aquatic and terrestrial) were screened at the request of the United States Air Force and species capable of degrading perchlorate to chloride were identified (Table 1). Subsequent investigations focused on long-term studies and possible factors that may influence phytoremediation of perchlorate-contaminated water. The specific objectives were to: (1) show that woody, edible, and wetland plants effectively remove perchlorate from water, (2) identify factors that enhance or inhibit uptake, phytodegradation and rhizodegradation of perchlorate, (3) isolate rhizosphere bacteria and verify their contribution to the degradation of perchlorate, (4) determine the efficacy of phytoremediation in the clean up of a mixed-contaminants of perchlorate and trichloroethylene (TCE).

Bench scale studies show that selected woody, edible, and aquatic plants, microbial mats and algae can be used to detoxify water, sediment and soil contaminated by perchlorate. The initial slow uptake and phytodegradation of perchlorate by plants exposed to perchlorate changes to very rapid removal by rhizodegradation after several days depending on the plant physiology and environmental conditions. Initial or prolonged exposure of rooted green plants to perchlorate-dosed media biostimulates the rapid growth of perchlorate-degrading microorganisms in the rhizosphere. Although rhizodegradation accounts for the removal of most of the perchlorate in solution by plants with roots, uptake of perchlorate into the plants may become significant in environments with high nitrate concentrations (a competing terminal electron acceptor). The results of these studies demonstrate that rhizotransformation predominates if nitrate is replaced by ammonium/urea as the nitrogen source and the trees have a higher fraction root mass. Exudates secreted by the plant roots supply nutrients (carbon and electron sources) that sustain the growth of rich and diverse consortia of the perchlorate-degrading microorganisms. Rhizodegradation is a very rapid process that minimizes the uptake of perchlorate into the tree leaves and branches. Any perchlorate taken up into the green plants is not simply accumulated, but slowly transformed. Degradation of perchlorate by pureed and crude extracts of edible plants (spinach and French tarragon) provided direct evidence of phytodegradation of perchlorate.

Willow trees were used to successfully treat water contaminated by both perchlorate and TCE in bench-scale tests. The rate of perchlorate removal from solution in willow bioreactors with and without TCE was the same. The simultaneous phytotransformation of perchlorate and TCE observed in our greenhouse tests was verified and confirmed in experiments conducted with the radiolabeled forms of these compounds. No evidence of long-term phytoaccumulation of either contaminant was observed.

Possible perchlorate phytoremediation schemes may include (1) an intensively cultivated plantation of trees with phreatophytic characteristics at field sites with shallow groundwater, (2) irrigation of planted trees with perchlorate-contaminated groundwater pumped from deep aquifers; and (3) use of constructed anaerobic treatment wetlands. The costs of phytoremediation of perchlorate are similar to those of phytoremediation system currently used to treat organic contaminants and nutrients in soils and groundwater.

A potentially effective algae and microbial mat-based bioreactor treatment system for the rapid removal of perchlorate from water (to non-toxic levels - <4 ppb, or <2 ppb if background noise is insignificant) at perchlorate concentrations within the range of 0 to 300 mg/L (ppm) was also designed and tested. The essential components of the design are a reaction vessel, microbial mats or algae, light, and the bioactive solids. The microbial mat bioreactors performed better and rapidly degraded perchlorate in solution at a faster rate (half-life = 1.2 days). Additionally, the microbial mats survived harsh environmental conditions better than the algae. Possible application of the microbial mats and algae systems could be in treatment ponds exposed to sunlight.

Table 1. Different plants, algae, microbial mats, nutrient amendments and bioreactor systems used in perchlorate degradation studies

Plant Name	Type of Bioreactor
Eastern Cottonwood (Hybrid populus)	2 L sand and hydroponic bioreactors Sand (bottom) plus Soil (above) planted with one tree and holding 10 L of water Sand (bottom) plus Soil (above) planted with one tree and in 250 L container
Black willow (Salix nigra)	2 L sand and hydroponic bioreactor Sand (bottom) plus Soil (above) planted with one tree and holding 10 L of water Sand (bottom) plus Soil (above) planted with one tree and in 250 L container
Willow (Salix caroliniana)	2 L hydroponic bioreactor Sand (bottom) plus potting Soil (above) planted with one tree and holding 10 L of water Ebb-and flow bioreactor
Eucalyptus cineria	2 L sand and hydroponic bioreactors
Parrot feather (Myriophyllum aquaticum)	40 L glass aquarium with freshwater lake sediment at the bottom
Selected wetland plants	Constructed Wetland containing 12 L of water and 4 types of plant species (Cattails, Elodea, duckweed, green algae)
French tarragon (Artemisia dracunculus)	20 mL serum bottles with the pureed whole plants plus deionized water
Spinach Spinacia oleracea	20 mL serum bottles with the pureed whole plants plus deionized water
Mixed-species microbial mats	60-mL serum bottles 5 and 50 L bioreactors
Freshwater green algae	50 L rectangular reactor
Nutrient amendments	Batch Vials, Columns and Field Developed an in-situ nutrient delivery system for perchlorate-contaminated soils.

Report(s)/Publication(s) (Additional Info Source):

Nzengung, Valentine A., Wang, Chuhua, Harvey, Greg. 1999. Plant-Mediated Transformation of Perchlorate

into Chloride, Environmental Science & Technology, vol. 33, pp. 1470-1478.

Nzengung, Valentine A., Chuhua Wang, Harvey, G., McCutcheon, S.C., and Wolfe, N.L. 1999. Phytoremediation of Perchlorate Contaminated Water: Laboratory Studies. Symposium Series: Fifth International Symposium on In Situ and On-Site Bioremediation: Phytoremediation. Editors; Leeson Andrea and B. C. Alleman. Battelle Press, pp 239-244.

Nzengung, Valentine A., Wang Chuhua. 2000. Influences on Phytoremediation of Perchlorate Contaminated Water. American Chemical Society (ACS) Special Symposium Series: Perchlorate in the Environment. Editor: Urbansky. Kluwer Academic/Plenum Publishers, New York. Chapter 21, pp 219 - 229.

O'Niell, L.W., Nzengung, Valentine A., Adesida Adebola. 2000. Treatment of Perchlorate Contaminated Water in Microbial Mat, Algae, and Ebb-and-Flow Hydroponic Bioreactors. Symposium Series: Case Studies in the Remediation of Chlorinated and Recalcitrant Compounds. Editors: Godage B. Wickramanayake, Arun R. Gavaskar, James T. Gibbs, and Jeffrey L. Means. Battelle Press, Columbus, Ohio. 2(7), Pp 101-106

Susarla, Sridhar, and Nzengung, Valentine A. Chapter 25: Degradation of Perchlorate by Plants. in Phytoremediation: Scientific Advances to Manage Contamination by Organic Compounds. Editors: Steven C. McCutcheon and Jerald L. Schnoor (In Preparation 2001.)

GWRTAC ID:	PERC0002		
Project Name:	Longhorn Army Ammunition Plant, Karnack, Texas - Phytoremediation		
City:	Karnack	**State/Province:**	TX

Report(s)/Publication(s) (GWRTAC Source):

Valentine A. Nzengung, Ph.D., Associate Professor Department of Geology, University of Georgia, Athens, Georgia 30605, Phone: 706-542-2699, Fax: 706-542-2425, Email: vnzengun@uga.edu

Project Summary:

The following text was excerpted from project summary information provided by University of Georgia personnel, September 2000:

Pilot testing of phytoremediation of perchlorate-contaminated groundwater is planned for Spring 2001 at the Longhorn Army Ammunition Plant in Karnack, Texas, pending the availability of funds. The US Army and the Air Force are expected to provide funding for the proposed field phytoremediation demonstration project.

Report(s)/Publication(s) (Additional Info Source):

Nzengung, Valentine A., Wang, Chuhua, Harvey, Greg. 1999. Plant-Mediated Transformation of Perchlorate into Chloride, Environmental Science & Technology, vol. 33, pp. 1470-1478.

Nzengung, Valentine A., Chuhua Wang, Harvey, G., McCutcheon, S.C., and Wolfe, N.L. 1999. Phytoremediation of Perchlorate Contaminated Water: Laboratory Studies. Symposium Series: Fifth International Symposium on In Situ and On-Site Bioremediation: Phytoremediation. Editors; Leeson Andrea and B. C. Alleman. Battelle Press, pp 239-244.

Nzengung, Valentine A., Wang Chuhua. 2000. Influences on Phytoremediation of Perchlorate Contaminated Water. American Chemical Society (ACS) Special Symposium Series: Perchlorate in the Environment. Editor: Urbansky. Kluwer Academic/Plenum Publishers, New York. Chapter 21, pp 219 - 229.

O'Niell, L.W., Nzengung, Valentine A., Adesida Adebola. 2000. Treatment of Perchlorate Contaminated Water in Microbial Mat, Algae, and Ebb-and-Flow Hydroponic Bioreactors. Symposium Series: Case Studies in the Remediation of Chlorinated and Recalcitrant Compounds. Editors: Godage B. Wickramanayake, Arun R. Gavaskar, James T. Gibbs, and Jeffrey L. Means. Battelle Press, Columbus, Ohio. 2(7), Pp 101-106

Susarla, Sridhar, and Nzengung, Valentine A. Chapter 25: Degradation of Perchlorate by Plants. in Phytoremediation: Scientific Advances to Manage Contamination by Organic Compounds. Editors: Steven C. McCutcheon and Jerald L. Schnoor (In Preparation 2001.)

GWRTAC ID:	PERC0003		
Project Name:	Soil Bioremediation of Perchlorate		
City:	Athens	**State/Province:**	GA

Report(s)/Publication(s) (GWRTAC Source):

Valentine A. Nzengung, Ph.D., Associate Professor Department of Geology, University of Georgia, Athens, Georgia 30605, Phone: 706-542-2699, Fax: 706-542-2425, Email: vnzengun@uga.edu

Project Summary:

The following text was excerpted from project summary information provided by University of Georgia personnel, September 2000:

To treat soils and sediment contaminated with perchlorate, an in-situ nutrient delivery system to apply known concentrations and volumes of nutrients into the subsurface so as to achieve perchlorate degradation at targeted depths was developed. In bench scale tests, soil from the Longhorn Army Ammunition Plant (LHAAP) in Texas contaminated with about 350 mg/kg of perchlorate was treated to non-detectable levels in less than 9 days. Batch tests have been completed, column studies are in progress and field tests will begin at the LHAAP in Karnack, Texas, in October 2000 and end in May 2001. The proprietary nutrient mix and delivery system can easily be adapted and optimized for soils with different concentrations of perchlorate and hydraulic conductivities. This low cost innovative in-situ soil treatment system avoids the traditional expensive and intrusive method of dig-and-treat.

Report(s)/Publication(s) (Additional Info Source):

GWRTAC ID:	PERC0004		
Project Name:	Longhorn Army Ammunition Plant, Karnack, Texas - In Situ Soil Bioremediation		
City:	Karnack	**State/Province:**	TX

Report(s)/Publication(s) (GWRTAC Source):

Valentine A. Nzengung, Ph.D., Associate Professor Department of Geology, University of Georgia, Athens, Georgia 30605, Phone: 706-542-2699, Fax: 706-542-2425, Email: vnzengun@uga.edu

Project Summary:

The following text was excerpted from project summary information provided by University of Georgia personnel, September 2000:

To treat soils and sediment contaminated with perchlorate, an in-situ nutrient delivery system to apply known concentrations and volumes of nutrients into the subsurface so as to achieve perchlorate degradation at targeted depths was developed. In bench scale tests, soil from the Longhorn Army Ammunition Plant (LHAAP) in Texas contaminated with about 350 mg/kg of perchlorate was treated to non-detectable levels in less than 9 days. Batch tests have been completed, column studies are in progress and field tests will begin at the LHAAP in Karnack, Texas, in October 2000 and end in May 2001. The proprietary nutrient mix and delivery system can easily be adapted and optimized for soils with different concentrations of perchlorate and hydraulic conductivities. This low cost innovative in-situ soil treatment system avoids the traditional expensive and intrusive method of dig-and-treat.

Report(s)/Publication(s) (Additional Info Source):

GWRTAC ID:	PERC0005		
Project Name:	Aerojet Facility, Rancho Cordova, (Sacramento) California		
City:	Rancho Cordova	**State/Province:**	CA

Report(s)/Publication(s) (GWRTAC Source):

Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ 08648, Project Summary Information, September 2000

Girard, M., 2000. “Pilot Treatability Study, Aerojet Sacramento, California” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excepted from project summary information provided by Envirogen, Inc., Lawrenceville, NJ, September 2000:

The GenCorp Aerojet Facility in Sacramento California is the site of the world’s first groundwater treatment system for perchlorate in groundwater. The $5 million facility treats up to 4,000 gpm of groundwater using 4 Envirogen fluidized bed reactors (FBR). The FBR system is designed to treat a water feed with a concentration of 8 mg/L (ppm) and the designed treatment goal is less than 18 ?g/L (ppb). Actual data is showing effluent of less than 4 ppb. The system began treating water late in 1998.

Aerojet evaluated several treatment strategies for perchlorate in groundwater, beginning in 1993, including ion exchange resins and biological reduction. The current system design was selected following the performance of field pilot studies using an FBR supplied by US Filter/Envirex. The pilot system treated a groundwater flow of 30 gpm, and data generated from the study were used for the design basis of the full-scale system. In 1998, Envirogen was awarded a contract by Gencorp Aerojet to design, build, install, and start up an fluidized bed reactor (FBR) system for the treatment of perchlorate-impacted groundwater underlying the Rancho Cordova, California site. The FBR is a reactor column that fosters the growth of microorganisms on a hydraulically-fluidized bed of media, usually sand or activated carbon. The fluidized media selected provides an extremely large surface area on which a film of microorganisms can grow thus producing a large inventory of biomass in a small reactor volume. The result is a system capable of high degradative performance for target contaminants in a relatively small and economical reactor volume. The FBR can be controlled to operate under aerobic, anaerobic or anoxic conditions depending upon the nature of the target compounds. The choice of media for the FBR bed is dependent upon the specifics of the treatment required. Sand is often selected for higher mass flow rates of contaminants where the yield of biomass is expected to be relatively high, i.e., high biofilm growth. Carbon is often selected for greatest assurance of producing low-concentration effluent, i.e., part-per-billion (ppb) levels.

At the Rancho Cordova site, four reactors using GAC media, ethanol as the electron donor, and nitrogen/phosphorous nutrients were designed and installed. Each reactor has a design capacity of 1800 gpm fluidization rate and 900 gpm feed rate. The four reactors are currently in use with a combined feed rate of about 3500 gpm (about 875 gpm each); about five million gallons per day of groundwater is treated. The system receives water from an existing treatment plant that has been in operation since 1981 and uses air-stripping to remove VOCs. The reactors supplied by Envirogen are fourteen feet in diameter and approximately twenty-one feet tall. Additional components of the treatment train include continuous sand filters to remove solids, primarily waste biomass, and solids handling equipment. Treated groundwater is reinjected at the site.

Typical influent and effluent water quality parameters through the FBR are presented below.

Parameter	Influent	Effluent

Dissolved O2	5.3 ppm	<0.5 ppm
Perchlorate	~3500 ppb	<4.0 ppb
TCE	1500 ppb	1500 ppb
NDMA	110 ppt	110 ppt
Nitrate-N	1.5 ppm	<0.11 ppm
Nitrite-N	<0.076 ppm	<0.076 ppm
Sulfate-S	6.0 ppm	6.0 ppm
Ethanol	NA	<1.0 ppm
pH	~7.5	~7.5

Report(s)/Publication(s) (Additional Info Source):

Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ 08648, Project Summary Information, September 2000

Girard, M., 2000. “Pilot Treatability Study, Aerojet Sacramento, California” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Guarini, B., 2000. “Biological Treatment of Groundwater Containing Perchlorate Using Fluidized Bed Reactors” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Hatzinger, Paul B., Mark R. Greene, Samuel Frisch, A. Paul Tonga, Joseph Manning, and William J. Guarini, Envirogen, Inc., Lawrenceville, NJ, 2000: “Biological Treatment of Perchlorate-Contaminated Groundwater Using Fluidized Bed Reactors” Presented at the 2nd International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 22-25, 2000

GWRTAC ID:	PERC0006		
Project Name:	In Situ Bioremediation of Perchlorate (SERDP #CU-1163)		
City:	Lawrenceville	**State/Province:**	NJ

Report(s)/Publication(s) (GWRTAC Source):

Hatzinger, P.B., 2000. “In Situ Bioremediation of Perchlorate in Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org

Hatzinger, Paul, 2000. Abstract from Technical Session 2B in “Environmental Challenges for the Next Decade”, Partners in Environmental Technology Technical Symposium & Workshop, Hyatt Regency, Crystal City, Arlington, Virginia, November 28-30, 2000

Project Summary:

The following text was excerpted from Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org, and Hatzinger, Paul, 2000. Abstract from Technical Session 2B in “Environmental Challenges for the Next Decade”, Partners in Environmental Technology Technical Symposium & Workshop, Hyatt Regency, Crystal City, Arlington, Virginia, November 28-30, 2000:

The objective of this SERDP project is to develop a biological treatment technology for the in-situ remediation of perchlorate in groundwater. Initially, aquifer solids and groundwater will be collected from field sites, and a consortia of microbes along with individual bacterial isolates, which are capable of perchlorate degradation, will be obtained. The conditions required for the in-situ biostimulation of perchlorate degradation will then be identified, and pilot-scale model aquifers will be constructed and operated. This will be followed by biodegradation modeling.

The discharge of contaminated effluents during the manufacture and replacement of propellants in military missiles and rockets has resulted in substantial perchlorate contamination in groundwater in several states, including California, Utah, Texas, and Nevada. The experiments proposed in this effort are designed to provide a fundamental understanding of the factors promoting perchlorate degradation in subsurface environments as well as the conditions that inhibit this process. Laboratory microcosms and flow-through model aquifers with sediments and groundwater collected from perchlorate impacted sites will be used during the project.

The research outlined in this proposal will provide extensive information on the following: (1) the potential for successful perchlorate remediation at subsurface sites by addition of electron donors (i.e., biostimulation); (2) the most effective electron donors to use in biostimulation efforts and the expected concentrations and remediation kinetics achievable with these donors; (3) the possibility for successful bioaugmentation (i.e., injection of bacterial isolates) for subsurface perchlorate remediation; and (4) the probable influence of alternative electron acceptors and environmental variables on perchlorate reduction during biostimulation and/or bioaugmentation efforts. These data will provide the fundamental knowledge required for the design and implementation of pilot-scale and full-scale remediation efforts at perchlorate contaminated sites. This is an FY2000 New Start SERDP project.

Research is being conducted to develop effective methods for in situ treatment of perchlorate in subsurface environments. The research approach is as follows:

? Collect aquifer solids and groundwater
? Enumerate and isolate perchlorate degraders

? Conduct aquifer microcosm studies
? Conduct studies with flow-through model aquifers
? Apply functional models
? Evaluate methods for field implementation
? Conduct field demonstration
? Commercial application

Laboratory microcosm studies were performed using subsurface samples collected from the Jet Propulsion Laboratory (JPL) in Pasadena, CA, the Indian Head Division Naval Surface Warfare Center (IHDIV) in Indian Head, MD, Longhorne Army Ammunition Depot, Texas, a commercial facility in the Rocky Mountains, and a pristine site at Oyster Virginia. These studies were designed to evaluate: (1) the most effective electron donors (substrates) for growth of indigenous perchlorate-degrading bacteria, (2) the requirement for addition of exogenous perchlorate-degrading bacteria to aquifer samples, and (3) the influence of environmental conditions on biological perchlorate reduction.

At each site, after collection of aquifer samples, perchlorate-degrading bacteria were enumerated and isolated, and isolates identified and grouped using rRNA analysis. The aquifer microcosms were built inside serum bottles containing site sediments, site groundwater, and N2. The aquifer microcosms were tested in a variety of ways to assess some combination of electron donors, alternate electron acceptors, environmental variables, and potential for biostimulation and bioaugmentation. Rapid perchlorate biodegradation was observed in substrate-amended aquifer samples from three of the sites. The most effective substrates for stimulating perchlorate reduction varied by site. For example, in samples from the Rocky Mountain site, amendment with lactate, sucrose, or molasses caused perchlorate concentrations to decline from 57 mg/L to less than 0.1 mg/L in 14 days. In the JPL sediment/groundwater microcosms, perchlorate was reduced from 310 ug/L to <5 ug/L in ten days by ethanol, lactate, molasses, yeast extract/ethanol, and acetate. Additionally, methanol, hydrogen, propane, sucrose, and no addition of electron donors, caused degradation to <5 ug/L by Day 21. Benzoate was relatively ineffective. Bioaugmentation by various inoculum also resulted in perchlorate reduction to <5 ug/L by Day 10.
However, several other electron donors, including hydrogen gas and benzoate, did not stimulate perchlorate degradation in these microcosms, even after several weeks of incubation. Perchlorate biodegradation was not observed in subsurface samples from a location at IHDIV after amendment with ten different electron donors or a culture of perchlorate-degrading bacteria. Experiments are underway to evaluate the factors inhibiting perchlorate biodegradation at this location. The current data show that in situ biotreatment is a promising technology for perchlorate remediation, but that the remediation approach, including the choice of electron donors, may vary by site.

Report(s)/Publication(s) (Additional Info Source):

Hatzinger, P.B., 2000. “In Situ Bioremediation of Perchlorate in Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org

Hatzinger, Paul, 2000. Abstract from Technical Session 2B in “Environmental Challenges for the Next Decade”, Partners in Environmental Technology Technical Symposium & Workshop, Hyatt Regency, Crystal City, Arlington, Virginia, November 28-30, 2000

GWRTAC ID:	PERC0007		
Project Name:	U.S.-Switzerland Cooperative Research: Mobility and Interactions of Major Ions in Soils		
City:	Baton Rouge	**State/Province:**	LA

Report(s)/Publication(s) (GWRTAC Source):

NSF Award Abstract - #8713283, 1998. "U.S.-Switzerland Cooperative Research: Mobility and Interactions of Major Ions in Soils", available at https://www.fastlane.nsf.gov/servlet/showaward?award=8713283

Project Summary:

The following text was excerpted from NSF Award Abstract - #8713283, 1998. "U.S.-Switzerland Cooperative Research: Mobility and Interactions of Major Ions in Soils", available at https://www.fastlane.nsf.gov/servlet/showaward?award=8713283:

This award will enable Professor H. Magdi Selim, Louisiana State University, to collaborate with Professor Hannes Fluhler, Swiss Federal Institute of Technology, Zurich. They will study the mobility and retention of major ions in a soil solution, and they will develop a model for describing solute interactions and transport during transient and water-unsaturated flow in soil and geological strata. Laboratory and field experiments will measure ion-exchange selectivity coefficients and the affinity of exchange as a function of counter ions. The major ions to be considered include calcium, magnesium, potassium, and sodium. The counter ions are nitrate, chloride, and perchlorate. The research will try to determine whether the ion retention mechanisms are due to diffusion or other physical and chemical interactions. The studies, performed on Swiss and United States soils, complement each other. The research will be done in the field and laboratory, on different kinds of soils, and the various measurements will help determine the necessary parameters for validating a soil transport model based on ion exchange processes for multiple ions. Most current models do not incorporate multiple ion interactions, so the complete set of phenomena known to affect the mobility of solutes is ignored. Those models that do consider multiple ion interactions deal primarily with idealized systems of uniform and water-saturated soils. The two collaborators have successfully worked together in the past and the proposed research is an extension of their previous research.

Report(s)/Publication(s) (Additional Info Source):

NSF Award Abstract - #8713283, 1998. "U.S.-Switzerland Cooperative Research: Mobility and Interactions of Major Ions in Soils", available at https://www.fastlane.nsf.gov/servlet/showaward?award=8713283

GWRTAC ID:	PERC0008		
Project Name:	Aerojet Facility, San Gabriel, California		
City:	San Gabriel	**State/Province:**	CA

Report(s)/Publication(s) (GWRTAC Source):

Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ 08648, Project Summary Information

Project Summary:

The following text was excepted from project summary information provided by Envirogen, Inc., Lawrenceville, NJ, September 2000:

The Envirogen Team (U.S. Filter/Envirex, Inc.) has conducted pilot work for the Aerojet San Gabriel facility, using the anoxic fluidized bed reactor (FBR). This work included testing at different nitrate concentrations, optimization of additives, and studies of long-term stability.

The FBR is a reactor column that fosters the growth of microorganisms on a hydraulically-fluidized bed of media, usually sand or activated carbon. The fluidized media selected provides an extremely large surface area on which a film of microorganisms can grow thus producing a large inventory of biomass in a small reactor volume. The result is a system capable of high degradative performance for target contaminants in a relatively small and economical reactor volume. The FBR can be controlled to operate under aerobic, anaerobic or anoxic conditions depending upon the nature of the target compounds. The choice of media for the FBR bed is dependent upon the specifics of the treatment required. Sand is often selected for higher mass flow rates of contaminants where the yield of biomass is expected to be relatively high, i.e., high biofilm growth. Carbon is often selected for greatest assurance of producing low-concentration effluent, i.e., part-per-billion (ppb) levels.

The biological destruction of perchlorate by a biological fluidized bed is an anoxic reaction; the work is done by a consortium of organisms that would prefer to utilize oxygen, but in the absence of oxygen are able to use nitrate and perchlorate to degrade organic material. These are robust organisms and the fluid bed reactors provide a very stable physical environment in which very high concentrations of these organisms can be kept in contact with the water being treated. When nitrate is present, it in fact must be removed first before the organisms will tackle the perchlorate.

Report(s)/Publication(s) (Additional Info Source):

Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ 08648, Project Summary Information

Guarini, B., 2000. “Biological Treatment of Groundwater Containing Perchlorate Using Fluidized Bed Reactors” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0009		
Project Name:	Anoxic Fluidized Bed Reactor (FBR) Optimization, Lawrenceville, NJ		
City:	Lawrenceville	**State/Province:**	NJ

Report(s)/Publication(s) (GWRTAC Source):

Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ 08648, Project Summary Information

Project Summary:

The following text was excepted from project summary information provided by Envirogen, Inc., Lawrenceville, NJ, September 2000:

The FBR is a reactor column that fosters the growth of microorganisms on a hydraulically-fluidized bed of media, usually sand or activated carbon. The fluidized media selected provides an extremely large surface area on which a film of microorganisms can grow thus producing a large inventory of biomass in a small reactor volume. The result is a system capable of high degradative performance for target contaminants in a relatively small and economical reactor volume. The FBR can be controlled to operate under aerobic, anaerobic or anoxic conditions depending upon the nature of the target compounds. The choice of media for the FBR bed is dependent upon the specifics of the treatment required. Sand is often selected for higher mass flow rates of contaminants where the yield of biomass is expected to be relatively high, i.e., high biofilm growth. Carbon is often selected for greatest assurance of producing low-concentration effluent, i.e., part-per-billion (ppb) level s.

The biological destruction of perchlorate by a biological fluidized bed is an anoxic reaction; the work is done by a consortium of organisms that would prefer to utilize oxygen, but in the absence of oxygen are able to use nitrate and perchlorate to degrade organic material. These are robust organisms and the fluid bed reactors provide a very stable physical environment in which very high concentrations of these organisms can be kept in contact with the water being treated. When nitrate is present, it in fact must be removed first before the organisms will tackle the perchlorate.

The Envirogen Team (U.S. Filter/Envirex, Inc.) engineers and microbiologists have worked together to optimize the perchlorate treatment process, using the anoxic fluidized bed reactor (FBR). These optimization studies performed on perchlorate-affected water from Aerojet and other sites have resulted in a number of process improvements relating to co-substrates, nutrients, and higher reactor loading rates. The pilot work included research on sand versus carbon media in FBRs, control of filamentous blooms and alternative substrates to ethanol.

Envirogen operated pilot-scale FBR systems for Aerojet in order to evaluate alternative FBR media and alternative electron donors (carbon sources) for perchlorate treatment. The test program consisted of side-by-side evaluation of three FBR systems for the direct comparison of FBR performance with GAC versus sand media and ethanol versus methanol carbon sources. The evaluation showed that GAC media yielded a quicker startup and provided better buffering against process upsets than sand media. The biological perchlorate removal performance with either media was similar using both synthetic feed (i.e., ammonium perchlorate dissolved in tap water at a concentration of 25 mg/L) and actual site contaminated groundwater (perchlorate concentration of 6-8 mg/L). The best performing carbon source was ethanol. The FBR system that used methanol never achieved the same perchlorate removal capacity as the two systems that were fed ethanol. These results were used to finalize the design of a full-scale FBR system to treat 4,000 gpm of perchlorate contaminated groundwater.

In subsequent testing, it was found that mixtures of ethanol and methanol (50/50 on a total carbon basis) were as effective as pure ethanol in perchlorate reduction. However, when the carbon source was changed to pure methanol, perchlorate removal performance dramatically dropped. High perchlorate removal performance was recovered when the carbon source was changed back to the mixture of ethanol and methanol.

Report(s)/Publication(s) (Additional Info Source):

Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ 08648, Project Summary Information

Guarini, B., 2000. “Biological Treatment of Groundwater Containing Perchlorate Using Fluidized Bed Reactors” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0010		
Project Name:	Confidential Chemical Company Site, High Concentration Perchlorate/Chlorate Treatmen		
City:	Not Specified	**State/Province:**	N/S

Report(s)/Publication(s) (GWRTAC Source):

Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ 08648, Project Summary Information

Project Summary:

The following text was excepted from project summary information provided by Envirogen, Inc., Lawrenceville, NJ, September 2000:

The FBR is a reactor column that fosters the growth of microorganisms on a hydraulically-fluidized bed of media, usually sand or activated carbon. The fluidized media selected provides an extremely large surface area on which a film of microorganisms can grow thus producing a large inventory of biomass in a small reactor volume. The result is a system capable of high degradative performance for target contaminants in a relatively small and economical reactor volume. The FBR can be controlled to operate under aerobic, anaerobic or anoxic conditions depending upon the nature of the target compounds. The choice of media for the FBR bed is dependent upon the specifics of the treatment required. Sand is often selected for higher mass flow rates of contaminants where the yield of biomass is expected to be relatively high, i.e., high biofilm growth. Carbon is often selected for greatest assurance of producing low-concentration effluent, i.e., part-per-billion (ppb) levels.

The biological destruction of perchlorate by a biological fluidized bed is an anoxic reaction; the work is done by a consortium of organisms that would prefer to utilize oxygen, but in the absence of oxygen are able to use nitrate and perchlorate to degrade organic material. These are robust organisms and the fluid bed reactors provide a very stable physical environment in which very high concentrations of these organisms can be kept in contact with the water being treated. When nitrate is present, it in fact must be removed first before the organisms will tackle the perchlorate.

A confidential chemical company asked the Envirogen-US Filter/Envirex team to perform laboratory pilot-scale Fluidized Bed Reactor (FBR) treatability work using water samples they shipped to Envirogen's pilot plant facility in Lawrenceville, New Jersey. The purpose of this treatability study was to demonstrate the performance of the first stage in a two-stage FBR system to remove nitrate, chlorate and perchlorate. The target effluent perchlorate concentration from the first-stage FBR was less than 5 mg/L, the inlet perchlorate concentration was 370 mg/L.

Two pilot FBR systems were operated in parallel at two different loading rates, corresponding to 2.1 hour and 3.1 hour hydraulic retention times (HRT). The contaminated water was collected from three sources and was blended at Envirogen in the ratio specified by the client. The two reactors were fed from a common feed tank. During the testwork, samples of the FBR feed and effluents were collected on a routine basis and analyzed for perchlorate, chlorate, nitrate and other organic and inorganic parameters following USEPA methodologies.

The reactors were in operation for a total of thirty-four days. Both the high loaded FBR (2.1 hr HRT) and the moderate loaded FBR (3.1 hr HRT) achieved greater than 99.9% perchlorate reduction after biomass buildup and acclimation. In both reactors, the chlorate and nitrate were completely removed before the perchlorate.

The treatability work demonstrated that FBR systems utilizing sand media are an effective method for treating high TDS water with perchlorate. A total of 388 reactor volumes were processed by FBR #1 while FBR #2 processed 270 reactor volumes. Fourteen sampling events occurred during the steady operation of the FBRs.

Report(s)/Publication(s) (Additional Info Source):

Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ 08648, Project Summary Information

Guarini, B., 2000. “Biological Treatment of Groundwater Containing Perchlorate Using Fluidized Bed Reactors” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Hatzinger, Paul B., Mark R. Greene, Samuel Frisch, A. Paul Tonga, Joseph Manning, and William J. Guarini, 2000. "Biological Treatment of Perchlorate-Contaminated Groundwater Using Fluidized Bed Reactors" Presented at the 2nd International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 22-25, 2000.

GWRTAC ID:	PERC0011
Project Name:	NASA/California Institute of Technology Jet Propulsion Laboratory, Anoxic FBR
City:	Pasadena
State/Province:	CA

Report(s)/Publication(s) (GWRTAC Source):

Executive Summary of report provided by Naval Facilities Engineering Command (NAVFAC) personnel, November 2000

Project Summary:

The following text was excerpted from Executive Summary of report provided by Naval Facilities Engineering Command (NAVFAC) personnel, November 2000:

The National Aeronautics and Space Administration (NASA), the Naval Facilities Engineering Command (NAVFAC), and the Naval Facilities Engineering Service Center (NFESC) are conducting a test of a Fluidized Bed Bioreactor to destroy perchlorate in groundwater at the Jet Propulsion Laboratory (JPL) in Pasadena, California. The system is being tested for its ability to achieve non-detectable levels of perchlorate in the effluent assuming an influent concentration between 350 and 740 ug/l. Groundwater will be extracted at a flow rate of 5-6 gpm from JPL Monitoring Well #7 and fed through the FBR system described below.

Fluidized Bed Technology

The Fluidized Bed Reactor (FBR) is a fixed-film reactor column that fosters the growth of microorganisms on a hydraulically fluidized bed of media (activated carbon). The activated carbon media is selected for greatest assurance of producing a low-concentration effluent, i.e., part-per-billion (ppb) levels of contaminants of concern (COCs). The fluidized media provides an extremely large surface area on which a film of microorganisms can grow and produce a large inventory of biomass in a small reactor volume. The result of this biological growth is a system capable of high degradative performance for target contaminants in a relatively small and economical reactor volume. The activated carbon can also adsorb the organics in the groundwater. This leads to secondary removal of degradable organics. The FBR perchlorate destruction system is capable of reducing perchlorate concentrations to less than 4 ?g/L, the current analytical reporting detection limit. These levels are reached at ambient water temperatures.

The biological process inside the FBR completely destroys the perchlorate molecule. The products of the biochemical reaction are chloride ions and oxygen. Perchlorate is not transferred from one medium to another for subsequent treatment and/or disposal. The process also destroys nitrate, often necessary if considering reinjection of the groundwater. The only waste byproduct generated from the biodegradation of perchlorate and nitrate is a small volume of excess biosolids. These solids are removed from the system on a continuous basis. They are nonhazardous and can be disposed in a number of cost-effective manners.

The FBR is simple in design, containing a provision for distribution of the influent liquid flow and a component to control the expansion of the fluidized bed when necessary. When biological growth occurs on the fluid bed media particles, their diameter increases and their effective density is reduced, resulting in a bed expansion beyond that experienced with unseeded media. Under conditions resulting in extensive biofilm growth, it may be necessary to control the biofilm thickness to prevent the density of the biofilm-covered media from decreasing to the point where bed carryover occurs.

Treatment System Components

The basic components of an FBR system for treatment of nitrate and perchlorate include the bioreactor, granular activated carbon (GAC) bed media, a fluid distribution system in the bottom of the reactor, feed and influent pumps, a nutrient addition system, a pH control mechanism and a bed height control component when required. The complete treatment system at JPL also contains four GAC canisters for treating chlorinated volatile organic carbons (VOCs) and a supplemental Ion Exchange (IX) unit for removal of any perchlorate or nitrate not removed by the FBR.

Influent groundwater feed is combined with the effluent recycle from the FBR and pumped into the bottom of the FBR through the distribution system, fluidizing the media contained in the reactor. Nitrogen and Phosphorous (in the form of dibasic ammonium phosphate and urea) and ethanol are pumped continually into the reactor flow representing respectively a nutrient to support biomass growth and a carbon source to promote nitrate-N and perchlorate reduction in the FBR. Because biological nitrate-N reduction (denitrification) produces hydroxyl ions tending to raise the pH in the FBR if not neutralized, acid is metered into the reactor flow to maintain the pH in the FBR below 8 as necessary.

From the FBR, treated groundwater is passed through two sets of parallel configured GAC beds to remove any remaining chlorinated VOCs. The groundwater then passes through two ion exchange (IX) beds to remove any perchlorate not destroyed during the pilot test. This extra IX process would not be necessary on a full-scale FBR system, and is only added here to protect from discharge of perchlorate during system modifications and testing.

Process Microbiology

Biological treatment of perchlorate is a relatively new, but field-proven technology. Full-scale (4,000 gpm) and pilot-scale (5-20 gpm) systems are currently in service using biological means to reduce perchlorate. The process can be viewed as similar to nitrate reduction (denitrification) where in the absence of oxygen, the nitrate anion serves as the terminal electron acceptor for microbial metabolic activity. The microorganisms in these systems are facultative aerobes, meaning they require oxygen or a suitable substitute (i.e., nitrate or perchlorate) for normal activities. Aerobic operation without oxygen addition is termed anoxic. For perchlorate removal, the dissolved oxygen and nitrate anions have to be removed before perchlorate can be completely removed. There is evidence that perchlorate reduction can occur simultaneously with nitrate reduction, but to achieve high perchlorate removal efficiencies (i.e., effluent concentrations below 4 ppb), all the nitrate needs to be reduced before the perchlorate. The same carbon source (electron donor) can be used to remove dissolved oxygen, reduce nitrate, and reduce perchlorate. A sufficient quantity of these electron donors has to be provided to effect these biochemical reactions.

Several microbial strains have been isolated with the ability to degrade perchlorate using the anion as a terminal electron acceptor. Many of these strains also reduce nitrate, and it is thought that the same enzyme system may be employed for either reduction. The enzymatic pathways involved in perchlorate reduction have yet to be fully elucidated. However, it has been suggested that a perchlorate reductase catalyses an initial two-step reduction of perchlorate (ClO_4^-) to chlorate (ClO_3^-) and then chlorite (ClO_2^-). The chlorite is further reduced by chlorite dismutase to chloride (Cl^-) and oxygen (O_2). Thus, microbial degradation of perchlorate yields two innocuous products, chloride and oxygen.

The reduction of perchlorate to chloride is a very favorable process from a thermodynamic perspective. In fact, based on its reduction potential ($E_0 = 1.287$ V), perchlorate may yield more energy to a microorganism during reduction than even oxygen ($E_0 = 1.229$ V). This means bacteria capable of using perchlorate are likely to have a distinct ecological advantage in contaminated environments. All of the energy from perchlorate reduction appears to come from the perchlorate to chlorite reaction. The reduction of chlorite while yielding little energy is necessary because it removes a toxicant for the microbes. Without microorganisms that can remove chlorite, the FBR system will have great difficulty in maintaining sustainable operation. For this reason, it is important to use the appropriate seed material when initiating FBR operation.

If necessary, treatment of perchlorate in the groundwater will also be performed using established ion exchange technology. The strong base anion resin to be used for this process is capable of removing perchlorate to below currently accepted detection limits of 4 ppb. Laboratory testing on a number of contaminated waters has demonstrated the versatility of ion exchange to remove both high and low levels of perchlorate from waters of varying dissolved mineral content. The perchlorate ion, having a high affinity for the selected resin, is preferentially exchanged over the other ions in solution. The resin will quickly equilibrate with the influent, such that the effluent from the ion exchange unit will be the same in composition as the influent, with the exception that the treated water is now free of perchlorate. Perchlorate loaded resin has been tested by an independent laboratory and has been found to not be a hazardous material in accordance with a specific DOT required test. This resin will be transported to an approved facility for final destruction.

Pilot Demonstration Objectives

Demonstrate the effectiveness of the fluidized bed reactor (FBR).
Demonstrate that the FBR technology can reliably treat perchlorate-contaminated water to <4 ug/l.
Develop full-scale design parameters.
Demonstrate the robustness/reliability and operations simplicity of the design.

The pilot FBR is an actual commercial size unit currently in operation at many facilities. These units use full-scale control strategies, and are designed for around the clock operation. No scale up factor is required in moving to a full-scale treatment system. In contrast, the bench-scale FBR is used primarily to indicate if biological treatment of a waste stream is feasible. It is not equipped with the process controls of pilot/full-scale systems that preclude much of the operator attention that may create delays during a laboratory study. The laboratory bench-scale study results did indicate that the perchlorate could be successfully reduced biologically. However, the bench-scale system does not demonstrate the robust nature of an actual commercial system.

System Components

Cartridge Filter

The pilot system includes one in-line cartridge filter. The cartridge filter is a USFilter model FCROF4005 filter and is located downstream of the FBR and upstream of the FBR ion exchange polishers. The filter housing is 6” diameter x 40” high and is constructed of 304 stainless steel. The filter media is Rogard Type 2 media density polypropylene, 5 micron.

Fluidized Bed Reactor (FBR)

The pilot FBR is self-contained and includes a reactor 20" diameter by 15' tall, growth control system, media separation system, fluidization system (including fluidization pump), and granular activated carbon as the growth media.

Ion Exchange Unit (IX)

The pilot system includes one Anion Ion Exchange system. The system is located downstream of the GAC beds (below). The ion exchange system includes two vessels arranged in a lead-lag configuration. The vessels are USFilter model ZWDJOP-2598 vessels constructed of fiberglass reinforced plastic (FBR). Each vessel is designed to contain 2 cubic feet of resin. The resin used for this pilot program is anionic, Type II strong base resin. Each ion exchange vessel is 10” diameter and 58” high and weighs 165 lbs (vessel, water, & resin).

Chemical Feed Systems

Ethanol Feed System
Denatured ethanol is stored in 55 gallon drums with drum containment. The drum is vented to the atmosphere. The ethanol is fed to the FBR influent with an explosion proof diaphragm metering pump. A fire extinguisher will be included with the ethanol feed system.

Nutrient Feed System
Nutrients are made up of a mix of dibasic ammonium phosphate and urea. They are fed to the FBR influent via a 6 gpd diaphragm metering pump. Nutrients are mixed in a 25 gallon plastic tank.

pH adjustment system (if required)
In the event that pH adjustment is required, a 6 gpd diaphragm metering pump and a 25 gallon plastic tank are included.

Storage Tanks

One 300-gallon plastic tank is located downstream of the FBR for post aeration.

GAC Adsorption

The pilot system contains four USFilter/Westates ASC-200-2-CC-601 carbon adsorbers to remove chlorinated organics. These systems are located following the post-aeration tank after the FBR. The vessels contain a 12x30 virgin coconut shell carbon.

This pilot project is scheduled for completion in December 2000, and a report is to be issued on the project during the first quarter of 2001.

Report(s)/Publication(s) (Additional Info Source):

Executive Summary of report provided by Naval Facilities Engineering Command (NAVFAC) personnel, November 2000

Guarini, B., 2000. “Biological Treatment of Groundwater Containing Perchlorate Using Fluidized Bed Reactors” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0012		
Project Name:	NASA/California Institute of Technology Jet Propulsion Laboratory, Packed Bed Reactor		
City:	Pasadena	**State/Province:**	CA

Report(s)/Publication(s) (GWRTAC Source):

Information provided by Naval Facilities Engineering Command (NAVFAC) personnel, November 2000

Project Summary:

The following text was excerpted from information provided by Naval Facilities Engineering Command (NAVFAC) personnel, November 2000:

An effective, economical treatment technique is needed for groundwater impacted with low levels of ClO4-. Of the available treatment technologies currently considered feasible for groundwater treatment (IE, RO and biotreatment via bioreactors), the PBR may be preferred for the following reasons:

It destroys ClO4- rather than concentrating it, as do IE and RO;
It is easier to operate than other current biological techniques, and potentially better suited to the lower concentration groundwater application;
Conventional equipment can be easily retrofitted for use as PBRs, thereby increasing its implementability.

The PBR potentially is an effective and economical method for treating lower concentrations of ClO4- in groundwater. To our knowledge, the PBR has not been tested yet for the ClO4- application in the field.

Objectives

The primary objective of the proposed study is to demonstrate proof-of-concept for the PBR to treat low concentrations of ClO4- (<1 mg/L) in groundwater at a field scale. In addition, the study will evaluate three different inoculum/electron donor combinations in an effort to identify an efficient, cost-effective technique for obtaining a stable, effective ClO4- reducing system for future applications. This will involve evaluation of PBR performance using three separate PBR columns in parallel, each with a specific inoculum/electron donor combination, which will reflect the inoculum sources discussed above. The columns will be operated simultaneously at flow rates up to approximately 2 gallons per minute (gpm). Specific objectives of the proposed project are as follows:

1. Assess the time needed for each inoculum/electron donor combination to achieve effective colonization.
2. Evaluate achievable effluent ClO4- levels for each inoculum/electron donor combination.
3. Evaluate the residence time for each system versus treatment efficiency.
4. Evaluate population dynamics for each system using polymerase chain reaction (PCR) analysis.
5. Generate preliminary estimate of the footprint required for larger, full-scale systems.
6. Generate preliminary estimate of costs/kgallon of water treated for larger, full-scale systems.

It should be emphasized that this field test is primarily to demonstrate proof-of-concept and to evaluate various approaches to biofilm development; the success of the bench-scale may not be achieved at the field-scale. Furthermore, optimal levels of nutrients will not be evaluated in this experiment.

Inoculum/Electron Donor Combinations and Reactor Design

To address these objectives, three PBR columns will be constructed and operated. A general overview of the reactor design and experimental procedures that will be used to address the objectives is provided in this section.

Inocula/electron donor combinations will include:

1. Perc1ase/acetate
2. Food processing waste/ethanol (upon further consultation with US Filter)
3. JPL enrichment cultures/acetate (upon further consultation with Dr. Paul Hatzinger)

Extracted groundwater (from MW-7) will be pumped into a holding tank. The water will be pumped out of the holding tank and split into three streams, to which the electron donors (acetate or ethanol) and nutrients (N and P) will be added. Nutrients (approx. 10 mg/L nitrate and 2 mg/L phosphate) will be dosed into flash mixing tanks. From the flash mixing tanks, the groundwater will be pumped into the bioreactor tanks containing Celite, a pelletized diatomaceous earth product, which will serve as a medium for the microorganisms to attach to. The bioreactor tanks will also contain heating elements to heat the groundwater to approximately 25o C. Bioreactor effluents will be combined and will undergo additional treatment to address residual carbon, VOCs, and ClO4- (if any), consisting of aerobic biological treatment, LPGAC treatment, and ion exchange. Final effluent will be held in a 21,000-gallon tank (frac tank) prior to final discharge, pending receipt of analytical results.

Test Strategy

The major objectives of the proposed study are to demonstrate proof-of-concept for the PBR to treat low concentrations of ClO4- (<1 mg/L) in groundwater at a field scale, and to evaluate three different inoculum/electron donor combinations to identify a cost-effective technique for future applications. Influent and effluent ClO4- concentrations, as well as respective electron donor (as total organic carbon) and NO3- levels will be measured periodically (see Section 4.3.2). As mentioned, electron donors will be maintained at concentrations in excess of what is required (present in effluent), and will not be optimized for this study. Ammonium and phosphate will be added at low concentrations to ensure that they will not be limiting in the reactor, but will not be tracked analytically. Influent and effluent pH and temperature will also be monitored using field instruments. Analytical results will be reported within 2 days following sample submission during the early portion of the test, thus allowing for changes to be made in reactor operating parameters in response to system performance. Laboratory turnaround time may be increased later in the test if deemed appropriate. Testing strategies are summarized below:

1. The time required to achieve effective colonization will be conducted during startup procedures (described below, Section 4.3.1). As noted, ClO4- concentrations in each system will be monitored during startup using a ClO4--specific probe while the reactors are operated in a re-circulation mode. Effective colonization time will be defined as the time required for ClO4- concentrations to drop from 100 mg/L (initially added to the medium) to below 1 mg/L.
2. Achievable effluent ClO4- concentrations, and residence time versus column efficiency, will be established for each column as follows: Determine an initial residence times such that non-detectable effluent ClO4- levels are achieved. This is expected to be approximately 1.5 to 1.0 hours. Incrementally decrease residence times until ClO4- breakthrough is achieved. Increase residence time to prior increment where non-detectable ClO4- levels were observed, to verify results. With respect to this experiment, this will be defined as the optimal residence time for each reactor, and the systems will be operated at this rate for the duration of the experiment. This will provide evidence needed to comparatively evaluate the performance of the systems.
3. Population dynamics will be evaluated using polymerase chain reaction (PCR) analysis. Initial inocula, along with weekly bacterial samples from each column will be analyzed to determine gross shifts in populations over the course of the experiment. It is noted that this analysis does not identify the bacteria present, rather it will provide an indication of whether the populations are changing over time. These analyses will be carried out at the University of California, Riverside.

This pilot project is scheduled to begin in January 2001.

Report(s)/Publication(s) (Additional Info Source):

Information provided by Naval Facilities Engineering Command (NAVFAC) personnel, November 2000

GWRTAC ID:	PERC0013		
Project Name:	Former Army Ammunition Plant, U.S. Army Corps of Engineers		
City:	Not Specified	**State/Province:**	N/S

Report(s)/Publication(s) (GWRTAC Source):

Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ 08648, Project Summary Information

Project Summary:

The following text was excepted from project summary information provided by Envirogen, Inc., Lawrenceville, NJ, September 2000:

The Envirogen Team (U.S. Filter/Envirex, Inc.) has conducted pilot work for the U.S. Army Corps of Engineers for groundwater streams, using the anoxic fluidized bed reactor (FBR). The FBR is a reactor column that fosters the growth of microorganisms on a hydraulically-fluidized bed of media, usually sand or activated carbon. The fluidized media selected provides an extremely large surface area on which a film of microorganisms can grow thus producing a large inventory of biomass in a small reactor volume. The result is a system capable of high degradative performance for target contaminants in a relatively small and economical reactor volume. The FBR can be controlled to operate under aerobic, anaerobic or anoxic conditions depending upon the nature of the target compounds. The choice of media for the FBR bed is dependent upon the specifics of the treatment required. Sand is often selected for higher mass flow rates of contaminants where the yield of biomass is expected to be relatively high, i.e., high biofilm growth. Carbon is often selected for greatest assurance of producing low-concentration effluent, i.e., part-per-billion (ppb) levels.

The biological destruction of perchlorate by a biological fluidized bed is an anoxic reaction; the work is done by a consortium of organisms that would prefer to utilize oxygen, but in the absence of oxygen are able to use nitrate and perchlorate to degrade organic material. These are robust organisms and the fluid bed reactors provide a very stable physical environment in which very high concentrations of these organisms can be kept in contact with the water being treated. When nitrate is present, it in fact must be removed first before the organisms will tackle the perchlorate.

Report(s)/Publication(s) (Additional Info Source):

Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ 08648, Project Summary Information

Guarini, B., 2000. “Biological Treatment of Groundwater Containing Perchlorate Using Fluidized Bed Reactors” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID: PERC0014

Project Name: Application of Bioreactor Systems to Low-Concentration Contaminated Water (AWWARF

City: Chicago **State/Province:** IL

Report(s)/Publication(s) (GWRTAC Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

Project Summary:

The following text was excerpted from information supplied by American Water Works Association Research Foundation (AWWARF), December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm:

This research will evaluate the efficiency of a biological process to reduce perchlorate concentrations of up to 1,000 ug/L to levels of 4-18 ug/L. The research will also evaluate the impact of co-contaminants on process performance, characterized process effluents, and define post treatment requirements. The research is to be completed in 2001.

Objective

1. Evaluate the efficiency of a biological process to reduce perchlorate concentrations of up to 1,000 micrograms per liter to drinking water action levels of 4-18 micrograms per liter,
2. Evaluate the impact of co-contaminants, such as nitrate and volatile organic compounds (VOCs), on process performance, and
3. Characterize process effluents and define post treatment requirements.

Background

A limited number of bioreactor systems have been successfully developed to treat water streams with high concentrations of perchlorate. Examples are the Aerojet process using a GAC/fluidized bed under anoxic conditions and the suspended growth reactor using W.succinogens HAP1 developed by Tyndall A.F.B. The ability of a bioreactor to reduce low concentrations of perchlorate, approximately 1,000 micrograms per liter or less, to drinking water action levels of 4-18 micrograms per liter, is an important knowledge gap. Another important knowledge gap is whether bioreactors developed for removal of nitrate (denitrification) can also be applied to removal of perchlorate.

Research Approach

Perchlorate contamination of drinking water is currently impacting at least 12 million consumers. Effective treatment technologies for perchlorate removal or destruction are needed immediately. In order to expedite the research process, this project will be undertaken in two phases with the intent that one of the contractors selected for Phase I will continue as the contractor for Phase II. Phase II continuation of the project will be contingent upon several factors, including: success of Phase I, availability of funding for Phase II, and PAC and AWWARF approval of the detailed scope for Phase II work. The AWWA Research Foundation reserves the right to issue a Request for Proposals (RFP) for Phase II work if this is deemed appropriate. The Crafton-Redlands Plume in the Redlands, California area will be required to be investigated as a pilot-scale study site in Phase II.

Phase I

This project should begin with a brief literature review of potential bioreactor treatment systems potentially applicable to perchlorate contamination. This literature search should include bioreactor systems used for similar contaminants, such as nitrate. Based on this information, bench-scale experiments should be planned and conducted to evaluate several conditions pertinent to drinking water and low concentrations of perchlorate. Example factors to consider are:

1. Reactor type and configuration (fixed-film, continuous-flow).
2. Influent concentration of perchlorate (between 1,000 micrograms per liter and the action level (18 micrograms per liter).
3. Carbon source and nutrient requirements.
4. Identification of reaction mechanism and possible formation of reaction intermediates.
5. Determine reaction rates.
6. Operating conditions (ranges) (e.g., pH, temperature, residence time).
7. Influence of co-contaminants, including nitrate and VOCs such as trichloroethylene (TCE), perchloroethylene (PCE), etc. It is the intent that these tests be conducted on real water matrices that are as representative as possible of those waters known to be impacted by perchlorate.
8. Effect of influent dissolved oxygen on operating performance.
9. Characterization of the effluent concentrations of perchlorate, chloride, total organic carbon, heterotrophic plate count, pathogens and disinfectant byproduct formation potential, as well as establishing mass balances for the treatment process.
10. Identification of post treatment requirements, especially the need for filtration and disinfection.
11. Estimate costs and scale-up issues.

Results of the Phase I work should be summarized in a final report. In addition to documenting Phase I activities and results, this report should also be suitable for use in Phase II activities. The goal of Phase II activities (not directly funded in this RFP) is to further develop design data and operating procedures to accomplish the desired perchlorate removals at pilot-scale. A brief description of currently anticipated Phase II activities is presented below. Additional details concerning Phase II activities will be developed in the course of the Phase I work.

Phase II

Following completion of the bench-scale work, a separate pilot-scale project should be initiated approximately two years from now. The pilot-scale work will further develop the most promising bench-scale biological treatment system. In general, the pilot-scale work should evaluate:

Systems integration
Scaling factors
Process control capital & operating costs
Operability

Report(s)/Publication(s) (Additional Info Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

GWRTAC ID:	PERC0015
Project Name:	Application of Bioreactor Systems to Low-Concentration Contaminated Water (AWWARF

City: State College ***State/Province:*** PA

Report(s)/Publication(s) (GWRTAC Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

Liu, J., and J. Batista, 2000. “A Hybrid (Membrane/Biological) System to Remove Perchlorate from Drinking Waters” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

The Pennsylvania State University website of Dr. Bruce E. Logan - Ongoing research topics and topical webpage links, available at http://www.engr.psu.edu/ce/enve/logan.htm.

Project Summary:

The following text was excerpted from information supplied by American Water Works Association Research Foundation (AWWARF), December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm; and
ongoing research topics and topical webpage links, Dr. Bruce E. Logan webpage, The Pennsylvania State University website, available at http://www.engr.psu.edu/ce/enve/logan.htm:

This research will evaluate the efficiency of a biological process to reduce perchlorate concentrations of up to 1,000 ug/L to levels of 4-18 ug/L. The research will also evaluate the impact of co-contaminants on process performance, characterized process effluents, and define post treatment requirements. The research is to be completed in 2001.

Objective

Evaluate the efficiency of a biological process to reduce perchlorate concentrations of up to 1,000 micrograms per liter to drinking water action levels of 4-18 micrograms per liter,
Evaluate the impact of co-contaminants, such as nitrate and volatile organic compounds (VOCs), on process performance, and
Characterize process effluents and define post treatment requirements.

Background

A limited number of bioreactor systems have been successfully developed to treat water streams with high concentrations of perchlorate. Examples are the Aerojet process using a GAC/fluidized bed under anoxic conditions and the suspended growth reactor using W.succinogens HAP1 developed by Tyndall A.F.B. The ability of a bioreactor to reduce low concentrations of perchlorate, approximately 1,000 micrograms per liter or less, to drinking water action levels of 4-18 micrograms per liter, is an important knowledge gap. Another important knowledge gap is whether bioreactors developed for removal of nitrate (denitrification) can also be applied to removal of perchlorate.

Perchlorate contamination of drinking water is currently impacting at least 12 million consumers. Effective treatment technologies for perchlorate removal or destruction are needed immediately. In order to expedite the research process, this project will be undertaken in two phases with the intent that one of the contractors selected for Phase I will continue as the contractor for Phase II. Phase II continuation of the project will be contingent upon several factors, including: success of Phase I, availability of funding for Phase II, and PAC and AWWARF approval of the detailed scope for Phase II work. The AWWA Research Foundation reserves the right to issue a Request for Proposals (RFP) for Phase II work if this is deemed appropriate. The Crafton-

Redlands Plume in the Redlands, California area will be required to be investigated as a pilot-scale study site in Phase II.

Research Approach

Perchlorate has recently been detected in several surface waters and ground water wells used to supply drinking water at concentrations above the detection limit (0.4 ppb) to 0.37%. The California Department of Health Services (CDHS), based on EPA work, has established a provisional action level of 18 ppb for drinking water due to perchlorate's interference with iodine
in the production of hormones in the thyroid. The presence of perchlorate at these high concentrations in the environment, coupled with a very low drinking water standard, has created a national water contamination crisis in the US potentially affecting 12 million people. Perchlorate is readily biodegradable, and under proper conditions, can be reduced to non-detectable levels by fixed and suspended cultures of microorganisms. Since 1993, the PI has been conducting research on microbes that can respire chlorate or perchlorate: that is, they can use either of these compounds as an electron acceptor in the oxidation of many common substrates such as acetate, simple sugars and amino acids.

Phase I

This project should begin with a brief literature review of potential bioreactor treatment systems potentially applicable to perchlorate contamination. This literature search should include bioreactor systems used for similar contaminants, such as nitrate. Based on this information, bench-scale experiments should be planned and conducted to evaluate several conditions pertinent to drinking water and low concentrations of perchlorate. Example factors to consider are:

Reactor type and configuration (fixed-film, continuous-flow).
Influent concentration of perchlorate (between 1,000 micrograms per liter and the action level (18 micrograms per liter).
Carbon source and nutrient requirements.
Identification of reaction mechanism and possible formation of reaction intermediates.
Determine reaction rates.
Operating conditions (ranges) (e.g., pH, temperature, residence time).
Influence of co-contaminants, including nitrate and VOCs such as trichloroethylene (TCE), perchloroethylene (PCE), etc. It is the intent that these tests be conducted on real water matrices that are as representative as possible of those waters known to be impacted by perchlorate.
Effect of influent dissolved oxygen on operating performance.
Characterization of the effluent concentrations of perchlorate, chloride, total organic carbon, heterotrophic plate count, pathogens and disinfectant byproduct formation potential, as well as establishing mass balances for the treatment process.
Identification of post treatment requirements, especially the need for filtration and disinfection.
Estimate costs and scale-up issues.

Results of the Phase I work should be summarized in a final report. In addition to documenting Phase I activities and results, this report should also be suitable for use in Phase II activities. The goal of Phase II activities (not directly funded in this RFP) is to further develop design data and operating procedures to accomplish the desired perchlorate removals at pilot-scale. A brief description of currently anticipated Phase II activities is presented below. Additional details concerning Phase II activities will be developed in the course of the Phase I work.

Researchers have proposed here to conduct bench scale experiments on three different fixed-film biological treatment processes that should be capable of being scaled up to treat large quantities of drinking water. These treatment systems are: a packed bed (slow sand filter) amended with soluble substrates (acetate, methanol, and ethanol); a hydrogen gas fed four-phase (hydrogen gas, water, biofilm, and support media), unsaturated trickle-type packed column; a membrane-bound biofilm reactor. The hydrogen gas-based systems offer an additional potential advantage of achieving chlorinated aliphatic reduction by hydrogen-oxidizing bacteria under highly reducing conditions. With information gained in this proposal, we will estimate the costs of treating waters
using the reactors and feed substrates that successfully remove perchlorate down to drinking water levels

(<18 ug/L). Based on the engineering and economic analysis, one of these treatment systems will be selected for further testing in Phase II at the Crafton-Redlands site in Redlands, CA.

This project will involve researchers at Penn State University, the University of Nevada, Las Vegas, the City of Redlands, and Camp, Dresser and McKee (CDM) consulting Engineering. In order to assess the general nature of the findings, and to test the performance of the systems for Phase II work, water samples will be obtained from two sites: the Crafton-Redlands site, and a
perchlorate contaminated areas in Nevada (the Nevada Wash area and Lake Mead).

The purpose of the Phase I project was to evaluate three different fixed-film biological treatment processes at the bench scale in order to determine their feasibility for being scaled up to treat large quantities of perchlorate-contaminated water to drinking water levels (<18 ug/L). These treatment systems were: a packed bed (slow sand or GAC filter) amended with soluble substrates (acetate, lactate, methanol, and ethanol); a hydrogen gas fed four-phase (hydrogen gas, water, biofilm, and support media), unsaturated trickle-type packed column; a membrane-bound biofilm reactor. Based on bench tests, we were to estimate the costs of treating waters using in full scale systems and to recommend one of these treatment systems for pilot-scale testing at the Crafton-Redlands site in Redlands, CA.

All three systems successfully removed perchlorate at rates sufficient to achieve an acceptable level of perchlorate removal for subsequent treatment for potable use. Our economic and engineering analysis indicated that the least-expensive, most reliable system was an acetate-fed packed bed reactor. The packed-bed sand reactor achieved the highest perchlorate removal rates of the three systems. In addition, there was a precedent for using an acetate-fed biological reactor for drinking water treatment in the U.S., making it likely that a reactor of this type would gain public acceptance. Nitrate has been treated using an acetate-fed packed bed reactor for drinking water pretreatment at a site in Coyle, Oklahoma. In addition, biological denitrifying systems have been successfully used in Europe for several years. The wider acceptance of biologically activated filters in the U.S. also points to new trends in the acceptance by water utilities to incorporate biological treatment into drinking water treatment trains. These factors, coupled with a national trend towards "green engineering" and sustainable technologies, suggests that an acetate fed bioreactor is a feasible perchlorate treatment technology.

Phase II

Following completion of the bench-scale work, a separate pilot-scale project should be initiated approximately two years from now. The pilot-scale work will further develop the most promising bench-scale biological treatment system. In general, the pilot-scale work should evaluate:

Systems integration
Scaling factors
Process control capital & operating costs
Operability

The primary purpose of Phase 2 will be to conduct pilot-scale testing at the Crafton-Redlands site in Redlands, CA, of an acetate-fed, packed-bed bioreactor, referred to here as the Penn State University Perchlorate Treatment (PSU-O4) System. To fully evaluate scale up and operating considerations, we will field test two acetate fed reactors, one packed with sand and the other with plastic media.

The Crafton-Redlands groundwater source contains necessary trace minerals for biological growth of perchlorate-reducing bacteria. However, in addition to perchlorate, it contains as competing electron acceptors, dissolved oxygen and nitrate-nitrogen. Dissolved oxygen is the preferred electron acceptor and the system is designed to biologically remove this first in the treatment system. As flow progresses through the reactor, nitrate and perchlorate will be simultaneous removed by the perchlorate-acclimated culture. All three electron acceptors will be removed in the fixed bed reactor by adding an electron donor (acetate) at sufficiently high concentrations to ensure their complete removal. A small amount of ammonia phosphate and ammonia-nitrogen may be needed to satisfy bacterial nutritional requirements. Residual electron donor in the effluent will be removed in a post treatment system (biological aerobic filter).
The major questions, or outstanding issues, that will be addressed during this phase of the project are:
· What are the major design criteria for facilities to reliably remove perchlorate with the tested processes?

· How much will the facility cost to construct and operate? Costs of the various processes tested can then be compared with each other to determine what is the best approach to treat perchlorate-laden waters.
· How much time is needed to stabilize the process?
· How difficult will it be to operate? For example, is it more difficult to operate and maintain process stability than a POTW wastewater treatment facility?
· What are the auxiliary needs for this process? Do we need to treat the waste product before discharging to a sewer or stream?
· What treatment processes are needed downstream of the bioreactor to produce water that meets drinking water standards?
· What will the primacy regulatory agencies require to approve this process?

Report(s)/Publication(s) (Additional Info Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

Liu, J., and J. Batista, 2000. “A Hybrid (Membrane/Biological) System to Remove Perchlorate from Drinking Waters” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

The Pennsylvania State University website of Dr. Bruce E. Logan - Ongoing research topics and topical webpage links, available at http://www.engr.psu.edu/ce/enve/logan.htm.

GWRTAC ID: PERC0016

Project Name: Investigation of Methods for Perchlorate Destruction in Aqueous Waste Stream (AWWAR

City: State College **State/Province:** PA

Report(s)/Publication(s) (GWRTAC Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

Cannon, Fred S. and Chongzheng Na, 2000. “Perchlorate Removal Using Tailored Granular Activated Carbon and Chemical Regeneration” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excerpted from information supplied by American Water Works Association Research Foundation (AWWARF), December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm; and,
Cannon, Fred S. and Chongzheng Na, 2000. “Perchlorate Removal Using Tailored Granular Activated Carbon and Chemical Regeneration” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

This research will evaluate non-biological technologies for destruction of perchlorate to allow waste stream disposal or recycle.

Objective

Evaluate at bench-scale, non-biological technologies for destruction of perchlorate which will allow safe waste stream disposal or recycle.

Background

A number of processes are available for perchlorate removal from drinking water. Many of these processes, e.g., ion exchange, membranes, etc., are likely to produce concentrated waste streams containing perchlorate. A means of dealing with the concentrated perchlorate stream is needed for successful implementation and use of the primary processes.

Research Approach

Perchlorate contamination of drinking water is currently impacting the source-water of at least 12 million consumers. Effective treatment technologies for perchlorate removal or destruction are needed immediately. In order to expedite the research process, this project will be undertaken in two phases with the intent that one of the contractors selected for Phase I will continue as the contractor for Phase II. Phase II continuation of the project will be contingent upon several factors including: success of Phase I, availability of funding for Phase II, and PAC and AWWARF approval of the detailed scope for Phase II work. The AWWA Research Foundation reserves the right to issue a Request for Proposals (RFP) for Phase II work if this is deemed appropriate. The Crafton-Redlands Plume in the Redlands, California area will be required to be investigated as a pilot-scale study site in Phase II.

Phase I

Phase I research will be conducted at the bench- or laboratory-scale. Before this work is initiated a discussion of environmentally acceptable levels of perchlorate in various residuals generated by drinking water facilities should be presented. Types of residual (e.g., liquid, solid) together with final disposal options should be addressed. The desired target level(s) for perchlorate in various residuals will serve as guidance for the laboratory- bench-scale studies which should:

Determine impact/limitations of a residual's physical and chemical components on the perchlorate treatment process, e.g. nitrate (NO3), total dissolved solids (TDS), trichloroethylene (TCE), natural organic matter (NOM), etc.
Characterize process by-products and potential impacts on final disposal of residual.
Determine chloride mass balance.

Decisions would be made at the end of Phase I to determine whether or not to proceed to Phase II and the best option for distribution of Phase I results (e.g., printed report, journal article).

Phase II

Following completion of the laboratory- bench-scale work in Phase I, a separate pilot-scale project would be initiated in approximately two years. The pilot-scale work will further develop the most promising bench-scale treatment system(s). In general, the pilot-scale work would evaluate:

Process at higher flow rate
Cost effectiveness and reliability
Operational and maintenance issues
Treatability of other contaminants (e.g., NO3, TCE, TDS, NOM, etc.)
Efficiency of process
Secondary waste disposal/treatment
Engineering safety of the process

The researcher would evaluate further scale-up issues for a demonstration-scale unit and prepare a conceptual preliminary design for a full-scale unit.

This research is jointly funded by the AWWARF and the EPA, and capitalizes on the granular activated carbon (GAC) infrastructure that is already installed at many of the water utilities that process perchlorate-contaminated water.

The rapid small-scale column test (RSSCT) has been employed to evaluate GAC's perchlorate adsorption capacity. The RSSCT ensures that the experimental conditions, such as flow rate, empty bed contact time (EBCT) and carbon mass, is compatible to those in the full-scale GAC beds, by simulating the full-scale breakthrough curve in a small RSSCT column.

The RSSCT experiments showed that preloading with an iron-organic complexing solution improved GAC's perchlorate adsorption capacity. Specifically, after preloaded with a protocol that employed an iron-organic complexing solution, a bituminous SAI GAC exhibited 20-25% more capacity than its non-preloaded counterpart. This was observed when the preloaded GAC was dried at 105 deg. C. before use. Moreover, when the preloaded GAC was maintained wet, it exhibited 40-45% more capacity than did the non-preloaded GAC. The adsorption capacity of the dry preloaded SAI GAC was 0.29 mg perchlorate/g GAC; the wet preloaded GAC was 0.34 mg/g; and these compared with 0.24 mg/g that the non-preloaded GAC had achieved.

When the preloaded GAC was exhausted in its capacity to adsorb perchlorate, tests showed that a reductin solution restored 65-74% of the initial adsorption capacity that the GAC preloaded with iron-organic complexing solution had initially hosted, and this capacity could be maintained through several cycles of water service.

The City of Redlands, California hosts it Texas Street water treatment plant that has been equipped with 24 GAC contactor vessels (or 12 pairs of vessels). This GAC facility was initially installed to remove trichloroethylene (TCE, a solvent) and dibromochloropropane (DBCP, a pesticide) from a groundwater plume. Each pair of two vessels together contain 40,000 pounds of GAC, and they were designed to together provide a 40 minute empty bed contact time (EBCT) in each vessel pair at 4.3 MGD, or 30 minute EBCT at 6.5 MGD or 20 minute EBCT at 8.6 MGD. These have been operated with two vessels in series, such that at any given time 12 vessels are in the "lead" mode, and 12 are in "follow" mode. As conventionally operated for TCE and DBCP removal, when the organic contaminants penetrated half way through the "follow" vessel, the "lead" vessel was taken out of service and regenerated. At this time, this "follow" vessel became the new "lead" vessel, and a new "follow" vessel commenced service downstream of it. On the basis of organic loading parameters, the Redlands staff have been taking a GAC vessel out for thermal reactivation after it has been in operation for 18 months while operating at roughly 4.3 MGD. Reactivation of this bituminous GAC (Westates Northwestern LB 830) has been performed off site by U.S. Filter Westates.

The Texas Street plant has been treating water from Well 31 A, which can deliver 4.3 MGD, and is one of Redland's higher-yielding wells. This groundwater originates from within the Crafion-Redlands plume area; and in addition to the TCE and DBCP, this groundwater also contains 60-138 ppb perchlorate. Once perchlorate was detected in this well, the Texas Street plant was shut down. The City of Redlands also has two other wells (30A and 32) that can deliver water through the Texas Street plant; and well 32 samples contained 20-50 ppb perchlorate. After isolating high-nitrate water tables from the upper levels of these two well screens, wells 30A and 32 are expected to deliver 2.3 MGD; and thus the projected capacity for the Texas Street plant will ultimately be 6.5 MGD. Redlands also has other groundwater and surface water sources that contain scant perchlorate. In the summer, Redland's peak day water demands of 45-50 MGD are just matched by their system-wide water treatment capacity; and water production at Texas Street will soon become crucial for meeting these summer demands.

The City of Redlands conducted testing regarding perchlorate removal by full-scale GAC vessels that commenced operation on May 5, 1997 and remained in service through a sampling event on June 3, 1997. During this month, the flow averaged 3.6 MGD through their 12 pairs of vessels, and the flow was 4.3 MGD on June 3, which corresponded to a 40-minute EBCT through two vessels in series. During May 5- June 3, there had been 93 MG of water that had processed through the Texas Street GAC beds, and there had been 730 skid-bed volumes (i.e. the volume of both beds in a skid together)processed through vessels 1 A and 1 B together. During most of the operations time, groundwater originated from Redlands Well 3 lA, which was analyzed to contain 62-138 ppb perchlorate.

On June 3, 1997, water was sampled from Vessels lA and lB at eight port locations. Resultant perchlorate concentrations as shown in Table 1. This table highlights that the GAC confined its perchlorate mass transfer zone within 15-20 minutes. The data also shows that when these GAC vessels were operating in the above-described mode, they could have processed roughly 1280 skid-bed volumes of groundwater before 18 ppb perchlorate would have broken through. This would correspond to six weeks of operation until change-out of a given single bed, with a 40 minute empty bed contact time (EBCT) through each of the beds.

Table 1: Perchlorate Removal through City of Redlands GAC Vessels on June 3, 1997, following Start-up on May 5, 1997

Sample Port	C104, ppb	Skid-Bed Volumes Processed above This Sample Port*
Vessel lA		
1/8 port	101	5840
2/8 port	97	2920
3/8 port	87	1950
4/8 port	39	1460
Vessel lB		
5/8port	5	1170
6/8 port	<4	980
7/8 port	<4	840
8/8 port	<4	730

*Skidbed volumes based on 93 MG total water processed, May 5-June 3, 1997; and 1.1 times as much flow rate through Vessels 1 A&B than was averaged through all.

This six weeks of operation between change-outs, as required by perchlorate loading, would be short relative to the 18 months between change outs as required relative to organic loading requirements. None-the-less, the authors emphasize that this currently available commercial GAC was indeed effective at removing perchlorate. It just was not effective for very long, nor for as low a cost as for other conventional water treatment operations that are designed to remove other contaminants. The intent of the research herein has been to build on this finite adsorptive capacity, move beyond what has previously been available commercially, and to tailor a GAC and interim chemical regeneration protocol that would translate an effective but expensive technology into an effective and inexpensive technology.

Penn State Testing

On the foundation afforded by this limited perchlorate adsorption capacity, our Penn State research has explored means of (a) enhancing the adsorption capacity of tailored GACs, while also (b) chemically regenerating the GAC with an anionic reducing compound, so that the GAC could sustain an acceptable overall adsorption capacity between thermal reactivation cycles. To this end, Penn State bench scale tests have employed rapid small scale column tests (RSSCT's) to process Redlands water from Well 31A. By this protocol, we have appraise what perchlorate-removal enhancement could be anticipated by pre-loading a bituminous GAC with iron-organic complexing solution. The RSSGT tests have aimed at modeling full-scale performance when a bed has a 20 minute EBCT, 3.14 gpm/ft2 loading, 10 foot depth, and #8 x 30 GAC mesh size. The RSSGT beds have hosted a 3.56 mm EBGT, 0.9 gpm/ft2 loading, 0.49-0.59 foot depth, and #60 x 80 mesh size. The objective of this research has been to extend the service life of GAC beds so that the GAC would be able to serve for perchlorate removal as long as it serves for the removal of organic compounds. To achieve this goal, the author has employed an iron-organic complex preloading protocol to improve GAC's perchlorate adsorption capacity, and also an in-situ chemical regeneration protocol to restore the capacity of perchlorate-spent GAC.
Rapid small-scale column tests (RSSCT) were conducted to simulate full-scale performance.

RSSCT Simulation:

A comparison of the full-scale breakthrough curve and those of the RSSGT columns indicated the proportional-RSSCT columns that used SM GAC offered a fairly good simulation of full-scale breakthrough. This similarity indicated that the intraparticle diffusivity of perchlorate is a linear function of particle size. It is also noted that the simulated proportional breakthrough curves were sharper than the full-scale breakthrough curve. This greater sharpness results when one uses a Remin, instead of the Reynolds number of the full-scale bed in RSSGT columns, and this represents an unavoidable, and perhaps somewhat inconsequential limitation of the RSSGT simulation method.

Other proportional-RSSGT columns that employed Westates GAC and Hydrodarco GAC had the same steep slope as the column that employed SAl GAC. Perchlorate broke through the Hydrodarco GAC sooner than for SAl, and perchlorate broke through Westates GAC later than through SAl GAC. In contrast, the constant-RSSGT column did not show any similarity to the full-scale breakthrough curve and instead exhibited breakthrough far sooner than for the full-scale GAC. Therefore, the proportional-RSSGT was selected as the most representative simulation of the full-scale adsorption behavior.

Performance of Non-Preloaded GACs

The limited adsorption capacity of commercially-available GAC is also evident. Perchlorate started to break through when the adsorption beds had processed 1,200 to 1,800 bed volumes (BV) of water, and full breakthrough occurs within 2,000-2,500 BV when the beds operated with the full-scale equivalent of a 20 minute EBCT and employed bituminous GACs. The Westates bituminous GAC initiated 10% breakthrough at 1,800 BV, while the SAl bituminous GAC initiated 10% breakthrough at 1,200 BV, and the full-scale reactivated ATP carbon initiated 10% breakthrough at 1,500 BV.

The 2,000-2,500 BV to full breakthrough represented roughly one-tenth of the bed volumes to break through that the City of Redlands has observed for the volatile TCE and pesticide DBCP. The perchlorate data implies that after operating a bed at 40 minutes empty bed contact time (EBCT) for six weeks, the carbon would need to be replenished in its capacity to adsorb perchlorate. If this replenishment were to be achieved by merely replacing the GAC or thermally reactivating it, the costs and inconveniences would be too prohibitive for this to be a viable perchlorate treatment option. However, if the perchlorate capacity could be replenished by a less costly protocol of chemical regeneration, then GAC treatment could serve as a viable approach for removing perchlorate. Moreover, if the GAC could be tailored so that it had an enhanced capacity for removing perchlorate, this treatment approach could become yet more viable. It was these dual objectives that prompted this research herein. The first aim was to enhance the perchlorate adsorption capacity by preloading the GAC with iron and an organic complex solution.

Effects of Iron-Complex Preloading on Perchlorate Adsorption

In order to test whether preloading with an iron-organic complex solution could enhance the perchlorate adsorption capacity of GAC, the authors preloaded an iron-organic complexing solution onto the GAC. When the preloading was employed, the SAT carbons exhibited a significant enhancement in perchlorate adsorption as compared to their non-preloaded counterparts.

Compared to an 80% breakthrough at 1780-1790 BV for the non-preloaded GAC, the preloaded GACs achieved 80% breakthrough at 2070-2220 BV, which represented 16-24% enhancement. The distinction between these two linear regressions was statistically significant, as determined by employing the F-test method.

Moreover, the non-preloaded GACs accumulated 0.24 mg perchlorate/g GAC by the time of full breakthrough, compared to 0.29 mg/g for the preloaded GAC and this represented a 22% improvement. The influent perchlorate concentration was 70 ppb.

Table 1 Comparison of Perchlorate Removal of Non-Preloaded SAl GAC
and the SAT GAC Preloaded with iron-organic complexing solution

SAI GAC	Bed Volumes at 10% Break-through, BV10	Bed Volumes at 80% Break-through, BV80	Enhancement to 80% Breakthrough(2) (%)	C104- Adsorption Capacity(1),q (mg/g GAC)	Adsorption Capacity Enhancement(3) (%)
Non-Preloaded	1270	1780	---	0.236	---
Preloaded & Pre-dried	1570	2160	21	0.289	22
Preloaded & Maintained Wet	1920	2400 (5)	35	0.336 (4)	42

(1) The average influent perchlorate concentration of non-preloaded or preloaded carbon is calculated as the mathematical mean of all the RSSCT average influent concentrations. For the non-preloaded carbon, it was 75 ppb; for the preloaded carbon, it is 76 ppb. A carbon mass of 9.8 grams has been used in calculation;

(2) Calculated as (BV80,a2 - BV80,a1)/BV80, a1 x 100;

(3) Calculated as (q Preloaded - q Non-Preloaded)/q Non-Preloaded x 100;

(4) Breakthrough curves extrapolated to C/C0=1 using a slope of 0.2 C/Co to 500 BV.

Chemical Regeneration

When GAC became exhausted in its capacity to adsorb perchlorate, a reducing solution was able to restore much of its adsorption capacity by washing out the adsorbed perchlorate. The wastewater from description contained perchlorate levels as high as 7,000-15,000 ppb, which was 100-2 15 times that in Redlands' groundwater. Experiments showed that after chemically regenerating the preloaded SAl carbon, the GAC restored 50-74% of its initial adsorption capacity.

Summary

In summary, the strategy of preloading with iron and an organic complex solution and chemical regeneration offers a viable approach for removing perchlorate from groundwater, and this protocol could successfully achieve a proposed drinking water standard of 18 ppb perchlorate or lower. By preloading a GAC with an iron - organic complexing solution, one could improve perchlorate adsorption by 40-45%, and by chemically regenerating the GAC with a reducing solution, 50-74% of the GACs perchlorate adsorption capacity could be restored. Researchers at Penn State could regain perchlorate adsorption capacity through 3 cycles. Thus this approach offers a technically viable method for removing perchlorate. Research continues by the Penn State team to improve this method and yet further enhance its viability and cost effectiveness. Full-scale demonstration testing is proceeding at Redlands, CA. The full scale data to date indicates that if the Redlands plant were to operate at 4.3 MGD, they could operate their tailored GAC beds for roughly 70-90 days for the first cycle of use, and then for 35-50 or more days following subsequent chemical regeneration cycles. This appears to represent a technically, economically, and practically viable approach to removing perchlorate from drinking water.

Report(s)/Publication(s) (Additional Info Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

Cannon, Fred S. and Chongzheng Na, 2000. “Perchlorate Removal Using Tailored Granular Activated Carbon and Chemical Regeneration” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0017
Project Name:	Investigation of Methods for Perchlorate Destruction in Aqueous Waste Stream (AWWAR
City:	Potsdam
State/Province:	NY

Report(s)/Publication(s) (GWRTAC Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

Project Summary:

The following text was excerpted from information supplied by American Water Works Association Research Foundation (AWWARF), December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm:

This research will evaluate non-biological technologies for destruction of perchlorate to allow waste stream disposal or recycle.

Objective

Evaluate at bench-scale, non-biological technologies for destruction of perchlorate which will allow safe waste stream disposal or recycle.

Background

A number of processes are available for perchlorate removal from drinking water. Many of these processes, e.g., ion exchange, membranes, etc., are likely to produce concentrated waste streams containing perchlorate. A means of dealing with the concentrated perchlorate stream is needed for successful implementation and use of the primary processes.

Research Approach

Perchlorate contamination of drinking water is currently impacting the source-water of at least 12 million consumers. Effective treatment technologies for perchlorate removal or destruction are needed immediately. In order to expedite the research process, this project will be undertaken in two phases with the intent that one of the contractors selected for Phase I will continue as the contractor for Phase II. Phase II continuation of the project will be contingent upon several factors including: success of Phase I, availability of funding for Phase II, and PAC and AWWARF approval of the detailed scope for Phase II work. The AWWA Research Foundation reserves the right to issue a Request for Proposals (RFP) for Phase II work if this is deemed appropriate. The Crafton-Redlands Plume in the Redlands, California area will be required to be investigated as a pilot-scale study site in Phase II.

Phase I research will be conducted at the bench- or laboratory-scale. Before this work is initiated a discussion of environmentally acceptable levels of perchlorate in various residuals generated by drinking water facilities should be presented. Types of residual (e.g., liquid, solid) together with final disposal options should be addressed. The desired target level(s) for perchlorate in various residuals will serve as guidance for the laboratory- bench-scale studies which should:

Determine impact/limitations of a residual's physical and chemical components on the perchlorate treatment process, e.g. nitrate (NO3), total dissolved solids (TDS), trichloroethylene (TCE), natural organic matter (NOM), etc.
Characterize process by-products and potential impacts on final disposal of residual.
Determine chloride mass balance.

Decisions would be made at the end of Phase I to determine whether or not to proceed to Phase II and the best option for distribution of Phase I results (e.g., printed report, journal article).

Phase II

Following completion of the laboratory- bench-scale work in Phase I, a separate pilot-scale project would be initiated in approximately two years. The pilot-scale work will further develop the most promising bench-scale treatment system(s). In general, the pilot-scale work would evaluate:

Process at higher flow rate
Cost effectiveness and reliability
Operational and maintenance issues
Treatability of other contaminants (e.g., NO3, TCE, TDS, NOM, etc.)
Efficiency of process
Secondary waste disposal/treatment
Engineering safety of the process

The researcher would evaluate further scale-up issues for a demonstration-scale unit and prepare a conceptual preliminary design for a full-scale unit.

Report(s)/Publication(s) (Additional Info Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

GWRTAC ID:	PERC0018		
Project Name:	Removal of Perchlorate and Bromate in Conventional Ozone/GAC Systems (AWWARF #		
City:	Urbana	**State/Province:**	IL

Report(s)/Publication(s) (GWRTAC Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

Project Summary:

The following text was excerpted from information supplied by American Water Works Association Research Foundation (AWWARF), December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm:

This research will determine whether conventional ozone/granular activated carbon systems can be modified to remove perchlorate and bromate without sacrificing system performance.

Objective

The goal of this research is to determine whether the conventional ozone/GAC process can be operated in a manner that will accomplish the removal of perchlorate in drinking water sources. The research should be concentrated on removing perchlorate to below the drinking water action levels of 4-18 ?g/L. Perchlorate removal should be done without interfering with the system performance for its other functions, such as chemical oxidation of contaminants, disinfection, biological stabilization and adsorption. Because the conditions required for bromate removal may be similar to those required for perchlorate removal, bromate removal should also be investigated. Specific objectives are: to determine whether perchlorate and bromate are removed by the chemical reactions associated with the application of the oxidant and its reactions with activated carbon; to determine whether the ozone/GAC process can be modified so that perchlorate and bromate can be removed by chemical means; and, to determine whether the process can be modified to remove perchlorate and bromate biologically.

Background

Perchlorate and bromate are thermodynamically unstable in water. However, their activation energies for reaction with water to produce chloride and bromide, respectively, are very high. Therefore, their reaction rates at ambient conditions and in dilute solutions, are negligible. However, the presence of a catalyst can speed up these reactions. Such a catalyst may be either inorganic or biological. The chloride in perchlorate is at its highest oxidation state, so there is no possibility of removing perchlorate by oxidizing it. The best option for destroying both perchlorate and bromate appears to be to use them as electron acceptors, and thus to reduce them to other forms, such as chloride and bromide, respectively. Activated carbon is a reduced form of carbon that can supply electrons for reduction processes, but research is needed to determine the best way to condition the activated carbon surface so that the desired chemical reactions can take place. Research is also needed to demonstrate that the activated carbon surface is not fouled by natural organic matter. Studies should be done to determine whether removal of perchlorate and bromate can occur by this means.

Research Approach

Perchlorate contamination of drinking water is currently impacting at least 12 million consumers. Effective treatment technologies for perchlorate removal or destruction are needed immediately. In order to expedite the research process, this project will be undertaken in two phases with the intent that the contractor selected for Phase I will continue as the contractor for Phase II. Phase II continuation of the project will be contingent upon several factors including: success of Phase I, availability of funding for Phase II, and PAC and AWWARF approval of the detailed scope for Phase II work. The AWWA Research Foundation reserves the right to issue a Request for Proposals (RFP) for Phase II work if this is deemed appropriate. The Crafton-Redlands Plume in the Redlands, California area will be required to be investigated as a pilot-scale study site in Phase II.

Phase I

Ozonation prior to GAC treatment generally increases the amount of biological activity in the adsorber (GAC) by converting a portion of the natural organic matter into biodegradable compounds. Research is needed to determine if the biological activity can remove bromate and perchlorate. Critical questions related to the biological reduction of bromate and perchlorate include: 1) is it possible to develop a biofilm that will result in the removal of both chemicals in a reasonable time, 2) what are the procedures and time required to develop the biofilm, 3) what are the chemical concentrations that must be maintained and operating procedures that must be used to maintain the biofilm, and 4) are any of the other functions (disinfection, adsorption, biological stabilization) of the ozone/GAC processes impeded if it is also used for removal of these species?

Bench scale studies will be used to determine whether removal will occur and, if so, under what water quality conditions. There seem to be multiple roles activated carbon can take in the reduction of perchlorate. Activated carbon can either supply electrons for reduction processes from the reduced form of carbon, or facilitate the development of a biofilm that can enhance biological reduction of perchlorate and bromate. For these reasons, this RFP requests that bench-scale experiments be conducted to determine the technical feasibility and treatment conditions necessary for the planning of larger-scale studies. The following research activities should be considered:

Activated Carbon Studies. Conduct a preliminary assessment of the ability for fresh/virgin GAC (with and without preozonation) to reduce perchlorate and bromate in natural waters. Determine the extent that natural organic matter prevents perchlorate and bromate reduction. Determine the effect of biological growth on the removal of perchlorate and bromate by GAC after ozonation. Determine whether presence or addition of ammonia and resulting nitrification may help to create sufficient reducing conditions for treatment of perchlorate and bromate. The researcher may also explore the ability of other reduced surfaces, e.g., iron, etc. to supply electrons for reduction processes.

Ozonation Studies. Explore water quality conditions under which ozonation may result in by-products (e.g., peroxide, aqueous electrons) that donate electrons sufficiently to facilitate the product of selected ozone by-products that can contribute to perchlorate and bromate.

Preventing adverse effects. The addition of inorganic or organic substances could promote biological growth in the distribution system, introduce undesirable tastes and odors to the water, or cause other adverse effects. Special emphasis should be given to determining whether sufficient electron donors will be available after ozonation of natural water so that the addition of a substance such as ethanol for this purpose can be avoided. Top priority must be given to experiments that show that the desired removals can be achieved without adding inorganic or organic substances. Any detrimental effects of developing reducing conditions should be investigated.

The results of this study should be summarized in a final report. In addition to documenting Phase I activities and results, this report should also be suitable for use in Phase II activities. The goal of Phase II (not directly funded in this RFP) will be to develop design data and operating procedures to accomplish the desired perchlorate and bromate removals at pilot scale. A brief description of currently anticipated Phase II activities is presented below. Additional details concerning Phase II activities will be developed in the course of Phase I work.

Phase II

Promising approaches to reducing perchlorate and bromate will be investigated in detail. The process needs to be refined at the bench scale, and a pilot study will need to show that the process will work at a larger scale. The pilot scale conditions should be representative of those encountered in field operations. The goal of this research will be to develop design data and operating procedures to accomplish the desired removals. Successful pilot scale work should also include characterization of the GAC biofilm itself. Such issues as the distribution of the biofilm, type of dominant bacteria (aerobic, facultative, anaerobic) and sensitivity to water quality changes should be investigated.

Report(s)/Publication(s) (Additional Info Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

GWRTAC ID:	PERC0019
Project Name:	Treatability of Perchlorate-Containing Water by Reverse Osmosis and Nanofiltration (AW
City:	Boulder
State/Province:	CO

Report(s)/Publication(s) (GWRTAC Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

Project Summary:

The following text was excerpted from information supplied by American Water Works Association Research Foundation (AWWARF), December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm:

This research will determine ranges treatable by reverse osmosis and nanofiltration, and will evaluate effects of water quality parameters on process performance and perchlorate removal.

Objective

To determine the removal/rejection of perchlorate by RO (reverse osmosis) and NF (nanofiltration); to evaluate the effects of water quality parameters on process performance and removal of perchlorate using RO and NF; to determine the maximum feedwater recovery of perchlorate using RO and NF (usually limited by salt solubility); and to characterize the concentrate stream and investigate concentrate treatment and disposal options.

Background

A recently-developed analytical method can detect perchlorate contamination down to a concentration of 4 micrograms per liter (4 ppb). Application of this method has resulted in the detection of perchlorate in a variety of ground and surface waters in California, Nevada, and Utah. In some areas, perchlorate has been found in excess of the State of California Department of Health Services provisional action level of 18 micrograms per liter (18 ppb). This has resulted in the shutdown of some water supply sources. Consequently, there is substantial interest among water utilities to minimize exposure to this chemical in drinking water.

RO and NF are established water treatment technologies used for the removal of contaminants such as salts, disinfection by-product precursors, nitrates, and selected pesticides. While it is anticipated that these processes may be effective for the removal of perchlorate, there is little to no peer-reviewed data that demonstrates their applicability to perchlorate contamination at concentrations of 1000 micrograms per liter (1 mg/L) and lower. Moreover, there is no information on the impact of background water quality matrices on the removal of perchlorate using RO and NF.

Membrane separation processes for perchlorate removal will result in the production of up to 20 percent concentrate. One issue of concern in using membrane separation processes is the potential for losses of excessive quantities of water with the disposal of the concentrate. The potential for the presence of co-contaminants in the concentrate require that consideration be given to how to dispose of concentrates with significant levels of hazardous materials present (i.e., metals and/or radioactive components). There may be considerable regulatory concern in disposing of the waste and concerns with worker safety.

Research Approach

Perchlorate contamination of drinking water is currently impacting at least 12 million consumers in the U.S. Effective treatment technologies for perchlorate removal or destruction are needed immediately. In order to expedite the research process, this project will be undertaken in two phases with the intent that the contractor selected for Phase I will continue as the contractor for Phase II. Phase II continuation of the project will be contingent upon several factors including: the success of Phase I, availability of funding for Phase II, and PAC and AWWARF approval of the detailed scope of work for Phase II. AWWARF reserves the right to issue an RFP (Request for Proposals) for Phase II work if this is deemed appropriate.

Phase I

As a part of Phase I, the researcher will perform a literature review. This literature review should identify past and ongoing research related to the removal of chemical species similar to perchlorate (such as, but not limited to, nitrate and bromate). As part of the review, the researcher will estimate the efficacy of perchlorate removal based on membrane composition and charge and on the potential for ion-coupling of perchlorate (in the presence of low perchlorate concentrations). The researcher should also find information on the effect of other water quality parameters on perchlorate removal. Because perchlorate is an oxidant, the researcher should investigate the potential for long-term oxidation damage to NF and RO membranes.

The researcher will conduct a bench-scale membrane screening study in order to assess:

Applicable feedwater concentrations and achievable permeate levels. (The researchers can expect to work with perchlorate feedwater concentrations of up to 1 mg/L. This concentration upper limit represents real-world perchlorate concentrations that utilities find in their source waters.)

Impact of selected water quality parameters (i.e., ionic strength, TDS/conductivity, hardness, alkalinity, total organic carbon, pH, and temperature) on perchlorate removal efficiency. Natural waters should be used for testing where possible although it is recognized that tests with model waters may be necessary. The researcher will determine which feedwater quality to use to perform the membrane testing.

Pretreatment that may be necessary, and the conditions under which pretreatment may be necessary, to decrease membrane fouling or increase the rejection of perchlorate

The mechanism for the removal of perchlorate

Impact of membrane polymer type on perchlorate rejection

The researcher will also characterize concentrate production from the RO and NF bench systems. The researcher should optimize RO and NF processes so that a minimum volume of concentrate solution is produced in order to minimize water losses. The researcher will identify contaminants of concern with regard to concentrate disposal or reuse and determine possible treatment options to improve disposal permitting or reuse. The researcher will also identify regulatory and chemical barriers to those treatment options. Finally, the researcher should conduct bench-scale feasibility testing of the possible treatment options.

The results of Phase I work will be summarized in a final report. In addition to documenting Phase I activities and results, this report should also be suitable for use in Phase II activities. The goal of Phase II (which is not directly funded in this RFP) would be to develop design data and operating procedures to accomplish the desired removal of perchlorate at pilot- and full-scale. A brief description of currently anticipated Phase II activities is presented below. Additional details concerning Phase II activities will be developed in the course of Phase I work.

Phase II

Following completion of the bench-scale work from Phase I, a separate pilot-scale project should be initiated in the year 2000. Phase II of this study will focus on the pilot-scale testing of promising membrane treatment schemes to:

1. Confirm perchlorate removal efficiencies that were determined at bench-scale

2. Optimize membrane system operational conditions

3. Minimize generation of the concentrate stream

The researcher will also investigate and employ membrane system pretreatment. A minimum of one groundwater and one surface water should be employed at this scale, with these waters representing either the most difficult to treat, or the most prevalent water quality that has been impacted by perchlorate. The Crafton-Redlands Plume in Redlands, California area will be a required pilot-scale study site for Phase II work. As a part of Phase II, pilot testing of concentrate treatment methods would also be conducted. It is expected that the reject treatment process employed will be that which was most promising during Phase I.

Report(s)/Publication(s) (Additional Info Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

GWRTAC ID:	PERC0020
Project Name:	Treatability of Perchlorate in Groundwater Using Ion Exchange Technology (AWWARF #
City:	Houston
State/Province:	TX

Report(s)/Publication(s) (GWRTAC Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

Project Summary:

The following text was excerpted from information supplied by American Water Works Association Research Foundation (AWWARF), December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm:

This research will develop and optimized ion exchange process to address low concentration perchlorate contamination of groundwater.

Objective

Develop and demonstrate an optimized ion exchange process to treat low concentration perchlorate contamination of groundwater (less than 1,000 micrograms per liter). Costs of plant equipment and costs of operation, generation of waste brines and rinse water and waste disposal costs should be minimized. The process must be suitable for use by public water treatment utilities. Key items of investigation will be the choice of ion exchange resins, the process, the regenerant and regeneration method, product water quality, and water system compatibility of the treated water.

Background

In a recent Aerojet study addressing perchlorate contamination at their Rancho Cordova site, Aerojet started with a screening of available treatment technologies. From this screening ion exchange technology seemed the most viable for effective treatment of large quantities of contaminated water. Aerojet then devoted considerable effort to develop an ion exchange treatment system for perchlorate contamination. However, the Aerojet work ended with the development of a biological treatment process. Issues to consider in development of an ion exchange treatment process for perchlorate include the following.

Perchlorate has a high affinity for ion-exchange resins. The perchlorate ion is weakly hydrated in aqueous solutions and will therefore prefer attachment to hydrophobic resins. The perchlorate ion has a stronger affinity for resins than the nitrate ion.

The high affinity of perchlorate for resins leads to low leakages from the resin, but it also leads to difficulties in the use of sodium chloride as a regenerant. This will lead to low regeneration efficiencies and low perchlorate in the waste brine.

It can be reasonably concluded that nitrate selective resins (Triethyl, Tripropyl and Tributyl substituted resins and highly cross linked resins) which are hydrophobic may not be useful for perchlorate removal because of regeneration difficulties. However, hydrophilic resins such as weak base resins with primary, secondary, or tertiary amine functional groups in the hydrogen chloride form or gel type strong base resins bearing one or more hydroxyl groups may show less affinity for perchlorate and therefore allow more efficient regeneration using sodium chloride.

A preferred resin for perchlorate has not been selected.

Competition with other anions and the relative selectivity of perchlorate in various drinking waters has not been determined. Selectivity orders, however, can be assumed from published literature and may change depending on drinking water composition.

The best resin to use, the method of regeneration of the resin, and regenerant disposal are key issues to resolve.

A nitrate ion exchange process with brine denitrification and reuse has been developed and may be modified to satisfy project objectives.

The combination of ion exchange and biological treatment of waste brines to remove perchlorate may be a practical solution that will allow several cycles of waste brine reuse.

Nitrate and arsenic are present in many groundwaters. The effect of these contaminants on any process developed for treatment of perchlorate by ion exchange is unknown. Similarly, the effect of perchlorate on existing ion exchange plants removing nitrate or arsenic is also unknown.

Final concentrations of perchlorate in treated water should be in the range of 18 micrograms per liter or less. The California Department of Health Services established a provisional action level for perchlorate in drinking water of 18 micrograms per liter.

Research Approach

Perchlorate contamination of drinking water is currently impacting at least 12 million consumers. Effective treatment technologies for perchlorate removal or destruction are needed immediately. In order to expedite the research process, this project will be undertaken in two phases with the intent that the contractor selected for Phase I will continue as the contractor for Phase II. Phase II continuation of the project will be contingent upon several factors including: success of Phase I, availability of funding for Phase II, and PAC and AWWARF approval of the detailed scope for Phase II work. The AWWA Research Foundation reserves the right to issue a Request for Proposals (RFP) for Phase II work if this is deemed appropriate. The Crafton-Redlands Plume in the Redlands, California area will be required to be investigated as a pilot-scale study site in Phase II.

Phase I

As a part of this project the researcher will perform a literature review. This literature review should identify past and ongoing ion exchange research related to the removal of perchlorate, or chemicals similar to perchlorate, such as nitrate and bromate. As part of the review, attempts should be made to identify ion exchange resin characteristics of interest. If possible, these characteristics should be cross-referenced to expected water quality parameters of interest. Additional project activities should include the following.

1. Establish the composition of at least three test waters based on the occurrence of perchlorate in the environment. The test waters should contain variations of chloride, sulfate, perchlorate, and alkalinity. Nitrate and arsenic should also be considered for consideration in some test waters. The use of actual perchlorate-contaminated water, possibly spiking with perchorate, sulfate, nitrate, volatile organic compounds or other contaminants to simulate other percholorate contaminated waters may also be considered.

2. Select representative resins from available strong and weak base resins. The use of NSF-approved resins or other resins approved by regulatory agencies for drinking water applications are preferred unless valuable research data can be obtained from unapproved resins.

3. Screen representative resins using column tests. Measure adsorption and regeneration for at least three cycles after a mass balance is demonstrated for the process. Choose regenerant and regenerant concentration.

4. Perform bench-scale testing to establish optimum empty bed contact time, quality of the effluent, and quality of the spent regenerant. Establish the effect of water quality parameters on the media. Demonstrate that process data shows that mass balances of perchlorate and nitrate are achieved. Address media fouling issues, especially as related to naturally occurrring organics. The use of both fixed bed and moving bed bench scale tests should be considered for this work.

5. Establish conditions for biological degradation of perchlorate in regenerant. Determine suitability of regenerant for reuse.

6. Combine ion-exchange and biological degradation components in a single bench-scale system. Run for at least three cycles after material balances for perchlorate and nitrate are obtained.

7. Practical methods of on-line monitoring of perchlorate levels in the treated water should be considered for this work. Alternatively, other methods of determining the amount of water which can be treated for perchlorate contamination by a given ion exchange process should be demonstrated.

8. Prepare a pilot-scale system design with a capacity of approximately 500,000 to 1,000,000 gallons per day to verify bench-scale results. The characteristics that should be considered in the design of this pilot scale system should include the following:

Chemical composition of the untreated water.
Chemical composition of the treated water.
Sequence of process steps for each ion exchange vessel.
Cubic feet of resin in one bed volume in one vessel.
Total number of vessels required for treatment.
Mass of regenerant per cubic foot of resin.
Concentration of the regenerant.
Gallons of water treated by one vessel (one bed volume of resin) before regeneration is required.
Gallons of rinse water and backwash water required per bed volume of resin.
Total dissolved solids (TDS) of rinse water tail and TDS of first two bed volumes of treated water.
Amount of treated and untreated water which can be blended.
Cost of regenerant and other chemicals per million gallons of treated water.
Composition of waste brines and water waters.
Provide preliminary cost estimate for scale-up to demonstration scale system.

The results of this Phase I study should be summarized in a final report. Researchers should consider that the ultimate objective of this work is operation of a full-scale water treatment plant. The final Phase I report should contain a projection of typical operating plant characteristics and costs based on available data or reasonable estimates thereof.

In addition to documenting Phase I activities and results, the final Phase I report should also be suitable for use in Phase II activities. The goal of Phase II (not directly funded in this RFP) would be to develop design data and operating procedures to verify the desired perchlorate removals at pilot scale. A brief description of currently anticipated Phase II activities is presented below. Additional details concerning Phase II activities will be developed in the course of Phase I work.

Phase II

Phase II of this study will primarily focus on pilot scale testing of promising ion exchange treatment schemes. Pilot-scale work will be done on several groundwaters from actual water supplies, with the focus on confirmation and optimization of the system operational conditions. Phase II will also address treatment of the waste stream. The general intent will be to verify the perchlorate removal efficiencies determined at the bench scale, optimize system operational conditions, characterize the waste stream, and minimize generation of the waste stream.

Report(s)/Publication(s) (Additional Info Source):

American Water Works Association Research Foundation (AWWARF) Information, December 2000, and AWWARF website, available at http://www.awwarf.com/research/perch.htm.

GWRTAC ID:	PERC0021
Project Name:	Biodegradation of Subsurface Pollutants by Chlorate-Respiring Microorganisms (NSF #9

City: State College **State/Province:** PA

Report(s)/Publication(s) (GWRTAC Source):

NSF Award Abstract - #9714575, 1999. "Biodegradation of Subsurface Pollutants by Chlorate-Respiring Microorganisms", available at https://www.fastlane.nsf.gov/servlet/showaward?award=9714575

Project Summary:

The following text was excerpted from NSF Award Abstract - #9714575, 1999. "Biodegradation of Subsurface Pollutants by Chlorate-Respiring Microorganisms", available at https://www.fastlane.nsf.gov/servlet/showaward?award=9714575:

Prior exploratory research on this topic was conducted by the Principal Investigator under NSF Small Grant for Exploratory Research Number 94-14423. The objective of research on this renewal award is to continue determination of the feasibility of using microorganisms capable of using chlorate as an electron acceptor in their metabolic processes for decontamination of soil and aquifers. The investigators plan on studying chlorate-based microbial respiration in contrast with molecular oxygen pathways by use of respiratory inhibitors to dissect the electron transport chain. Soil and aquifer contaminants to be investigated in this research for determination of their biodegradability by chlorate-respiring microorganisms include toluene, p-xylene, ethylbenzene, naphthalene, carbon tetrachloride, chlorophenol, chlorobenzoate, benzene, pentane and phenol. The contemplated decontamination process based on results of the proposed research would involve simultaneous injection of chlorates and chlorate-respiring organisms into the contaminated soil or aquifer. Results of this project are expected to provide the basis for its potential application in engineering design of a system to decontaminate soil and groundwater aquifers by use of sodium chlorate as a source of respiratory oxygen under conditions that prevent or inhibit use of oxygen from atmospheric sources. In contrast to other potential chemical electron acceptors such as nitrates and sulfates, byproducts of which are potential groundwater pollutants, the only byproduct of biochemical chlorate utilization is the chloride ion. ***

Subsurface bioremediation is limited in part by the availability of suitable electron acceptors for microorganisms capable of degrading target chemicals. Compounds investigated by others (such as nitrate, sulfate and hydrogen peroxide) have disadvantages that can include: low solubility, toxicity, low energy yields (resulting in slow growth rates of targeted microorganisms), and/or long acclimation times. It is proposed to investigate the potential for using chlorate ($ClO3-$) as an alternate electron acceptor for subsurface remediation processes coupled with injection of chlorate reducing microorganisms (CRMs). CRMs are good candidates for bioaugmentation for several reasons. Because chlorate is not a naturally occurring compound in nature, it is unlikely that there is large native chlorate-respiring population in-situ that would compete with injected microbes for chlorate. CRMs have they have high growth rates and high yields (characteristics which are more comparable to aerobic than anaerobic microbes) which should help them survive in a competitive soil community. The only byproduct of chlorate is chloride ion, resulting in no long term adverse effect of addition of chlorate to subsurface environments. It is hypothesized that simultaneous injection of chlorate and CRMs (acclimate to specific pollutants) into contaminated soils should result in high specificity of target pollutant degradation since only these targeted microorganisms will be capable of chlorate-supported growth.

CRMs are likely a subset of denitrifying microorganisms. From comparison with pollutant degradation abilities of denitrifiers, it is hypothesized chemicals degraded by chlorate reducers could include those degraded under denitrifying conditions. Chemicals selected for study that meet this criterion include: toluene, p-xylene, ethylbenzene, naphthalene, chlorophenol, chlorobenzoate, carbon tetrachloride, and phenol; two additional chemicals selected for study that are thought to be persistent under denitrifying conditions are benzene and pentane. To test our hypothesis that CRMs can be found that degrade these pollutants we will attempt to acclimate mixed cultures of CRMs to these chemicals and, if successful, demonstrate their degradative abilities in batch, chemostat, and column studies.

The physiology of microbial chlorate reduction is not well understood, and we also propose to study chlorate respiration to contrast the pathways for electron transport to chlorate with the pathways for molecular oxygen by using a series of respiratory inhibitors. In both cases, reducing equivalents enter the respiratory chain via dehydrogenases, such as NADH dehydrogenase, and are passed sequentially down a chain or carriers that can include iron-sulfur proteins, quinones, and a series of cytochromes. By inhibiting the action of these different carriers at selected points, it is possible to dissect the electron transport chain and compare components that participate in electron transport to oxygen, nitrate and chlorate.

It is envisioned that this research will show that co-injection of chlorate and chlorate+ pollutant-acclimated microbes is a viable method of selectively stimulating the degradation of target pollutants for subsurface bioremediation. Furthermore, the proposed research will also provide fundamental information on the properties of CRMs and the physiology of microbial chlorate respiration.

Report(s)/Publication(s) (Additional Info Source):

NSF Award Abstract - #9714575, 1999. "Biodegradation of Subsurface Pollutants by Chlorate-Respiring Microorganisms", available at https://www.fastlane.nsf.gov/servlet/showaward?award=9714575

GWRTAC ID: PERC0022

Project Name: Respiratory Enzymes Used for Perchlorate Reduction by Microorganisms (NSF #000190

City: State College **State/Province:** PA

Report(s)/Publication(s) (GWRTAC Source):

NSF Award Abstract - #0001900, 2000. "Respiratory Enzymes Used for Perchlorate Reduction", available at https://www.fastlane.nsf.gov/servlet/showaward?award=0001900

Project Summary:

The following text was excerpted from NSF Award Abstract - #0001900, 2000. "Respiratory Enzymes Used for Perchlorate Reduction", available at https://www.fastlane.nsf.gov/servlet/showaward?award=0001900:

The objective of this research is to elucidate the physiology of perchlorate reducing microorganisms (PRMs). Perchlorate has been detected in ground waters and it endangers the drinking water supply of more than twelve million people. Perchlorate can be used as an electron acceptor by many newly isolated strains of bacteria. Evidence suggests that in the last step of perchlorate reduction, a chlorite dismutase produces molecular oxygen. This is an interesting biological development because oxygen is a preferred electron acceptor. Under fully aerobic conditions, even capable bacteria do not reduce perchlorate. Nitrates can also interfere with perchlorate reduction. Using respiratory inhibitors, the researchers will probe the transfer of electrons along the respiratory chain in PRMs in order to determine how perchlorate and chlorate are used for cell respiration. Through the use of other chemicals, such as chloramphenicol to inhibit protein synthesis, it will be determined whether different pathways are inducible or constitutive and what conditions are necessary to maintain perchlorate-reducing conditions in bacterial cultures. This research will provide information necessary for the development of drinking water, wastewater and in-situ treatment systems to biologically remove perchlorate.
Perchlorate has been detected in ground waters generally at levels of 50-200 ppb primarily as a result of its production and use as solid rocket propellant. Although there is no current drinking water standard for perchlorate, it has been included on the federal Contaminant Candidate List (CCL), 32 ppb has been proposed as a federal limit, and the current California action guideline is 18 ppb. Perchlorate endangers the drinking water supply of more than 12 million people. Surprisingly, perchlorate can be used as an electron acceptor by many newly isolated strains of bacteria. There is substantial evidence that the biochemical pathway for perchlorate reduction proceeds via ClO4--->ClO3---> ClO2---> Cl-+ O2. In the last step, a chlorite dismutase produces molecular oxygen. This is an interesting biological development because oxygen is a preferred electron acceptor. Under fully aerobic conditions, perchlorate is not reduced even by capable bacteria. Nitrate can also interfere with perchlorate reduction.

Several drinking water, wastewater, and in-situ treatment systems are being developed to biologically remove perchlorate, but there is little ongoing research directed toward the physiology of perchlorate reducing microorganisms (PRMs). Biological perchlorate treatment systems will rely upon maintenance of a functioning PRM population in these engineered reactors. Understanding the respiratory pathways used by bacteria will be important to the long term operation of such reactors. For example, is perchlorate respiration constitutive or induced among capable bacteria? If induced, what factors lead to perchlorate enzyme induction? Does nitrate stimulate perchlorate reduction, or will the presence of high concentrations of nitrate shift anaerobic respiration away from perchlorate-reducing populations toward a solely denitrifying community?

This research project is directed at analyzing the electron transport chain (ETC) used by PRMs to degrade perchlorate. Little is known about the enzymes necessary to complete the reduction of perchlorate to chloride. Many PRMs are a subset of denitrifying microorganisms but not all denitrifiers are PRMs. Denitrifiers partially develop branched respiratory pathways that shuttle electrons to reduced nitrogen forms (NO3-, NO2-, N2O and NO) under anoxic conditions. It is not known whether PRMs use aerobic respiratory enzymes, whether some of the denitrifying enzymes are necessary, or whether other, new respiratory enzymes are used for electron transport. Using respiratory inhibitors we will probe the transfer of electrons along the respiratory chain in PRMs in order to determine how perchlorate and chlorate are used for cell respiration. Through the use of other chemicals, such as chloramphenicol to inhibit protein synthesis, we will determine whether different pathways are inducible or constitutive and what conditions are necessary to maintain perchlorate reducing conditions in bacterial cultures.

Report(s)/Publication(s) (Additional Info Source):

NSF Award Abstract - #0001900, 2000. "Respiratory Enzymes Used for Perchlorate Reduction", available at https://www.fastlane.nsf.gov/servlet/showaward?award=0001900

GWRTAC ID:	PERC0023
Project Name:	In Situ Perchlorate Degradation

City: State College ***State/Province:*** PA

Report(s)/Publication(s) (GWRTAC Source):

Gillespie, Rick, and Stephen Koenigsberg, 2000. “Time-Release Electron Donor Technology for the Accelerated Bioremediation of Perchlorate” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

The Pennsylvania State University website of Dr. Bruce E. Logan - Ongoing research topics and topical webpage links, available at http://www.engr.psu.edu/ce/enve/logan.htm.

Project Summary:

The following text was excerpted from The Pennsylvania State University website of Dr. Bruce E. Logan - Ongoing research topics and topical webpage links, available at http://www.engr.psu.edu/ce/enve/logan.htm; and,
Gillespie, Rick, and Stephen Koenigsberg, 2000. “Time-Release Electron Donor Technology for the Accelerated Bioremediation of Perchlorate” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

Part of the recalcitrance of perchlorate in groundwater may be a result of the lack of suitable conditions for in situ degradation. Therefore, researchers at Penn State are investigating methods to stimulate in situ degradation by determining if perchlorate reduction is limited by one of three factors: insufficient microorganisms in the soil capable of perchlorate degradation; lack of anaerobic conditions; lack of sufficient oxidizable substrate (i.e. insufficient electron donor). The abundance of chlorate and perchlorate reducing microorganisms (CRMs and PRMs) is being examined as a part of an ongoing NSF grant. The effect of anaerobic conditions and the importance of sufficient electron acceptors is being examined by determining the effect of lactate on perchlorate degradation.

A significant body of literature supports the validity of enhancing biological reductive dechlorination with organic substrates that serve as electron donors. Typically, substrates are fermented to produce an electron donor such as hydrogen, which in turn can be used in the benign transformation of chlorinated hydrocarbons and oxyanions such as nitrate and perchlorate. Implementation of an appropriate time-release electron donor system can eliminate major design, capital and operational costs, is minimally invasive and is invisible during the working phase.

Hydrogen Release Compound (HRC™) has been developed by Regnesis Bioremediation Products as a low-cost treatment option for in-situ anaerobic bioremediation of chlorinated aliphatic hydrocarbons (CAHs). HRC is a proprietary, environmentally safe, food quality, polylactate ester specially formulated for slow release of lactic acid upon hydration. HRC® releases lactic acid for up to one year. Bioremediation with HRC is a multi-step process. Indigenous anaerobic microbes (such as acetogens) metabolize the lactic acid released by HRC® as a nutrient source, and produce hydrogen. The resulting hydrogen can be used by reductive dehalogenators which are capable of dechlorinating CAHs. Major target compounds in this group include PCE, TCE, and TCA as well as their daughter products. By providing a long-lasting, time-released hydrogen source, HRC® can enhance anaerobic reductive dechlorination of chlorinated aliphatic hydrocarbons. HRC® is injected into the aquifer using direct-push technology, or bore-hole backfill, and is a moderately flowable material that facilitates passive treatment of dissolved phase plumes.

Through a gift by Regenesis to Bruce Logan's research efforts, researchers have investigated whether HRC® can be used to support biological perchlorate reduction. Batch tests were conducted with pure and mixed cultures to demonstrate biological perchlorate reduction in comparison to abiotic and non-amended controls.

Further experiments were planned with packed soil columns to demonstrate long term efficiency of the HRC® in supporting in situ perchlorate degradation. HRC® has been used in a large number of chlorinated hydrocarbon laboratory experiments and field applications. In these studies the reduction of the nitrate oxyanion is duly noted. Full details can be found at www.regenesis.com. With respect to oxyanions such as perchlorate, Regenesis supported laboratory studies that were eventually published by Logan et al. Regenesis is now poised to bring these results to the field in a series of trials, to test the hypothesis by Logan that HRC® as well as lactate can be an effective method for stimulating in situ reduction of perchlorate.

Report(s)/Publication(s) (Additional Info Source):

Gillespie, Rick, and Stephen Koenigsberg, 2000. “Time-Release Electron Donor Technology for the Accelerated Bioremediation of Perchlorate” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Logan, B.E., H. Zhang, J. Wu, R. Unz, and S.S. Koenigsberg, 2000. The Potential for In Situ Perchlorate Degradation In: Case Studies in the Remediation of Chlorinated and Recalcitrant Compounds, G.B. Wickramanayake, A.R. Gavaskar, J.T. Gibbs, and J.L. Means, eds., Battelle Press, Columbus, OH, pp. 87-92.

The Pennsylvania State University website of Dr. Bruce E. Logan - Ongoing research topics and topical webpage links, available at http://www.engr.psu.edu/ce/enve/logan.htm.

GWRTAC ID: PERC0024

Project Name: Calgon Carbon Corp. - ISEP(R) Continuous Ion Exchange

City: Los Angeles **State/Province:** CA

Report(s)/Publication(s) (GWRTAC Source):

Calgon Carbon Corporation Press Release - December 7, 1998, available at www.findarticles.com.

Sase, Richard K., 2000. “Perchlorate Treatment Technology Fast Track to a Solution” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Wagner, Norman, and Charles Drewry, 2000. “Commercial Systems Treating both High and Low Strength Perchlorate Applications Utilizing Ion Exchange” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas

Project Summary:

The following text was excerpted from Calgon Carbon Corporation Press Release - December 7, 1998, available at www.findarticles.com;
Sase, Richard K., 2000. “Perchlorate Treatment Technology Fast Track to a Solution” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas; and,
Wagner, Norman, and Charles Drewry, 2000. “Commercial Systems Treating both High and Low Strength Perchlorate Applications Utilizing Ion Exchange” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

The Main San Gabriel Basin Watermaster (Watermaster) manages the drinking water supplies within the Main San Gabriel Basin, a 167 square mile basin area drained by the San Gabriel River. The basin is located east of Los Angeles, in Los Angeles County, California, and meets 80-90% of the Valley’s water demand, for over one million people. The Main San Gabriel Basin is designated as a Superfund site due to VOC contamination from use of industrial solvents and chemicals; four areas within the Basin are named as Superfund Sites. Perchlorate was discovered in groundwater in the Basin in May 1997, leading to the shutdown of eight public drinking water wells. Four of the wells were shutdown, groundwater from another two wells was “blended”, and two wells were inactivated due to other contaminants. A four-pronged approach was taken to fast-track development of a perchlorate treatment technology for the Main San Gabriel Basin. In October, 1997, the San Gabriel Perchlorate Coordinating Team was formed, and in June 1998 a screening study by California Polytechnical Institute, Pomona was sponsored. An ion exchange study by Montgomery Watson was sponsored in February 1999, and a joint study was undertaken with Calgon Carbon Corporation in October 1998. The San Gabriel Perchlorate Coordinating Team consists of local and regional water agencies, regional, state, and federal regulatory agencies, potentially responsible parties (PRPs), and highly-specialized technical consultants, and was formed to share information, pool research resources, and to fast-track the peer and regulatory review process. The screening study by California Polytechnical Institute investigated various biological, chemical, and physical treatment methods. Their main findings on biological treatment were that: 1. pilot studies indicated perchlorate is destroyed, so that no wastestreams are produced; 2. the addition of microorganisms and disinfection products were concerns; 3. regulatory approval (for drinking water treatment) could be time consuming; and, 4. additional studies should be conducted. The California Polytechnical Institute study made the following main conclusions for physical treatment: 1. ion exchange was the most promising alternative; 2. The Calgon Carbon Corporation ISEP TM treatment system resulted in low waste brine (<1%); 3. ion exchange technology is currently used in public drinking water systems; and, 4. waste brine disposal may become a problem in the future. The main conclusions on biological treatment by the California Polytechnical Institute study were: 1. reverse osmosis (RO) was a proven technology that should remove perchlorate; 2. a large volume of waste brine (10-30%) could be produced; and 3. disposal of the waste brine was a major concern.

Montgomery Watson undertook bench/pilot-scale tests of anion exchange technology, testing commercially available strong-base resins. Perchlorate concentrations in the bench-scale influent were 200 ug/L, and in the pilot-scale influent were 90 ug/L. Treated effluent perchlorate concentrations at both bench- and pilot-scale were non detectable. It was found that polystyrene resins were very difficult to regenerate, and that polyacrylic resins treated 725 bed volumes before breakthrough, and were then fully regenerated.

The Watermaster solicited engineers, contractors, suppliers, and manufacturers to participate in a joint venture, where Watermaster would provide the site and source water, and the joint venture partner would provide a “black box” treatment plant. The only proposal for this joint venture that was accepted was that for the Calgon Carbon Corporation ISEP TM treatment process. The pilot testing was performed on the Big Dalton Well, Baldwin Park, California. The flow rate to the pilot ISEP TM system was 4.28 gpm; brine produced was 0.75% of the inflow. The influent perchlorate concentration of 18-76 ppb, was treated to an effluent concentration of <4 ppb. Based on these results, Calgon Carbon Corporation was retained to construct a full-scale ISEP TM treatment plant for the La Puente Valley County Water District. Construction was completed in March 2000, and the plant was tested from February 10 to March 12, 2000. Reliability and ease of operation were proven in subsequent, intermittent operations, and the waste brine produced is 0.85% of the inflow.

Calgon Carbon Corporation conducted the first laboratory tests of the ISEP® and ISEP++® systems in January 1998. Calgon Carbon Corporation announced on December 7, 1998, that it had successfully completed field trials for the removal of perchlorate from groundwater in California's San Gabriel Valley utilizing an ISEP® continuous ion exchange system which was designed and manufactured by Advanced Separation Technologies, a subsidiary of Calgon Carbon. Perchlorate is often present in groundwater where rocket fuels, fireworks, and explosives have been manufactured. The month-long trial, which was supported by the Main San Gabriel Basin Watermaster and conducted at the Big Dalton well site, demonstrated ISEP®'s capability to exceed requirements by reducing perchlorate concentration in the groundwater on a continuous, ongoing basis to below California's Provisional Action Level of 18 parts per billion (ppb).

A summary of the results was presented to the Watermaster. The data show that the ISEP® system exceeded requirements, consistently reducing perchlorate concentration in the groundwater from influent levels of 18-76 ppb to below the detection level limit of 4 ppb at a 4.28 gpm flow rate. The results also demonstrate that the ISEP® reduced the concentration of nitrate in the groundwater by about 60%.

These results confirm the capability of the ISEP® to reliably, consistently, and economically remove small amounts of perchlorate in contaminated water and to concurrently reduce the concentrations of other ionic contaminants such as nitrate and sulfate to insignificant levels. Calgon Carbon Corporation produces, supplies and designs products, services, and technologies for the purification, separation, and concentration of liquids and gases. Advanced Separation Technologies Incorporated, based in Lakeland, Florida, is a worldwide supplier of the patented ISEP® Continuous Contactor for ion exchange, chromatography, and adsorption.

Report(s)/Publication(s) (Additional Info Source):

Calgon Carbon Corporation Press Release - December 7, 1998, available at www.findarticles.com.

Sase, Richard K., 2000. “Perchlorate Treatment Technology Fast Track to a Solution” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Wagner, Norman, and Charles Drewry, 2000. “Commercial Systems Treating both High and Low Strength Perchlorate Applications Utilizing Ion Exchange” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas

GWRTAC ID:	PERC0025
Project Name:	Insoluble Organic Substrates ("Edible Oils") for Degradation of Perchlorate
City:	Edwards AFB
State/Province:	CA

Report(s)/Publication(s) (GWRTAC Source):

Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1205, available at http://www.serdp.org

Solutions-IES, Inc. 3722 Benson Drive, Raleigh, North Carolina, Technology Development Information

Project Summary:

The following text was excerpted from Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1205, available at http://www.serdp.org; and,
Solutions-IES, Inc. 3722 Benson Drive, Raleigh, North Carolina, Technology Development Information:

An alternative barrier system to control the migration of chlorinated solvents is being developed by immobilizing food-grade edible oils in the aquifer to enhance reductive dehalogenation of the contaminants. In this process, low-solubility, edible oils are immobilized in a barrier configuration to enhance the aerobic biodegradation of contaminants that enter the barrier. An oil-in-water emulsion is first prepared using food-grade edible oils and then injected into the contaminated aquifer in a barrier configuration using either conventional wells or Geoprobe points. As the emulsion passes through the aquifer, a portion of the oil becomes trapped within the pores leaving a residual oil phase to support long-term reduction of contaminants that enter the barrier. This technology has the potential to be useful for the treatment of a wide variety of contaminants including chlorinated solvents, heavy metals, chromium, perchlorate, and oxidized radionuclides A current FY 2001 New Start, SERDP project focuses on the enhanced reductive dehalogenation of chlorinated solvents. Edible oil barriers have tremendous cost and operational advantages over other competing technologies, including zero valent iron barriers and anaerobic bioremediation using soluble substrates. Construction costs for zero valent iron barriers typically are in the range of $100 per square foot of barrier. In comparison, installation of an edible oil barrier is estimated to cost approximately $15 per square foot of barrier. If the edible oil barrier technology can be developed adequately, this approach has the potential to reduce the cost and improve the effectiveness of aquifer remediation for chlorinated solvents significantly.

Solutions-IES, Inc. has evaluated, tested and designed systems for the introduction of both soluble and insoluble organic substrates into contaminated aquifers. During laboratory development of this technology, several low-cost readily available substrates were shown in laboratory microcosms to effectively promote anaerobic reductive dechlorination, resulting in complete transformation of chlorinated solvents to non-chlorinated end-products. While both soluble and insoluble substrates can effectively enhance bioremediation, the promise of insoluble versus soluble substrates is a reduction in long-term O&M costs. Solutions-IES is currently working with the Air Force Center for Environmental Excellence (AFCEE) at three Air Force bases installing, operating, and evaluating pilot- and full-scale remediations using insoluble organic substrates for the degradation of chlorinated aliphatic hydrocarbons in the aquifer. The technology is also being used at two industrial remediation sites. Field results to date have shown the ability to successfully distribute the organic substrate into the contaminated aquifer, quickly establish a reducing subsurface environment, and subsequently measure decreasing concentrations of the target chlorinated solvents. Solutions-IES is currently working with AFCEE and has applied to NFESC to fund similar demonstrations for the degradation of perchlorate, an inorganic contaminant found frequently at military installations. A field demonstration is planned at Edwards Air Force Base, California.

Report(s)/Publication(s) (Additional Info Source):

Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1205, available at http://www.serdp.org

Solutions-IES, Inc. 3722 Benson Drive, Raleigh, North Carolina, Technology Development Information

---

GWRTAC ID: PERC0026

Project Name: Isolation of Perchlorate Reducing Bacterial Culture

City: Tyndall AFB **State/Province:** FL

Report(s)/Publication(s) (GWRTAC Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Project Summary:

The following text was excerpted from project summary information supplied by Applied Research Associates, Inc., (ARA), Panama City, FL, November 2000:

ARA pioneered serious R&D efforts for perchlorate destruction technologies beginning in 1989 when a program to develop biodegradation technology for perchlorate was initiated under sponsorship of the United States Air Force. At that time biodegradation was recognized as a viable process to treat dilute AP waste streams and treat contaminated ground water. Attaway and Smith isolated an organism capable of reducing perchlorate and designated the bacterium HAP-1 (Attaway, H., and Smith, M. 1993. “Reduction of Perchlorate by an Anaerobic Enrichment Culture.” Journal of Industrial Microbiology. 12: 408-412). Laboratory studies were conducted in batch and continuous stirred tank reactors (CSTRs). Subsequent efforts culminated in the positive identification of the bacterium responsible for perchlorate reduction as Wolinella succinogenes (Wallace, W., Ward, T., Breen, A., Attaway, H. 1996. “Identification of an Anaerobic Bacterium Which Reduces Perchlorate and Chlorate as Wolinella succinogenes.” Journal of Industrial Microbiology. 16: 68-72). These effloets resulted in very stable, predictable perchlorate reduction rates exceeding 0.5 g/l per hour. As a result of ARA’s efforts, a patent has been granted to the Air Force, United States Patent 5,302,285. “Propellant Wastewater Treatment Process.” April 12, 1994. ARA has licensed this technology.

Report(s)/Publication(s) (Additional Info Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

GWRTAC ID:	PERC0027
Project Name:	Perchlorate Biodegradation Pilot-scale Design, Construction, and Demonstration

City: Tyndall AFB **State/Province:** FL

Report(s)/Publication(s) (GWRTAC Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Project Summary:

The following text was excerpted from project summary information supplied by Applied Research Associates, Inc., (ARA), Panama City, FL, November 2000:

ARA designed, fabricated, and successfully tested a continuous-flow pilot system at Tyndall AFB, Florida capable of treating up to 1000 gallons per day of effluent. The prototype consisted of a single, anaerobic, continuous-stirred-tank-reactor (CSTR) and ancillary equipment for nutrient preparation and feeding, pH control, and feed and effluent handling. The process was demonstrated on ammonium perchlorate wastewater generated by the washout of Minuteman booster motors. Concentrated AP wastewater was diluted to 500-3000 ppm for this demonstration.

Report(s)/Publication(s) (Additional Info Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

GWRTAC ID:	PERC0028		
Project Name:	Prototype Design, Construction, and Demonstration		
City:	Tyndall AFB	***State/Province:***	FL

Report(s)/Publication(s) (GWRTAC Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Project Summary:

The following text was excerpted from project summary information supplied by Applied Research Associates, Inc., (ARA), Panama City, FL, November 2000:

In 1996, ARA accomplished optimization studies that led to the first industrial application of perchlorate biodegradation. Through a Cooperative Research and Development Agreement (CRDA) with Thiokol Corporation, Defense and Launch Vehicle Division, the prototype biodegradation process was integrated into existing waste treatment processes at Thiokol's production facility near Brigham City, Utah. ARA modified the previously developed pilot process to treat perchlorate wastewater containing salts, corrosion inhibitors consisting of nitrate and nitrite, and other contaminants. The redesigned process consisted of two anoxic, suspended-growth reactors that could be operated in series or parallel depending on feed characteristics. The process is operated by Thiokol under the CRDA and has a capacity of over 3000 gallons per day, depending on perchlorate and salt concentration. This process has operated continuously since start-up on December 8, 1997, and has never been re-inoculated.

Report(s)/Publication(s) (Additional Info Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Coppola, Edward N., 2000, "Perchlorate Treatment Technologies: Biodegradation Prototype Thermal Decomposition" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0029
Project Name:	Prototype Process Optimization

City:	Brigham City	**State/Province:**	UT

Report(s)/Publication(s) (GWRTAC Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Project Summary:

The following text was excerpted from project summary information supplied by Applied Research Associates, Inc., (ARA), Panama City, FL, November 2000:

ARA was sponsored by the JOCG to reduce operating cost and improve performance of the Thiokol Prototype by conversion to low-cost nutrients. Several low-cost materials were identified and evaluated for use as nutrients. A carbohydrate byproduct (CBP), was identified and evaluated as the best replacement for the brewer's yeast and cheese whey mixture which was the original nutrient. CBP is a low-cost, pumpable byproduct from the food processing industry that contains amino acids, proteins, sugars, and micronutrients, which aid system performance. CBP demonstrated better performance than other nutrients and performed well over a broader concentration range.

The prototype was converted from the yeast-whey nutrient blend to CBP in May 1999. Since conversion, good performance has been maintained. Actual nutrient and chemical costs were reduced over 90%, from an average of $1.76 to $0.16 per pound of perchlorate reduced. During 1999, 15,400 pounds of perchlorate in wastewater were destroyed by the prototype at Thiokol. The weighted-monthly average perchlorate feed concentration ranged form 300 to 4,400 mg/L.

ARA has licensed Air Force patent 5,302,258 with the intent to further develop and commercialize perchlorate biodegradation technology for demilitarization, wastewater, groundwater, and drinking water applications. As a result of advancement in perchlorate biodegradation technology, ARA was issued Patent 6,077,432, "Biodegradation of Ammonium Perchlorate, Nitrate, Hydrolysates and Other Energetic Materials", on 20 June 2000.

Report(s)/Publication(s) (Additional Info Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Coppola, Edward N., 2000, "Perchlorate Treatment Technologies: Biodegradation Prototype Thermal Decomposition" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0030
Project Name:	Treatability Studies on Groundwater from Henderson, NV
City:	Panama City
State/Province:	FL

Report(s)/Publication(s) (GWRTAC Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Project Summary:

The following text was excerpted from project summary information supplied by Applied Research Associates, Inc., (ARA), Panama City, FL, November 2000:

The discovery of perchlorate in the Colorado River led to the identification of a source area near Henderson, Nevada. Ammonium perchlorate has been manufactured in this area since the 1950s. Perchlorate in the soil and groundwater has contaminated shallow aquifers that feed the Las Vegas Wash, which flows into Lake Mead and the Colorado River. Water from one test well in this aquifer had a perchlorate concentration of 3700-ppm, which is over 200,000 times the 18-ppb action level established by the California Department of Health Services (DHS). Lake Mead supplies drinking water to over 12 million people in southern Nevada and California. Perchlorate concentration in Lake Mead, and in the drinking water from Lake Mead, has been measured near the 18-ppb action level established by the California DHS. Therefore, this is an acute problem and potential excellent application for perchlorate biodegradation. The nominal composition of water treated from aquifers near Henderson, Nevada is provided in the table below.

Nominal Composition of Contaminated Groundwater from Henderson, NV

Component	Concentration, mg/l	Component	Concentration, mg/l
Perchlorate, ClO_4^-	100-1500	Calcium, Ca^{+2}	800
Chlorate, ClO_3^-	300-3500	Magnesium, Mg^{+2}	400
Sulfate, SO_4^-	1700	Nitrate, NO_3^-	20-200
Chloride, Cl^-	2000	Boron	14
Sodium, Na^+	1800	Chromium (VI)	0.1-9

ARA has conducted over 30,000 hours of bench-scale reactor studies to optimize and reduce the operating cost for a biodegradation process that can treat various sources of this ground water. Studies were conducted in different reactor configurations using various nutrients to minimize nutrient consumption and cost. Both chlorate and perchlorate were effectively reduced to chloride. Chromium did not inhibit perchlorate reduction and was reduced to chromium (III) in the process. Chromium (VI) was reduced from 8-9 ppm to less than 0.2 ppm. Nitrate was also simultaneously completely reduced.

Report(s)/Publication(s) (Additional Info Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

GWRTAC ID:	PERC0031
Project Name:	Full-Scale Design of a 1.2 MGD Groundwater Treatment Plant
City:	Henderson
State/Province:	NV

Report(s)/Publication(s) (GWRTAC Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Project Summary:

The following text was excerpted from project summary information supplied by Applied Research Associates, Inc., (ARA), Panama City, FL, November 2000:

ARA has completed the design of a full-scale, I.2 MGD (825 gpm) groundwater treatment plant for the Kerr-McGee Chemical, LLC facility in Henderson, Nevada. The plant is designed to reduce perchlorate, from several groundwater sources, from an average of 400 ppm to below 18 ppb. At design conditions, perchlorate removal and destruction will be 4,000 pounds per day, with simultaneous reduction of nitrate and chlorate, with less than an eight-hour hydraulic residence time. The anoxic process is configured with two trains of two, suspended-growth, continuous-stirred-tank reactors in series. The anoxic effluent is further treated by a conventional aerobic activated sludge process to reduce BOD and meet all NPDES permit requirements. Effluent will be discharged to the Las Vegas Wash and Lake Mead. The nutrient and chemical cost for this treatment plant equates to approximately 30 cents per pound of perchlorate removed and destroyed.

Report(s)/Publication(s) (Additional Info Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

GWRTAC ID:	PERC0032		
Project Name:	Catalytic Reduction using Oxorhenium (v) Oxazoline Complexes		
City:	Los Angeles	**State/Province:**	CA

Report(s)/Publication(s) (GWRTAC Source):

Abstract Clean and Efficient Catalytic Reduction of Perchlorate by Mahdi M. Abu-Omar,* Lee D. McPherson, Joachin Arias, and Virginie M. Béreau, Department of Chemistry and Biochemistry, University of California, 405 Hilgard Avenue, Los Angeles, CA 90095-1569, USA, January 2001

Project Summary:

The following text was excerpted from abstract Clean and Efficient Catalytic Reduction of Perchlorate by Mahdi M. Abu-Omar,? Lee D. McPherson, Joachin Arias, and Virginie M. Béreau
Department of Chemistry and Biochemistry, University of California, 405 Hilgard Avenue, Los Angeles, CA 90095-1569, USA, January 2001:

Perchlorate (ClO_4^-) has been recognized recently as a water contaminant in the U.S., and has been added to EPA's (Environmental Protection Agency) "Contaminant Candidate List" (CCL) and "Unregulated Chemicals Monitoring Rule" (UCMR). Removal of perchlorate from water is difficult because of its high solubility and kinetic inertness. Oxorhenium(V) oxazoline complexes catalyze the reduction of perchlorate to chloride with organic sulfides (Scheme 1). Turnover numbers of 280 hr-1 are easily achieved without any sign of catalyst deactivation. The rate-controlling step under steady-state conditions is the oxidation of oxorhenium(V) to dioxorhenium(VII). However, product inhibition with respect to chloride is observed. In the absence of a reductant, oxorhenium(V) oxazoline complexes could be used for spectrophotometric detection of perchlorate since the green oxorhenium(V) reacts with ClO_4^- to give the red dioxorhenium(VII).

The oxazoline ligand is being functionalized to allow for catalyst tethering and immobilization on solid support. The development of a highly active heterogeneous catalyst is necessary since catalyst recovery and recycling is a prerequisite to application. Another avenue that we are currently exploring is the utility of these oxorhenium(V) complexes as catalysts in the electrochemical reduction of perchlorate.

Report(s)/Publication(s) (Additional Info Source):

Abu-Omar, M.M., L. D. McPherson, J. Arias, and V. M. Béreau, 2000. "Clean and Efficient Reduction of Perchlorate." Angew. Chem. Int. Ed. 2000, 39, 4310-4313.

Abu-Omar, M.M. and J. H. Espenson, 1995. "Facile Abstraction of Successive Oxygen Atoms from Perchlorate Ions by Methylrhenium Dioxide." Inorg. Chem. 1995, 34, 6239-6240.

Abu-Omar, M.M., E. H. Appleman, and J. H. Espenson, 1996. "Oxygen-Transfer Reactions of Methylrhenium Oxides." Inorg. Chem. 1996, 35, 7751-7757.

Abu-Omar, Mahdi M., 2000. "Clean and Efficient Catalytic Remediation of Perchlorate" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID: PERC0033

Project Name: Demonstration of Perchlorate Reduction in Rejectate from Reverse Osmosis

City: Panama City **State/Province:** FL

Report(s)/Publication(s) (GWRTAC Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Project Summary:

The following text was excerpted from project summary information supplied by Applied Research Associates, Inc., (ARA), Panama City, FL, November 2000:

The purpose of this study was to evaluate the biodegradation of perchlorate in rejectate from the treatment of contaminated groundwater by reverse osmosis (RO). Because of the large volumes of water required for this study, surrogate RO rejectate water was prepared based on actual groundwater analysis. Appropriate salts were used to prepare RO rejectates that represented a 5x (RO) and a 10x (RO2) concentration of the groundwater constituents. A bench-scale version of a full-scale, patented reactor system was employed in this study. This reactor system was operated as a fixed-film process and as a suspended-growth, continuous-stirred-tank-reactor (CSTR) process. Over three months of testing was conducted to evaluate the affects of reactor configuration, residence time, feed water (RO & RO2), and nutrient.

Perchlorate reduction was evaluated by ion chromatography. Due to the high concentration of dissolved solids in this water, the detection limit using this method was limited to approximately 20 parts-per-billion. During steady-state operation, perchlorate was routinely reduced from approximately 10 parts-per-million (ppm) in the feed to below the detection limit for ion chromatography. In addition to complete perchlorate reduction, nitrate was also completely reduced. Reduction of a potential co-contaminant, chromium (VI), was also evaluated. 120 ppb of chromium was added to RO rejectate feed water as chromate ($CrO4=$). This limited test showed that this process simultaneously reduced chromium (VI), measured at 80 ppb in the feed, to below the detection limit of 10 ppb.

Report(s)/Publication(s) (Additional Info Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

GWRTAC ID:	PERC0034		
Project Name:	Transformation of Perchlorate into Chloride by Newly Isolated Bacterium		
City:	Arnhem	**State/Province:**	The Netherland

Report(s)/Publication(s) (GWRTAC Source):

G. B. Rikken, A. G. M. Kroon, C. G. van Ginkel, 1996. Akzo Nobel Central Research, Analytical and Environmental Chemistry Department, P.O. Box 9300, 6800 SB Arnhem, The Netherlands. Fax: 026-3 66 2528, “Transformation of (per)chlorate into chloride by a newly isolated bacterium: reduction and dismutation” in Applied Microbiology and Biotechnology, Vol. 45, Issue 3, pp. 420-426, available at http://link.springer.de/link/service/journals/00253/tocs.htm .

Project Summary:

The following text was excerpted from the abstract for G. B. Rikken, A. G. M. Kroon, C. G. van Ginkel, 1996. Akzo Nobel Central Research, Analytical and Environmental Chemistry Department, P.O. Box 9300, 6800 SB Arnhem, The Netherlands. Fax: 026-3 66 2528, “Transformation of (per)chlorate into chloride by a newly isolated bacterium: reduction and dismutation” in Applied Microbiology and Biotechnology, Vol. 45, Issue 3, pp. 420-426, available at http://link.springer.de/link/service/journals/00253/tocs.htm .

Bacterial strain GR-1 was isolated from activated sludge for its ability to oxidize acetate with perchlorate as electron acceptor. Sequencing of 16S rDNA revealed the isolate to belong to the <beta> subgroup of Proteobacteria. When strain GR-1 was grown on acetate and perchlorate, the release of chloride was proportional to the disappearance of perchlorate, showing that this compound was completely reduced. In addition to perchlorate, strain GR-1 used chlorate, oxygen, nitrate and Mn(IV) as electron acceptor. The oxidation of acetate is coupled to the reduction of perchlorate and chlorate, whereas chlorite reduction is not affected by the addition of acetate. Strain GR-1 disproportionates chlorite into molecular oxygen and chloride. As a consequence, the strain oxidizes acetate by simultaneously reducing perchlorate to chlorite and molecular oxygen to water. Comparison of growth yields with oxygen, chlorate and perchlorate and calculated <Delta>G0$^\prime$ values confirms this finding.

Report(s)/Publication(s) (Additional Info Source):

G. B. Rikken, A. G. M. Kroon, C. G. van Ginkel, 1996. Akzo Nobel Central Research, Analytical and Environmental Chemistry Department, P.O. Box 9300, 6800 SB Arnhem, The Netherlands. Fax: 026-3 66 2528, “Transformation of (per)chlorate into chloride by a newly isolated bacterium: reduction and dismutation” in Applied Microbiology and Biotechnology, Vol. 45, Issue 3, pp. 420-426, available at http://link.springer.de/link/service/journals/00253/tocs.htm .

GWRTAC ID:	PERC0035		
Project Name:	Bifunctional Anion Exchange Resin Development - U.S. Patent No. 6,059,975 - Regener		
City:	Oak Ridge	***State/Province:***	TN

Report(s)/Publication(s) (GWRTAC Source):

Gu, Baohua, and G.M. Brown, 2000, “Efficient Removal of Perchlorate (ClO4-) From Contaminated Water by Highly Selective, Regenerable Bifunctional Resins” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excerpted from Gu, Baohua, and G.M. Brown, 2000, “Efficient Removal of Perchlorate (ClO4-) From Contaminated Water by Highly Selective, Regenerable Bifunctional Resins” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

The Oak Ridge National Laboratory (ORNL) and University of Tennessee have recently developed a new class of bifunctional anion exchange resins (U.S. patent # 6,059,975), which are highly selective for sorption of ClO4- from contaminated groundwater or surface water. The bifunctional anion exchange resins were initially developed under DOE sponsorship for pertechnetate (TcO4-) removal at ppt levels. Perchlorate behaves similarly to pertechnetate, as both are large, poorly hydrated anions. The bifunctional resins consist of quaternary ammonium groups with both large (C6) and small (C2) alkyl groups resulting in high selectivity and good exchange kinetics.

Laboratory studies utilized a flow rate of 17 bed volumes per minute, and influent perchlorate concentrations of 1,000 or 10,000 ppb. The chemistry of the synthetic water used in the laboratory studies was as follows: 106 mg/L chlorine, 0 mg/L fluorine, 31 mg/L nitrate, 49 mg/L sulfate, 183 mg/L bicarbonate, 1,000-10,000 ug/L perchlorate, and pH 8.3. The bifuntional resin tested was RO-02-119, with trihexylamine/triethylamine functional groups synthesized at the University of Tennessee, Knoxville. Commercial monofunctional resins tested included Purolite A-520E, with triethylamine functional groups by Purolite International, and Sybron SR-6, with tributylamine functional groups by Sybron Chemicals, Inc. Test results indicate that the bifunctional resins are highly selective toward ClO4- and perform about five times better than one of the best commercial nitrate-selective resins (Purolite® A-520E).

Additionally, a new regeneration technology (U.S. patent pending, 09/491,242) has been developed at ORNL so that these anion-exchange resins can be used repeatedly over a long-term operation. The regeneration process uses tetrachloroferrate (FeCl4-), is cost-effective and generates minimal amounts of secondary wastes. No decrease in resin performance after seven cycles of perchlorate loading and regeneration were noted, on tests with the D-3696 resin column (10 x 22 mm), with 17 BV/minute flow, and 10 mg/L initial perchlorate concentration. Therefore, the new resin and new regeneration technology offer a promising solution to remediate the ClO4— contaminated groundwater or surface water by using either the conventional pump-and-treat or the funnel-and-gate treatment configurations (with regenerable treatment systems).

Report(s)/Publication(s) (Additional Info Source):

Gu, Baohua, and G.M. Brown, 2000, “Efficient Removal of Perchlorate (ClO4-) From Contaminated Water by Highly Selective, Regenerable Bifunctional Resins” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0036		
Project Name:	U.S. Navy, Southern Division, NAVFAC, Soil Remediation, McGregor, Texas		
City:	McGregor	**State/Province:**	TX

Report(s)/Publication(s) (GWRTAC Source):

EnSafe Consultants, EnSafe, Inc., 5724 Summer Trees Drive, Memphis, TN 38134, phone 901-752-1690, Project Summary Information, December, 2000

Project Summary:

The following text was excerpted from project summary information provided by EnSafe Consultants, EnSafe, Inc., Memphis, TN, December, 2000:

Naval Weapons Industrial Reserve Plant (NWIRP) McGregor, approximately 20 miles southwest of Waco, Texas, is an inactive, government-owned, contractor-operated facility, originally established in 1942 as the Bluebonnet Ordnance Plant by the U.S. Army Ordnance Corps. Several property owners and tenants have operated onsite during its 50-year history including the United States Army, Navy, and Air Force; the site is currently owned by the U.S. Navy's Naval Air Systems Command. In general, industrial activities included weapons and weapons systems (e.g., bombs, missiles, and explosives) and solid-fuel rocket propulsion systems (primary component: ammonium perchlorate) manufacturing.

As part of interim stabilization measures (ISMs) for the site, the Texas Natural Resource Conservation Commission (TNRCC) required EnSafe and the Navy to evaluate and install treatment systems that would abate offsite migration of perchlorate-contaminated surface and groundwater. The ISM Evaluation Plan recommended biological treatment as the most viable option for groundwater treatment. In addition, surface soil sampling indicated the existence of approximately 1,500 cubic yards (yd3) of soil with a maximum concentration of 1,800 mg/kg and a mean concentration of 500 mg/kg. Because perchlorate serves as an electron acceptor in the absence of oxygen in microbial reactions, anaerobic treatment of contaminated soil was proposed as the most feasible treatment option.

Before constructing the anaerobic landfarming unit, bench-scale studies were performed to obtain design information including (1) the types of additives such as carbon and nitrogen nutrients, (2) the need for microbial inoculation, and (3) a biodegradation rate estimate. Two carbon sources, fructose and citric acid were evaluated in the bench-scale study. Furthermore, tests were performed using both indigenous and previously acclimated microorganisms. Rapid perchlorate degradation was observed in a few days. A first order biodegradation rate of 0.13 day-1 was estimated.

Following the successful bench-scale study, contaminated site soil was transported in October 1999 to an onsite engineered treatment cell that was lined with a 30-mil HDPE liner. The bottom of the treatment cell is 500 x 30 feet. The sides are sloped 2H:1V, and the cell is approximately six feet deep. The perchlorate-contaminated soil was approximately 2.5 feet deep after it was placed in the cell. The perchlorate-contaminated soil was mixed with citric acid (carbon source), nitrogen and phosphorus fertilizer (micronutrients), and soda ash (buffer) in designed quantities and ratios based on the bench-scale study before it was placed into treatment cell. In addition, the soil was saturated as it was placed in the treatment cell. Additional water was added maintain at least 2 inches of water above the soil to foster and sustain anaerobic conditions. Finally, the cell was covered with a 6-mil HDPE liner.

After six months, soil was sampled at six random locations and analyzed for perchlorate. All six samples were below the regulatory target cleanup level of 270 ug/kg. Furthermore, the perchlorate concentration in the water used to flood the cell was below its detection limit of 4 ug/L.

Report(s)/Publication(s) (Additional Info Source):

Britto, R., 2000. "Mechanisms of Perchlorate Degradation: An Overview" in Perchlorate Treatment Technology

Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Cowan, D. 2000. Innovative abatement and remediation of perchlorate at McGregor, Texas weapons plant site. Soil Sediment & Groundwater (June/July):25.

Cowan, D. 2000. "In Situ Perchlorate Bioremediation for Soil and Groundwater" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Perlmutter, M. 2000. "Implementation of Innovative In Situ Biotreatment Technology" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

EnSafe Consultants, EnSafe, Inc., 5724 Summer Trees Drive, Memphis, TN 38134, phone 901-752-1690, Project Summary Information, December, 2000

Perlmutter, M. "Bioremediation of Perchlorate-Contaminated Groundwater at Naval Weapons Reserve Plant McGregor, Texas", in National Defense Industrial Association Proceedings, 26th Environmental Symposium and Exhibition, Long Beach, CA, March 27-30, 2000.

Britto, R., 2000. "Enhancement and Optimization of Perchlorate Treatment in Soil and Groundwater", in Remediation of Chlorinated and Recalcitrant Compouns, Battelle, Monterrey, CA, May 22-25, 2000.

Perlmutter, M., 2000. (1) "Concept to Pilot-Scale: Ex Situ Biotreatment of Perchlorate-Contaminated Soil and Groundwater" and (2) "Innovative Technology: In Situ Biotreatment of Perchlorate-Contaminated Groundwater", in Air and Waste Management Association, 93rd Annual Conference and Exhibition, Salt Lake City, Utah, June 18-22, 2000.

(1) Mechanisms of Perchlorate Degradation: An Overview (2) In Situ Perchlorate Bioremediation for Soil and Groundwater, and (3) Implementation of Innovative In Situ Biotreatment Technology at NWIRP, McGregor, Texas, 5th Annual Joint Services Pollution Prevention and Hazardous Waste Management Conference and Exhibition, San Antonio, Texas, August 23, 2000.

Bioremediation of Perchlorate-Contaminated Groundwater and Soil at NWIRP McGregor, Texas, Society of American Military Engineers, Fort Worth, Texas Post, October 3, 2000.

Abating and Remediating Perchlorate, The Military Engineer, Society of American Military Engineers, November -December 2000, Vol. 92, No. 608.

GWRTAC ID:	PERC0037
Project Name:	Titanium Ions for Perchlorate Reduction

City:	Georgetown	**State/Province:**	VA

Report(s)/Publication(s) (GWRTAC Source):

Early, Joseph E., Giulio Amadei, and Daniel Tofan, 2000. “Rapid Reduction of Perchlorate Ion by Ti(III) Complexes in Homogeneous and Heterogeneous Media” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excerpted from project summary information provided by Georgetown University; and Early, Joseph E., Giulio Amadei, and Daniel Tofan, 2000. “Rapid Reduction of Perchlorate Ion by Ti(III) Complexes in Homogeneous and Heterogeneous Media” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

It has been known for a long time that titanous ions (Ti3+) reduce perchlorate ions in acidic aqueous solutions, but that reaction is quite slow, generally having a half-time of many hours or a few days. Laboratory research carried out by Professor Joseph E. Earley, Sr., and his associates in the Chemistry Department of Georgetown University of Washington DC 20057 has identified reaction media in which this reaction (reduction of perchlorate to chloride by Ti(III)) takes place quite rapidly (half-time of minutes). The same group has also synthesized several new organic ligands that efficiently catalyze reduction of perchlorates by titanous ions in ordinary acid aqueous media. Further, they have developed methods to bind such catalytic ligands to semi-solid supports which provide an appropriate reaction environment for rapid destruction of perchlorates by titanous species. These heterogeneous catalytic media can be used in flow or batch methods to efficiently and rapidly reduce perchlorates to chlorides. The ultimate products of the Ti(III)-perchlorate reaction are titanium dioxide (titania) and chloride salts, non-toxic and environmentally benign products. A patent describing these processes and the new chemical principles they involve is pending. These methods and principles can be further developed (preferably, by arrangement, in an industrial or government laboratory) to provide rapid, convenient, and environmentally benign methods of destruction of perchlorates, including solutions of high acidity and/or high salt concentrations, for which biological remediation is not feasible. The reactant Ti(III) is inexpensive and readily available. The produce Ti(IV) can be reduced to Ti (III) by electrochemical or chemical means. Batch and/or continuous flow methods can be developed to use the chemical principles discussed in the patent (pending) for destruction of perchlorates.

Report(s)/Publication(s) (Additional Info Source):

Early, Joseph E., Giulio Amadei, and Daniel Tofan, 2000. “Rapid Reduction of Perchlorate Ion by Ti(III) Complexes in Homogeneous and Heterogeneous Media” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Urbansky, Edward T., Ed. 1999. Chapter 9, Perchlorate in the Environment, Kluwer Academic/Plenum Publishers, New York, New York

GWRTAC ID:	PERC0038
Project Name:	Bioremediation of Perchlorate in Ground Water
City:	Riverside
State/Province:	CA

Report(s)/Publication(s) (GWRTAC Source):

Research Summary W-902 in Research Program Activities of Water Resources Center, University of California 1998-1999, available at http://waterresources.ucr.edu/publications/AR9899-copy%20(1).pdf.

Project Summary:

The following text was excerpted from Research Summary W-902 in Research Program Activities of Water Resources Center, University of California 1998-1999, available at http://waterresources.ucr.edu/publications/AR9899-copy%20(1).pdf:

Bioremediation is a viable option for perchlorate removal from ground water, as some bacteria can transform perchlorate into an innocuous end product, chloride. The bacterium, percIace, was isolated from a biosolids enrichment. This bacterium can use perchlorate as an alternate electron acceptor, instead of oxygen, for growth. In batch culture, this isolate completely transformed perchlorate into chloride in 48 hours with simultaneous removal of nitrate. PercIace will reduce perchlorate when acetate is the carbon source. Optimum growth conditions include a pH between 7.0 and 7.2 and a temperature of 30 deg.C. Anaerobic conditions are important, as the bacterium will also use oxygen as an electron acceptor and will not begin to reduce perchlorate until all of the oxygen is removed from the medium. PerIcace was not identifiable by standard methods, indicating that it may be a novel organism.

PercIace was tested in a flow-through system to stimulate a potential bioreactor design. Using a 30-ml glass column, perIace was immobilized on a sand matrix. At various flow rates through the column, the bacterium was able to completely remove perchlorate and nitrate from mineral salts medium. A 300-ml column made of PVC pipe was designed with diatomaceous earth pellets (Celite) as the solid support for the bacterium. This column was used to demonstrate the removal of 738 g L-1 perchlorate from San Gabriel Valley ground water to levels below the State Action Level. A residence time in the column of 5 hours resulted in removal of perchlorate to less than 4 ppb, the current detection limit. At a residence time of 2.5 hours, perIace removed perchlorate from the ground water to below the State Action Level.

These studies demonstrated the potential for perIace to be used as a means for removing perchlorate from ground water in a flow-through bioreactor system. It appears that the extent of perchlorate removal is flow rate dependent. A contributing factor may also be the distribution of biomass throughout the reactor. Another, larger column study is currently underway. This study intends to minimize the residence time of ground water in the column by increasing the biomass attached to the solid support. A faster flow of water through the column will make the system more economically feasible.

Another aspect of the project involves investigation of alternative carbon sources for perchlorate bioremediation. A stable consortium of bacteria, which can grow with hydrogen as the electron donor, perchlorate as the electron acceptor and bicarbonate as the carbon source, has been cultured. Investigation of the growth kinetics of this consortium demonstrated that it can use bicarbonate and perchlorate already present in ground water as a growth substrate. This consortium may be a valuable bioremediation tool, as the consortium would not require the addition of a carbon source for growth.

Water utilities need treatment methods that can reliably reduce perchlorate concentrations to low or non-detectable levels. The treatment method must be cost-effective, acceptable to regulatory agencies and the public, cause not other water quality problems and minimize waste generation. Because the perchlorate ion is nonvolatile and highly soluble in water, it cannot be removed by conventional methods. The most commonly used method for reducing perchlorate levels in contaminated water supplies is to blend the water with an uncontaminated supply. Some cities, including Loma Linda and Redlands, must purchase expensive water to meet the demands of these communities.

The use of microorganisms immobilized in a flow-through bioreactor for the removal of nitrate is a common strategy used in Europe and one such system is in place in the United States. Development of this type of system for perchlorate removal would be a great advance in technology, as current remediation methods such as ion exchange and reverse osmosis, are capable only of concentrating perchlorate, not destroying it. Bacterial metabolism of this contaminant would be an efficient, cost-effective process for completely removing perchlorate from the environment.

Report(s)/Publication(s) (Additional Info Source):

Giblin, T., D.C. Herman, and W.T. Frankenberger, Jr. 1999. Bacterial reduction of perchlorate and nitrate in groundwater by perlace. Presented at the Perchlorate Conference, Ontario, California.

Giblin, T., D.C. Herman, and W.T. Frankenberger, Jr. 1999. An autotrophic system for removal of perchlorate from groundwater. Presented at the Perchlorate Symposium, Annual Meeting of the American Chemical Society. New Orleans, August.

Herman, D.C. and W.T. Frankenberger, Jr. 1999. Bacterial reduction of perchlorate and nitrate in groundwater, in Journal of Environmental Quality 28:1018-1024.

Herman, D.C. and W.T. Frankenberger, Jr. 1998. Microbial-mediated reduction of perchlorate in groundwater, in Journal of Environmental Quality 27:750-754.

Research Summary W-902 in Research Program Activities of Water Resources Center, University of California 1998-1999, available at http://waterresources.ucr.edu/publications/AR9899-copy%20(1).pdf.

GWRTAC ID:	PERC0039		
Project Name:	NASA/California Institute of Technology Jet Propulsion Laboratory, Ion Exchange Bed R		
City:	Pasadena	**State/Province:**	CA

Report(s)/Publication(s) (GWRTAC Source):

Executive Summary, Pilot Study conducted by Calgon Carbon Corporation at JPL, 1998-1999

Project Summary:

The following text was excerpted from Executive Summary, Pilot Study conducted by Calgon Carbon Corporation at JPL, 1998-1999:

A study funded by National Aeronautics and Space Administration (NASA) to demonstrate the removal of trichloroethylene (TCE), 1,2-dichloroethane (DCA), carbon tetrachloride (CCl4) and perchlorate (ClO4-) from groundwater at Jet Propulsion Laboratory (JPL) has recently been completed by Calgon Carbon Corporation. Calgon Carbon successfully utilized its integrated granular activated carbon (GAC) and ISEP+TM treatment systems for the removal of the contaminants from ground water during the study conducted between September 15, 1998 – March 5, 1999. Results indicated that the organic contaminants were reduced to low levels and perchlorate in various inlet concentration levels (up to about 1200 ppb) was removed to non-detectable levels (<4 ppb) in treated water. In addition, the system was successful in removing other anionic species such as nitrate and sulfate from the groundwater to low levels in treated water, while producing minimal amounts of regeneration waste.

The integrated ISEP+TM system (comprising continuous ion exchange system (ISEP® and perchlorate and nitrate destruction module (PNDM) was successfully demonstrated for about 10 days. Perchlorate and nitrate present in regeneration waste from ISEP® were destroyed and substantial amounts of sulfate (exceeding 96%) was removed in the PNDM. The regenerant (brine), thus “purified” in the PNDM, was recycled and was effective in regenerating the resin for the period of the study. The overall process waste from the integrated ISEP+TM system for treating up to about 1200 ppb perchlorate was about 0.16%, based on the volume of feed water. Over one-half of a million gallons of ground water at the JPL site was successfully treated to produce a high quality water with non-detectable TCE, DCA and CCL4 concentrations, non-detectable perchlorate (< 4 ppb), low nitrate (<2 ppm) and sulfate (<2 ppm) concentrations.

Testing at various process conditions enabled Calgon Carbon to optimize each of the process units of the ISEP+TM system and confirm steady-state operation. Sufficient operating data were obtained from this pilot study to design full-scale ISEP® system and to further develop the ISEP+TM integrated system for the complex treatment needs of JPL and other sites.

Report(s)/Publication(s) (Additional Info Source):

Executive Summary, Pilot Study conducted by Calgon Carbon Corporation at JPL, 1998-1999

Wagner, Norman, and Charles Drewry, 2000. “Commercial Systems Treating both High and Low Strength Perchlorate Applications Utilizing Ion Exchange” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas

GWRTAC ID:	PERC0040		
Project Name:	Calgon Carbon Corp. Ion Exchange Bed Regeneration / Umpqua Ion Exchange Bed Reg		
City:	Pittsburgh	**State/Province:**	PA

Report(s)/Publication(s) (GWRTAC Source):

“SBIR Success at Marshall”, in Aerospace Technology Innovation, Vol. 7, No. 4, July/August 1999, Small Business/SBIR, available at http://nctn.hq.nasa.gov/innovation/Innovation74/sbir.htm

Project Summary:

The following text was excerpted from “SBIR Success at Marshall”, in Aerospace Technology Innovation, Vol. 7, No. 4, July/August 1999, Small Business/SBIR, available at http://nctn.hq.nasa.gov/innovation/Innovation74/sbir.htm:

An effective catalytic oxidation system to remove contaminants during long-term manned space missions has reached its primary SBIR Phase II goal and is being marketed to the private sector. A contract between Marshall Space Flight Center and Umpqua Research Company in Myrtle Creek, Oregon, originally focused on the stringent water quality requirements of long-term manned space flight, with the manufacture of light hardware as the primary Phase II goal. The main focus for near-term commercialization is the International Space Station. Continued sales are expected for long-term missions to the Moon and Mars.

The U.S. Air Force has also funded the technology for the destruction of environmental contaminants associated with aviation fuel, solvents, soluble propellant and munitions byproducts. The National Science Foundation has supported the effort for phenol, trichlorethylene, methylene blue and benzene contaminants.

The energy-efficient operation of the catalytic oxidation system offers excellent heat recovery, with contaminant destruction depending primarily on operation temperature and catalyst contact time. It destroys most waterborne organic compounds. Soluble alcohols, ketones, amides, amines, aromatics and halocarbon levels have been oxidized using dissolved elemental oxygen to form carbon dioxide, water and constituent inorganic species. At the same time, the system has the capability to eliminate such inorganic contaminants as nitrite.

Calgon Carbon Corporation has signed an exclusive license for use of the Umpqua Research Company developed catalytic oxidation system technology in treating perchlorate-containing brines that have resulted from the regeneration of ion-exchange beds used to remove perchlorate from groundwater. An initial pilot scale test is in progress at NASA's Jet Propulsion Laboratory. Additional Phase III development work will be funded by Calgon to reduce catalysts' costs and to minimize the formation of unwanted reaction byproducts.

Report(s)/Publication(s) (Additional Info Source):

“SBIR Success at Marshall”, in Aerospace Technology Innovation, Vol. 7, No. 4, July/August 1999, Small Business/SBIR, available at http://nctn.hq.nasa.gov/innovation/Innovation74/sbir.htm

GWRTAC ID: PERC0041

Project Name: Bifunctional Anion Exchange Resin Pilot

City: Edwards AFB **State/Province:** CA

Report(s)/Publication(s) (GWRTAC Source):

Gu, Baohua, and G.M. Brown, 2000, “Efficient Removal of Perchlorate (ClO4-) From Contaminated Water by Highly Selective, Regenerable Bifunctional Resins” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excerpted from Gu, Baohua, and G.M. Brown, 2000, “Efficient Removal of Perchlorate (ClO4-) From Contaminated Water by Highly Selective, Regenerable Bifunctional Resins” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

The Oak Ridge National Laboratory (ORNL) and University of Tennessee have recently developed a new class of bifunctional anion exchange resins (U.S. patent # 6,059,975), which are highly selective for sorption of ClO4- from contaminated groundwater or surface water. The bifunctional anion exchange resins were initially developed under DOE sponsorship for pertechnetate (TcO4-) removal at ppt levels. Perchlorate behaves similarly to pertechnetate, as both are large, poorly hydrated anions. The bifunctional resins consist of quaternary ammonium groups with both large (C6) and small (C2) alkyl groups resulting in high selectivity and good exchange kinetics.

The field study utilized a flow rate of 2 bed volumes per minute, and influent perchlorate concentrations of about 50 ppb. The chemistry of the groundwater used in the field study was as follows: 7 mg/L chlorine, 0 mg/L fluorine, 61.2 mg/L nitrate, 14.9 mg/L sulfate, 98.6 mg/L bicarbonate, ~50 ug/L perchlorate, and pH 6.9. The bifuntional resin tested was D-3696, with trihexylamine/triethylamine functional groups, which is the Purolite International, Inc. scale-up version of the bifunctional resin synthesized at the University of Tennessee. The small-scale field experiment demonstrated that the bifunctional resin was able to treat ~110,000 bed volumes of groundwater in about 40 days before a 10% breakthrough of ClO4- occurred (running at ~2 bed volumes per minute with an initial ClO4- concentration of ~50 ug/L). The bifunctional resins are particularly effective in removing trace quantities of ClO4- in groundwater to below the detection limit (~3 ug/L). No pretreatment is needed to remove either dissolved organic matter or other competing anions (such as Cl-, SO42-, HCO3-, or NO3-), which may be present at 3-5 orders of magnitude higher than that of ClO4- in the groundwater or surface water. The treatment process does not involve addition or removal of unwanted organic or inorganic components in the water because of the high selectivity of the bifunctional resins.

Additionally, a new regeneration technology (U.S. patent pending, 09/491,242) has been developed at ORNL so that these anion-exchange resins can be used repeatedly over a long-term operation. The regeneration process uses tetrachloroferrate (FeCl4-), is cost-effective and generates minimal amounts of secondary wastes. No decrease in resin performance after seven cycles of perchlorate loading and regeneration were noted, on tests with the D-3696 resin column (10 x 22 mm), with 17 BV/minute flow, and 10 mg/L initial perchlorate concentration. Therefore, the new resin and new regeneration technology offer a promising solution to remediate the ClO4— contaminated groundwater or surface water by using either the conventional pump-and-treat or the funnel-and-gate treatment configurations (with regenerable treatment systems).

Report(s)/Publication(s) (Additional Info Source):

Gu, Baohua, and G.M. Brown, 2000, “Efficient Removal of Perchlorate (ClO4-) From Contaminated Water by Highly Selective, Regenerable Bifunctional Resins” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August

21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID: PERC0042

Project Name: In Situ Bioreduction and Removal of Ammonium Perchlorate (SERDP #CU-1162)

City: Carbondale **State/Province:** IL

Report(s)/Publication(s) (GWRTAC Source):

Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org

Project Summary:

The following text was excerpted from Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org:

The objectives of this project will be addressed under the following hypotheses: (1) perchlorate-reducing bacteria are ubiquitous and indigenous to perchlorate-contaminated environments; (2) all perchlorate-reducing bacteria contain a conserved chlorite dismutase enzyme; (3) indigenous microbial perchlorate reduction can be stimulated in contaminated environments easily; (4) the stimulated perchlorate reducing population can remove perchlorate concentrations to levels significantly lower than 18 ug/L; (5) the rate of microbial perchlorate reduction will be affected by environmental conditions; (6) the stimulated perchlorate-reducing population also will enhance biodegradation of co-contaminating organics.

This project will provide a better understanding of the microbiology involved in microbial perchlorate reduction and removal. The factors controlling the applicability of these microorganisms to the in-situ treatment of ammonium perchlorate contamination of natural water supplies will be determined. In addition, this work will assist in the development of protocols and molecular tools required for the modeling and application of in-situ bioremediation strategies to treat perchlorate contamination in the environment.

Results from these studies will provide a better understanding of the microbiology involved in perchlorate reduction ad the factors controlling the activity of these organisms. These studies also will allow for the development of a molecular probe that will be specific for all perchlorate-reducing bacteria. Such a probe could be used for predictive determinations of the success of a biological in-situ treatment process and also as a monitoring tool for intrinsic or enhanced bioremediative efforts. Finally, this study will identify the potential of a stimulated perchlorate-reducing population.

Report(s)/Publication(s) (Additional Info Source):

Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org

GWRTAC ID: PERC0043

Project Name: In Situ Bioremediation of Perchlorate-Impacted Groundwater (SERDP #CU-1164)

City: Guelph **State/Province:** ON

Report(s)/Publication(s) (GWRTAC Source):

Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org

Cox, Evan, 2000. Abstract from Technical Session 2B and Poster 118 in “Environmental Challenges for the Next Decade”, Partners in Environmental Technology Technical Symposium & Workshop, Hyatt Regency, Crystal City, Arlington, Virginia, November 28-30, 2000

Project Summary:

The following text was excerpted from Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org;
Cox, Evan, 2000. Abstract from Technical Session 2B and Poster 118 in “Environmental Challenges for the Next Decade”, Partners in Environmental Technology Technical Symposium & Workshop, Hyatt Regency, Crystal City, Arlington, Virginia, November 28-30, 2000; and,
Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

This research program consists of (1) laboratory microcosm studies to evaluate the ubiquity of perchlorate-degrading bacteria in groundwater at a variety of impacted Department of Defense (DoD), Department of Energy (DOE), and defense contractor facilities and to assess the applicability of in-situ bioremediation as a remedial technology in a variety of geochemical environments followed by (2) small-scale field pilot testing at one of the test sites to demonstrate that perchlorate can be biodegraded under field conditions and to generate initial design and cost data for potential technology scale-up and validation.

Groundwater contamination related to the production, handling, and use of rocket propellants such as ammonium perchlorate has been identified as a widespread problem at DoD, DOE, and defense contractor facilities. Few cost-effective technologies exist for the treatment of perchlorate-contaminated groundwater. Of the technologies being evaluated, in-situ bioremediation is among the most promising because it has the potential to destroy perchlorate in place rather than transferring perchlorate to another waste stream (e.g., impacted resin or brine) requiring treatment or disposal. Ex situ bioreactors are currently being used at several sites to control the expansion of perchlorate groundwater plumes. While these systems are effective in their roles, they do little to address the long-term source areas that are driving the perchlorate plumes. By comparison, in situ bioremediation systems are proving to be cost-effective alternatives for destroying perchlorate source areas in soil and groundwater. The key benefit of destroying these source areas is reduced duration and cost of remediation of perchlorate-impacted sites. The product of this research will be the development of a robust, reliable, and cost-effective treatment technology for perchlorate-impacted groundwater. This is an FY 2000 New Start project.

The SERDP research goals include the following:

Evaluate the ubiquity of perchlorate biodegraders and the applicability of in situ bioremediation
Assess geochemical tolerance ranges, including concentration, pH, salinity, competing electron acceptors

(nitrate, sulfate)
Assess treatment of mixed plumes (TCE, BTEX, NDMA)
Demonstrate in situ bioremediation in the field

Task 1 - Site Screening, involved 1) Laboratory microcosm testing using soil and groundwater from geochemically different sites; 2) Assessment of the level of intrinsic degradation; 3) Evaluation of the potential to enhance biodegradation through addition of various electron donors (acetate, molasses, oleate, edible oils); 4) Identification of sites for further lab/field pilot testing.

The six SERDP test sites include 1) Edwards Air Force Base, California; 2) A DoD Site, West Virginia; 3) Rocket Manufacturer, California; 4) Aerojet Superfund Site, California; 5) U.S. Navy, California; and 6) Industrial Site, Nevada.

Some pertinent information and site characteristics of the SERDP test sites are presented below.

1) Edwards Air Force Base, California - A rocket manufacturing site, underlain by alluvial deposits to over 250 feet bgs, with the water table located approximately 125 feet bgs. Groundwater chemistry consists of the following: perchlorate up to 160 mg/L; nitrate = 1 mg/L; sulfate = 180 mg/L; oxygen = 2 mg/L; redox potential = +200 mV; chloride = 360 mg/L; and pH = 6.2. Intrinsic biodegradation, and enhanced biodegradation through addition of electron donors acetate, molasses, and oleate, were evaluated in triplicate microcosms. Perchlorate concentrations were reduced from about 100 mg/L to below the MDL of 0.05 mg/L in about 17 days with addition of molasses, and in about 21 days with addition of acetate. Oleate was not very effective in accelerating biodegradation of perchlorate at a rate higher than the active control.

2) A DoD Site, West Virginia - This site is underlain by 20 feet of sandy silt alluvium over fractured bedrock, with the water table located approximately 15 feet bgs. Groundwater chemistry consists of the following: perchlorate = approximately 10 mg/L; nitrate = 4 mg/L; sulfate = 55 mg/L; redox potential = 285 mV; chloride = 25 mg/L; and pH = 6.7. Intrinsic biodegradation, and enhanced biodegradation through addition of electron donors acetate and molasses were evaluated in triplicate microcosms. Perchlorate concentrations were reduced from about 10 mg/L to below the MDL of 0.05 mg/L in about 4 days with addition of both acetate and molasses. Intrinsic biodegradation during this time was nearly negligible.

3) Rocket Manufacturer, California - An active perchlorate grinder station underlain by silts to fine sands, with the water table located approximately 15 feet bgs. Groundwater chemistry consists of the following: perchlorate up to 1,200 mg/L; nitrate = 2 mg/L; sulfate = 75 mg/L; redox potential = -10 mV; VOCs (TCE, TCA) also are present. Intrinsic biodegradation, and enhanced biodegradation through addition of an electron donor treatment were evaluated. From a starting concentration of about 7,000 ug/L, the electron donor succeeded in reducting the perchlorate concentration to nearly 0 ug/L after 20 days. At this time, perchlorate was re-spiked to a concentration of nearly 80,000 ug/L; a molasses electron donor was re-spiked at day 28, and perchlorate again was reduced to nearly 0 ug/L by after approximately 32 days of incubation. During this time, the sterile control and the active control stayed constant.

4) Aerojet Superfund Site, California- The site is underlain by an alluvial aquifer consisting of interbedded silts, sands, and gravel, with the water table present at 20 feet bgs. Groundwater chemistry consists of the following: perchlorate = 15 mg/L; nitrate = 5 mg/L; sulfate = 10 mg/L; oxygen = 4 mg/L; redox potential = +200 mV; TCE = 3 mg/L; and pH = 6.8. Lab studies revealed that perchlorate was degraded from its initial concentration of about 20,000 ug/L to <10 ug/L in about 22 days using both molasses and CMA treatment as electron donors. It was also shown that electron donors alone (molasses or food waste) would not degrade the TCE beyond cis-DCE; bioaugmentation by KB-1 was also needed to complete the reductive dehalogenation process. This site was selected for the in situ bioremediation field demonstration, which is discussed as a separate project.

Significant laboratory and/or field demonstrations have shown the applicability of bioremediation approaches for the remediation of perchlorate source areas in soil and groundwater. For example, we have successfully demonstrated the use of simple anaerobic composting techniques to remediate shallow impacted soils at several rocket manufacturing sites in California to prevent continuing perchlorate impacts to groundwater (via infiltration) and surface water (via overland flow). In groundwater studies, we have consistently (over multiple sites) demonstrated the biodegradation of perchlorate from concentrations up to 500,000 mg/L to concentrations that comply with the provisional action level (PAL) of 18 mg/L. The process is rapid (perchlorate degradation half-lives at six different sites have ranged from 1 to 5 days), robust, and can be accomplished using a variety of different electron donors including alcohols, volatile fatty acids and sugars. As an added benefit, recent studies have demonstrated that ability to jointly biodegrade perchlorate and chlorinated solvents such as tetrachloroethene (PCE) and trichloroethene (TCE), which are common co-contaminants at DoD and propulsion contractor facilities.

Report(s)/Publication(s) (Additional Info Source):

Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org

Cox, Evan, 2000. Abstract from Technical Session 2B and Poster 118 in “Environmental Challenges for the Next Decade”, Partners in Environmental Technology Technical Symposium & Workshop, Hyatt Regency, Crystal City, Arlington, Virginia, November 28-30, 2000

GWRTAC ID:	PERC0044
Project Name:	Mechanistic Chemistry of Transition Metal Oxygen and Oxo Complexes (NSF #9982004)

City:	Ames	**State/Province:**	IA

Report(s)/Publication(s) (GWRTAC Source):

NSF Award Abstract - #9982004, 2000. "Mechanistic Chemistry of Transition Metal Oxygen and Oxo Complexes", available at https://www.fastlane.nsf.gov/servlet/showaward?award=9982004

Project Summary:

The following text was excerpted from NSF Award Abstract - #9982004, 2000. "Mechanistic Chemistry of Transition Metal Oxygen and Oxo Complexes", available at https://www.fastlane.nsf.gov/servlet/showaward?award=9982004:

Dr. James Espenson and Dr. Andreja Bakac of Iowa State University are supported by the Inorganic, Bioinorganic, and Organometallic Chemistry program for a program of research dealing with the mechanisms of processes in which a single oxygen atom (or equivalent fragment) is transferred from one atom to another during chemical processes. Several classes of such reactions will be studied. One of these is the catalysis of reductions of perchlorate ion by anions such as molybdate. The reactivity of nitric oxide (NO) with superoxo metal complexes and metal ions and related reactions will be explored. The research will also extend to the transfer of fragments that resemble oxygen (such as sulfur) and groups such as NR and CR2 that are isoelectronic with oxygen.
Many chemical reactions that are of major practical significance involve movement of an oxygen atom originally attached to one molecule to another location, where that atom is attached to a quite different molecule. Other chemical entities (sulfur atoms, small organic fragments) participate in chemical changes that are quite similar, in important respects, to these simple atom-transfer processes. Drs. Espenson and Bakac will investigate several systems that hold promise of greatly extending understanding of the fundamental principles that govern atom-transfer reactions. At least two of these systems are also of major and immediate practical interest. Contamination by perchlorate ion is an emerging environmental hazard in many parts of the United States. Reduction by atom transfer is the best way to destroy perchlorate ion. Nitric oxide (NO) is known to be an important signaling agent within biological organisms. The functioning of this species is greatly influenced by atom transfer processes. Fundamental understanding sought in this research will bear on these and other important processes.

Report(s)/Publication(s) (Additional Info Source):

NSF Award Abstract - #9982004, 2000. "Mechanistic Chemistry of Transition Metal Oxygen and Oxo Complexes", available at https://www.fastlane.nsf.gov/servlet/showaward?award=9982004

GWRTAC ID:	PERC0045
Project Name:	Phytoremediation By Native Saltcedar, Las Vegas, Nevada

City: Las Vegas **State/Province:** NV

Report(s)/Publication(s) (GWRTAC Source):

Raloff, J. "Living Routes to Toxic Routs" in Science News Online, July 29, 2000, available at http://www.sciencenews.org/20000729/note5.asp.

Project Summary:

The following text was excerpted from Raloff, J. "Living Routes to Toxic Routs" in Science News Online, July 29, 2000, available at http://www.sciencenews.org/20000729/note5.asp:

Last fall, the federal government ruled that by 2001, community water suppliers must begin monitoring perchlorate. Utilities are now investigating how they might deal with this toxic mineral salt if it shows up in drinking-water sources.

A paper in the July 10 Science of the Total Environment suggests planting salt cedar (Tamarix ramosissima)—or tamarisk—along affected waterways. These shrubby trees mine salt from the water about them. Among the salts they sop up is perchlorate, finds Edward T. Urbansky's team at the Environmental Protection Agency's research lab in Cincinnati. Stalks of the plant submerged in the Las Vegas Wash, a stream near Las Vegas, picked up 300 micrograms of perchlorate per gram of tissue. Even dry twigs growing well above the water acquired 5 mg/g. Ironically, the federal government considers salt cedar—an invasive Asian native—to be a nuisance plant warranting removal. However, having had more than a century to put down U.S. roots throughout the arid West, where perchlorate contamination is common, "salt cedar must now be regarded as a major part of [that] ecosystem," Urbansky and his colleagues say. Instead of targeting the plant for removal, they suggest it be explored as a trap for the toxic agent.

Report(s)/Publication(s) (Additional Info Source):

Raloff, J. "Living Routes to Toxic Routs" in Science News Online, July 29, 2000, available at http://www.sciencenews.org/20000729/note5.asp.

Additional information about saltcedar provided by the Alien Plant Working Group is available at http://www.nps.gov/plants/alien/fact/tama1.htm.

Urbansky, E.T., et al. 2000. Perchlorate uptake by salt cedar (Tamarix ramosissima) in the Las Vegas Wash riparian ecosystem. Science of the Total Environment (July).

GWRTAC ID:	PERC0046		
Project Name:	Biological Treatment at Low Concentrations in Water - Phase 1		
City:	San Gabriel	**State/Province:**	CA

Report(s)/Publication(s) (GWRTAC Source):

Catts, John J., 1998. “Biological Treatment of Perchlorate at Low Concentrations in Water” Presentation from Perchlorate Stakeholder's Forum, held May 19-21, 1998, Henderson, Nevada, available at http://www.epa.gov/safewater/ccl/perchlor/tab2.html.

Project Summary:

The following text was excerpted from Catts, John J., 1998. “Biological Treatment of Perchlorate at Low Concentrations in Water” Presentation from Perchlorate Stakeholder's Forum, held May 19-21, 1998, Henderson, Nevada, available at http://www.epa.gov/safewater/ccl/perchlor/tab2.html:

Treatability studies were conducted to evaluate treatment of water containing 50 to 100 ug/L perchlorate and 4 to 6 mg/L nitrate to determine whether perchlorate effluent concentrations of 18 ug/L or lower can be achieved. The treatment technology evaluated was an attached-growth fluidized bed bioreactor (FBR), with granular activated carbon (GAC) media. Nutrient (N and P) and organic substrate (ethanol) addition via feed systems are an integral part of the treatment system. Testing took place in December 1997 through mid March 1998. Perchlorate destruction versus influent dissolved oxygen, dissolved oxygen, nitrate, and ethanol reactor profiles, and phosphorous concentrations were closely examined. Conclusions were that the FBR technology can treat low concentrations of perchlorate; treated water contained <4 ug/L perchlorate and <0.1 mg/L nitrate; alternative microorganisms can be utilized; and the effluent could be rendered potable after disinfection and filtration. Additional conclusions were that there was an observed preference for nitrate; the ethanol substrate was not detected in produced water; only minimum phosphorous is required; dissolved oxygen and redox potential can be used as operational controls; the retention time can be adjusted by equipment configuration and recycle, and no VOC reduction products were detected.

Report(s)/Publication(s) (Additional Info Source):

Catts, John J., 1998. “Biological Treatment of Perchlorate at Low Concentrations in Water” Presentation from Perchlorate Stakeholder's Forum, held May 19-21, 1998, Henderson, Nevada, available at http://www.epa.gov/safewater/ccl/perchlor/tab2.html.

GWRTAC ID:	PERC0047		
Project Name:	Biological Treatment at Low Concentrations in Water - Phase 2		
City:	La Puente	***State/Province:***	CA

Report(s)/Publication(s) (GWRTAC Source):

Catts, John J., 1998. “Biological Treatment of Perchlorate at Low Concentrations in Water” Presentation from Perchlorate Stakeholder's Forum, held May 19-21, 1998, Henderson, Nevada, available at http://www.epa.gov/safewater/ccl/perchlor/tab2.html.

Project Summary:

The following text was excerpted from Catts, John J., 1998. “Biological Treatment of Perchlorate at Low Concentrations in Water” Presentation from Perchlorate Stakeholder's Forum, held May 19-21, 1998, Henderson, Nevada, available at http://www.epa.gov/safewater/ccl/perchlor/tab2.html:

Treatability studies were conducted to evaluate treatment of water containing 50 to 100 ug/L perchlorate and 4 to 6 mg/L nitrate to determine whether perchlorate effluent concentrations of 18 ug/L or lower can be achieved. The treatment technology evaluated was an attached-growth fluidized bed bioreactor (FBR), with granular activated carbon (GAC) media. Nutrient (N and P) and organic substrate (ethanol) addition via feed systems are an integral part of the treatment system. Testing took place in December 1997 through mid March 1998. Perchlorate destruction versus influent dissolved oxygen, dissolved oxygen, nitrate, and ethanol reactor profiles, and phosphorous concentrations were closely examined. Conclusions were that the FBR technology can treat low concentrations of perchlorate; treated water contained <4 ug/L perchlorate and <0.1 mg/L nitrate; alternative microorganisms can be utilized; and the effluent could be rendered potable after disinfection and filtration. Additional conclusions were that there was an observed preference for nitrate; the ethanol substrate was not detected in produced water; only minimum phosphorous is required; dissolved oxygen and redox potential can be used as operational controls; the retention time can be adjusted by equipment configuration and recycle, and no VOC reduction products were detected.

A Phase 2 treatability study was planned to collect engineering data for scale up to flow rates of between 500 and 1,000 gpm. Addition of disinfection and filtration treatment train aspects was planned, and startup was planned for 1999.

Report(s)/Publication(s) (Additional Info Source):

Catts, John J., 1998. “Biological Treatment of Perchlorate at Low Concentrations in Water” Presentation from Perchlorate Stakeholder's Forum, held May 19-21, 1998, Henderson, Nevada, available at http://www.epa.gov/safewater/ccl/perchlor/tab2.html.

GWRTAC ID:	PERC0048		
Project Name:	Full-Scale ISEP(R) Groundwater Treatment Plant		
City:	La Puente	**State/Province:**	CA

Report(s)/Publication(s) (GWRTAC Source):

Calgon Carbon Corporation, Pittsburgh, Pennsylvania, Project Summary Information, December 2000

Project Summary:

The following text was excerpted from Calgon Carbon Corporation, Pittsburgh, Pennsylvania, Project Summary Information, December 2000;
July 11, 1999 Press Release, available at http://www.findarticles.com, and
Wagner, Norman, and Charles Drewry, 2000. “Commercial Systems Treating both High and Low Strength Perchlorate Applications Utilizing Ion Exchange” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

Calgon Carbon Corporation announced on July 11, 1999, that it had been awarded a contract from the La Puente Valley County Water District in Southern California to supply the first commercial ISEP® system to remove perchlorate and to provide a Rayox(R) Tower to destroy N-nitrosodimethylamine (NDMA) in water from three of its wells. The wells have been shut down since 1997, when the contaminants were first detected. The contract is valued at over $3.0 million. Partial funding for the project will be provided by grants from the Main San Gabriel Basin Watermaster, the San Gabriel Basin Water Quality Authority, and the Upper San Gabriel Valley Municipal Water District.

The ISEP system utilizes Calgon Carbon's patented continuous ion exchange contactor which removes the perchlorate from drinking water. The Rayox Tower employs Calgon Carbon's proprietary, medium-pressure, ultraviolet (UV) lamps to destroy NDMA on-site. The two systems will treat approximately 2,500 gallons of water per minute. The ISEP will reduce the concentration of perchlorate from 200 parts per billion (ppb) to less than 5 ppb, while the Rayox Tower will reduce the NDMA from 900 parts per trillion (ppt) to less than 5 ppt.

Perchlorate, which prevents proper functioning of the thyroid gland, is a component of rocket fuels, fireworks, and explosives. NDMA, a suspected carcinogen, is a by-product of liquid rocket fuel combustion and has been found as a by-product in the manufacture of rubber products and certain chemical intermediates. Improved analytical testing methods in recent years have permitted the detection of the contaminants in low concentrations in drinking water.
Calgon Carbon has been utilizing its UV technology to treat NDMA since 1991. However, no method for removing perchlorate from drinking water had been demonstrated until the ISEP successfully removed perchlorate in trials at two separate sites in the Greater Los Angeles Area last year. The La Puente installation will be the world's first commercial application of the ISEP to remove perchlorate from drinking water. In addition to removing perchlorate and NDMA, the Calgon Carbon systems will also reduce nitrates and sulfates in the treated water.

This report presents the results for the on-site testing of Calgon Carbon Corporation’s (CCC) ISEP and Rayox UV/Oxidation processes for treatment of drinking water containing perchlorate, NDMA and 1,4-dioxane. The testing plan was formulated to provide supporting data for a treatment permit from California Department of Health Services (DHS) for the La Puente Valley County Water District treatment plant at 1695 Puente Avenue in Baldwin Park, California. The on-site tests were performed in phases. First, the ISEP system was tested to determine optimal operating brine rates. Second, at the minimal safe brine-operating rate, the Rayox system was tested to evaluate treatment efficiency and performance. Finally, both systems were studied to observe the effects of lower flow rates. During all phases, water quality parameters were measured to ensure they met DHS requirements.

The objectives of this test were:

? Assess the performance of the ISEP and Rayox UV/Oxidation processes under full operating conditions.
? Determine the treatment requirements for perchlorate, nitrate, and sulfate removal in the ISEP process and the destruction of NDMA and 1,4-dioxane in the Rayox UV/Oxidation process.
? Recommend final operating conditions to ensure treatment to specifications at all times under varying water quality conditions.

The results of the testing have shown that:

? Perchlorate can be removed to non-detect (ND) levels at full flow conditions at a waste brine rate of 0.85%.
? Sulfate removal to ND levels and nitrate removal to < 1.0 mg/l is also obtained at the 0.85% waste brine rate.
? Volatile organics were completely removed by the existing treatment plant air stripers installed upstream of the CCC processes.
? Due to the longer path length of the Rayox tower, the electrical energy per order (EE/O) for the Rayox UV/Oxidation process obtained in this test was less than 0.4, which is lower than the design EE/O of 1.8.
? 1,4-dioxane influent levels were non-detect during the test period so no treatment data was obtained for this compound. Based on previous experience and a list of treatment efficiencies in Section 7.2, the expected EE/O should be 1.3. Therefore, 1,4-dioxane levels up to 4 ppb would be treated to below 0.5 ppb with 8 lamps operating at a peroxide level of 3 ppm.
? Operation of 8 lamps total in both Rayox towers at an average power consumption of 20 kVA per lamp was sufficient to reduce the NDMA to < 2 ppt in the treated water.

Based on a review of the data obtained during the testing, the following recommendations are made for ongoing operation of the treatment plant at full-scale flow conditions under varying water quality conditions that will ensure removal of the contaminants to specified levels.

? The minimum waste brine rate to remove perchlorate to ND was 0.8%. For long term operation of the ISEP a waste brine rate of 0.90% based on a flow set point of 2,500 gpm is recommended. The actual waste brine rate at a well flow rate of 2,300 gpm would be 0.97% at this setting. This setting would be capable of treating perchlorate levels in the feed up to 100 ug/l at the typical nitrate and sulfate levels obtained during the testing.

? NDMA removal to < 2 ppt was obtained when operating 8 lamps at the well flow rate of 2,300 gpm. Operating with 12 lamps at an average power consumption of 20 kVA per lamp is recommended to achieve treatment of NDMA to < 2 ppt over the duration of the operating life of the lamps.

? Hydrogen peroxide should be added at the rate of 2 to 3 ppm to ensure removal of 1,4-dioxane should it be detected in the raw water.

The maximum treatment capacity of the system is estimated to be in excess of 600 ug/l for perchlorate and 3,000 ppt for NDMA. Increasing the brine use rate in the ISEP and operating additional lamps in the Rayox towers can realize these treatment conditions. Significantly higher levels of perchlorate could be treated by making modifications to the brine addition equipment to increase the brine flow rate above the current design. Periodic sampling of the well and the treated water should be done to make adjustments in the operating conditions as required to meet the specifications for the treatment plant.

The La Puente Valley County Water District CCC ISEP System was commissioned in February 2000, and as of August 2000, operates 19 hours per day to control the perchlorate plume. The ISEP system was accepted by the California Department of Health Services for perchlorate and nitrate drinking water applications. An emergency use permit was approved, and the operating permit is currently under review by California Department of Health Services – Metropolitan District. As of March 31, 2000, the actual capital costs associated with the system were $4,070,041. The engineering and permits for the California Department of Health Services testing were $882,608, for a total of $4,952,649. The actual operating costs for the system totaled $227.66/AF, including wells, air strippers, booster, ISEP, brine disposal, Rayox, peroxide, and maintenance and labor.

Report(s)/Publication(s) (Additional Info Source):

Calgon Carbon Corporation July 11, 1999 Press Release, available at http://www.findarticles.com

Sase, Richard K., 2000. "Perchlorate Treatment Technology Fast Track to a Solution" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas

Wagner, Norman, and Charles Drewry, 2000. "Commercial Systems Treating both High and Low Strength Perchlorate Applications Utilizing Ion Exchange" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas

---

GWRTAC ID: PERC0049

Project Name: Thermal Regeneration of Ion Exchange Brine

City: Panama City ***State/Province:*** FL

Report(s)/Publication(s) (GWRTAC Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Project Summary:

The following text was excerpted from project summary information supplied by Applied Research Associates, Inc., (ARA), Panama City, FL, November 2000:

ARA developed an Integrated Thermal Treatment Process that can regenerate the salt brine effluent from ion exchange processes. The spent brine used to regenerate the ion exchange resin can be less than 1% of the volume of the treated groundwater. In this process brine is concentrated and nitrate and sulfate salts are destroyed/rejected from the brine in effluent streams, while the perchlorate is thermally destroyed, effectively regenerating the brine. The regenerated brine can then be recycled for reuse in the ion exchange process, greatly reducing the costs associated with spent brine disposal and salt replacement. While some NaCl loss in the effluent streams is inevitable, the effluent volume will only be 1-5% of the original brine. Therefore, brine disposal and replacement costs can be reduced 95-99%. An economic evaluation that included capital equipment cost, energy cost, and maintenance, showed that a 30% return on investment could be achieved based on a brine disposal and replacement cost equal to $100 per 1000 gallons of spent brine.

Report(s)/Publication(s) (Additional Info Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

GWRTAC ID:	PERC0050
Project Name:	Low Temperature Biodegradation Studies

City: Panama City ***State/Province:*** FL

Report(s)/Publication(s) (GWRTAC Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Project Summary:

The following text was excerpted from project summary information supplied by Applied Research Associates, Inc., (ARA), Panama City, November 2000:

Several studies were conducted on the ARA suspended-growth, anoxic process to determine performance at near groundwater temperatures. The ability to perform at low temperatures would greatly reduce operating costs by reducing the need for supplemental heating. Perchlorate biodegradation has been demonstrated at 10oC, and lower at temperatures, in batch studies. Initial flow reactor studies demonstrated that perchlorate in groundwater was reduced from 650+ ppm to non-detect by the ARA process operated at 17-17.5oC and an 8-hour hydraulic residence time (HRT). At 15oC, perchlorate was not completely reduced in this water at an 8 hour HRT, but was reduced to less than 10 ppm. However, perchlorate in another groundwater sample was reduced from 300 ppm to non-detect at 15oC and an 8-hour HRT. There appears to be no temperature limitation for the ARA biodegradation process as long as residence time and nutrient can be adjusted to the feed composition as appropriate.

Report(s)/Publication(s) (Additional Info Source):

Applied Research Associates, Inc., (ARA) 215 Harrison Avenue, Panama City, FL 32401, Project Summary Information, November 2000

Coppola, Edward N., 2000, “Perchlorate Treatment Technologies: Biodegradation Prototype Thermal Decomposition” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID: PERC0051

Project Name: Treatability Studies for Perchlorate Treatment

City: Los Alamos **State/Province:** NM

Report(s)/Publication(s) (GWRTAC Source):

Worland, V. Peter, 2001: "Pilot Scale Tests to Remove Perchlorate from the RLWTF Effluent by Ion Exchange", FWO-WFM, January 30, 2001

Project Summary:

The following text was excerpted from Worland, V. Peter, 2001: "Pilot Scale Tests to Remove Perchlorate from the RLWTF Effluent by Ion Exchange", FWO-WFM, January 30, 2001:

Perchlorate is present in the influent to the Radioactive Liquid Waste Treatment Facility (RLWTF) at Los Alamos National Laboratory (LANL) at concentrations up to several thousand parts per billion (ppb). Perchlorate affects hormone production in the human thyroid and is a suspected, but not proven, carcinogen. The California Department of Health Services has issued a health advisory limit of 18 ppb for perchlorate in drinking water.

Pilot tests to remove perchlorate from the RLWTF effluent are being conducted. This report describes the results from ion exchange tests performed to remove perchlorate from the current RLWTF effluent. Testing began on September 6, 2000, and continuted through publication date of January 2001.

Perchloric acid is the major source of perchlorate ion in the RLWTF influent. This acid is used in analytical chemistry labs and for metal dissolution. Influent perchlorate concentrations to the RLWTF range from several 100 to several 1,000 ppb. The range of perchlorate concentration in the Raw Weekly Composite (RWC) to the RLWTF was found to range from just over 3 mg/L (3,000 ppb) for the week ending August 20, 2000 to less than 0.1 mg/L (100 ppb) for the week ending November 12, 2000. If the reverse osmosis (RO) treatment unit is not used to produce effluent from the RLWTF, then effluent concentrations of perchlorate are essentially equal to the influent perchlorate concentrations. Even when the RO unit is used to make effluent, the RLWTF effluent normally exceeds 18 ppb health advisory limit for drinking water.

The RLWTF effluent is discharged to the environment into Mortandad Canyon via a National Pollutant Discharge Elimination System permitted outfall. Perchlorate concentrations in shallow groundwater monitoring wells (from one to forty feet below the surface) in Mortandad Canyon are found to be in the 80 to 220 ppb range. Perchlorate has been detected 646 feet below the floor of Mortandad Canyon in a perched groundwater zone at a concentration of 12 ppb. The upper surface of the regional groundwater aquifer is at a depth of 900 feet below the floor of Mortandad Canyon. No perchlorate contamination of the drinking water aquifer underlying Mortandad Canyon has been found. However, the potential for groundwater contamination of perchlorate in Mortandad Canyon due to RLWTF effluent does exist. (Perchlorate-contaminated groundwater at LANL is addressed in PERC0052).

Based upon suggestions from IX experts from US Filter, a Type I, strong base anion (SBA) exchange resin was selected for removal of perchlorate from the RLWTF effluent. The resin is USF A-464. It is a porous gel anion resin. The polymetric matrix is composed of styrene divinylbenzene activated with quaternary amines for strong base characteristics. Two 0.25 cubic foot resin vessels were obtained of this resin. The resin in one vessel had hydroxide as the exchangeable anion (OH-SBA), the exchangeable anion in the other vessel was chloride (CL-SBA). Each vessel is 15.25 centimeters (cm) in diameter and 38 cm in length.

Batch Pilot Tests

For the batch pilot tests, flow into each vessel was 2.5 liters/minute (lpm). The hydraulic loading rate was 3.4 gpm/ft2. The actual contact time of the water with the resin was 40 seconds. The RLWTF discharges a 5 lpm stream of effluent to the environment for 50 minutes per day; this stream was split between the two resin vessels, so that each received a 2.5 lpm stream for 50 minutes per day. A bed volume (BV) is the volume of space taken up by both the resin beads and the interstitial space between the resin beads. The empty BV of each vessel is 7.14 liters, thus 17.5 BV of water passed through each vessel per discharge. At the end of each discharge period, 500 ml samples were collected of the plant effluent (resin vessel influent) and the treated effluent frome each vessel. Use of the vessels was initiated on September 6, 2000, and the last samples analyzed were obtained on January 9, 2001. Thus nearly 1,100 BV (7,900 liters) of water have passed through each column in the time period, and 62 discharges were sampled and analyzed.

In the batch pilot tests, the concentration of perchlorate in the feed to the resin volumes varied dramatically, from 100 to 1,600 ppb, due to fluctuating perchlorate concentrations in the influent to the RLWTF, and depending upon whether or not the Reverse Osmosis (RO) is being operated after the tubular ultrafilter. Perchlorate was completely removed from 1,069 BV of the RLWTF plant effluent by both the chloride and hydroxide resins, which each contained 1.87 gallons of resin. The 1.87 gallons of resin thus removed perchlorate from 1,999 (1.87 x 1,069) gallons of RLWTF effluent. The perchlorate concentrations in the effluent from the two columns were generally at the detection limit of 4 ppb.

BVs to breakthrough of several anions was determined for each resin, and is given below.

Anions	CL-SBA	OH-SBA
Perchlorate	>1,069	>1,069
Sulfate	~250	~260
Nitrate	~200	~80
Chloride	-------	~80
Fluoride	~80	~80

Continuous Pilot Tests

For the continuous pilot tests, two additional IX columns were obtained to be run in a continuous mode. By operating the new columns in continuous mode, feeding 500 BVs per day, information on breakthrough and exhaustion of the columns could be obtained more quickly than in batch mode. For the continuous mode tests, feed to the columns was from the north or south 20,000 gallon steel effluent tanks. The columns were fed by a peristaltic pump at 2.5 lpm for the CL-SBA resin and at 1.0 lpm for the OH-SBA resin.

With this configuration, the CL-SBA resin was fed >4,000 BV in 15 days. Breakthrough of perchlorate (column effluent concentrations >18 ppb) was noted between 1,800 and 2,100 BVs), and complete exhaustion of the column with respect to perchlorate was noted at just over 4,000 BV. The influent perchlorate concentration to the resins had varied during the test. From BVs 400-700 and 1,200-1,500, the perchlorate concentration ranged from 80-120 ppb. During BVs 3,200-3,500, the perchlorate concentrations were 1,300 ppb. During the reamining period of CL-SBA operation, the perchlorate concentrations were in the 500-800 ppb range. Breakthrough observations of major anions revealed chloride C/C0 greater than 1.0 due to the desorption of the chloride anion by sulfates, nitrates, and perchlorates. Fluoride breakthrough occurred almost initially. Breakthrough of nitrate, sulfate and perchlorate was seen at 200, 800, and 2,000 BVs, respectively. At 4,000 BVs, nearly 14,000 mg perchlorate had been loaded onto the 0.25 cu. ft. or resin, or 56 gms perchlorate per cu. ft. resin.

For the OH-SBA continuous mode tests, the feed rate was reduced to 1.0 lpm to assess the kinetic rate of flow. Breakthrough of perchlorate occurred after feeding 1,750 BVs of RLWTF effluent. The average perchlorate feed concentration to the OH-SBA resin was greater than the continuous feed to thee Cl-SBA resin. Total exhaustion of the OH-SBA resin occurred at 3,400 BVs. Both breakthrough and exhaustion of not only perchlorate, but also sulfate and nitrate, occurred at lower BVs in the OH-SBA resin than in the Cl-SBA resin; this may be due to the higher levels of perchlorate, sulfate, and other anions in the feed concentration rather than the slower feed rate. For the OH-SBA test, 20,000 mg/0.25 cu. ft. of resin, or 80 gms perchlorate per cu. ft. of resin, was loaded onto the resin. Thus, higher perchlorate concentrations in the feed result in greater loadings of perchlorate onto the resin.

In summary, pilot tests indicate that both the CL-SBA and OH-SBA US Filter A-464 resins can remove 100% of the perchlorate ion over a feed volume of 1,700 bed volumes. Conservatively, additional perchlorate removal (50%) continues for another 1,700 bed volumes until the resin is exhausted with respect to perchlorate. Feed solutions to the columns were actual RLWTF effluent, containing 400 to 600 mg/L of other dissolved solids including the anions: sulfate, chloride, nitrate, bicarbonate, and fluoride. Applying conservative design principles for scale up, two columns operated in series could remove 100% of the perchlorate from 5,100 BV of RLWTF feed, using the first column as a "roughing" column and the second column as a "polishing" column, and rotating the polishing column into the roughing column mode upon breakthrough in the original roughing column. Two IX vessels with a capacity to hold 28 cu. ft. of resin each are available at the RLWTF, providing capability of treating 532,950 gal. of RLWTF effluent. After treating 5 million gallons in a typical year of RLWTF operation, exhausted resin would fill 36 55 gal. Drums, and would likely be a low level waste that would be shipped to an off-site incinerator for thermal processing. Cost analyses were performed for the RLWTF at LANL.

Recommendation is made to pilot test two additional resins (Rohm & Haas IMAC HP555 and Sybron Chemical SR-7) that are suspected to have higher selectivity for perchlorate than the US Filter A-464 resin pilot tested at the RLWTF. The Rohm & Haas resin is projected to remove three times the amount of perchlorate that is removed by USF-A-464, but the resin is three times as expensive. However, the three-fold decrease in waste volumen, and less manpower and related expenses to remove the resins and prepare them for offsite shipment could result in a cost savings if the resin performs as expected.

Recommendation is made to incinerate rather than to chemically regenerate the perchlorate loaded resins to eliminate handling of a secondary highly concentrated perchlorate stream.

Report(s)/Publication(s) (Additional Info Source):

Worland, V. Peter, 2001: "Pilot Scale Tests to Remove Perchlorate from the RLWTF Effluent by Ion Exchange", FWO-WFM, January 30, 2001

GWRTAC ID: PERC0052

Project Name: Permeable Reactive Barrier Feasibility

City: Los Alamos **State/Province:** NM

Report(s)/Publication(s) (GWRTAC Source):

The following text was excerpted from project summary information provided by representatives of Las Alamos National Laboratory, April 2001

Project Summary:

The following text was excerpted from project summary information provided by representatives of Las Alamos National Laboratory, April 2001:

Groundwater in Mortandad Canyon at Los Alamos National Laboratory, Los Alamos, NM, is being treated using a Multi-Barrier technology that consists of four different layers of materials arranged as a Permeable Reactive Barrier (PRB). Among the targeted contaminants is perchlorate. The perchlorate in the groundwater results from the use of perchloric acid in the chemical oxidation and dissolution of plutonium and other actinides during processing and analysis. Removal of perchlorate from process wastewater has not been attempted until recently, resulting in a plume of the highly-mobile perchlorate anion in groundwater emerging from the discharge point in Mortandad Canyon. Treatment to remove perchlorate from LANL wastewater was initiated when the EPA and other agencies clearly identified it as an emerging and wide-spread concern in the nation's groundwaters, and as the health effects were shown to be of concern as a risk to human health. The contaminated groundwater that exists in Mortandad Canyon is the subject of in situ treatment using our PRB technology.

The perchlorate removal mechanism in the LANL Multi-Barrier is through microbial reduction to harmless chloride ions. The Multi-Barrier uses two layers that provide biological activity sufficient to reduce perchlorate to non-detectable levels. Both of these layers are made from inexpensive waste materials. Both hydroxyapatite obtained as fishbone, and a carbon-based support material (pecan shell waste) are capable of supporting the growth of a microbial biofilm that is highly effective at reducing both nitrate, the primary contaminant targeted in this groundwater, and perchlorate to non-detectable levels as the groundwater flows through the barrier. Both materials also serve other purposes in the system, primarily radionuclide and metal removal processes.

Laboratory studies have been performed using both batch and column systems, as well as a 2-dimensional mock-up of a full-scale Multi-Barrier system. The groundwater used in these tests is from a single well, MCO-5 in Mortandad Canyon. The perchlorate concentration in this well at the time of sampling was about 350 ppb. These results have been or will be reported at several national and international conferences in early 2001, and are to be published in a book chapter. The Multi-Barrier is also targeted at removal of actinide-contaminated colloidal particles, soluble actinides and metals, and other minor biodegradable wastewater contaminants such as organic nitrogen and carbon compounds (VOC/SVOCs).

A field-scale system will be installed in Mortandad Canyon in the fall of 2001 at a site downstream from the discharge point for the LANL Radioactive Liquid Waste Treatment Facility, an NPDES-permitted surface water discharge outfall (see PERC0051). This project is a field-scale demonstration of the Multi-Barrier system that will have multiple sampling points at strategic locations in each layer, and at points above and below the barrier. It will be used to provide data on the efficacy of the approach, and on the persistance of the barrier materials over long time periods. The barrier is expected to perform the groundwater cleanup function for 10 years or more, and will be sampled periodically throughout this period for characterization of the groundwater and to document performance. The materials will also be sampled periodically to assess their persistance and to analyze changes in material structure and composition, and in microbial population composition with time.

Report(s)/Publication(s) (Additional Info Source):

B.A. Strietelmeier, M.L. Espinosa, M.W. Jones, J.D. Adams, E.M. Hodge, S.D. Ware, P.A. Leonard, P. Longmire, J.P. Kaszuba and J.L. Conca, 2001, Remediation of Nitrate-Contaminated Groundwater Using a Biobarrier, Environmental Science and Waste Technology Division, Facilities and Waste Operations Division, and Earth and Environmental Systems Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, proceedings from the Waste Management 2001 Conference, Tucson, AZ, March-April 2001.

Taylor, T.P. and N.N. Sauer, 2000, Remediation of Inorganic Contaminated Groundwater Using Multi-Barrier Reactive Treatment Wall Technology, Gordon Research Conference, Modeling of Flow in Permeable Media, Andover, NH.

Habas, S.E., T.P. Taylor, N.N. Sauer, J.L. Conca, B.A. Strietelmeier, J.P. Kaszuba, M.L. Espinosa and S.D. Ware, 2000, Multiple Reactive Barrier Wall Technology for Remediation of Inorganic Contaminated Groundwater, Robert A. Laudise, ACS Symposium, Union College, NY.

T P. Taylor, B.A. Strietelmeier, S.D. Ware, M.L. Espinosa, N.N. Sauer, J.L. Conca, 2001, Use of Novel Reactive Barrier Materials for Treatment of Strontium, Uranium, Nitrates and Perchlorates in Groundwater, Los Alamos National Laboratory, Los Alamos, NM 87545, to be presented at the 2001 International Containment & Remediation Technology Conference and Exhibition in Orlando, FL, June 10-13, 2001. (Abstract accepted)

B.A. Strietelmeier, M.L. Espinosa, J.D. Adams, P.A. Leonard and E.M. Hodge, 2001, Use of a Unique Biobarrier to Remediate Nitrate and Perchlorate in Groundwater, Los Alamos National Laboratory, Los Alamos, NM 87545, to be presented at the 2001 International Containment & Remediation Technology Conference and Exhibition in Orlando, FL, June 10-13, 2001. (Abstract accepted)

T.P. Taylor, N.N. Sauer, J.L. Conca, B.A. Strietelmeier, J.P. Kaszuba, M.W. Jones and S.D. Ware, 2001, Reactive Barrier Treatment Wall Technology for Remediation of Inorganic Contaminated Groundwater, Los Alamos National Laboratory, Los Alamos, NM 87545, USA, to be presented at the Groundwater 2001 conference, Sheffield, England. (Abstract accepted)

J. Conca, E. Strietelmeier, N. Lu, S.D. Ware, T.P. Taylor, J. Kaszuba and J. Wright, 2001, Remediation of Groundwater Contaminated with Radionuclides, Metals and Nitrates Using a Four-Component Permeable Reactive MultiBarrier - Treatability Study and Field Design, Los Alamos National Laboratory, Los Alamos, NM 87545, UFA Ventures, Inc., Richland, WA 99352, submission to book entitled "Handbook of Groundwater Remediation of Trace Metals, Radionuclides, and Nutrients with Permeable Reactive Barriers," D. Naftz, S.J. Morrison, J.A. Davis and C.C. Fuller, editors, due fall 2001 from Academic Press, San Diego, CA. (In preparation)

D. Krier, J. Kaszuba, J. Conca, P. Longmire, E. Strietelmeier and D. Meadows, 2001, A Multiple Permeable Reactive Barrier Installation at Los Alamos National Laboratory, NM: Progress Report, Los Alamos National Laboratory, Los Alamos, NM 87545 and The IT Group, Los Alamos, NM 87544, to be presented to the Association of Engineering Geologist annual meeting, St Louis, MO, September, 2001. (Abstract submitted)

GWRTAC ID:	PERC0053
Project Name:	Composting for Treatment of Explosives

City:	Pueblo Army Depot	**State/Province:**	CO

Report(s)/Publication(s) (GWRTAC Source):

Colorado Department of Public Health and Environment, Notes from conversation with representative, December 2000

Project Summary:

The following text was excerpted from notes from conversation with representative of Colorado Department of Public Health and Environment, December 2000:

Perchlorate has been detected in soil at Pueblo Army Depot, Colorado. Currently at this site, composting is being performed to remediate soils known to be contaminated with HMX and RDX. It was planned to sample these soils to determine whether they were also contaminated with perchlorate, and if so, also monitor the biodegradation of perchlorate.

Report(s)/Publication(s) (Additional Info Source):

GWRTAC ID: PERC0054

Project Name: In Situ Bioremediation of Perchlorate-Impacted Groundwater (SERDP #CU-1164)

City: Toronto **State/Province:** ON

Report(s)/Publication(s) (GWRTAC Source):

Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org

Waller, Allison, 2000. Abstract from Poster 117 in “Environmental Challenges for the Next Decade”, Partners in Environmental Technology Technical Symposium & Workshop, Hyatt Regency, Crystal City, Arlington, Virginia, November 28-30, 2000

Project Summary:

The following text was excerpted from Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org; and
Waller, Allison, 2000. Abstract from Poster 117 in “Environmental Challenges for the Next Decade”, Partners in Environmental Technology Technical Symposium & Workshop, Hyatt Regency, Crystal City, Arlington, Virginia, November 28-30, 2000:

This research program consists of (1) laboratory microcosm studies to evaluate the ubiquity of perchlorate-degrading bacteria in groundwater at a variety of impacted Department of Defense (DoD), Department of Energy (DOE), and defense contractor facilities and to assess the applicability of in-situ bioremediation as a remedial technology in a variety of geochemical environments followed by (2) small-scale field pilot testing at one of the test sites to demonstrate that perchlorate can be biodegraded under field conditions and to generate initial design and cost data for potential technology scale-up and validation.

Groundwater contamination related to the production, handling, and use of rocket propellants such as ammonium perchlorate has been identified as a widespread problem at DoD, DOE, and defense contractor facilities. Few cost-effective technologies exist for the treatment of perchlorate-contaminated groundwater. Of the technologies being evaluated, in-situ bioremediation is among the most promising because it has the potential to destroy perchlorate in place rather than transferring perchlorate to another waste stream (e.g., impacted resin or brine) requiring treatment or disposal. Ex situ bioreactors are currently being used at several sites to control the expansion of perchlorate groundwater plumes. While these systems are effective in their roles, they do little to address the long-term source areas that are driving the perchlorate plumes. By comparison, in situ bioremediation systems are proving to be cost-effective alternatives for destroying perchlorate source areas in soil and groundwater. The key benefit of destroying these source areas is reduced duration and cost of remediation of perchlorate-impacted sites. The product of this research will be the development of a robust, reliable, and cost-effective treatment technology for perchlorate-impacted groundwater. This is an FY 2000 New Start project.

Research is being conducted to assess the ubiquity of perchlorate-degrading bacteria in subsurface environments, and to assess the widespread applicability of in situ bioremediation as a groundwater treatment technology for perchlorate impacted aquifers. Contaminated groundwater and soil has been collected from six geographically and geologically different sites throughout the United States for laboratory microcosm testing. Initial perchlorate concentrations in groundwater at these sites ranged from 100 mg/L to in excess of 660,000 mg/L. Perchlorate biodegradation has been stimulated for each of these sites using acetate or molasses as electron donors. Slow release electron donors such as oleate have also promoted perchlorate reduction. For each site, we have been able to biodegrade perchlorate to concentrations well below the Provisional Action Level of 18 mg/L.

Current project activities include: i) enumeration and isolation of perchlorate-degrading microorganisms from each of the different test sites; ii) evaluation of the geochemical tolerance ranges for perchlorate biodegradation, including the effects of high concentrations of perchlorate and competing electron acceptors such as nitrate and sulfate; and iii) assessment of the joint reduction of chlorinated solvents such as trichloroethene (TCE) and perchlorate.

Report(s)/Publication(s) (Additional Info Source):

Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Strategic Environmental Research and Development Program (SERDP) Research Abstract Cleanup CU-1163, available at http://www.serdp.org

Waller, Allison, 2000. Abstract from Poster 117 in “Environmental Challenges for the Next Decade”, Partners in Environmental Technology Technical Symposium & Workshop, Hyatt Regency, Crystal City, Arlington, Virginia, November 28-30, 2000

GWRTAC ID:	PERC0055
Project Name:	U.S. Navy, Southern Division, NAVFAC, Groundwater Remediation, McGregor, Texas
City:	McGregor
State/Province:	TX

Report(s)/Publication(s) (GWRTAC Source):

EnSafe Consultants, EnSafe, Inc., 5724 Summer Trees Drive, Memphis, TN 38134, phone 901-752-1690, Project Summary Information, December, 2000

Project Summary:

The following text was excerpted from project summary information provided by EnSafe Consultants, EnSafe, Inc., Memphis, TN, December 2000:

Naval Weapons Industrial Reserve Plant (NWIRP) McGregor, approximately 20 miles southwest of Waco, Texas, is an inactive, government-owned, contractor-operated facility, originally established in 1942 as the Bluebonnet Ordnance Plant by the U.S. Army Ordnance Corps. Several property owners and tenants have operated onsite during its 50-year history including the United States Army, Navy, and Air Force; the site is currently owned by the U.S. Navy's Naval Air Systems Command. In general, industrial activities included weapons and weapons systems (e.g., bombs, missiles, and explosives) and solid-fuel rocket propulsion systems (primary component: ammonium perchlorate) manufacturing.

As part of interim stabilization measures (ISMs) for the site, the Texas Natural Resource Conservation Commission (TNRCC) required EnSafe and the Navy to evaluate and install treatment systems that would abate offsite migration of perchlorate-contaminated surface and groundwater. The ISM Evaluation Plan recommended biological treatment as the most viable option for groundwater treatment.

Prior to installing pilot or full-scale biological treatment systems to treat perchlorate-contaminated groundwater, bench-scale studies were performed. Bench-scale studies simulated continual flow bioreactor-type systems (ex situ) as well as in situ column studies. The bench-scale studies' objectives as follows:

Demonstrate that perchlorate-contaminated water could be treated to regulatory cleanup levels stipulated by the TNRCC
Provide an estimate of the best carbon source to achieve and sustain the anaerobic conditions required for perchlorate degradation
Examine several media that could be used for biofilm in the proposed attached growth systems
Estimate maximum perchlorate mass loading rates prior to breakthrough and evaluate degradation rates

Several bench-scale set-ups were evaluated to achieve the aforementioned objectives. Carbon sources included fructose, acetate, and citrate for the ex situ evaluation, and mushroom compost, canola, cottonseed meal, and GAC for the in situ tests. Ex situ media included sand, plastic Bio-rings, gravel, and regraded plastic beads. In all cases, microorganisms from POTW sewage sludge were used to develop and acclimate a perchlorate-reducing microbial population.

Bench-scale studies indicated that perchlorate-contaminated water could be treated either in an above ground bioreactor (pump-and-treat) or in situ. Among the synthetic substrates, acetate was the most effective and reliable. As expected, sand was shown to be a viable media for microorganism surface attachment due to its large surface area. However, the Bio-rings were shown to be the most applicable because of their handling ease and minimal clogging potential (compared to sand) in a full-scale bioreactor. At the maximum surface loading rate of 4.2 x 10-4 gpm/ft2, which was used to guide ex situ pilot-scale system design, perchlorate was treated to less than 20 µg/L. Among the natural organic sources, compost and cottonseed meal produced the best results removing >99% and 98% of the perchlorate from the influent stream, respectively.

Based on the bench-scale studies' success, field-scale treatment was implemented. A pump-and-treat system with an aboveground bioreactor and a bio-barrier were both installed. The aboveground bioreactor was a 5-ft-diameter, 18-ft tall carbon steel tank filled with 40 cubic feet of 2 and ¾-inch Bio-rings, with a potassium acetate carbon source.

At an influent flow rate of 43 gpm (1.5 x 10-3 gpm/ft2 surface loading rate), perchlorate concentrations were reduced from 23,000 µg/L to <20 µg/L. In other words, the pilot-scale bioreactor removed approximately 12 pounds of perchlorate per day. The hydraulic residence time for the bioreactor ranged from 50 minutes to four hours. Perchlorate-contaminated groundwater was originally to be collected in strategically place high permeability trenches to intercept groundwater prior to exfiltration or offsite migration. However, because perchlorate concentrations in groundwater were reduced to nondetect by the in situ biobarrier, the pilot-scale system was modified to recirculate a finite quantity of water through the system to evaluate the technology. Because no perchlorate-contaminated water was added to the closed-loop system, sodium perchlorate and amendments were added continuously to the influent using positive displacement pumps. As such, no co-contaminants were introduced to the system, and, because it was a closed-loop system, TDS concentrations escalated over time.

Report(s)/Publication(s) (Additional Info Source):

Britto, R., 2000. "Mechanisms of Perchlorate Degradation: An Overview" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Cowan, D. 2000. Innovative abatement and remediation of perchlorate at McGregor, Texas weapons plant site. Soil Sediment & Groundwater (June/July):25.

Cowan, D. 2000. "In Situ Perchlorate Bioremediation for Soil and Groundwater" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Perlmutter, M. 2000. "Implementation of Innovative In Situ Biotreatment Technology" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

EnSafe Consultants, EnSafe, Inc., 5724 Summer Trees Drive, Memphis, TN 38134, phone 901-752-1690, Project Summary Information, December, 2000

Perlmutter, M. "Bioremediation of Perchlorate-Contaminated Groundwater at Naval Weapons Reserve Plant McGregor, Texas", in National Defense Industrial Association Proceedings, 26th Environmental Symposium and Exhibition, Long Beach, CA, March 27-30, 2000.

Britto, R., 2000. "Enhancement and Optimization of Perchlorate Treatment in Soil and Groundwater", in Remediation of Chlorinated and Recalcitrant Compouns, Battelle, Monterrey, CA, May 22-25, 2000.

Perlmutter, M., 2000. (1) "Concept to Pilot-Scale: Ex Situ Biotreatment of Perchlorate-Contaminated Soil and Groundwater" and (2) "Innovative Technology: In Situ Biotreatment of Perchlorate-Contaminated Groundwater", in Air and Waste Management Association, 93rd Annual Conference and Exhibition, Salt Lake City, Utah, June 18-22, 2000.

(1) Mechanisms of Perchlorate Degradation: An Overview (2) In Situ Perchlorate Bioremediation for Soil and Groundwater, and (3) Implementation of Innovative In Situ Biotreatment Technology at NWIRP, McGregor, Texas, 5th Annual Joint Services Pollution Prevention and Hazardous Waste Management Conference and Exhibition, San Antonio, Texas, August 23, 2000.

Bioremediation of Perchlorate-Contaminated Groundwater and Soil at NWIRP McGregor, Texas, Society of American Military Engineers, Fort Worth, Texas Post, October 3, 2000.

Abating and Remediating Perchlorate, The Military Engineer, Society of American Military Engineers, November -December 2000, Vol. 92, No. 608.

GWRTAC ID: PERC0056

Project Name: U.S. Navy, Southern Division, NAVFAC, In Situ Groundwater Remediation, McGregor, T

City: McGregor **State/Province:** TX

Report(s)/Publication(s) (GWRTAC Source):

EnSafe Consultants, EnSafe, Inc., 5724 Summer Trees Drive, Memphis, TN 38134, phone 901-752-1690, Project Summary Information, December, 2000

Project Summary:

This text was excerpted from project summary information provided by EnSafe Consultants, EnSafe, Inc., Memphis, TN, December 2000:

Naval Weapons Industrial Reserve Plant (NWIRP) McGregor, approximately 20 miles southwest of Waco, Texas, is an inactive, government-owned, contractor-operated facility, originally established in 1942 as the Bluebonnet Ordnance Plant by the U.S. Army Ordnance Corps. Several property owners and tenants have operated onsite during its 50-year history including the United States Army, Navy, and Air Force; the site is currently owned by the U.S. Navy's Naval Air Systems Command. In general, industrial activities included weapons and weapons systems (e.g., bombs, missiles, and explosives) and solid-fuel rocket propulsion systems (primary component: ammonium perchlorate) manufacturing.

As part of interim stabilization measures (ISMs) for the site, the Texas Natural Resource Conservation Commission (TNRCC) required EnSafe and the Navy to evaluate and install treatment systems that would abate offsite migration of perchlorate-contaminated surface and groundwater. The ISM Evaluation Plan recommended biological treatment as the most viable option for groundwater treatment.

Prior to installing pilot or full-scale biological treatment systems to treat perchlorate-contaminated groundwater, bench-scale studies were performed. Bench-scale studies simulated continual flow bioreactor-type systems (ex situ) as well as in situ column studies. The bench-scale studies' objectives as follows:

Demonstrate that perchlorate-contaminated water could be treated to regulatory cleanup levels stipulated by the TNRCC
Provide an estimate of the best carbon source to achieve and sustain the anaerobic conditions required for perchlorate degradation
Examine several media that could be used for biofilm in the proposed attached growth systems
Estimate maximum perchlorate mass loading rates prior to breakthrough and evaluate degradation rates

Several bench-scale set-ups were evaluated to achieve the aforementioned objectives. Carbon sources included fructose, acetate, and citrate for the ex situ evaluation, and mushroom compost, canola, cottonseed meal, and GAC for the in situ tests. Ex situ media included sand, plastic Bio-rings, gravel, and regraded plastic beads. In all cases, microorganisms from POTW sewage sludge were used to develop and acclimate a perchlorate-reducing microbial population. Figures 1 and 2 present the two experiments: simulated bioreactor (ex situ) treatment and in situ treatment.

Bench-scale studies indicated that perchlorate-contaminated water could be treated either in an above ground bioreactor (pump-and-treat) or in situ. Among the synthetic substrates, acetate was the most effective and reliable. As expected, sand was shown to be a viable media for microorganism surface attachment due to its large surface area. However, the Bio-rings were shown to be the most applicable because of their handling ease and minimal clogging potential (compared to sand) in a full-scale bioreactor. At the maximum surface loading rate of 4.2 x 10-4 gpm/ft2, which was used to guide ex situ pilot-scale system design, perchlorate was treated to less than 20 µg/L. Among the natural organic sources, compost and cottonseed meal produced the best results removing >99% and 98% of the perchlorate from the influent stream, respectively.

For the in situ groundwater treatment system, bio-barriers were installed as cutoff or collection trenches since they were originally intended to serve as a groundwater collection system. However, after the successes in the bench-scale tests, the trench system was modified in the middle of construction activities and installed as a bio-barrier in October 1999. More than 3,000 feet of the 5,500-foot trench system was modified to serve as a bio-barrier. NWIRP McGregor is generally underlain by a thin layer of soil typically less than six feet thick. The soil sits atop a water-bearing, fractured limestone between 10 and 25 feet thick. Underneath the fractured limestone is a non-water-bearing gray limestone, which is less weathered and contains fewer fractures and porosity features than the upper layer. The cutoff/collection trench (A-line) extends down through the fractured limestone water-bearing zone and intersects the underlying nonwater-bearing bedrock approximately 15 to 25 feet below ground surface. The B-line and C-line collection trenches are approximately 8 to 15 feet deep.

Compost, cottonseed, and cottonseed meal were blended with drainage aggregate in bench-scale-derived quantities and used as backfill material for the trenches. Temporary monitoring points were installed at selected locations to obtain geochemical information during the pilot-study. These in-trench-monitoring points, along with existing upgradient and downgradient monitoring wells, were used to examine the efficacy of the bio-barrier system to reduce perchlorate. The hydraulic conductivity of the surrounding material decreases with depth. Near the surface it is 10-4 to 10-5 cm/s and decreases to 10-7 to 10-8 cm/s near the confining unit.

Within three weeks of trench construction completion, perchlorate concentrations in trench groundwater decreased from 27,000 ?g/L to below laboratory detection limits. Perchlorate-contaminated groundwater, once migrating offsite, is now intercepted and treated by the PRB. The area of the plume being captured is roughly 125 acres, with a volume of 150,000,000 gallons.

After 12 months of operation, the in situ system is still treating perchlorate-contaminated groundwater to below detection levels. Furthermore, there is analytical evidence that downgradient perchlorate concentrations are being influenced (i.e., reduced) by the in situ system. Because it is still considered a pilot-scale system, effectiveness monitoring continues. As an added benefit, the anaerobic conditions fostered by the in situ treatment system have also promoted reductive dechlorination of trace levels of VOCs. The in situ treatment system is projected to remain effective for 8 to 15 years.

Report(s)/Publication(s) (Additional Info Source):

Britto, R., 2000. "Mechanisms of Perchlorate Degradation: An Overview" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Cowan, D. 2000. Innovative abatement and remediation of perchlorate at McGregor, Texas weapons plant site. Soil Sediment & Groundwater (June/July):25.

Cowan, D. 2000. "In Situ Perchlorate Bioremediation for Soil and Groundwater" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Perlmutter, M. 2000. "Implementation of Innovative In Situ Biotreatment Technology" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

EnSafe Consultants, EnSafe, Inc., 5724 Summer Trees Drive, Memphis, TN 38134, phone 901-752-1690, Project Summary Information, December, 2000

Perlmutter, M. "Bioremediation of Perchlorate-Contaminated Groundwater at Naval Weapons Reserve Plant McGregor, Texas", in National Defense Industrial Association Proceedings, 26th Environmental Symposium and Exhibition, Long Beach, CA, March 27-30, 2000.

Britto, R., 2000. "Enhancement and Optimization of Perchlorate Treatment in Soil and Groundwater", in Remediation of Chlorinated and Recalcitrant Compouns, Battelle, Monterrey, CA, May 22-25, 2000.

Perlmutter, M., 2000. (1) "Concept to Pilot-Scale: Ex Situ Biotreatment of Perchlorate-Contaminated Soil and Groundwater" and (2) "Innovative Technology: In Situ Biotreatment of Perchlorate-Contaminated

Groundwater", in Air and Waste Management Association, 93rd Annual Conference and Exhibition, Salt Lake City, Utah, June 18-22, 2000.

(1) Mechanisms of Perchlorate Degradation: An Overview (2) In Situ Perchlorate Bioremediation for Soil and Groundwater, and (3) Implementation of Innovative In Situ Biotreatment Technology at NWIRP, McGregor, Texas, 5th Annual Joint Services Pollution Prevention and Hazardous Waste Management Conference and Exhibition, San Antonio, Texas, August 23, 2000.

Bioremediation of Perchlorate-Contaminated Groundwater and Soil at NWIRP McGregor, Texas, Society of American Military Engineers, Fort Worth, Texas Post, October 3, 2000.

Abating and Remediating Perchlorate, The Military Engineer, Society of American Military Engineers, November -December 2000, Vol. 92, No. 608.

GWRTAC ID: PERC0057

Project Name: Zero Valent Iron Reduction or Adsorption on Fe0 and Goethite

City: San Diego **State/Province:** CA

Report(s)/Publication(s) (GWRTAC Source):

Gurol, Mirat D., and Kyehee Kim, 2000. "Investigation of Perchlorate Removal in Drinking Water Sources by Chemical Methods", Chapter 10, in Perchlorate in the Environment, Edited by Edward T. Urbansky, Kluwer Academic/Plenum Publishers, New York, New York, 2000.

Project Summary:

The following text was excerpted from Gurol, Mirat D., and Kyehee Kim, 2000. "Investigation of Perchlorate Removal in Drinking Water Sources by Chemical Methods", Chapter 10, in Perchlorate in the Environment, Edited by Edward T. Urbansky, Kluwer Academic/Plenum Publishers, New York, New York, 2000:

INTRODUCTION

Soon after a new IC method that achieved a method detection limit of approximately 1 ppb was developed in 1997, perchlorate has been detected in many drinking water wells and surface and groundwater in the western states, including Colorado River water. Perchlorate is a chemical of health concern due to its interference with the activity of the thyroid gland, and therefore its removal from drinking water sources is very desirable. A few promising technologies are being developed for removal of perchlorate, however, the stability of perchlorate makes treatment technologies difficult, especially at low concentration levels. There is no doubt that perchlorate can be removed from water by separation processes, such as ion exchange and reverse osmosis. Many researchers have been also investigating biological techniques to reduce perchlorate by organic chemicals, e.g., ethanol, acetate, and lactate under anaerobic conditions. A recent literature review indicates that many metals, including Ti(III), V(II), Cr(II), Mo(III) are capable of reducing perchlorate to chloride or chlorate 1 However, perchlorate reduction by common reducing agents, e.g , Fe0, S2032, and 5Q32, is believed to be too sluggish to be practically useful.

The present study was designed to evaluate the interaction of perchlorate with metallic iron and an iron oxide mineral. The objectives were to investigate the feasibility of (1) perchlorate reduction by metallic iron (Fe0) using ultraviolet light to promote the reaction, and (2) adsorption of perchlorate on the surfaces of metallic iron and goethite crystal(alpha-Fe(O)OH) under various conditions.

BACKGROUND

Perchlorate ion is the conjugate base of perchloric acid with a pI(. value of-7, existing in ground and surface waters as the salts of ammonium, potassium, magnesium, or sodium. The chlorine atom in perchlorate has an oxidation valence of +7, and its reduction to chloride or chlorate is thermodynamically very favorable.

However, the reduction reactions of perchlorate are kinetically controlled by their large activation energies. An input of energy as heat or light or the presence of a catalyst would be needed to accelerate the reaction rate. Metallic (Fe0) iron was used as the reducing agent of choice in our study, because zero-valent metals, mainly Fe, Sn, and Zn, have been effective in enhancing the rate of removal of a wide range of heavy metals and halogenated compounds under anoxic conditions. These reactions involve the dissolution of ions, e.g., Fe2', from the metal surface coupled with release of electrons, which provide reduction and dehalogenation of the targeted chemicals. However, the reaction rates are generally quite low, and depend upon such parameters as pH, temperature and surface area of the metal under consideration In fact, reduction of perchlorate by metallic iron has been tried earlier by Yarmoff and Amrhein,6 who reported no observable change in perchlorate concentration. In the present study, ultraviolet (UV) light was used as a catalyst since perchlorate is known to absorb UV in the wavelength range shorter than 185 nm.7 Furthermore, radiolytic decomposition of perchlorate by the action of X-rays and y-rays on the alkali metal and alkaline earth perchlorates has been reported by Prince and Johnson.8 Chemically identifiable fragments, including 02-, C103-, C102-, C102-, C10-

, CL-, 0-, ClOO, ClO3- and ClO4- have been detected in radiated samples.

RESULTS AND DISCUSSION

Perchlorate Removal in Fe-UV System.

While no appreciable reduction was observed in the presence of 10 g L-1 Fe0, about 37% of 1000 ug L-1 of perchlorate was removed within 3 h, indicating the feasibility of the following reactions:

$$4Fe0 + ClO4- + 8H+ = Cl- + 4Fe2+ + 4H20 \qquad (1)$$

$$Fe0 + C104- + 2H+ = C103- + Fe2+ + H20 \qquad (2)$$

The direct role of Fe0 as a reactant implies the involvement of reactive sites on the metal and, therefore, the quantity and the condition of the metal surface is expected to strongly influence the rate of perchlorate reduction.

Irradiation by UV light has been tried to accelerate removal of perchlorate by Fe0. While UV light without any Fe0 could not reduce the perchlorate concentration, simultaneous application of Fe0 and UV light was very effective on perchlorate removal. Furthermore, increasing the Fe0 concentration for a constant light intensity increased the perchlorate removal rate. In the presence of UV light, perchlorate was reduced by 77% by 100 gL-1 of Fe0 in 3 h, whereas the removal was only 37% without UV. These experiments were conducted in unbuffered neutral solutions (pH about 6.6) where the pH has increased by up to 2.0 units at the end of the experiments. The results of additional experiments showed that removal rate of perchlorate was a function of the UV intensity. For example, 77% removal of perchlorate was achieved with 100 g L-1 of Fe0 and a total UV intensity of 0.9 W cm~2, while only 40% of perchlorate was removed using the same concentration of Fe0 , but a total UV intensity of 0.6 W cm2. Furthermore, ion chromatograms of the treated samples showed significant increase in peaks that belong to C1- and C103-. Conversion of perchlorate to these ions was complete, with more than 99 % of perchlorate reduced to Cl while less than 1% converted to ClO3-;. Hence, it is apparent from these results that 1) UV light acts as a catalyst, 2) both the concentration of Fe0 and dosage of UV affect the reaction rate significantly, and 3) perchlorate is reduced quantitatively to Cl-, with less than 1% reduced to CLO3-;. Mechanistically, it is conceivable that perchlorate ion first adsorbs on the surface of Fe0, and then undergoes an electron transfer process that is facilitated by UV excitation.

Perchlorate Removal in Fe0-H3P04 and FeOOH-H3P04 Systems

The metallic iron in the presence of phosphoric acid was capable of removing large amounts of perchlorate from water. However, within about 5 min of contact, perchlorate concentration started to increase, indicating that the removal was due to a reversible adsorption on the metallic surface. The initially low pH of about 1, which was provided by phosphoric acid, started to increase in parallel with perchlorate desorption, which is coupled with pH increase. The pH increase might be due to the dissolution of reduce the metallic iron to ferrous ion and the reduction of water. It should be noted that no removal very effective of perchlorate was observed when sulfuric or hydrochloric acids were used in amounts to also reduce the p11 to less than 2. The same process was repeated for goethite. Orthophosphate is known to have high affinity towards iron and iron oxide surfaces. Hence, it is conceivable that the removal of perchlorate is due to a complexation between perchlorate and phosphoric acid followed by adsorption of the complex on the surfaces of the particles. However, as in the case for metallic iron, proved to be very effective in removing perchlorate in the presence of phosphoric acid perchlorate concentration stared to increase upon prolonged contact. The desorption rate was however very slow for goethite for the same initial pH of 2.5, and particle concentration of 12 g L-1. This could be due to stronger binding of the complex on goethite compared to metallic iron, or more likely goethite particles having mostly internal surface provided by the porous structure, which provides resistance to back diffusion of the complex.

Perchlorate removal was observed only at acidic pH values. In fact, the desorption during the contact is very likely due to pH of the suspension increasing from initial pH values of about 2 to more than 3 during prolonged contact, for both metallic iron and goethite. This pH dependence might be explained in the context of speciation of the surface and phosphate

Hence, when the pH is about 2, the surface becomes positively charged due to the dominance of FeOH2+ sites, whereas the dominant phosphate species is phosphoric acid, which is neutral. In the case of complexation between H3P04 and C104-, the complex will have a net charge of -1, and therefore will exhibit an electrostatic attraction towards the positively charged surface. However, the negatively charged phosphate species that become dominant at elevated pH values may not necessarily form a complex with C104-, and there should be no removal of perchlorate at higher pH. It should be noted that C104 did not adsorb well on the positively charged surface in the absence of phosphoric acid, as checked by reducing the pH to 2 with HCI and H2S04 acids. Additional experiments were conducted using FeOOH-H3P04 system for lower initial perchlorate concentrations of 200 and 500 ug L-1, keeping all other conditions the same. The removal of perchlorate as C/C0, where C0 is the initial concentration, is discussed for three different initial concentrations of perchlorate. About 70-75% of perchlorate was removed for all three cases within the first few minutes. However, it was released back to the solution upon prolonged contact, although more slowly for the lowest perchlorate concentration. The percent removal of perchlorate was independent of its initial concentration.

CONCLUSIONS

Two innovative chemical processes were investigated to determine the feasibility of perchlorate removal from water. The first process involves the exposure of perchlorate simultaneously to metallic iron and UV light under anoxic conditions. Despite the concerns of many researchers regarding the high kinetic inertness of perchlorate, it was shown that perchlorate can be reduced by metallic iron, and furthermore that UV light can accelerate the reaction rate to levels that could make the process viable for practical applications.*

The results can be summarized as follows: (1) UV light promotes the reaction, while metallic iron provides electrons for reduction of perchlorate, (2) both the concentration of metallic iron and dosage of UV affect the reaction rate significantly, and (3) more than 99% of perchlorate is reduced to CI, with less than 1% reduced to C103. It is believed that perchlorate ion is adsorbed on the surface of metallic iron, and then undergoes an electron transfer process that is facilitated by UV excitation. It should be noted that C104 absorbs light at wavelengths shorter than 185 nm; however, the low pressure mercury lamps used in this study generate light primarily at 254 nm (99%), with only 1% emitted at 185 rim. Thus, these lamps are not efficient for C104 excitement. Better results can be obtained by using lamps that emit primarily at lower wavelength. The second process involves the contact of perchlorate with the surfaces of metallic iron or an iron oxide mineral (goethite) in the presence of phosphoric acid. The experimental results suggest that perchlorate can be removed up to almost 100% during the initial phases of the contact in the pH ranges of 2.0-2.5. This removal is believed to be due to formation of a complex between perchlorate and phosphoric acid that subsequently adsorbs to particle surfaces. At higher pH values very little removal of perchlorate can be observed. However, even at acidic pH, continuous contact with the surface-coupled with agitation and pH rise-seems to release the perchlorate back to the solution. It is obvious that the particles must be separated from solution before desorption of perchlorate if this is to be used as a treatment method. Unfortunately, the requirement of very acidic conditions and subsequent neutralization for pH restoration might make this process relatively expensive for typical applications.

* Patent application date: August 1999.

Report(s)/Publication(s) (Additional Info Source):

Gurol, Mirat D., and Kyehee Kim, 2000. "Investigation of Perchlorate Removal in Drinking Water Sources by Chemical Methods", Chapter 10, in Perchlorate in the Environment, Edited by Edward T. Urbansky, Kluwer Academic/Plenum Publishers, New York, New York, 2000.

GWRTAC ID:	PERC0058
Project Name:	Multi-Cell Respirometry Unit Test of Perchlorate Destruction

City:	Indian Head	***State/Province:***	MD

Report(s)/Publication(s) (GWRTAC Source):

Indian Head Division Naval Surface Warfare Center (IHDIV) in Indian Head, MD, Denix Website

Project Summary:

The following text was excerpted from Indian Head Division Naval Surface Warfare Center (IHDIV) in Indian Head, MD, Denix Website:

Engineers at the Indian Head Division Naval Surface Warfare Center (IHDIV) in Indian Head, MD have obtained a multi-cell respirometry unit to enable testing of potential perchlorate destruction via conventional STP processes. This work may assist in the establishment of pre-treatment criteria for perchlorate discharge to POTWs.

Report(s)/Publication(s) (Additional Info Source):

Indian Head Division Naval Surface Warfare Center (IHDIV) in Indian Head, MD, Denix Website

GWRTAC ID: PERC0059

Project Name: Calgon Carbon Corp. Remediation of Seepage by Ion Exchange

City: Henderson **State/Province:** NV

Report(s)/Publication(s) (GWRTAC Source):

Wagner, Norman, and Charles Drewry, 2000. “Commercial Systems Treating both High and Low Strength Perchlorate Applications Utilizing Ion Exchange” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas

Project Summary:

The following text was excerpted from Wagner, Norman, and Charles Drewry, 2000. “Commercial Systems Treating both High and Low Strength Perchlorate Applications Utilizing Ion Exchange” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

Calgon Carbon Corporation commissioned the first perchlorate remediation system at Henderson, Nevada in November 1999, and the system has been in continuous operation since that time. The installation is designed to treat perchlorate-containing seep water draining into Lake Mead. This ion exchange system is designed to remove 100 ppm of perchlorate from 450 gpm of water. Actual perchlorate concentrations range between 80 to 110 ppm, and actual flow rates have varied from 200 to 560 gpm. The system is designed to achieve 97% perchlorate removal. Typical effluent perchlorate concentrations are non detectable on an ion selective electrode (< 2 ppm).

PERC0060 – Influence of Humic Substances and Sulfate on Ion Exchange Resins

PRP/Site Owner Contacts (Name, Title, Address, Phone, Fax, Email)

Not Applicable

Funding Source/Sponsor Contacts (Name, Title, Address, Phone, Fax, Email)

Not Specified

Regulatory Agency Contacts (Name, Title, Address, Phone, Fax, Email)

Not Applicable

Technical Team Contacts (Name, Title, Address, Phone, Fax, Email)

Jacimaria Batista, Adriano Vieira, and Frank X. McGarvey, Department of Civil and Environmental Engineering, UNLV University of Nevada, Las Vegas

GWRTAC Information Source

Batista, Jacimaria, Adriano Vieira, and Frank X. McGarvey “The Influence of Humic Substances and Sulfate on the Removal of Perchlorate from a Groundwater by Ion-Exchange Resins” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

References (URLs, Journal or Report Citations, etc.)

Batista, Jacimaria, Adriano Vieira, and Frank X. McGarvey "The Influence of Humic Substances and Sulfate on the Removal of Perchlorate from a Groundwater by Ion-Exchange Resins" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excerpted from Batista, Jacimaria, Adriano Vieira, and Frank X. McGarvey "The Influence of Humic Substances and Sulfate on the Removal of Perchlorate from a Groundwater by Ion-Exchange Resins" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

The objectives of this study were to examine the potential of ion exchange to remove perchlorate from a "real" water from a contaminated site in the Las Vegas valley using different types of resins. Ion exchange resins were provided to UNLV for this work by Sybron Chemicals and Purolite. Ion exchange technology was immediately investigated for perchlorate treatment because of its previous use for nitrate and arsenate removal, and because it is a familiar technology to the water industry. Several strong and weak-base anionic exchange resins were tested. Fixed-bed column tests were performed using 1.5-2.5 cm ID glass columns with one-foot resin beds. Columns were fed with the contaminated groundwater from the Las Vegas Valley. Regeneration was performed with sodium chloride. Anions were analyzed by ion-chromatography. Organic carbon was analyzed by TOC analyzer. The average concentration of major anions in the "real" water, given in mg/L was perchlorate – 80.3; chlorine – 2,009; nitrate – 48.8; sulfate – 1,968; TOC – 45.3.

The following conclusions were made, based on the study.

1. For two styrenic strong-base (ASB1 and ASB2), the total column utilization were only 48% and 36% respectively, indicating that about 50% of the resin capacity was occupied by anions other than perchlorate.
2. High concentrations of sulfate in the water rapidly saturated the resin. Perchlorate was continuously removed from the water by pushing sulfate out of the resin.
3. For a macroporous strong-base syrenic resin (ASB1 PC), about 21% of the column capacity were utilized by perchlorate. This resin exchanged considerable amount of humic acids and perchlorate and they could be stripped out easier from ASB1 PC than from ASB1 and ASB2.
4. The capacity of the styrenic weak-base (AFP 329) for perchlorate was moderately affected by the presence of humic substances as compared to other resins. Humic acids were not exchanged with this resin.
5. The efficiency of the strong-base acrylic resin (Macro T) was significantly affected by the presence of humic substances contained in the "real" water. Perchlorate did not exchange with this resin. This resin showed the highest TOC concentration in the regenerant brine.
6. The presence of humic acids in waters may significantly affect the removal of perchlorate by ion exchange resins.

A research recommendation made was to examine the effects of humic acids and other anions (e.g. sulfates, nitrate) on perchlorate removal by ion exchange resins, by using binary solutions of humic acids and different anions at different concentrations.

Report(s)/Publication(s) (Additional Info Source):

Wagner, Norman, and Charles Drewry, 2000. "Commercial Systems Treating both High and Low Strength Perchlorate Applications Utilizing Ion Exchange" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas

GWRTAC ID:	PERC0060		
Project Name:	Influence of Humic Substances and Sulfate on Ion Exchange Resins		
City:	Las Vegas	**State/Province:**	NV

Report(s)/Publication(s) (GWRTAC Source):

Batista, Jacimaria, Adriano Vieira, and Frank X. McGarvey "The Influence of Humic Substances and Sulfate on the Removal of Perchlorate from a Groundwater by Ion-Exchange Resins" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excerpted from Batista, Jacimaria, Adriano Vieira, and Frank X. McGarvey "The Influence of Humic Substances and Sulfate on the Removal of Perchlorate from a Groundwater by Ion-Exchange Resins" in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

The objectives of this study were to examine the potential of ion exchange to remove perchlorate from a "real" water from a contaminated site in the Las Vegas valley using different types of resins. Ion exchange resins were provided to UNLV for this work by Sybron Chemicals and Purolite. Ion exchange technology was immediately investigated for perchlorate treatment because of its previous use for nitrate and arsenate removal, and because it is a familiar technology to the water industry. Several strong and weak-base anionic exchange resins were tested. Fixed-bed column tests were performed using 1.5-2.5 cm ID glass columns with one-foot resin beds. Columns were fed with the contaminated groundwater from the Las Vegas Valley. Regeneration was performed with sodium chloride. Anions were analyzed by ion-chromatography. Organic carbon was analyzed by TOC analyzer. The average concentration of major anions in the "real" water, given in mg/L was perchlorate – 80.3; chlorine – 2,009; nitrate – 48.8; sulfate – 1,968; TOC – 45.3.

The following conclusions were made, based on the study.

1. For two styrenic strong-base (ASB1 and ASB2), the total column utilization were only 48% and 36% respectively, indicating that about 50% of the resin capacity was occupied by anions other than perchlorate.
2. High concentrations of sulfate in the water rapidly saturated the resin. Perchlorate was continuously removed from the water by pushing sulfate out of the resin.
3. For a macroporous strong-base syrenic resin (ASB1 PC), about 21% of the column capacity were utilized by perchlorate. This resin exchanged considerable amount of humic acids and perchlorate and they could be stripped out easier from ASB1 PC than from ASB1 and ASB2.
4. The capacity of the styrenic weak-base (AFP 329) for perchlorate was moderately affected by the presence of humic substances as compared to other resins. Humic acids were not exchanged with this resin.
5. The efficiency of the strong-base acrylic resin (Macro T) was significantly affected by the presence of humic substances contained in the "real" water. Perchlorate did not exchange with this resin. This resin showed the highest TOC concentration in the regenerant brine.
6. The presence of humic acids in waters may significantly affect the removal of perchlorate by ion exchange resins.

A research recommendation made was to examine the effects of humic acids and other anions (e.g. sulfates, nitrate) on perchlorate removal by ion exchange resins, by using binary solutions of humic acids and different anions at different concentrations.

Report(s)/Publication(s) (Additional Info Source):

Batista, Jacimaria, Adriano Vieira, and Frank X. McGarvey "The Influence of Humic Substances and Sulfate on the Removal of Perchlorate from a Groundwater by Ion-Exchange Resins" in Perchlorate Treatment

Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0061		
Project Name:	Patented Hall Bioreactor		
City:	Not Specified	***State/Province:***	CA

Report(s)/Publication(s) (GWRTAC Source):

Hall, P.J., 2000. “Perchlorate Remediation at a DoD Facility”, in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excerpted from Hall, P.J., 2000. “Perchlorate Remediation at a DoD Facility”, in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

EcoMat, Inc. is a California-based firm that makes and sells advanced biological remediation systems, including systems for denitrification. The bacteria that provide denitrification are readily found in nature. They are facultative anaerobes that can utilize oxygen for metabolic energy from sources other than dissolved oxygen. These bacteria will take oxygen from the easiest supply and then look for more. In water treatment they remove oxygen based upon the following preferred sequence:

Dissolved oxygen
Nitrate (product is gaseous nitrogen)
Perchlorate (product is chloride)
Sulfate (product is hydrogen sulfide)

As such, EcoMat became involved in a project to provide a small system to remove perchlorate from test water. The project site is a DoD facility located in southern California. Under the Installation Restoration Program (IRP), Earth Tech, Inc. has a contract to provide environmental services, including evaluating the perchlorate levels in shallow groundwater beneath the facility. The test water that they pump from this activity is temporarily stored in Baker tanks on the site. The major contaminant in this water is perchlorate, at concentrations varying from 300 to 1,000 ppb. Beginning in October 1999, Earth Tech evaluated EcoMat’s ability to remediate perchlorate, and in December 1999, they contracted EcoMat to provide a small system to remove perchlorate from test water.

EcoMat designed a system to achieve perchlorate removal from the Baker tanks within a period of several months. Initially, without sufficient information to determine the hydraulic residence time to remove perchlorate to non-detectable levels, the system was designed for a residence time of approximately one-half hour with an active volume of 200 liters. Given average tank volumes of 20,000 gallons, this would enable complete reduction in a period of seven days after the bacteria are firmly established.

EcoMat had designed and built an identical system and installed it in the John G. Shedd Aquarium in Chicago. Denitrification bacteria that were exposed to perchlorate were placed in the reactors and the skid was transported to southern California. At the site, the system was functioning and reducing perchlorate within a few days, and systems operation was transferred to Earth Tech, with continued telephone consult from EcoMat. After several months during which operating problems were overcome, the tanks were completely clean of perchlorate, below the detectable concentration. The system was then moved to a similar site on the base, where it remains in operation.

The system design begins with water from the Baker tank being drawn into the top of the deaeration reactor, reflecting EcoMat’s understanding that a two-stage process works best for biological oxygen removal. In the deaeration tank is a large number of ordinary bio-balls that provide surface for bacterial growth. The reactor is designed to reduce the dissolved oxygen concentration from saturation down to a concentration of 0.5—1.0

ppm. This is the optimum concentration for either denitrification or perchlorate remediation. If the dissolved oxygen concentration rises above one ppm, the remediation is ineffective, and if it drops to near-anaerobic concentrations, the threat of sulfate attack arises. Hydrogen sulfide can be injurious to the bacteria, stopping the remediation activity. Although the bacteria can be revived very easily by restarting the process, time is wasted if oxygen levels are not monitored.

From the bottom of the deaeration reactor, water is then drawn into the bottom of the patented Hall reactor, the key element of EcoMat's process. The reactor is designed to hold a mass of floating media and maintain continuous circulation of the media along with the water in the reactor. This mixing is attained without any internal moving parts, but rather, by external pump re-circulation. Continuous circulation is extremely important as it provides for uniform, low concentrations of the contaminant under all influent contaminant concentrations. In this manner, no upper limit on the allowable inlet concentrations is needed.

The Eco-Link media that fills the Hall reactor is a polyurethane-based sponge that is cut into one-centimeter cubes. The media last for up to several years, and are kept reasonably clean and capable of supporting bacteria colonies by virtue of their gentle collisions with each other and with the walls of the reactor. When functioning to produce a gas, as in denitrification, the size of the interstitial spaces within the sponge is designed to permit passage of gas out, as well as passage of water into, these spaces. At the same time, the surface area involved is sufficiently great to provide for large bacteria concentrations and high interaction efficiency.

The overflow from the Hall reactor is recycled back into the deaeration reactor during the startup period to form colonies of bacteria. In normal operation the effluent is discharged from the system. In cases where drinking water purity is desired, a post-treatment system can be added to the process to control the small amount of biosolids that leaves the system. This is the only residual stream that results from the process. In case of upset conditions, water can be returned tot he Baker tanks.

Both reactors require feed of a carbon source (electron donor) to feed the bacteria. EcoMat has studied a variety of available sources as find the best one is methanol. Methanol residual of less than 2 ppm is considered non-hazardous and EcoMat's systems normally run at undetectable concentrations (below 0.5 ppm). Methanol is not only the lowest cost commercially available carbon source but is also maintains the lowest level of biosolids. Alternative carbon sources, such as ethanol, tend to “gum up” the works. The major requirement for methanol is for removal of dissolved oxygen in the deaeration reactor, as oxygen levels are so much greater than perchlorate levels in the first stage of the process. For fire safety reasons, the methanol is dissolved in water (generally 50%). The rate of feed of methanol is so small that even if it were to exit unused, the concentration would not reach hazardous levels.

While the bacteria involved in denitrification are hardy, best operations are realized when temperatures are controlled between limits of 8 deg. C. and 35 deg. C. During normal flow, the influent water maintains adequate temperature control. During startup, when recirculation is 100%, care should be taken to turn on the circulation pump in the Hall reactor for a relatively small time period each day.

The way the system works is that the bacteria can “eat” a constant rate of contaminant. Thus the flow rate of water through the system isn't a significant parameter in the design. The most significant system size factor, which determines the basic system size, is the total amount of material that is to be removed per day. This number is the product of the flow times the concentration. For example, for a system that will remediate 1,000 gpm of water having a concentration of 10 ppm, the amount of contaminant to be removed is 120 pounds per day. For this example, EcoMat estimates that it can build, own, and operate this system, at the currently demonstrated sizing criteria, at total cost to the customer of $.50 per thousand gallons.

The system is built on a four by four foot skid. Startup operations involve continuously recycling the water through the reactors while feeding methanol and assuring that there is adequate perchlorate in the water. This recirculation need not be constant, and in warm weather, when the bacteria may overheat, it is best to circulate for no more than a few hours per day. Periodic measurements are made of the dissolved oxygen levels leaving the deaeration reactor. When the dissolved oxygen level is below 1.0 ppm, the system can be opened in stages, until it is wide open. After startup, operations remain continuous, and it is only necessary to check the system once daily to be sure that no spurious upset has taken place. The methanol source only needs to be replenished every few weeks.

At this DoD site there were a number of upsets, particularly during the early operating days. First, someone driving by pulled the main power plug. A few days passed before the operators realized that there was something wrong. During that time, the bacteria used up all of the oxygen and perchlorate and started producing hydrogen sulfide. The system turned black and smelled characteristically of that material. The system was re-started and within a few days it returned to normal operation.

Earth Tech was not concerned with optimizing the time for performing the remediation of the water from the Baker tanks. With a retention time of one half-hour, the remediation proceeded sufficiently rapidly. However, based upon EcoMat's denitrification experience, much shorter retention times may be feasible for perchlorate remediation, further reducing the cost of new systems. EcoMat is pursuing this possibility.

Measurements were made by Earth Tech on a regular basis. As a result of the "closed loop" feature, it was possible to control the outlet so that only when the effluent perchlorate concentrations were below the allowable level (ND) would water be discharged to a cleaned water baker tank. Initial results during the startup period were as follows (in ug/L):

Date	Inlet	Outlet
2/17	350	21
2/18	390	16
2/21	390	410*
3/06	350	ND
3/07	370	ND
3/08	340	9
3/09	320	ND
3/10	320	19
3/15	260	24**
3/23	300	ND

* Power loss
** New tank

When the Baker tanks were emptied, the system was moved to another location at the DoD site, where it is presently in operation.

Reactors 15 times the size of the subject reactor are currently in operation, and EcoMat has designed reactors as large as 100 cubic meters. The reactors may be ganged together to provide adequate volume for any flow rate. EcoMat plans to offer its perchlorate remediation process to customers as a build-own-operate package, with pricing in the range of $.50/1,000 gallons. For very large systems it would be cost effective to implement on-line measurement capabilities with SCADA systems to transmit data to a remote operations center, facilitating satisfactory operations.

Report(s)/Publication(s) (Additional Info Source):

Hall, P.J., 2000. "Perchlorate Remediation at a DoD Facility", in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0062		
Project Name:	Aerojet In Situ Bioremediation Field Demonstration		
City:	San Gabriel	***State/Province:***	CA

Report(s)/Publication(s) (GWRTAC Source):

Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excerpted from Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

The Aerojet Superfund Site, California was selected for the SERDP in situ bioremediation field demonstration. The site is underlain by an alluvial aquifer consisting of interbedded silts, sands, and gravel, with the water table present at 20 feet bgs. Groundwater chemistry consists of the following: perchlorate = 15 mg/L; nitrate = 5 mg/L; sulfate = 10 mg/L; oxygen = 4 mg/L; redox potential = +200 mV; TCE = 3 mg/L; and pH = 6.8.

At the site, the perchlorate plume is co-mingled with TCE, and the pilot was undertaken to determine if these contaminants could be jointly bioremediated. After demonstration at the microcosm level, the in situ anaerobic bioremediation of perchlorate and TCE pilot project was initiated in May 2000. The target aquifer was located 100 feet bgs. The goal of the pilot was to control migration of the 800-foot wide perchlorate/TCE plume. The field demonstration was designed as a closed loop (65 feet), with a re-circulation rate of 5-10 gpm, and a residence time of 21 days. One nutrient delivery well and one extraction well were utilized, and two biomonitor wells were located between the delivery and extraction wells, in a straight-line pattern. In the biomonitor well located 15 feet from the nutrient delivery well, perchlorate was reduced from about 10 mg/L to about 1 mg/L in about 11-12 days. In the biomonitor well located 35 feet from the nutrient delivery well, perchlorate was reduced from about 10 mg/L to about 1 mg/L in about 18-20 days.

Report(s)/Publication(s) (Additional Info Source):

Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0063
Project Name:	Aerojet Bioremdiation of Soil from Former Burn Area by Anaerobic Composting

City:	San Gabriel	***State/Province:***	CA

Report(s)/Publication(s) (GWRTAC Source):

Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excerpted from Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

The Aerojet Superfund Site, California was selected for a pilot demonstration anaerobic composting of soils from the former perchlorate burn area. In this area, perchlorate concentrations up to 4,200 mg/kg were detected. Soils consist of low permeability, silty clay soil. The remedial goal was to prevent perchlorate infiltration to groundwater at concentrations exceeding the preventive action limit of 18 ppb. Bench-scale studies showed that degradation half-lives were on the order of 2 to 4 days, and treatment and bioaugmented treatment both resulted in perchlorate reduction from 22-28 mg/kg to <3 mg/kg after 20 days. The compost pile dimensions for the field demonstration were 7 feet at the base, and a maximum 5 foot height. A plastic liner was emplaced beneath the pile, and clean soil berms were constructed around the circumference to contain potential leachate. A second pile was left unlined. A plastic tarp covered the top of the pile, and temperature and moisture probes were installed within the pile to measure these parameters using a datalogger. The field results showed that for both the lined and the unlined compost pile, perchlorate concentrations were reduced from about 23 mg/kg to near the PQL of 0.1 mg/kg in about seven days; the degradation half-life was determined to be one to two days.

Report(s)/Publication(s) (Additional Info Source):

Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0064
Project Name:	Rocket Manufacturing Site Soil Bioremediation by Anaerobic Composting

City: Bay Area **State/Province:** CA

Report(s)/Publication(s) (GWRTAC Source):

Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excerpted from Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:

A Rocked Manufacturing Site, California was selected for a pilot demonstration anaerobic composting of soils from an active perchlorate grinder station. In this area, perchlorate concentrations up to 2,100 mg/kg were detected. Soils consist of low permeability, silty soil. The remedial goal was to prevent perchlorate impacts to surface water via overland flow during storm events. Bench-scale studies showed that using a 1:1 soil to compost ration, perchlorate was reduced from about 700 mg/kg to 0.24 mg/kg in about 90 days, and using a 1:10 soil to compost ratio, perchlorate was reduced from about 100 mg/kg to <0.1 mg/kg in about 70 days. The compost pile dimensions for the field demonstration were 7 feet at the base, and a maximum 5 foot height. A plastic liner was emplaced beneath the pile, and clean soil berms were constructed around the circumference to contain potential leachate. A plastic tarp covered the top of the pile, and temperature and moisture probes were installed within the pile to measure these parameters using a datalogger. The field results showed that perchlorate concentrations were reduced from about 170 mg/kg to levels consistently less than 0.64 mg/kg in about 38 days. The degradation half life was determined to be two to four days.

Report(s)/Publication(s) (Additional Info Source):

Cox, E., E. Edwards, S. Neville, M. Girard, 2000. “Cost-Effective Bioremediation of Perchlorate in Soil and Groundwater” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

GWRTAC ID:	PERC0065		
Project Name:	Baldwin Park Operable Unit of San Gabriel Basin, CA		
City:	Los Angeles	**State/Province:**	CA

Report(s)/Publication(s) (GWRTAC Source):

Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ 08648, Project Summary Information, September 2000

Girard, M., 2000. “Pilot Treatability Study, Aerojet Sacramento, California” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Project Summary:

The following text was excerpted from information provided by Envirogen, Inc., 4100 Quakerbridge Road, Lawrenceville, NJ;
and Girard, M., 2000. “Pilot Treatability Study, Aerojet Sacramento, California” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas:
The Baldwin Park Operable Unit Settling Parties (BPOUSP) are conducting a technology demonstration project that produces potable drinking water. The pilot plant is constructed at Aerojet’s Sacramento Facility adjacent to the Groundwater Extraction and Treatment (GET) E/F Treatment Plant.

The objectives of the pilot study are as follows:

Construct and operate a pilot treatment system that will demonstrate process performance in a size and configuration applicable to a full scale water treatment system.
Confirm destruction and removal efficiencies for nitrate, perchlorate, VOCs, NDMA, and 1,4-dioxane.
Establish operating parameters to assure optimal, reliable, and consistent treatment performance.
Determine unit process requirements to meet drinking water standards.
Obtain technology approval from California Department of Health Services (DHS) for use of the treatment train to produce drinking water in the San Gabriel Basin.

The pilot study design consists of the full-scale GAC/FBR, multimedia filters, UV/Chemical Oxidation (UV/OX), Liquid-phase Granular Activated Carbon (LP GAC), and disinfection. Details on the contaminants targeted by each component of the pilot plant are as follows:

Unit Process	Flow Rate	Target Contaminants
GAC/FB Bioreactor	900-1500 gpm	Nitrate, Perchlorate
Multi-Media Filter	350 gpm	Suspended Solids, Ethanol, Pathogens
UV/OX System	100 gpm	NDMA, 1,4-Dioxane, VOCs, Pathogens
Liquid Phase GAC	100 gpm	VOCs, Polishing
Disinfection	10 gpm	Pathogens
Lamella Clarifier	25-50 gpm	Biosolids

The pilot study is planned to answer several detailed questions on the operation of each specific unit process, with regard to its role in the process, and its position in the treatment train. Pilot study sampling points and sample analytical parameters are extensive. An expert peer review panel in place to review the project includes representatives from Stanford University, Montgomery Watson, USEPA/NRMRL, McGuire & Associates, California Department of Health Services, and U.S. EPA Region 9. The plant was constructed in December 1999, with system start up in February 2000. Operation will occur from March to October 2000.

Report(s)/Publication(s) (Additional Info Source):

Girard, M., 2000. “Pilot Treatability Study, Aerojet Sacramento, California” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.

Guarini, B., 2000. “Biological Treatment of Groundwater Containing Perchlorate Using Fluidized Bed Reactors” in Perchlorate Treatment Technology Workshop, 5th Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference & Exhibition, August 21-24, 2000, Henry B. Gonzalez Convention Center, San Antonio, Texas.