

# Perchlorate White Paper

## Introduction

Perchlorate is an inorganic chemical compound consisting of chlorine bonded to four oxygen atoms ( $\text{ClO}_4^-$ ) and is usually found as the anion component of a salt most often associated with either of these common cations: ammonium ( $\text{NH}_4^+$ ), sodium ( $\text{Na}^+$ ), or potassium ( $\text{K}^+$ ). A number of modern commercial explosives products may contain sodium perchlorate, ammonium perchlorate, or potassium perchlorate as a sensitizing agent or as a substance that is used in balancing fuel:oxygen blends.

Although perchlorate compounds were known to the commercial explosives industry prior to 1950, their use was limited due to availability and cost until governmental agencies started using substantial quantities for use as propellants. Because the cost of perchlorates are relatively high when compared to other chemicals used in the commercial explosive industry, perchlorates are incorporated into a limited number of explosive products when their unique characteristics are desired.

In recent years, sensitive analytical methods have been developed to detect perchlorate in water or food. At this time, the Environmental Protection Agency's ("EPA") Method 314 is accepted within the scientific community as having a minimum reporting level of 4 ppb and an MDL (detection) of 1 ppb. However, samples with high ionic strength impact the reliability and accuracy of this method. Contract laboratories and remediation experts recommend the use of other analytical methods such as IC-ESI-MS or LC-MS-MS if other ionic compounds or moderate total dissolved solids are present. This is of particular concern to the explosives industry if samples are taken from facility and field locations.<sup>1</sup>

In January 2005, the National Academies of Science ("NAS") released a report that established a peer reviewed reference dose for perchlorate at 0.0007 milligram per kilogram of body weight per day (mg/kg/day) without adversely affecting health. The academies' Committee to Assess the Health Implications of Perchlorate Ingestion concluded that the public, even the most sensitive populations, could ingest this amount of perchlorate through drinking water, food, and other sources every day for a lifetime and be safe.

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<sup>1</sup> Numerous documented cases demonstrate that use of Method 314.0 has resulted in the reporting of false positives and falsely elevated results. Additionally, the method has been used as the basis for laboratories reporting to sub-part per billion (ppb) levels despite the method's documented capability of 4.0  $\mu\text{g}/\text{L}$  (equivalent to ppb). Because of the known limitations of Method 314.0, EPA is revising the method.

On February 18, 2005 EPA, adopting the NAS report, established an official reference dose (RfD) of 0.0007 mg/kg/day of perchlorate. EPA's reference dose, which assumes total intake from both water and food sources, is deemed by the agency to be appropriate and protective for all populations, including the most sensitive subgroups. The selected reference dose contains a full ten-fold uncertainty factor to protect the most sensitive population, the fetuses of pregnant women who might have hypothyroidism or iodide deficiency. This uncertainty factor also covers variability among other human life stages, gender and individual sensitivities, protecting not only adults, but also other sensitive subpopulations such as premature neonates, infants and developing children. Using an accepted EPA calculation, the new RfD translates to a Drinking Water Equivalent Level (DWEL) of 24.5 ppb. A Drinking Water Equivalent Level, which assumes that all of a contaminant comes from drinking water, is the concentration of a contaminant in drinking water that will have no adverse effect with a margin of safety. Because there is a margin of safety built into the RfD and the DWEL, exposures above the DWEL are not necessarily considered unsafe. EPA's Superfund cleanup program plans to issue guidance based on the new RfD.

## Use of Perchlorate Compounds in Commercial Explosives

In 2002 approximately 2.51 million metric tons of explosives of all types were produced in the U.S. Coal mining consumed the greatest quantity of explosives at 68% of production, followed by quarrying and non-metal mining at 13%, metal mining at 8%, construction at 8%, and miscellaneous (pyrotechnics, demolition, avalanche control, etc) at 3% (Kramer, 2003

<http://minerals.usgs.gov/minerals/pubs/commodity/explosives/explomyb03.pdf>). These figures represent overall U.S. explosives production. What percentage of explosives products included in this total figure contain perchlorate is unknown. The quantity of perchlorate-containing explosives imported into the U.S. also is unknown. Demilitarized explosives may be used by the commercial sector. See, *Application of Demilitarized Gun & Rock Propellants in Commercial Explosives* (ISEE, 2004). However, it is unknown whether any of the demilitarized explosives mentioned in the report are/were actually recycled in the U.S. or whether any of these explosives contained perchlorate.

The use of perchlorate-containing blasting agents is limited. As noted above, perchlorate-containing commercial explosives and blasting agents are used in specialized high pressure, high energy applications. These products are manufactured and used specifically as an alternative to nitroglycerin (NG) based explosives products. Accordingly, given that NG-based explosives make up approximately 0.4% of the total commercial explosives market in the U.S., the perchlorate-based commercial explosives market can reasonably be projected to be even smaller.

Perchlorate-containing compounds can be found within a limited number of explosive products as either a naturally occurring contaminant (Chilean nitrate), or as a compound that was selected for incorporation into a particular product. Recently reviewed

information reveals that sodium chlorate is known to contain traces of the perchlorate anion; however, it was found through a polling of commercial explosive manufacturers that the last known use for sodium chlorate in the U.S. dates back greater than 75 years and appears to have been limited to primer formulations in blasting caps (detonators).

Chilean nitrate has been in global commerce since at least late-1800 for use as fertilizer, for saltpeter used in gunpowder, and as a feedstock for the production of nitric acid, explosives, and other end products. Recent studies performed by EPA, indicate that Chilean nitrate contains perchlorate at a concentration of between 500 to 2000 parts per million (EPA, 2000). At the present time, Chilean nitrate is the preferred source of sodium nitrate due to its affordability and handling characteristics; however, manufacturers of commercial explosives are studying other sources of sodium nitrate to determine if Chilean nitrate can be replaced. Currently, dynamites and a limited number of water gels and emulsions requiring the use of sodium nitrate may contain part per million levels of the perchlorate anion. The amount of the perchlorate anion present in the particular products that use Chilean nitrate is quite small. Accordingly, it is unlikely that these products, which would contain < 0.1% perchlorate, could detrimentally impact potable drinking water.

Delay powders used in detonator manufacturing may contain a small amount of potassium perchlorate (KClO<sub>4</sub>) in the delay mixture. In the manufacturing process, delay powder is pressed into place under significant pressure and encapsulated in a tube of metal inside a sealed aluminum shell. Delay powders are fuel rich. Consequently, once the powder is ignited the ensuing reaction favors the consumption of the potassium perchlorate. Post-detonation residual material is the balance of unreacted fuel and potassium chloride (low sodium table salt).

Most commercial detonators are manufactured to withstand significant water pressure without leakage. The integrity, configuration, and function of detonators coupled with the diminutive quantity of potassium perchlorate used in a detonator make it extremely unlikely that the use of detonators would create or be associated with the contamination of any potential source of potable water.

Generally, perchlorates are added to small-diameter high-energy packaged products, which are used in trenching, utility work, mining, and some construction activities. Perchlorates may also be used in seismic explosives products. These emulsion or water gel explosives may include sodium perchlorate to increase shock initiation sensitivity – the ease with which the product can be detonated by external shock (propagation and air gap sensitivity within a borehole as opposed to sympathetic detonation between boreholes). These types of explosives can be used in wet-hole conditions or below the water table and retain their explosive characteristics after being submerged for weeks or even months. (ISEE Blaster's Handbook) It is important to note, however, that the volume of products sensitized with perchlorates, when compared to the total volume of commercial explosives, is extremely small. Perchlorates are primarily used as the sensitizer of choice when a finished explosive product is designed for difficult blasting applications and/or those requiring high energy.

Given the physical properties of water gels and emulsions described above, it is not surprising that a blaster will often choose to use these water-resistant products when wet conditions are encountered. However, the particular sensitizing agent used in a water gel or emulsion is unrelated to the products' water resistance properties. Rather, the selection of an appropriate explosive (and sensitizing agent) is determined (in part) by the resilience that will be required to compensate for the dynamic and/or static pressures encountered in the blast area. Excessive dynamic and static pressures can be encountered in either wet or dry conditions. For example, in certain instances, water-saturated ground can create an environment where the dynamic and static pressure waves created by column pressure and sequential (timed) blasting can damage and reduce the sensitivity of an explosive. The pressures encountered in this situation act to compress or destroy the gas or microballoons that are the standard sensitization mechanism for water gels and emulsions. In such applications, perchlorates have been found particularly effective in maintaining the sensitivity of the explosive, even if some of the primary sensitizing microballoons are destroyed.

Perchlorate-containing explosives typically have a high density (i.e., they sink in water) and a high explosive energy (on volume basis) making them suitable for either wet/hard/dense rock blasting applications, or in general blasting applications to expand drilling patterns or to address excessive rock burdens. Additional situations where high energy and high explosive distribution characteristics are appropriate may include, but are not limited to, tight underground cuts (e.g., tunnel construction), tight trenching applications (2/3 or 3/3 patterns), high pre-compression conditions, deep wet trenches, and deep wet boreholes.

It is interesting to note, however, that the very properties that make water gels and emulsions appropriate for wet conditions are those properties that limit the release of perchlorate (or any other chemicals) into groundwater. The binding of the perchlorate in the emulsion or the gel matrix provides an effective barrier to water. The rheology of emulsions or gels further contributes to the retention of perchlorate by maintaining its integrity in the borehole. Lastly, perchlorate-containing products are delivered as packaged products. Provided that the integrity of the packaging remain intact, the packaging material prevents diffusion and dissolution of the explosive.

## Manufacturing of Explosives Containing Perchlorate Compounds

Currently, most commercial explosives manufacturers making perchlorate-containing products purchase perchlorate from third party chemical manufacturers. Perchlorate containing compounds are sold as either a dry or liquid product. During the manufacture of dry products, perchlorate crystals are precipitated from the solution and then dried and screened to produce a homogeneous granular product that is shipped in sacks and drums. In addition, sodium perchlorate, ammonium perchlorate and potassium perchlorate can be manufactured in liquid form as a concentrated water-based solution. These products generally are delivered via tanker truck.

To help prevent the release of perchlorate containing compounds at an explosives manufacturing site, best management practices (BMPs) should be developed and implemented. BMPs can be designed to be general in nature, or industry and/or site-specific. Examples of BMPs that can be/are used to address perchlorate include spill contingency plans, secondary containment, waterproof storage, and treatment of waste streams where necessary. If wastewater is generated at a manufacturing facility, a recommended management practice is reuse of the wastewater within the manufacturing process creating a zero discharge facility. When the liquid forms of perchlorate containing compounds are stored, used, and transported, properly developed and implemented BMPs are especially important.

As noted above, perchlorate raw materials can be received from a manufacturer in liquid or solid form. Liquid perchlorate solution commonly is delivered in tankers and is stored in aboveground tanks equipped with secondary containment. Perchlorate in solid form may be delivered in “super-sacks” or bags and typically is stored on pallets within buildings constructed with concrete floors. Perchlorate may also be supplied in drums. Perchlorate containing materials, like all oxidizers, are stored separately from potential fuels such as wood, oil, grease, etc in structures that also provide isolation from the environment. Perchlorate salts and solutions are very corrosive to steel, and degrade fiberglass and concrete. Measures should be taken ensure that storage vessels, piping, and secondary containment are protected against corrosion. In addition, measures should be taken to minimize the generation of dust during pouring/transfer operations of perchlorate in the solid form; any accumulation of perchlorate dust should be promptly cleaned up.

Some commercial explosives manufacturing facilities in operation today are equipped to ensure zero discharge of perchlorate wastewater. At these facilities, all wash water is captured and used in production while impacted containers are rinsed to remove all perchlorate before being disposed. A number of facilities capture and recycle all residual perchlorate solids into new product. At still other facilities, containers used to store perchlorates are rinsed and the resultant wastewater is sent to a POTW. Incineration at a RCRA Treatment Storage or Disposal Facility (TSDF) is another, albeit expensive, disposal option for any perchlorate wastes.

Explosives ready for use are stored in regulated, specially designed magazines either on or off site. There is little risk of release from packaged explosives where these are stored unless carelessness results in packaging puncture with subsequent leakage.

## Description and Field Use of Explosives Containing Perchlorate Compounds

The minimal quantity of perchlorates used in commercial explosives and blasting agents is unlikely to pose a significant threat to the environmental quality of the area in which such explosives are used.

In theory, explosives products that are properly detonated should result in the attachment of the chlorine molecule to either a sodium or potassium molecule to form the salts NaCl

or KCl chloride. Accordingly, even in a less than optimal detonation, only a negligible quantity of residual unconverted perchlorates should remain after the blast. However, no studies of residuals from either fully successful explosives detonations or misfire/incomplete detonations exist to support a hypothesis of 100% efficiency and, in practice, it is likely that some detectable residue of perchlorate will remain following detonation (assuming a 1ppb detection capability).

Any significant perchlorate contamination directly associated with blasting is more likely attributable to pre-blast loss of product such as improper spill cleanup, or misfires (Misfires are a serious safety concern at a blast site and inordinate care is taken to avoid their occurrence. Consequently, misfires are relatively infrequent. When misfires do occur, the situation is immediately addressed by the blaster to eliminate any potential hazards, including environmental hazards, posed by the situation).

It is important to recognize that the reaction chemistry involved in a detonation differs dramatically from the effects associated with the burning of perchlorates (e.g., in OB/OD units). While burning or deflagration activities have been known to leave residual perchlorate, the detonation of perchlorate-containing materials is an extremely efficient reaction.

The potential to contaminate surface or groundwater with the substances used in commercial explosives can be controlled through the implementation of certain measures. The IME document *Blasting; Best Practices* describes such measures (see Appendix).

## Perchlorate in Groundwater

As a salt, perchlorate exhibits the characteristics of high solubility and mobility in water as well as being very stable. These characteristics lead to the formation of long and persistent contaminant plumes when released into either ground water or surface water. The movement of perchlorate in soil is largely a function of the amount of water present. Perchlorate does not bind to soil particles. Perchlorate salts that are released to the soil in solid form will readily dissolve in whatever moisture is available. If sufficient infiltration occurs, the perchlorate will be completely leached from the soil. Soil moisture containing perchlorate in solution, can be taken up by plants through the roots and several ecological studies have demonstrated the tendency of some plants to concentrate the perchlorate in plant tissues. Some perchlorate may be held in solution in the vadose zone by capillary forces. In arid regions, crystallized perchlorate salts may accumulate at various horizons in the soil due to evaporation of infiltrating rainfall that leaches perchlorate from shallower depths.<sup>2</sup>

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<sup>2</sup> Best, E. P. H., S. L. Sprecher, S. L. Larson, and H. L. Fredrickson. 1998. *Environmental Behavior and Fate of Explosives from Groundwater from the Milan Army Ammunition Plant in Aquatic and Wetland Plants: Fate of TNT and RDX*. SFIM-AEC-ET-CR-97060. Prepared for the U.S. Army Environmental Center by the U.S. Army Engineer Waterways Experiment Station, Environmental Laboratory, Vicksburg, Miss.

In dilute concentrations typically found in groundwater, perchlorate behaves conservatively, with the center of mass of the plume moving at the same average velocity as the water. Dispersion will result in the contaminant front actually moving faster than the average groundwater velocity. Perchlorate is kinetically very stable under environmental conditions and will not react or degrade in solution under ambient conditions. Biodegradation of perchlorate in groundwater will not occur unless significant levels of organic carbon are present, oxygen and nitrate are depleted, and perchlorate-degrading anaerobic bacteria are present.

The measures that may be taken to protect nearby aquatic ecosystems or potable water sources is dependent upon having a reasonable estimate of the total amount of perchlorate that could potentially be released into the environment. At this time, the ecological impact of perchlorate is not well known, and as such, it is premature to speculate what measures, if any, might be appropriate. In addition, measures to abate perchlorate will be influenced by a number of factors, including rainfall and irrigation, dilution, natural attenuation, soil adsorption, and bioavailability.

Several states have regulations that have, or soon will have, established a cleanup goal for perchlorate. The recently issued NAS report and EPA RfD appears to have provided a cleanup goal for perchlorate at 24.5 ppb for sources of drinking water. The measures that are eventually implemented at a particular location to abate perchlorate impact will have to account for this extremely low cleanup goal.

In recent years, sensitive analytical methods to detect perchlorate in water or food have been developed. In 1997, the California Department of Health Services developed a sensitive method with a minimum detection limit (MDL) of < 1ppb and a minimum reporting level (MRL) of 4 ppb. By 1999, additional improvements to the method helped to establish EPA's Method 314, and the agency required its use for the analysis of perchlorate by the unregulated contaminant monitoring rule (UCMR), which also set the MRL at 4 ppb. However, samples with high ionic strength impact the reliability and accuracy of this method. Contract laboratories and remediation experts recommend the use of other analytical methods if other ionic compounds or moderate total dissolved solids are present. This is of particular concern to the explosives industry if samples are taken from facility and field locations.

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Smith, P.N., C. W. Theodorakis, T. A. Anderson, and R. J. Kendall. 2001. "Preliminary Assessment of Perchlorate in Ecological Receptors at the Longhorn Army Ammunition Plant (LHAAP), Karnack, Texas," *Ecotoxicology* **10**: 305–13.

Smith, P. N., L. Yu, S. T. McMurray, and T. A. Anderson. 2004. "Perchlorate in Water, Soil, Vegetation, and Rodents Collected from the Las Vegas Wash, Nevada, USA," *Environmental Pollution* **132**: 121–27.

The scientific community's desire to achieve lower minimum detection limits has resulted in more advanced techniques, such as the coupling of ion exchange chromatography with electrospray ionization mass spectrometry (IC-ESI-MS), and liquid chromatography coupled with tandem mass spectrometry (LC-MS-MS). These methods are more sensitive and the use of MS improves specificity, but instrumentation is expensive and therefore is not widely available. An evaluation study performed by Los Alamos during November 2001 found the MDL to be 0.05 ppb and the PQL to be 0.20 ppb using LC-MS-MS. Thus, although method 314 appears to be acceptable for most drinking water sources, in certain locations natural constituents in the groundwater may require more sophisticated instrumentation.

Since the potential for perchlorate impacts began receiving attention in the 1990s, the USGS has undertaken various analytical studies of samples from likely perchlorate containing geological formations in the southwestern U.S. These include playas, caliche-containing soils, dry lakebeds, and evaporite deposits. The initial test areas included samples from California, Utah, Nevada, Arizona, and New Mexico. Although USGS studies are ongoing, preliminary analytical results reveal that perchlorate appears to be naturally present in geological terrain where evapotranspiration greatly exceeds precipitation. In the initial round of sampling, more than 90 percent of the samples had detectable perchlorate, some at low concentrations and others involving sylvite potash deposits with perchlorate values up to 489 ppm (USGS Reports). Further USGS studies to verify and to expand possible areas are in progress.

It is important to keep in mind that perchlorate impacts may, or may not, be associated with explosive products given that there are naturally occurring sources, and that perchlorate is a commonly used chemical with commercial, industrial, and agricultural applications. Such general uses include, but are not limited to the following:

- Production of matches
- Air bag initiators for vehicles
- Nuclear Laboratories in actinide research
- Chemical Laboratories in analytical testing, desiccant, oxidizing agent, and digestion (perchloric acid)
- Engine oil testing to determine base number (BN) ASTM D2896
- Some electroplating operations
- Electro-machining, sodium perchlorate solution
- Electropolishing operations with perchloric acid
- Lithium-magnesium dioxide batteries as part of electrolyte
- Rare earth extractive metallurgy using perchloric acid
- Etching brass and copper with perchloric acid
- Paints and enamels
- Leather tanning extraction of chromium using perchloric acid
- Bleaching agent to destroy dyes
- Incidental ingredient/intermediate in leaching and disinfection agents used in waste water treatment
- Photography as flash powder



- Incidental byproduct in some sodium chlorate, which itself has many uses, including weed killer or herbicide and defoliant in agriculture and as chemical building block
- Incidental ingredient in fertilizers (largely historical, but soils previously treated may still contain perchlorate)
- Oxygen generators
- Road flares
- Ejection seats
- Propellant in model rocket engines
- Propellant in rockets used for research, satellite launches, and Space Shuttle
- Fireworks
- Perchloric acid production and its many uses

In addition, perchloric acid and perchlorates have the following specific commercial uses:

- Perchloric acid as catalyst in broad range of diverse reactions: acetylations, acylations, alkylations, chlorinations, polymerizations, esterifications, and hydrolyses
- Esterifications of cellulose to produce cellulose acetate
- Polymerizations of phenols with formaldehyde
- Polymerization of styrene
- Electrolytic solutions for the purpose of electropolishing, electromachining, and electrothining of metal parts, films, and alloys
- Perchloric acid employed as electrolyte in anodization of metals to produce non-corroding surfaces
- Pickling and passivation of iron and steels
- Dissolving refractory substances such as titanium slags, copper-yttrium oxide and metal fluorides
- Lithium perchlorate as an electrolyte in voltaic cells and batteries involving lithium or lithiated anodes, non-aqueous solvents or polymeric films, and manganese dioxide or other transition metal oxides
- In non-aqueous systems, zinc perchlorate and magnesium perchlorate serve as electrolyte for zinc and magnesium batteries, respectively
- Perchlorate salts serve as electrolytes in electropolymerization reactions involving monomers such as aniline, benzidine, azulene, biphenyl, divinylbenzene, and indole
- As aqueous electrolytes perchlorates are found in electrochromic devices and employed for anodic dissolution of difficultly oxidizable metals, such as lead and palladium
- Perchlorate salts as dopants in plastics and polymers to impart antistatic and conductive properties
- Perchlorate salts as dopants in polyvinyl chloride (PVC) to improve heat stability and fire retardation characteristics
- Lithium perchlorate as dopant in thin films of polymers such as polyethylene oxide (PEO), polyethylene glycol, or poly (vinylpyridine) to impart conductive properties in various electrochemical devices
- Anhydrous magnesium perchlorate as a desiccant or drying agent for industrial gases and other similar applications
- Determine the trace metals present in oxidizable substances
- As a laboratory reagent
- As an oxidizing agent
- For the destruction of organic matter

- As a dehydrating agent
- Starting material for the manufacture of pure ammonium perchlorate and in the production of high purity metal perchlorates
- As a stable reaction medium in the thermocatalytic production of chlorine dioxide
- As an acetylation catalyst for cellulose and glucose
- In the preparation of cellulose fibers
- For fluoride determination
- As an ingredient of electrolytic bath in deposition of lead
- In the electropolishing of metals

Moreover, there are several naturally occurring sources of perchlorate of which users should be made aware:

- Some Brines and Sedimentary Ores Associated with Mixed Marine and Non-Marine Evaporites
- Bromine
- Boron and Borates
- Gypsum and Anhydrite
- Nitrogen Compounds
- Potash
- Iodine
- Sodium Sulfate
- Sedimentary Phosphate

Perchlorate contamination may also be associated with landfill operations where perchlorate-containing materials have been disposed over time. Leachate from such landfills could have groundwater impacts.

Given the numerous potential sources that could lead to perchlorate contamination, it is important to consider the following prior to implicating explosive products as a potential cause:

- Past practices allowed at the mine by the owner/operators may have allowed the introduction of other perchlorate containing materials. A listing of other potential perchlorate containing materials should be developed and assessed.
- Groundwater chemistry within the area of concern should be studied and assessed. Having an understanding of the other anions and cations within the groundwater assists in determining if the groundwater located within one area is similar or different from groundwater located at a different area. Depicting such information in diagrams, such as Stiff Diagrams, help to compare and contrast groundwater samples.
- Isotope studies can be helpful in determining if the source of contamination is naturally occurring or manmade. For perchlorate, both the oxygen and chlorine

isotopes should be assessed, and for nitrate the nitrogen isotopes. Isotope studies can also assist in determining if different sources are commingling.

- Groundwater flow and contaminate concentration patterns within the area of concern must be well known in order to provide a nexus between source(s) and endpoint(s). The development of potentiometric maps indicating groundwater flow, and isoconcentration maps indicating the aerial extent of particular contaminants are helpful tools in assessing the source, nature and extent of contamination. To assist in resolving outstanding questions or the need for additional supporting documentation, instrumentation such as in-situ flow direction meters can be helpful and cost effective.

## Appendix

### **Blasting; Best Practices**

The potential to impact surface or groundwater with the substances used in commercial explosives can be controlled through the implementation of certain measures. Implementing such measures as part of a standard operating procedure will eliminate or minimize the potential for these substances to dissolve in or become associated with water. The specific measures included can be grouped into the following four (4) basic categories:

1. Education/Training of Explosive Users
2. Selection of Appropriate Explosives for the Job and Conditions
3. Explosives Loading and Handling
4. Attention to Technical Matters

#### 1. Education/Training of Explosive Users

Both the owners/operators of the location where explosives are being used and the personnel working with commercial explosives should be well informed of all applicable regulations as well as any potential consequences associated with the products' exposure to water. The federal Clean Water Act, or the equivalent state statute, regulates the release of substances, in particular those that can cause an undue risk to human health or the environment. In addition, the Resource Conservation and Recovery Act, governs the disposal of hazardous wastes.

#### 2. Selection of Appropriate Explosive for the Job and Conditions

Selecting the proper explosive for the particular job is critical to the prevention of surface or groundwater impact.

- ANFO (ammonium nitrate - fuel oil) is not water-resistant and should be avoided if contact with water is likely.
- Various types of commercial explosives are available to withstand exposure to water. Water-resistant explosives include the cartridge forms of gelatinous nitroglycerin, watergels and emulsions and the bulk forms of emulsions which are: 1) Site Mixed Emulsion (ammonium nitrate - fuel oil - emulsifier) is a water-resistant explosive, semi-solid. This is manufactured on site and detonated while still warm assuring complete detonation. 2) Repump Emulsion (ammonium nitrate - fuel oil - emulsifier) is a water-resistant explosive, semi solid, manufactured off site, transported and pumped into the borehole as needed.

#### 3. Explosives Loading and Handling

- All excess product in augers or hoses is to be recovered and used either in the next blasthole or recycled in the mixer/holding tank.
- Explosive spillage around the blasthole collar is to be controlled and any such spillage should be placed into the blasthole before stemming

- Water contacting explosives during cleanup is to be contained and managed in accordance with applicable regulations
- Minimize the amount of time that explosives are exposed to wet conditions within the blasthole. The blast should be initiated as near the time the loading is completed as safety and operational procedures allow.
- Avoid having explosives exposed to precipitation.
- To assure complete detonation of explosives placed into the ground, a sufficient number of boosters must be used.

#### 4. Attention to Technical Matters

- The actual physical conditions into which explosives are being placed must be taken into account.
- Personnel responsible for loading explosives into the boreholes should be in continuous communication with the drillers of those boreholes or supplied with adequate drill logs, so that any knowledge regarding fractures, crevices or cavities is obtained.
- Where Bulk ANFO or Emulsion is used in fractured, creviced or cavitied boreholes, plastic borehole sleeves and/or positioned inert stemming decks will be used to ensure total detonation of the explosives and avoidance of excessive charges.
- Choosing and placing the correct drilling patterns that results in the optimal use of explosives with all the explosives undergoing complete detonation.
- Quality assurance/quality control measures to maintain drilling accuracy that prevents the detonation in one blasthole from impacting the proper detonation in a nearby blasthole.
- Selecting the appropriate drilling equipment so that adequate borehole quality is maintained.
- Where appropriate to ensure complete detonation, two (2) primers will be used in each blasthole; one near the top and one near the bottom of the explosive column.
- Correct selection of delay timing for each blasthole to ensure detonation of the entire pattern, and the prevention of cut-off blastholes.