**Technology Status Report**

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GWRTAC S SERIES

# Technology Status Report Perchlorate Treatment Technologies First Edition


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# 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***

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Submitted by

Concurrent Technologies Corporation
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## 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 These reports are not intended as in-depth technical analyses and are not peer-reviewed.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.

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## 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


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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) |

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|---|---|---|---|---|---|---|---|---|---|---|
| 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) |

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|---|---|---|---|---|---|---|---|---|---|---|
| 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) |

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|---|---|---|---|---|---|---|---|---|---|---|
| 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™) | 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) |

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**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) |

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|---|---|---|---|---|---|---|---|---|---|---|
| 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) |

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| 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<br>Distribution of Case Studies by U.S. State, Canadian Province, or County<br>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<br>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<br>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<br><200 | Not Specified | Not Specified | 8,200,000 / Not Specified | 2.1 HRT<br>3.1 HRT<br>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<br>(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<br>(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<br>(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<br>738,000,000 | <4 (5 hr HRT)<br><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.**

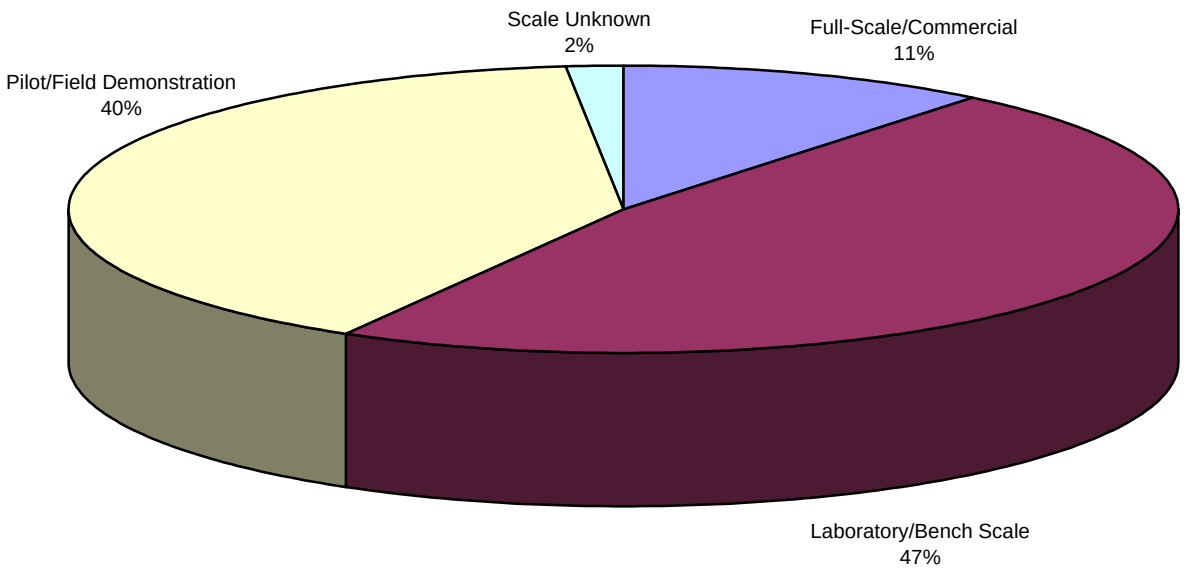
| | | Ex Situ Soil Treatment | | | | |
|---|---|---|---|---|---|---|
| GWRTAC ID | Project Name | Pre-Treatment Perchlorate Concentration (ppb) | Post-Treatment Perchlorate Concentration (ppb) | Pre-Treatment Co-Contaminants Concentration (ppb) | Post-Treatment Co-Contaminants Concentration (ppb) | Treatment 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.**

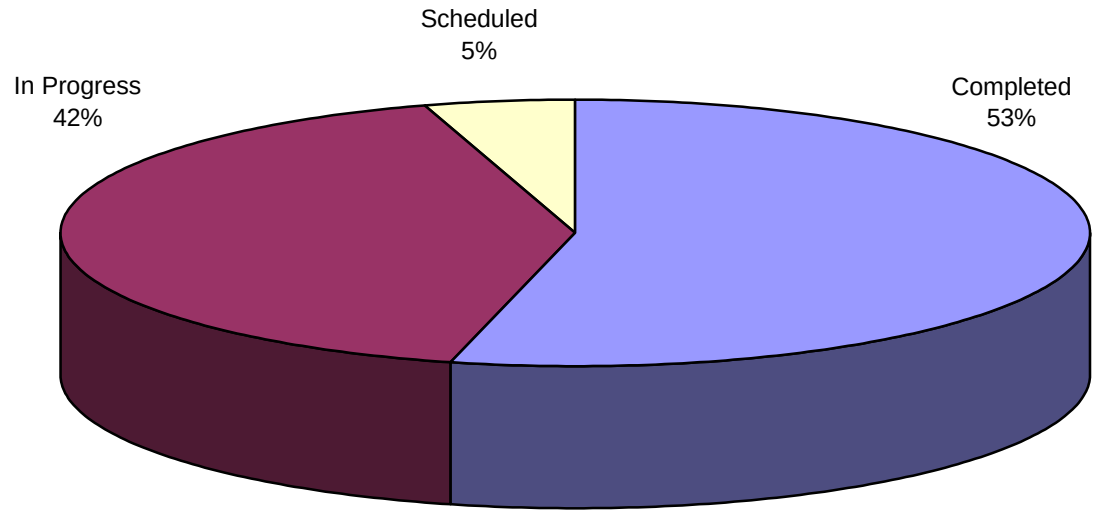
| | | In Situ Soil or Groundwater Contamination | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GWRTAC ID | Project Name | Perchlorate Concentration in Soil (ppb) | Co-Contaminants Concentration in Soil (ppb) | Perchlorate Concentration in Groundwater (ppb) | Co-Contaminants Concentration 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)



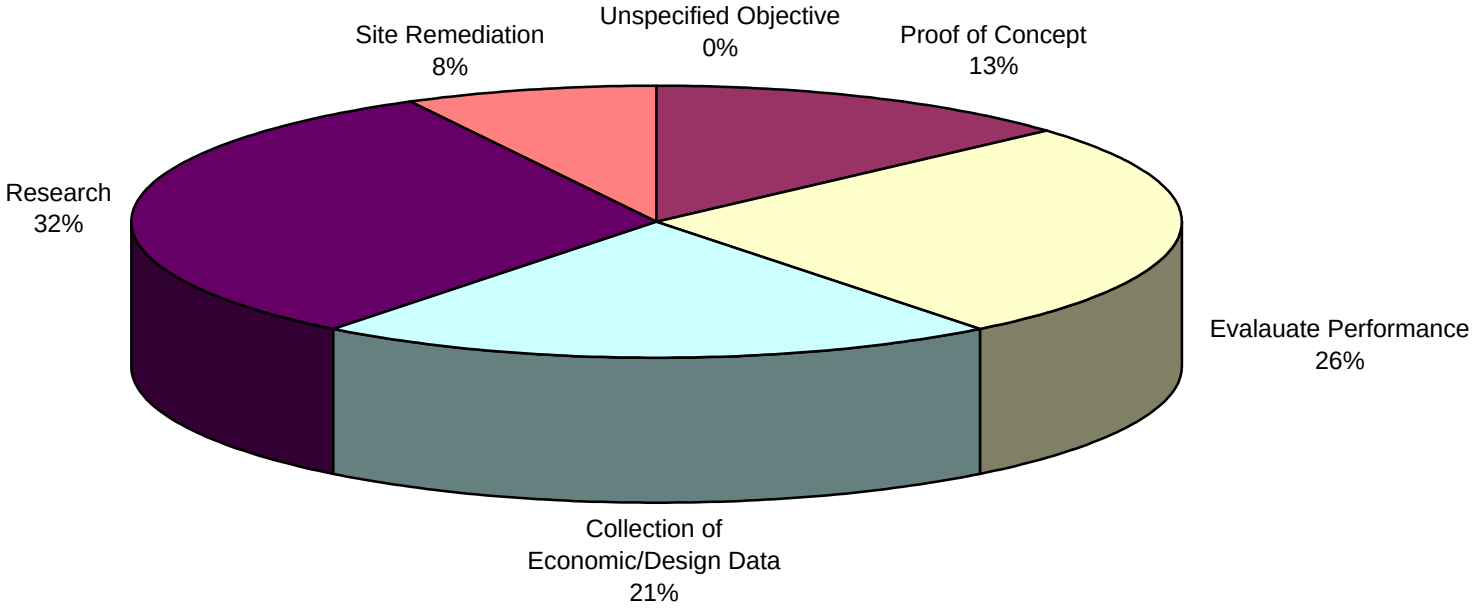

Total Number of Case Studies = 65

**Figure 2. Perchlorate Treatment Technologies - Project Status**




Total Number of Case Studies = 65

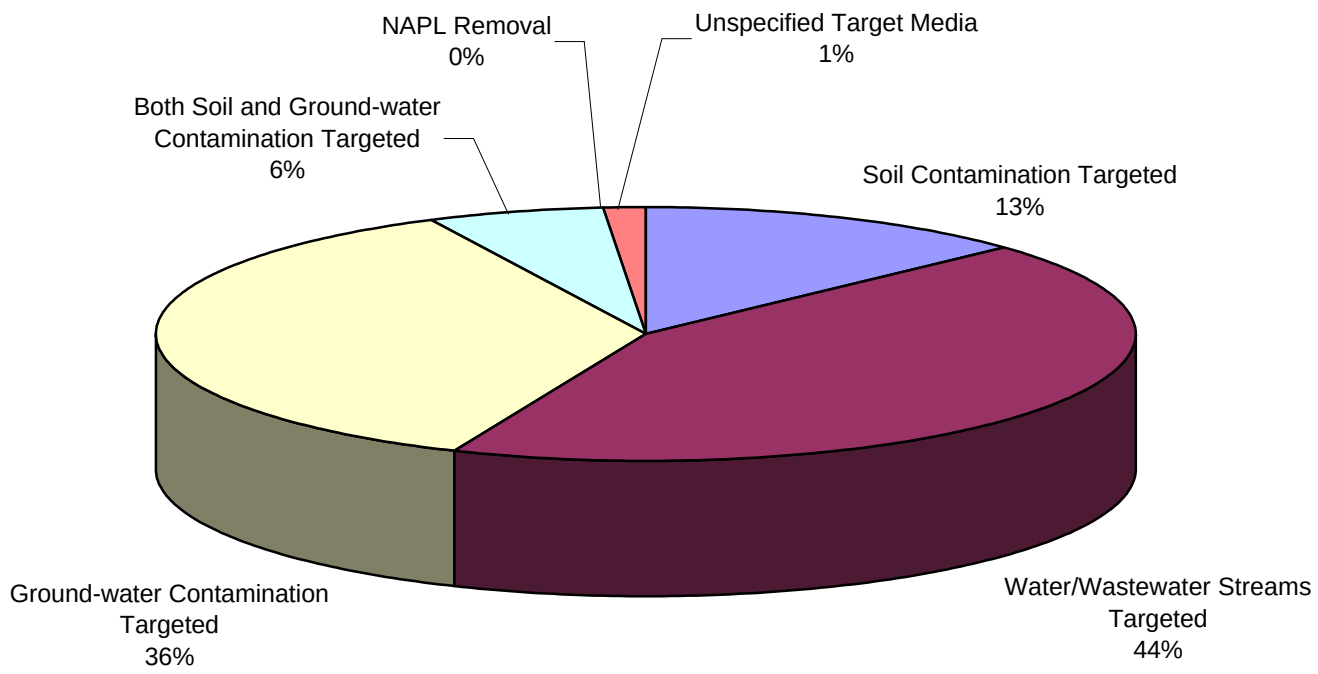
**Figure 3. Perchlorate Treatment Technologies - Project Objectives**
(May Include More than One Objective per Case Study)




Total Number of Case Studies = 65

Number of Responses on which Percentage Labels is Based = 104

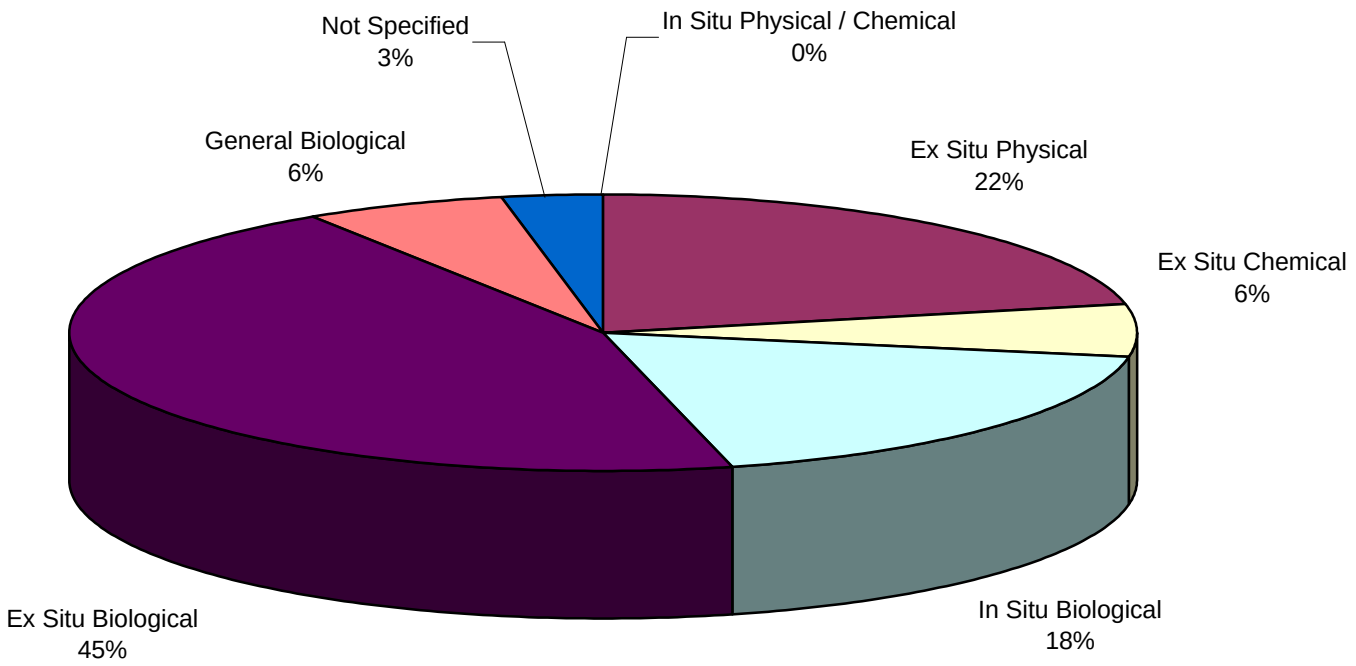
**Figure 4. Perchlorate Treatment Technologies - Environmental Media Targeted**
(May Include More than One Target Media per Case Study)




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)

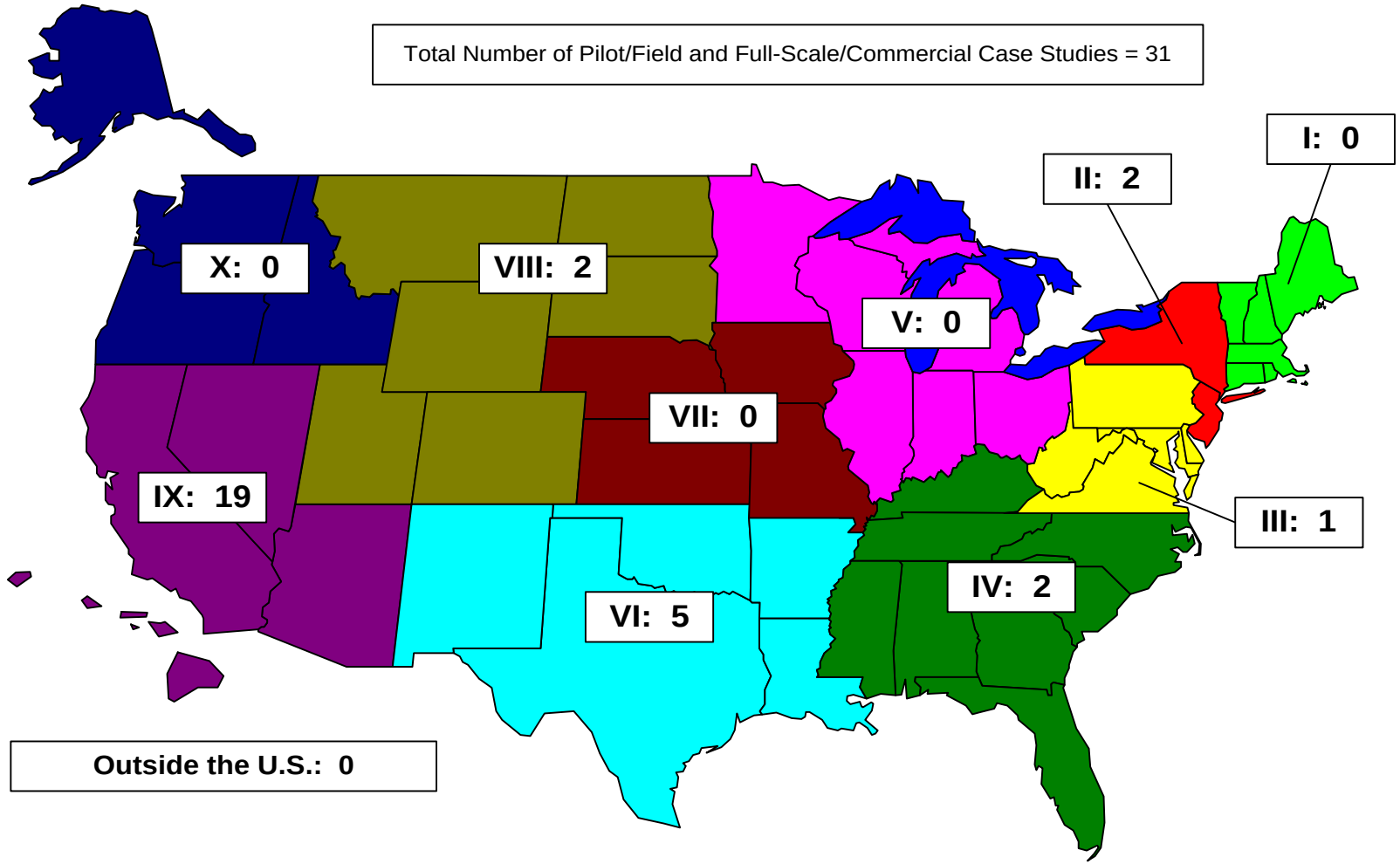
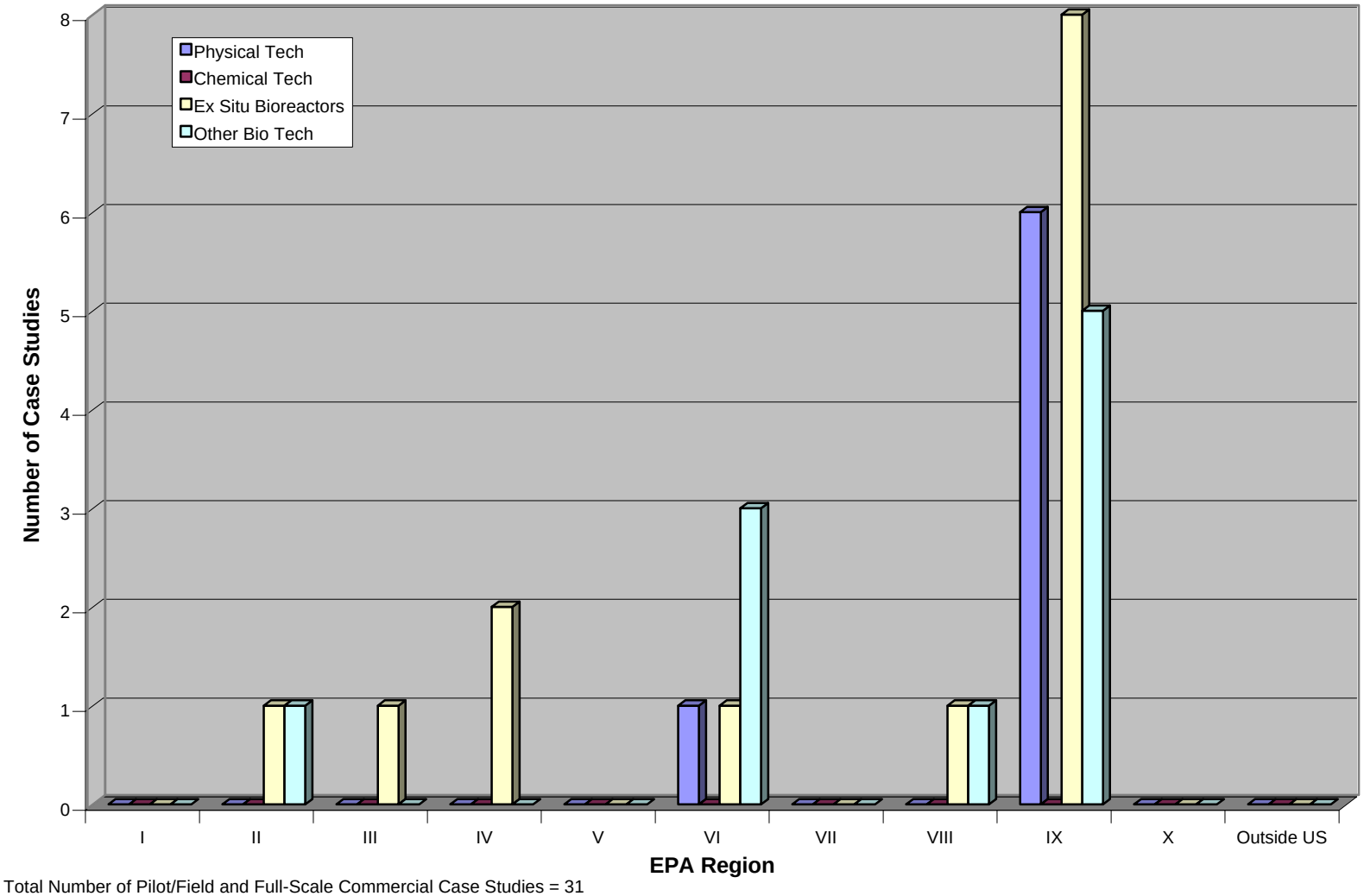


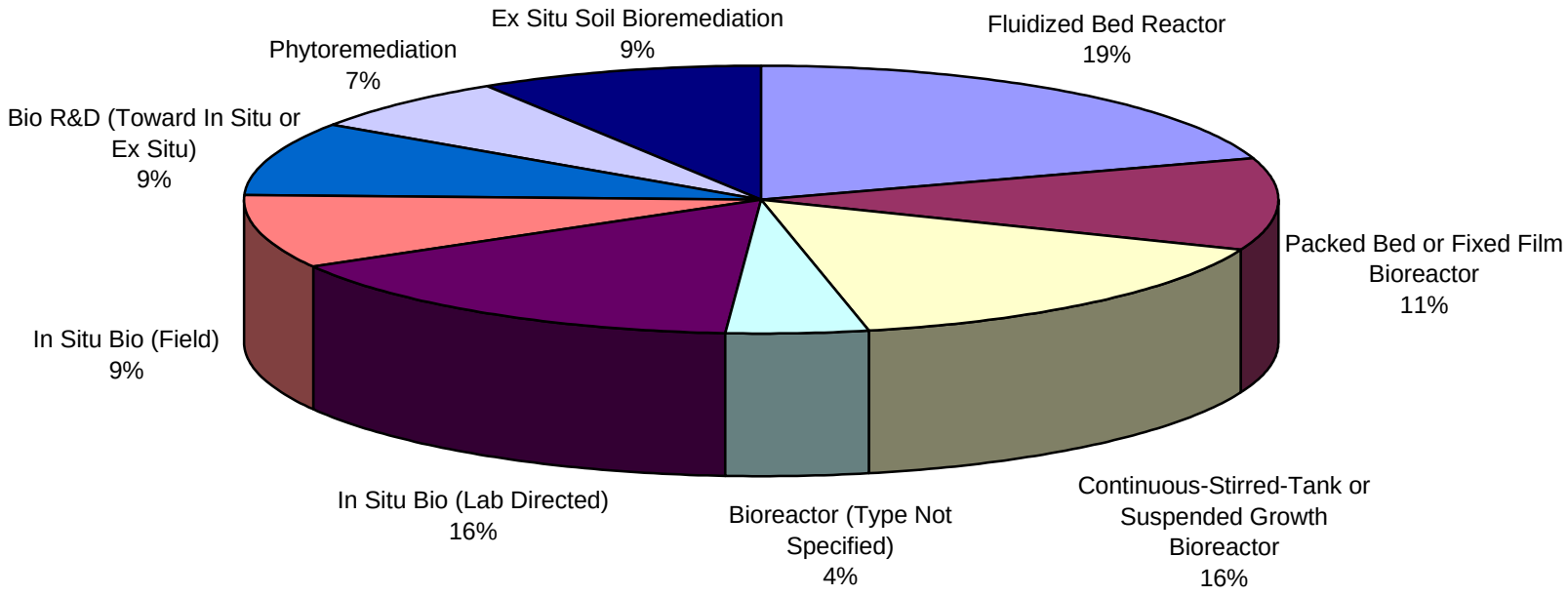
**Figure 7. Perchlorate Treatment Technologies - Distribution of Case Studies by EPA Region and General Technology Type**

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



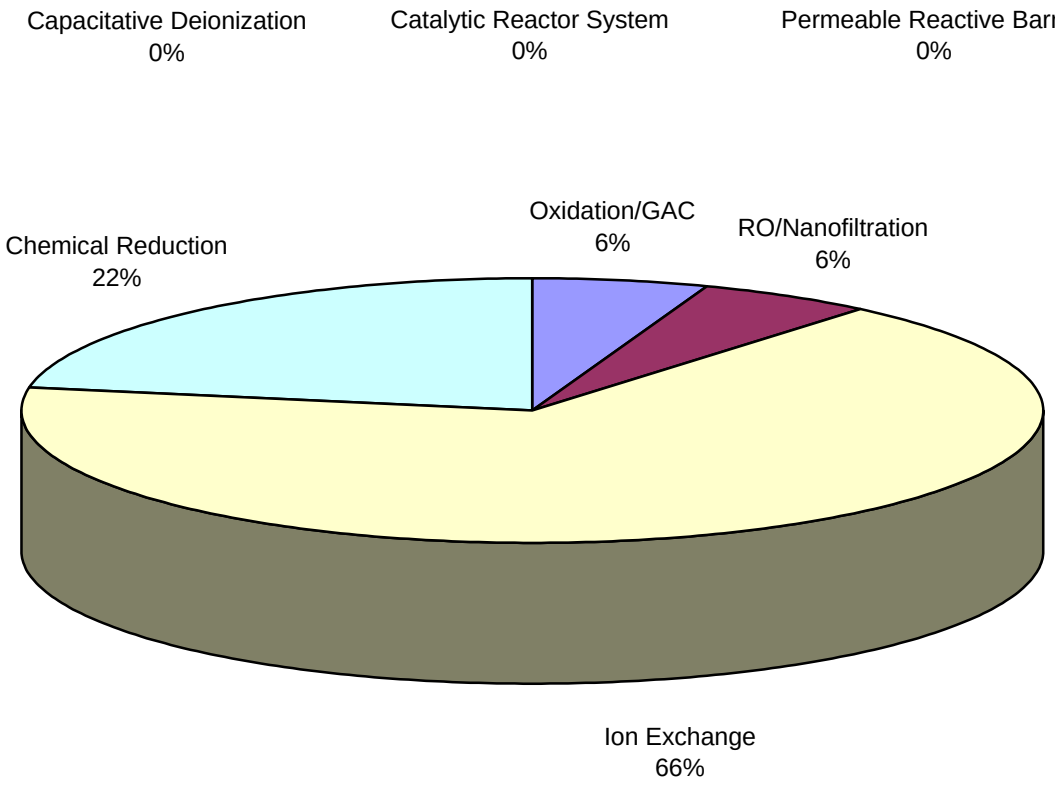

Total Number of Pilot/Field and Full-Scale Commercial Case Studies = 31

**Figure 8. Perchlorate Treatment Technologies - Biological Technology Type**



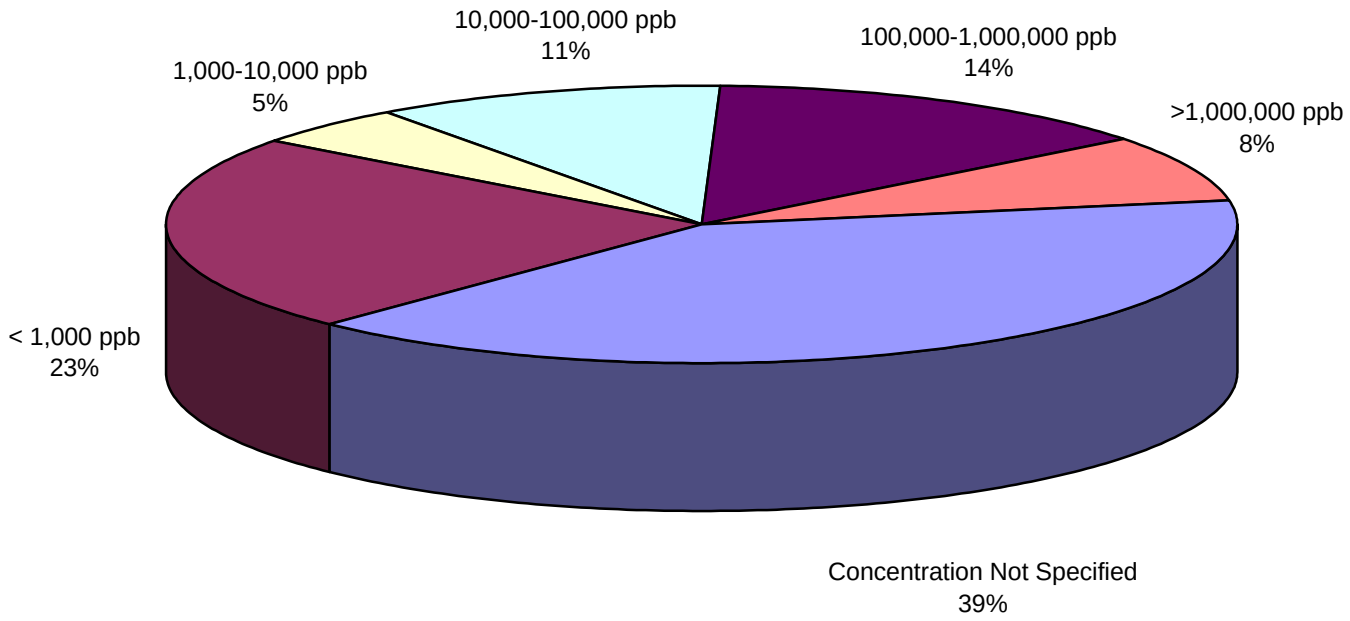

Total Number of Biological Case Studies = 45

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



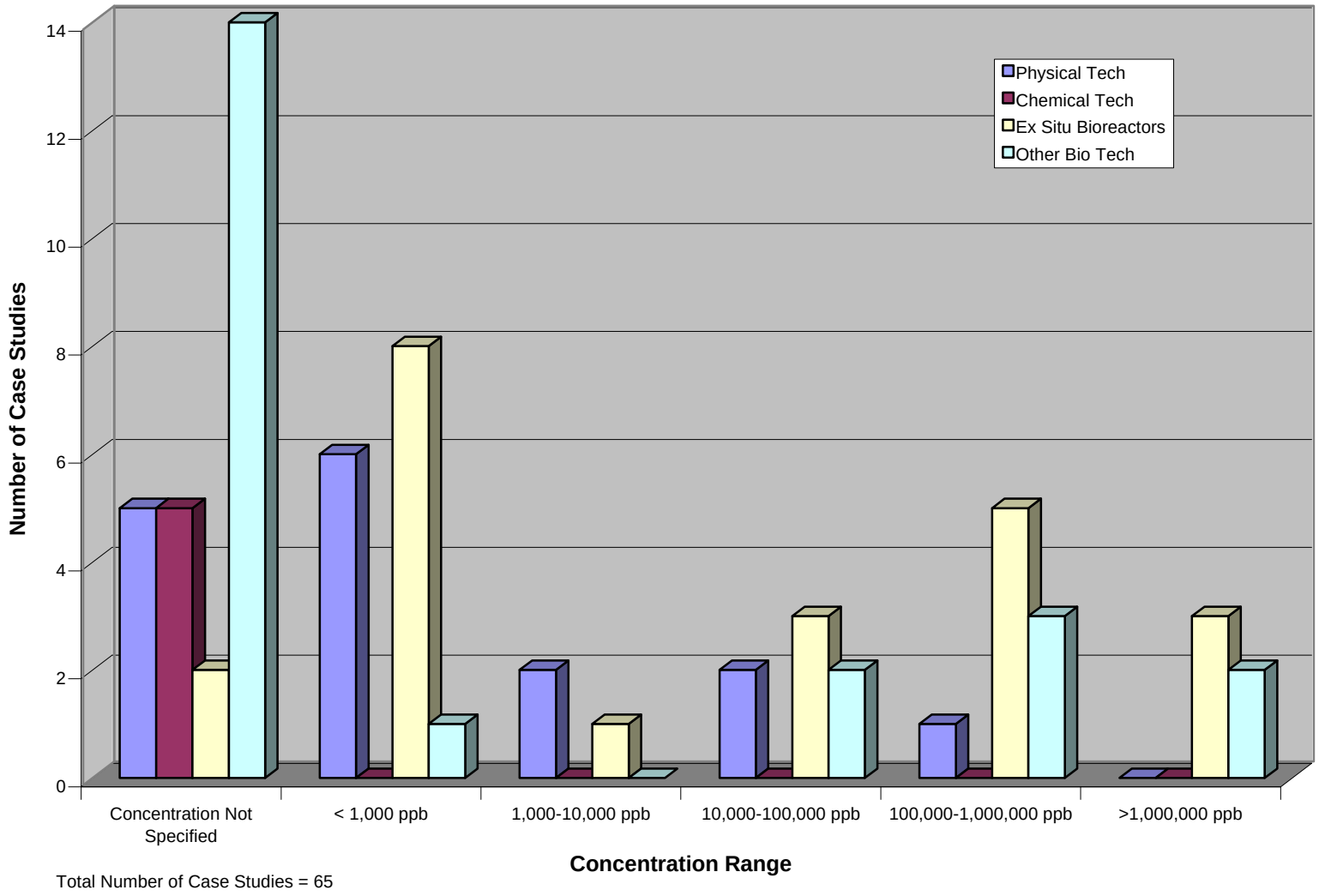

Total Number of Physical/Chemical Case Studies = 20

**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