8.0 STUDY CONCLUSIONS

Based on the historical data reviewed and the large amount of data collected as part of this study, the project team developed an extensive set of findings. These findings have been developed based on the most likely exposure routes within the study area and include potential exposure of plants, aquatic animals, terrestrial animals, and humans. Many of these findings on the occurrence of perchlorate in the study area and on potential human and ecological exposures to perchlorate are dependent upon continued remediation efforts by the U.S. Navy at the NWIRP site. A summary of findings is provided in the following sections, with references directing the reader to sections within the report that contain more detailed information. This conclusion section focuses on the presentation of findings related to major study objectives; it does not necessarily contain all individual conclusions identified during the study.

8.1 OCCURRENCE, FATE AND TRANSPORT OF PERCHLORATE IN WATERSHEDS

Before the exposure potential could be comprehensively evaluated and assessed by the project team, a better understanding of the occurrence, fate, and transport of perchlorate within local streams, Lake Belton, and Lake Waco was necessary. Sampling of stream water, lake water, intake water, and sediment pore water helped the study team better quantify perchlorate concentrations in affected media, their relative locations within the watersheds, and the fate of these contaminants. These sampling studies combined with monitoring of stream and groundwater levels also assisted in gaining a better understanding of how perchlorate moves through the Bosque and Leon River Watersheds overall. Study findings for streams and lakes are discussed further below.

8.1.1 Streams

8.1.1.1 Stream Surface Water

Conclusions pertaining to occurrence, fate, and transport of perchlorate in stream water are listed below. These conclusions are based on information contained in Section 5.1.1 Perchlorate Occurrence in Streams, Section 5.1.3 Groundwater/Surface Water Interactions, and Chapter 6 Updated Hydrologic Conceptual Site Model. Locations of monitoring stations discussed in this section are shown on **Plate 1**. The method detection limit in all surface water samples tested for perchlorate was 1 µg/L.

- Perchlorate does emanate from NWIRP and is regularly detected in Tributary M, Station Creek downstream of Tributary M, the South Bosque River, and Harris Creek. Perchlorate concentrations were found to decrease with distance downstream from NWIRP.
- No perchlorate was detected in the 262 samples collected from the Cowhouse Creek (CHC1) sampling station, which receives surface runoff from Fort

Hood. Based on this limited sampling, surface runoff from Fort Hood is not thought to contribute perchlorate to Lake Belton.

- Perchlorate concentrations detected at sampling locations in small tributaries and creeks were variable with time, except for sampling location Station Creek 1 (SC1). No perchlorate was detected in any of the samples collected at station SC1. Also, with the exception of one perchlorate detection in a duplicate sample, no perchlorate was detected in any of the samples collected at the Onion Creek 1 (OC1) monitoring station.
- Perchlorate concentrations in both watersheds are diluted to below detectable levels by the time surface runoff reaches the monitoring stations located on major streams including the Middle Bosque (MBR1) and Leon Rivers (LR1). All samples collected at the stations along these rivers during this study (218 samples on the Middle Bosque River and 230 samples on the Leon River) were below the method detection limit for perchlorate (< 1 μg/L). All detected perchlorate concentrations were well below estimated levels necessary to cause detectable concentrations in the lakes.
- No sampling station had detectable levels of perchlorate 100% of the time.
- Perchlorate travels further from NWIRP along the South Bosque River and along Harris Creek than along Station Creek. However, perchlorate concentrations in surface water are significantly lower in the Bosque River watershed compared to the Leon River Watershed.
- Lower perchlorate concentrations were observed during storm events, likely due to an increase in water volume and flow which contributed to further dilution of perchlorate.
- A first flushing effect, where perchlorate concentrations increase immediately or shortly after a rainfall event, was observed at monitoring stations SBR1 and SC3 during the first storm event, evidenced by a small spike in perchlorate concentrations following the storm. However, perchlorate concentrations were diluted rapidly due to increased flow. No other monitoring stations showed a first flush effect, but some uncertainty on possible first-flush effects remains. The two storm events sampled during the study were not the largest storms that occurred during the study period.
- Dynamic interaction between surface water and groundwater was observed at almost all locations along streams where monitoring stations and wells were installed. This interaction provides a pathway for contamination in groundwater to move to surface water and vice versa.
- A groundwater connection is evident between monitoring stations TRM1 and OC1. These two monitoring stations are on separate streams and located approximately two miles apart. Monitoring station SC3 also appears to be a key groundwater/surface water interaction area, as fluctuations in stream levels at station TRM1 are sometimes evident in groundwater at station SC3, approximately one mile downstream.

- Station Creek, draining to the Leon River, is seasonal and goes dry during certain times of the year, particularly in the summer months. Conversely, the streams draining to the Middle Bosque River do not typically go dry, even during the summer months or periods of low precipitation.

8.1.1.2 Stream Sediment Pore Water

Conclusions pertaining to occurrence and fate of perchlorate in stream sediment pore water are listed below. These conclusions are based on information contained in Section 5.2 Sediment. The perchlorate detection limit in all stream sediment pore water samples was 4 μg/L.

- Perchlorate was detected in stream sediment pore water along impacted streams.
- Perchlorate concentrations vary less in stream sediment pore water than in stream water, indicating that perchlorate is persistent in sediments of streams within the study area.
- A large capacity for natural attenuation of perchlorate exists in sediments of streams within the study area. The presence of nitrate controls the magnitude of perchlorate attenuation in sediments. Microorganisms in sediment prefer nitrate over perchlorate.
- Perchlorate was not detected below 30 cm of depth in the sediment.
- Biodegradation typically occurs in the top 10-20 cm of stream sediment and varies seasonally.
- Perchlorate degradation in sediments decreases during cooler seasons primarily due to less biological activity at cooler temperatures.
- Higher organic content in sediments (which is seasonal) may create anaerobic conditions, which are favorable to perchlorate degradation. There also may be seasonal variations in micro-organism populations which affect perchlorate degradation in sediments.

8.1.2 Lakes

Conclusions pertaining to occurrence, fate and transport of perchlorate in lake water and lake sediments are listed below. These conclusions are based on information contained in Section 5.1.2 Perchlorate Occurrence in Lakes, Section 5.1.4 Flow, and Section 5.2.2 Anoxic Study. The perchlorate method detection limit in all lake water, intake water, and lake sediment pore water samples was 1 μg/L.

- All lake samples collected by the study team during grab sampling and delta area sampling (22 samples) in Lake Waco were below detectable levels for perchlorate. All grab samples, delta area samples and ADCP transect samples (127 samples) collected from Lake Belton were below the method detection limit (1 μg/L) for perchlorate.
- No consistent preferential flow patterns were identified along the old river channel at the bottom of Lake Belton. Most preferential flows identified at the

surveyed transects were generally characterized as inconsistent and disonnected flows. The flows across most transects exhibited very low velocity and uniform flow characteristics.

- No preferential flows towards intakes were identified based on the four seasonal ADCP studies.
- Evidence of indigenous perchlorate-reducing micro-organisms was found in sediment samples collected throughout Lake Belton and in the water column during the anoxic study performed by the project team. Due to the anoxic conditions encountered below the thermocline, and due to the presence of sufficient electron donors, this lake likely has an ability to naturally reduce perchlorate. Lower temperatures decrease the rate of reduction, but reduction was proven to occur based on lab testing of sediment and water column samples.
- Since perchlorate was not detected in either lake during any of the sediment pore water or surface water sampling performed during this study, it appears that perchlorate accumulation is not occurring and perchlorate concentrations are not likely to increase in these lakes.

8.2 EXPOSURE ASSESSMENT RESULTS

Exposure assessment is an analysis of the potential exposure pathways between the source of a chemical or physical contaminant and human or ecological receptors. Using the information provided in the previous sections of this report and the conclusions regarding occurrence, fate and transport previously discussed above, the potential for perchlorate releases from the NWIRP site and associated impacts to various environmental media (soil, sediment, surface water, groundwater and biota) have been assessed. Conclusions regarding these exposures are provided in the following sections.

8.2.1 Human Exposure Findings

The human exposure analysis considered current and future land uses, human activities and receptors consistent with these land uses, and exposure pathways between human receptors and contaminated media. This analysis was intended only to assess the potential for human exposure to perchlorate; it was not intended to determine an appropriate exposure level, set a health level, or evaluate resulting health effects. Based on the study results, the vast majority of potential human receptors (i.e., the public water supply users) are at no risk of exposure to perchlorate. However, NWIRP vicinity residents and recreational users of the area have the potential to be exposed to perchlorate through consumption of plants, terrestrial animals, aquatic wildlife and/or ingestion of perchlorate-contaminated water from streams. More detailed findings related to human exposure to perchlorate are presented below. As discussed in Chapter 7, exposure to perchlorate through dermal contact or inhalation is highly unlikely. Therefore, this section only discusses exposure through ingestion of water and food.

8.2.1.1 Through Water

- Public water supply users are at no risk of exposure to perchlorate from their water source based on information collected during this study. No perchlorate was detected during public water supply intake sampling performed by the project team. A total of 77 samples were collected from water intakes within Lake Belton and Lake Waco and downstream of Lake Belton. All samples were below the method detection limit for perchlorate (1 µg/L).
- Historical data further support that public water supply users are not at risk of exposure to perchlorate from the water supply. The U.S. Navy collected 243 samples from intakes between February 1999 and December 2002. Only three of these samples had detectable perchlorate concentrations, all collected prior to July 2000. No detections were identified at any intakes since July 2000.
- Perchlorate does emanate from NWIRP and is regularly detected in Tributary M, Station Creek downstream of Tributary M, the South Bosque River, and Harris Creek. Therefore, any NWIRP vicinity residents or recreational users who use these streams as a drinking water source or for garden irrigation could be exposed to perchlorate.
- Because detectable concentrations of perchlorate have not been found in either Lake Waco or Lake Belton since August 2000, recreational users of Lake Waco and Lake Belton are not considered to be susceptible to exposure via incidental ingestion while swimming in the lakes. However, exposure via incidental ingestion during swimming or wading could occur elsewhere in the watersheds where perchlorate is present at detectable concentrations.

8.2.1.2 Through Food

Through Plants

- Based on field and lab data, the highest potential exposure to perchlorate from plants is most likely from leafy vegetation of plants growing near perchlorate-impacted streams.
- Based on laboratory and field data, people who irrigate vegetable/edible plant gardens with water containing perchlorate and consume the vegetables/edible plants produced will be exposed to perchlorate. The magnitude of that exposure decreases with distance from the NWIRP boundary.
- People who consume wild grapes, wild salads, etc. from perchlorate-impacted areas may be exposed to perchlorate. This exposure source is limited to plants along streams where perchlorate is detected regularly in surface water. Perchlorate uptake into vegetation decreases with increased distance from the impacted stream.

Through Fish

- Human exposure to perchlorate is possible through the consumption of fish, as perchlorate was detected in fish throughout both watersheds, including within Lake Belton and Lake Waco. However, exposure is unlikely due to the low

frequency of detections even in highly impacted areas. Most of the fish collected from streams in the study area (the most perchlorate-impacted areas) were not of legal size (>8 inches), and the streams identified to have the highest perchlorate concentrations are not large enough to support fish of legal catchable size.

- Lake Waco: There were a total of eight perchlorate detections in both fish fillets and heads. The detection limit varies with species and tissue type, but in general is around 50 ppb for fish tissues. Three of the detections were in fillets, out of 65 total fillets analyzed. The other five detections were in heads, out of 24 heads analyzed. The fish in which perchlorate was detected were large mouth bass, channel catfish, and black crappie. All of these fish were of legal size.
- Lake Belton: There were a total of six perchlorate detections in fish fillets out of 54 fillets analyzed. The detection limit varies with species and tissue type, but in general is around 50 ppb for fish tissues. There were no detections in the 18 fish heads analyzed. The fish in which perchlorate was detected were large mouth bass, channel catfish, spotted gar, and drum. All of these fish were of legal size, although spotted gar and drum are not typically desired species for human consumption.

Through Beef/Cattle/Livestock

- There was no indication of potential human exposure to perchlorate through consumption of beef from NWIRP area cattle. Although perchlorate was detected in the blood plasma of one animal, perchlorate was not detected in edible tissues typically consumed by people (detection limit of 23 ppb). These cattle had constant exposure to perchlorate in water for 14 weeks.
- No commercial dairies were identified within watershed areas where perchlorate impacts were identified. Non-commercial use of milk from local cattle or goats in the study area remains an area of uncertainty.
- Potential exposure through consumption of products from other livestock (chickens, pigs, etc.) remains an area of uncertainty.

8.2.2 Biological Exposure Findings

Based on the study results, plants within the study area have the potential to be exposed to perchlorate through uptake of contaminated water. Likewise, animals present within the study area have the potential to be exposed to perchlorate through consumption of plants, other animals within the food chain, and water from perchlorate-contaminated streams or springs. Findings regarding the plant and animal studies performed by the project team are presented below.

8.2.2.1 Plants

Perchlorate uptake was found to occur in algae, aquatic plants, and terrestrial plants in areas near NWIRP where surface water tested positive for perchlorate. However, no data

collected during this study suggested that perchlorate is toxic to plants. Findings relating to the nature of perchlorate uptake in plants are listed below. These conclusions are based on information contained in Section 5.3 Plants and Section 7.3 Ecological Exposure Analysis.

- Perchlorate concentrations in riparian and aquatic plants are less variable than concentrations in flowing water. Vegetative uptake of perchlorate is a function of both length of exposure and perchlorate concentration in the source water. Perchlorate uptake varies by species in both aquatic and terrestrial plants.
- Limited data indicate a bioconcentration factor (BCF) for algae from 1 to 15 (lower than terrestrial plant BCFs), but potentially as high as 300-400.
- Perchlorate accumulates in leafy, above-ground or above-water vegetation. Based on limited field data, perchlorate does not appear to concentrate as much in nuts and fruits as in leaves.
- In terrestrial plants, the perchlorate concentration increases throughout the growing season. In contrast, perchlorate concentrations appear to equilibrate in aquatic plants and do not change with season.
- Perchlorate concentrations found in tree leaves decreased with distance from contaminated surface water.
- Nitrate and perchlorate compete for uptake by plants; nitrate is preferred. In areas with high background concentrations of nitrate (such as the study area), excess nitrate will reduce perchlorate uptake by plants.
- Lab data support the field observations such as accumulation in above ground vegetation, BCFs, variation by species, and variation with length of exposure and concentration.
- Modeling data are consistent with field data, and predict perchlorate accumulation in leaves and roots. However, the actual relative concentrations between fruits and leaves appear to be reversed from those predicted by the model.
- To characterize potential exposure to higher organisms, plants may be a better indicator than water because of lower variability in perchlorate concentrations.
- Perchlorate is released from tree leaves after they fall.

8.2.2.2 Aquatic Animals

8.2.2.2.1 Fish

Perchlorate uptake was found to occur in fish in areas throughout the watersheds, even where surface water did not test positive for perchlorate. However, detections were sporadic, occurring only in some species and in a few fish at each location. Findings relating to the nature of perchlorate uptake in fish are listed below. These conclusions are based on information contained in Section 5.4.1 Fish and in Section 7.3 Ecological Exposure Analysis.

- Laboratory studies indicate that perchlorate is taken up by fish faster than it is excreted. Perchlorate is first detected in fish within hours or exposure, but levels in fish reach steady-state in days.
- In fish, perchlorate was found more in small insectivorous species.
- Algae are a good food source for aquatic organisms. Because of the algal BCFs, consumption of algae may be a significant exposure pathway of perchlorate to fish.
- When found in fish, perchlorate concentrations were almost always higher than that of the water from which they were collected; however, no bioconcentration of perchlorate was observed in laboratory studies at extreme perchlorate concentrations. These observations support food as another source of perchlorate exposure for fish.
- Fish thyroid histopathology indicates impact from perchlorate, increasing with higher observed perchlorate concentrations in water.
- Laboratory data show significant individual variation in perchlorate elimination rates for fish. This finding helps explain some of the field data variation in fish tissue residues.
- Laboratory tissue distribution studies indicate that uptake of perchlorate into the fillet is the slowest. Elimination of perchlorate from the fillet is also the slowest.
- Modeling and laboratory data are consistent on tissue distribution of perchlorate in fish. Modeled perchlorate uptake phase is five days, but laboratory data indicate that perchlorate uptake in fish occurs much faster than predicted by the model.
- Predicted thyroid impacts from the model are consistent with field data. Modeling data predict a decrease in thyroid hormones at the "worst-case" perchlorate exposure scenario (S Creek). This result could explain observed alterations of fish thyroid histology.
- Because population level and community level endpoints were not investigated in this study, the relationship between changes in thyroid histopathology and ecological impacts is unknown.

8.2.2.2.2 Frogs

Laboratory studies indicate that frogs can take up perchlorate and be affected by it, but the greatest potential exposure levels near NWIRP do not appear to be large enough to affect frog metamorphosis. Findings related to the nature of perchlorate impacts in frogs are listed below. These conclusions are based on information contained in Section 5.4.2 Frogs and in Section 7.3 Ecological Exposure Analysis.

- Native frog thyroid histology shows possible positive correlation in impact with perchlorate concentration. However, since the impact observed was on follical height alone, not on colloid depletion, and because only about 40% of

the impact could be explained by the presence of perchlorate, other factors may be involved.

- There is no evidence to suggest that perchlorate concentrations in the study area are high enough to affect frog metamorphosis.
- There is no evidence of alteration of sex ratios (ratio of males to females) in native frogs or lab frogs at the perchlorate concentrations detected within the study area.

8.2.2.3 Terrestrial Animals/Birds

8.2.2.3.1 Small Mammals and Birds

This study demonstrated that animals and birds in affected areas can be exposed to perchlorate either directly from drinking contaminated stream water or indirectly by consuming plants that have been exposed to perchlorate. Laboratory studies (Thuett et al., 2002) indicate the highest potential exposure levels near NWIRP may be sufficient to cause thyroid histopathological impacts in small mammals. These conclusions are based on information contained in Section 5.5.1 Small Mammals and Birds and in Section 7.3 Ecological Exposure Analysis.

- Residue data indicate perchlorate exposure to birds and small mammals.
- Bird exposure to perchlorate was limited to an area adjacent to the unnamed tributary near the wastewater treatment plant. Lack of perchlorate exposure to birds may be due to limited bird occurrence in other areas. Similar bird habitat existed near other contaminated streams, but bird trapping in these areas had limited success.
- Two areas were characterized as high exposure risk to terrestrial wildlife: the unnamed tributary near the wastewater treatment plant and the spring on Oglesby Road.
- An apparent exposure gradient exists for small mammals and birds, with exposure decreasing with distance from affected streams.
- Small mammal exposures to perchlorate determined in the field were large enough to cause thyroid histopathological impacts based on laboratory dosing studies with similar species.
- Consumption of vegetation appears to be the primary pathway of perchlorate exposure for small mammals.
- Modeling data for a "worst-case" perchlorate exposure (S Creek) predict perchlorate increases in small mammal tissue but not enough to suppress thyroid hormone production. No small mammals were captured at this location to support or refute the modeling data.
- Model results predict that with observed exposure levels, perchlorate would also be detected in bird eggs. However, monitoring data from sites with similar perchlorate contamination levels indicate little exposure to bird eggs.

8.2.2.3.2 Medium and Large Mammals

These conclusions are based on information included in Section 5.5.2 Medium Mammals.

- Perchlorate was not detected in medium mammals. Raccoons and opossum captured near the most contaminated stream in the study area (S Creek) did not contain perchlorate in blood (detection limit approximately 14 ppb).
- Raccoons and opossum captured near contaminated streams in the study area showed no signs of thyroid histology abnormalities.
- Thyroid hormone levels in medium-sized mammals captured near contaminated streams in the study area appeared normal, consistent with residue and thyroid histology data.
- Perchlorate exposure (approximately 25 ppb) to large mammals (cattle) in the study area did not adversely affect thyroid hormones.

8.3 SUMMARY

Based on all of the investigations completed during this study, as well as evidence that the current and historical remediation activities conducted by the U.S. Navy are having a significant and positive effect, the project team concluded that the approximately 500,000 public water supply users in the communities surrounding Lake Belton and Lake Waco are at no risk of exposure to perchlorate from this source. However, NWIRP vicinity residents/visitors could potentially be exposed to perchlorate if they consume produce from gardens irrigated with impacted stream or spring water, gather and consume wild edible vegetation near impacted streams, or drink water from impacted wells or streams. Similarly, people who consume fish caught in these watersheds could also potentially be exposed to perchlorate in fish fillets, although the risk of this exposure is thought to be low. This study also demonstrated that animals in affected areas can be exposed to perchlorate either directly from drinking contaminated stream water or indirectly by consuming plants or animals that have been exposed to perchlorate. An overview map of perchlorate detections in the study area is included on **Plate 6**.