4.0 STUDY DESCRIPTIONS

The development of the CSM and discussions during the February 21, 2002 technical meeting resulted in the identification of a number of high priority data gaps in the current knowledge regarding perchlorate contamination, migration, and fate within the Bosque and Leon River watersheds. Further investigations to resolve or reduce these high priority data gaps were conducted during this study to provide an accurate assessment of perchlorate exposures and risks to human health and the environment.

This chapter summarizes the studies conducted based on these identified high priority data gaps. Data and conclusions resulting from each of these studies are included in Chapter 5.

4.1 WATERSHED

High priority watershed studies that were identified include the following:

- Longitudinal Stream Sampling Studies
- Groundwater Dye Tracer Studies
- Lake Belton Perchlorate Bioreduction Bench-Scale Study
- Lake Belton Acoustic Doppler Current Profiler (ADCP) Study
- Lake Belton and Lake Waco Delta Areas Study
- Continued Intake Sampling

The objectives and methods of these studies are described further in the following subsections.

4.1.1 Longitudinal Stream Sampling Studies

Fifteen automated monitoring stations were installed along streams that discharge to Lake Waco and Lake Belton. Each monitoring station was programmed to collect surface water samples and to measure and record stream level and rainfall data. The overall rationale for the selected monitoring locations was to provide data that can be used to evaluate the perchlorate concentrations and associated flow rates entering Lake Waco and Lake Belton. The elements of the Longitudinal Stream Sampling Study include:

- Longitudinal surface water level/flow measurements within Harris Creek, Station Creek, Onion Creek, Tributary M, Cowhouse Creek, South Bosque River, Middle Bosque River and the Leon River.
- Longitudinal surface water sampling on Harris Creek, Station Creek, Onion Creek, Tributary M, Cowhouse Creek, South Bosque River, Middle Bosque River and the Leon River.
- Rainfall measurements within the study area.

- Installation of monitoring wells in close proximity to the stream sampling locations in order to collect groundwater elevation (water level) measurements.

4.1.2 Groundwater Dye Tracer Studies

The primary objective of the groundwater tracing activities was to confirm the hydraulic connection between shallow groundwater and the surface water in Station Creek, Onion Creek, Tributary M, Leon River, Harris Creek, South Bosque River, and the Middle Bosque River. The study plan included performing semi-quantitative groundwater dye-tracer tests at selected monitoring stations that were established during the Longitudinal Stream Sampling Study phase of the study.

The groundwater dye-tracer tests were considered to be semi-quantitative given the use of a fluorometer to confirm recovery of the injected dye. A fluorometer is capable of detecting dye concentrations several orders of magnitude lower than what can be detected visually. However, the varying concentrations of dye that pass a specific monitoring site during a given period of time would not have been precisely quantified during this field program.

As with all of the other field program components of this study, the planning phase of the dye tracer investigation involved the establishment of data quality objectives (DQOs). DQOs were developed using the seven-step process as outlined in the *Guidance for the Data Quality Objectives Process* (USEPA, 1994) and additional guidance as provided in *Data Quality Objectives for Hazardous Waste Site Investigations* (USEPA, 2000). After preparing the DQOs and reviewing the initial stream level and groundwater level data from the Longitudinal Stream Sampling monitoring stations, it was determined that the objectives of the groundwater dye tracer study could be substantially met using data from the longitudinal stream sampling monitoring stations. Further, due to uncertainties inherent in conducting dye tracer studies, the resultant data would not significantly improve the ability to meet the objectives of this phase of the study. Consequently, the project team decided not to perform the dye tracer study.

4.1.3 Lake Belton Perchlorate Bioreduction Bench-Scale Study

This study was conducted to develop a better understanding of the anoxic component of Lake Belton. The elements of the Lake Belton Perchlorate Bioreduction Bench-Scale Study included:

- Collection of lake water and sediment samples from the deepest portions of Lake Belton that likely have been under anoxic conditions for the longest period of time.
- Collection of lake water and sediment samples from shallower portions of Lake Belton where the thermocline is close to the water/sediment interface. These sampling locations close to the thermocline were included to assess natural variability within the water column.

To develop a better understanding of the anoxic component of Lake Belton, a series of microecology experiments were performed to determine the potential for natural perchlorate bioreduction in Lake Belton. These tests explored this potential in both the water column and the sediment at the water/sediment interface.

4.1.4 Lake Belton Acoustic Doppler Current Profiler (ADCP) Study

This study was conducted to better understand lake current changes throughout the year and to ascertain what effect changing flow patterns may have on perchlorate fate and transport within Lake Belton. This study was also performed to determine if preferential flow patterns occur in the lake along the thalweg of the old river channel or other submerged features.

For this study, an ADCP was attached to a boat and used to determine current velocity at 21 transects across Lake Belton. A total of four ADCP measurements were obtained at each transect, one during each season of the year. ADCP measurements were repeated on a seasonal basis in order to better understand lake current changes throughout the year and to ascertain what effect changing flow patterns may have on perchlorate fate and transport. The ADCP survey is limited to Lake Belton based on the assumption that Lake Waco is a well-mixed, homogeneous environment, both because of its shallow configuration and the presence of a mechanical aeration system. The recent raising of the Lake Waco pool by five feet may substantially change its flow and mixing characteristics. Because of the timing of this study, it was not possible to account for this change in the project team's assumptions.

4.1.5 Lake Belton and Lake Waco Delta Areas Study

This study was conducted to evaluate the presence and distribution of perchlorate in water and sediment within the delta areas of Lake Belton and Lake Waco. The elements of the study include:

- Establishment of a 20-point sampling grid on both the Lake Belton and Lake Waco delta areas using global positioning system (GPS).
- Collection of surface water and sediment pore water samples at each grid location on Lake Belton and Lake Waco.
- Collection of algae samples at 10 of the grid locations within the Lake Belton delta area.
- Collection of surface water samples at the Heather Run and Ridgewood Golf Course intakes from Lake Waco.

4.1.6 Intake Sampling

The project team collected monthly samples from the potable water and irrigation intakes located within Lake Waco and Lake Belton and downstream of the Lake Belton dam during the study. Potable water intakes sampled include the Bluebonnet intake, the Bell County Water Control and Improvement District #1 intake, the City of Gatesville intake, the City of Temple intake, and the City of Waco intake. Irrigation intakes sampled include Heather Run, Ridgewood Golf, and Wildflower Country Club.

The intake sampling conducted by the project team was a continuation of sampling at these intakes by the U.S. Navy. The U.S. Navy began collecting monthly surface water samples from these water intakes in March 1999 but decided to end this sampling effort in December 2002. The project team agreed to continue collecting samples at these locations through December 2003 because of the importance of these drinking water supplies to the public. Since the completion of this study, the City of Waco has continued sampling from intakes in Lake Waco.

4.2 ECOLOGICAL

High priority ecological studies that were identified include environmental occurrence and effects studies in plants and animals. A general description of these studies is provided below. Chapter 5 describes the ecological studies conducted by the study team in detail.

4.2.1 Plants

Evaluation of the potential movement of contaminants from water and/or soil to vegetation is critical for determining exposure routes to wildlife and humans. The conditions under which contaminants move from soil/sediment to plants are often initially characterized in the laboratory or greenhouse where the environment is more easily controlled and plant species can be selected for comparative purposes. Subsequent studies often utilize samples collected from the field.

Routes of perchlorate exposure in aquatic environments were identified as a data gap related to conditions within the study area. One possible route of uptake in fish is through the food chain, such as through the consumption of periphyton that have taken up and accumulated perchlorate from the water.

Perchlorate uptake by plants can be viewed as both a possible sequestration and perturbation process of perchlorate from sediments and streams. Terrestrial plants are capable of removing perchlorate from sediments and stream water and translocating it to leaves/fruits/nuts. Aquatic vegetation is capable of uptake directly from bulk stream water. Exposure of organisms through ingestion of plant material may depend on the availability of perchlorate to the plant (seasonal and spatial), distribution within the plant (leaves/fruits/nuts), as well as the length of exposure. The fate of perchlorate in the environment can also be influenced by the potential re-release of perchlorate from vegetation after uptake. As plants senesce (the fall leaf drop), vegetative tissues are returned to the soil/sediment. The return of perchlorate to the soil/sediment may be a beneficial process due to the movement of perchlorate from stable environments (aerated stream water or low carbon deeper sediments) to areas where rapid transformation can occur (top organic rich soil layers). On the other hand, uptake of perchlorate can also be viewed as another mechanism of exposure, especially if bioconcentration occurs in plant material.

An important question in the study area is the potential for wildlife and human exposure to perchlorate through the consumption of contaminated food. The use of irrigation water (surface or groundwater), which may be contaminated with perchlorate, to supply water for gardens is a relevant scenario in the study area. Under this scenario, it is critical to establish the relationship between perchlorate concentrations in irrigation water and perchlorate concentrations in edible vegetation. Laboratory and field investigations on perchlorate uptake into vegetation were conducted to address this exposure pathway.

4.2.2 Animals

Ecological investigations included laboratory and field studies on the aquatic and terrestrial components of the ecosystem.

4.2.2.1 Aquatic

Environmental contamination of water sources primarily occurs near military and industrial installations where perchlorate is handled. In contrast to the health effects data on humans and rodents, little data exist on potential ecological effects of environmental perchlorate contamination. Fish and wildlife are also chronically exposed to perchlorate in areas where such contamination exists.

In order to confirm perchlorate exposure, fish were collected from aquatic environments within the study area and analyzed for the presence of the perchlorate anion. The goals of this effort were to assess the exposure (and potential effects) of perchlorate in fish as well as to assess the exposure potential for perchlorate in humans through the consumption of contaminated fish.

Perchlorate is known to affect thyroid function, causing subsequent hormone disruption and potential perturbations of metabolic activities. Because the mechanism of iodide uptake and thyroid hormone synthesis is essentially identical in all vertebrates, the extensive data set on perchlorate mode of action that has been collected over the last 50-60 years can be used to predict potential affects in wildlife. Frogs (amphibians) are one of the groups at greatest risk, as they require normal thyroid hormone secretion to complete the transformation from tadpole to frog. If tadpoles do not complete this transformation they cannot reproduce. If metamorphosis is delayed, tadpoles are at risk of greater exposure to predators and pond drying. Finally, because metamorphosis is such a robust and dramatic morphological change, the effects of perchlorate can be observed using non-invasive endpoints such as limb emergence, tail resorption, or limb length.

In teleost fish, thyroid hormones promote growth, stimulate early gonadal development, stimulate steroidogenesis, and initiate metamorphosis in many fish. Because of the involvement of thyroid hormone in fitness components such as reproduction, growth, and development, thyroid endocrine disruption could ultimately be manifested at the population, community, or ecosystem level of biological organization. Although the mechanisms by which perchlorate acts on the thyroid have been well established, there is little information on the potential impact of perchlorate in ecologically relevant species. Uptake and depuration kinetics of perchlorate may provide a better understanding of perchlorate fate and effects in fishes, as well as providing information on the doseresponse of perchlorate in the environment. Also, there is little information on tissue distribution of perchlorate in fish.

4.2.2.2 Terrestrial

Small mammals and birds are routinely used as sentinel species to assess environmental exposure to chemicals (movement of chemicals from the environment into organisms) and the possible effects resulting from any exposure. Their utility is often tied directly to their diet, relative small home ranges or foraging areas, and position in the food chain. Thus, many small mammals and birds collected from a specific location can be viewed with confidence as living and feeding in the area of collection. In addition, their position near the bottom of most food chains makes them excellent conduits for chemical movement into top-level mammalian, reptile, and avian predators.

Perchlorate exerts its primary effect on animals by inhibiting uptake of iodide into the thyroid gland. This inhibition of iodide uptake in turn inhibits the production of thyroid hormones that are subsequently sent into the peripheral blood. Therefore, analyzing the concentration of thyroid hormones in blood (specifically plasma) samples from native animals is one effect measurement indicative of exposure to perchlorate in individual animals. Modeling can then be used to determine the impact, if any, on a population of individuals.

Perchlorate can be detected in soils at many contaminated sites, but it is most often associated with ground and surface water bodies. Therefore, aquatic organisms including fish, amphibians, and some reptiles are considered to be the most likely ecological receptors of perchlorate exposure. However, perchlorate has been detected in terrestrial organisms as well, indicating that exposure pathways to terrestrial organisms exist. Domestic animals inhabiting a pasture near perchlorate-contaminated water bodies may be at risk for exposure through drinking water or consumption of plant matter grown in the presence of perchlorate. For example, cattle are obligate herbivores. As such, they may be at risk for perchlorate exposure and subsequent effects since perchlorate can accumulate in plants. Beef and dairy cattle may represent a direct exposure pathway for perchlorate to humans.

4.3 DATA MANAGEMENT (GIS)

All digital data collected or generated and validated throughout the study are stored and managed in a centralized Geographic Information System (GIS) database system. The GIS was developed to facilitate storage of both spatial and non-geographic data. The GIS was developed in ArcSDE using an Oracle 9i spatial database. The GIS was used for data analysis, data conversion, data validation, data management and creation of maps and animations for the study. This system contains relevant spatial and tabular information for use during the study and possible use in future investigations. The information stored within the database includes topographical, hydrological, geological, ecological, stream height, groundwater elevation and analytical GIS layers. The system is used to organize, store, manage, analyze, and present pertinent study data. Additional tools were also developed for the import of data, data management and export into various formats for use in analysis, reports and presentations. These tools include a data import wizard, data importer, document viewer and graph manager. The GIS database system and developed import/export tools and graph manager are described in detail in **Appendix B**.