Evaluation of Potential Impact of ISDS in a Proposed Development Area Near Todd Creek, Adams County, Colorado

Project Final Report

August 25, 2005

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ACRONYMS AND ABREVIATIONS

AMSL	-	Above Mean Sea Level
BOD	-	Biochemical Oxygen Demand
CFD	-	Cumulative Frequency Diagram
CSM	-	Colorado School of Mines
CSEO	-	Colorado State Engineer's Office
DO	-	Dissolved Oxygen
ISDS	-	Individual Sewage Disposal Systems
MCL	-	Maximum Contaminant Level
NAQWA	-	National Water Quality Assesment
OWS	-	On-site Wastewater System
STE	-	Septic Tank Effluent
TCDA	-	Todd Creek Development Area
TDS	-	Total Dissolved Solids
TOC	-	Total Organic Carbon
USDA	-	U.S. Department of Agriculture
US EPA	-	U.S. Environmental Protection Agency
USGS	-	U.S. Geological Survey

GLOSSARY

alluvial - Pertaining to material carried or laid down by running water. Alluvium is the material deposited by streams. It includes gravel, sand, silt, and clay

BOD - Biochemical Oxygen Demand (BOD) is a measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. BOD is used as an indirect measure of the concentration of biologically degradable material present in organic wastes. It usually reflects the amount of oxygen consumed in five days by biological processes breaking down organic waste. BOD can also be used as an indicator of pollutant level, where the greater the BOD, the greater the degree of pollution.

boundary condition - The physical conditions at the boundaries of a system. A mathematical representation of boundary conditions must be specified in a numerical solute transport model.

breakthrough curve - A plot of relative concentration versus time at a given observation point.

conceptual model - The idealization of a hydrogeological system in which a mathematical model can be used. The conceptual model includes assumptions on the hydrostratigraphy, material properties, dimensionality, and governing processes.

cumulative frequency value - The value that corresponds to the percent of measurements of a parameter observed at or below that particular value. A cumulative frequency diagram illustrates the frequency distribution of a parameter of interest.

hydrostratigraphy - Stratigraphical organization based on grouping soil and aquifer units of similar properties into single equivalent units.

infiltration - The flow of water downward from the land surface into and through the upper soil layers

initial condition - Conditions prevailing at the beginning of a period of time. A mathematical representation of initial conditions must be specified in a numerical solute transport model.

mathematical model   -   A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some aquatic system.

numerical model   -   A mathematical model in which a set of mathematical operations is reduced to a form suitable for solution by simpler methods such as numerical analysis.

parameter sensistivity   -   A measure of the change in model output based on the change in the parameter's input value. This is a way of quantifying the importance or sensitivity of certain parameter inputs.

parameter uncertainty   -   the confidence level of a given parameter input value.

percolation   -   The downward flow of water through the pores or spaces of unsaturated rock or soil.

potentiometric surface   -   An imaginary surface formed by measuring the level to which water will rise in wells of a particular aquifer. For an unconfined aquifer the potentiometric surface is the water table; for a confined aquifer it is the static level of water in the wells. (Also known as the piezometric surface.)

Quaternary   -   The latest period of time in the stratigraphic column, 0 - 2 million years, represented by local accumulations of glacial (Pleistocene) and post-glacial (Holocene) deposits.

steady state   -   The condition of a system when physical and chemical properties do not vary with time.

vadose zone   -   The unsaturated soil zone. An area above the water table where soil pores are not fully saturated, although some water may be present. It is located vertically between the land surface and the surface of the saturated zone (ie, the water table).

1. **EXECUTIVE SUMMARY**

This report discusses a study completed at the Colorado School of Mines (CSM) intended to assess the potential impacts of Individual Sewage Disposal Systems (ISDS) to local water-resources near Todd Creek in Adams County, Colorado. Characterization of local geology, hydrology, water quality, and wastewater sources was completed in the Todd Creek Development Area (TCDA). A preliminary assessment was first conducted to determine if the potential exists for water-resources impact from ISDS, and thus warranting more complex modeling. This assessment was completed by using several simple models that estimated mass loading and mixing of reclaimed wastewater in the Arapahoe Aquifer. After the potential impact based on the results of the simple modeling was determined, efforts were then focused on vadose zone modeling, using a more complex numerical model, to further evaluate the degree of potential impact.

The site characterization efforts indicated that the Arapahoe Aquifer is the only local water-resource that is potentially vulnerable to contamination from ISDS. The Arapahoe Aquifer is a low-yield aquifer in the TCDA and currently is the source of water for some domestic residences in the area. The conceptual model for the Arapahoe Aquifer in the TCDA was obtained after a thorough analysis of twenty well logs collected from the Colorado State Engineer's office. The well logs show that the aquifer is a complex system of inter-bedded sands and shales associated with alluvial fan system deposits. The upper part of the aquifer has relatively more shale than the lower part of the aquifer; thus drinking water wells in the TCDA are screened in the lower part of the aquifer. In addition, it is possible that a relatively thick shale layer (30-60 feet thick) is present between the upper and lower Arapahoe throughout the site that would greatly retard contaminant transport. However, it is not possible to ascertain from the well logs whether this unit is laterally continuous. The degree of inter-connectedness of the sand units is not accurately known, but is an important control on how contaminants originating in the vadose zone may be transported throughout the aquifer. Thus, a conservative assumption is made that sand layers may be interconnected, and that transport to the aquifer from ISDS is possible.

Nitrate contamination was the main focus of this study. Arapahoe Aquifer wells that were sampled in this study were located in areas that have combined agricultural land-use and low-density residential developments with ISDS. Results of sampling show that most Arapahoe Aquifer water samples had no nitrate detected and only a few samples had nitrate detected at concentrations less than 1 mg NO_3-N/L. Ammonium levels in the Arapahoe water samples were consistently detected, but at concentrations less than 1 mg NH_4-N/L.   While it is not common to detect ammonium without nitrate, it is also not unusual. Current nitrogen levels in the Arapahoe Aquifer are not of concern to public health.

Results of vadose-zone modeling using best estimate for model parameters suggest that natural soils in the TCDA remove nearly all of ammonium and nitrate in soil-water originating from STE. Best estimates for model parameters that were uncertain (e.g., especially denitrification rate and nitrification) were assigned the 50th percentile cumulative frequency values taken from cumulative frequency distributions (CFDs) presented in McCray et al (2005). That is, 50% of the literature values reported from a variety of different sources for different soils are above this value, and 50% are below this value. These values were obtained from an extensive literature

review, and are the most reasonable in the absence of data specific to the TCDA. However, because there is uncertainty in the parameters of interest, especially the denitrification rate, the user accepts some risk that nitrogen contamination of the aquifer could still occur.

Results of model-sensitivity analyses show that model output is extremely sensitive to denitrification rate. Denitrification is the microbially facilitated process which accounts for conversion of nitrate to nitrogen gas.   This parameter is also a very uncertain and can vary over four orders of magnitude.   Using a reasonable lower-end rate would result in aquifer concentrations that significantly exceed the maximum contaminant level (MCL) for nitrate, set by the US Environmental Protection Agency (U.S. EPA). However, when using a denitrification rate an order of magnitude less than the 50 percent CFD value, the model predicts a nitrate concentration that is measurable but below the MCL of 10 mg-N/L.

A number of ISDS already exist in the TCDA with some upgradient of the wells sampled for this study. The current low level of nitrogen in the Arapahoe Aquifer supports the idea that there is adequate treatment of septic tank effluent (STE) in the natural soils, but the potential for impact to this aquifer if additional ISDS are implemented cannot be ignored. Given this information, it appears that there is a low to moderate risk of contaminating the Arapahoe aquifer from implementation of ISDS in the study area.

It is important to realize that, for this study area, modeling cannot be used to predict actual nitrate concentrations reaching the aquifer accurately without many measurements of denitrification rates in the study area.   Obtaining actual measurements of appropriate denitrification rates would require numerous laboratory column studies using site-specific soils or extensive in-situ field measurements beneath existing ISDS. These tasks would require a great deal of additional time and money, and thus are not within the scope of this study. However, the likelihood of aquifer impacts can be can be assessed through modeling.

For denitrification rate, or any uncertain parameter, the value used in the model should be based on the user's sensitivity to risk. There is always a degree of uncertainty associated with models, as models are a simplification of the real system. While this modeling analysis does not provide a risk based decision-support tool for Adams County and Tri-County Health Department, a discussion of risk versus uncertainty in the context of this study may be useful and is provided below.

The sensitivity of the individual input parameters, or combination of parameters, is important as it allows the decision maker to factor in the risk of the certainty of the model output using a common-sense approach. The decision maker's risk implies the willingness to accept the certainty, or uncertainty, of the model output. In the following example, we use denitrification rate for discussion, but any sensitive parameter should be considered. If the model is used to simulate the potential impacts of nitrogen to a sensitive environment (e.g., wetlands, important or limited drinking-water supply, etc.), the decision maker may be willing to accept only a small risk that impact will occur. Thus, the user wants to ensure that the model will not under predict the impact of the nitrogen load to the environment. In this case, the user may select a value from the CFD that represents the 25% value for the denitrification rate (25% of the reported values are below this value). This would result in denitrification that is significantly lower than the median

of those reported in the literature and would minimize the risk that the model would under-predict nitrogen concentrations reaching the receptor. For this case, it is likely but not certain that the model will over-predict the impact. That is, using the 25% CFD value does not guarantee a conservative final result because the system under study may actually be below the 25th percentile with respect to denitrification. If the user wishes to accept no risk that the receiving body would be impacted, then no denitrification could be assumed. However, the selection of an overly conservative value, such as the 0% value for denitrification, is likely to falsely bias the model output to suggest an impact to the environment when a higher nitrogen load might actually still result in no adverse impacts to the receptor.

Because of the uncertainty in denitrification rates, and thus potential impact to the aquifer, we recommend a monitoring program be implemented if numerous additional ISDS are installed in the study area. This is more cost effective than a costly experimental program to assess the uncertainty and best value for denitrification rates.

It is wise to include existing wells in a monitoring program. However, no wells currently exist immediately within the proposed development area. In addition, domestic wells always provide suspect information because samples must generally be collected from the homes water-distribution system. Thus, it is recommended that at least 6 dedicated monitoring wells be installed.

The monitoring program should include one up-gradient monitoring well to assess background water quality and ensure that contamination is not coming from other sources. The program should also include three monitoring wells located near the center but on the south-eastern portion of the development area, and two wells directly down-gradient of the proposed development to assess cumulative impacts. Monthly sampling is recommended at first to establish reliable baseline concentrations. Then, quarterly well sampling is recommended to continually assess water quality in the Arapahoe Aquifer. After 10 years following 100% build-out (or other period specified by Tri-County Health Department), if no impacts are detected, then monitoring frequency could be reduced (e.g., to yearly sampling).

Three wells are needed within the development area to provide statistically significant results on nitrate-concentration trends in the aquifer and enable determination of the groundwater hydraulic gradient (i.e., direction and velocity of groundwater flow) below the development. The hydraulic gradient from these wells can be used to determine the location of the background and down-gradient wells. Three wells would also be useful for conducting pump tests for accurate measurements of hydraulic conductivity for future groundwater modeling if impacts are detected. Two wells down-gradient would provide reliable indication of down-gradient impacts and also enable estimation of modeling parameters such as aquifer dispersion (dispersivity) if future work is required. **Section 8** of this report describes the recommendations and rationale for screening locations on each of the wells, which would ensure sample-collection at depths most likely to experience contamination, and also to allow for simple well tests to measure groundwater and contaminant transport modeling parameters.

Increasing nitrate concentrations in a monitoring well within a range that is less than a particular value set by Tri-County Health Department for three consecutive sampling efforts could prompt

additional action, such as installing enhanced nitrogen treatment units on ISDS nearest the impacted well. Detection of a single concentration greater than this limit could also warrant specific action. The limit could be set based in part on typical nitrate background levels in agricultural areas (less than 1 mg/L), or could be linked to some multiple of the background nitrate concentration. It is recommended that a nitrate level of 2 mg-N/L as an action level, which is 20% of the current MCL.

Water samples should be analyzed for nitrate, nitrite, ammonium, chloride, total dissolved solids (TDS), total coliform, and dissolved oxygen (DO). Monitoring for nitrate, nitrite and ammonium will assess how much nitrogen is in the Arapahoe Aquifer. Currently the average total ammonium-plus- nitrate levels in the aquifer appear to be less than 1 mg-N/L. If levels appear to increase to more than 2 mg-N/L (or another level specified by the health department) then preventive action procedures may need to be established. Nitrogen levels may vary or oscillate over time so it is important to keep a record of all past samples and to continually observe the general trend.

Chloride exists in STE at concentrations much higher than in natural groundwater. Chloride is a conservative chemical species that generally does not degrade in natural groundwater, is not removed through natural soil treatment, and that travels faster than other chemicals in vadose-zone and aquifer systems. Thus, chloride measurements can serve as a pre-cursor to contamination from other ISDS constituents (including nitrogen), may help determine if pollutants in monitoring wells originate from ISDS or other sources, and can be used to estimate the relative ratio of ISDS water and aquifer water (mixing factors). Increasing chloride levels may be reason to increase sampling frequency. Current chloride levels in the Arapahoe Aquifer appear to be less than 2 mg/L. If there is a noticeable increase in chloride concentration (greater than 5 mg/L for consecutive sampling events), it likely indicates that water originating from ISDS is recharging the Arapahoe Aquifer in significant volumes. This does not necessarily mean that nitrate pollution is imminent, but could warrant increased sampling frequency (i.e., monthly). If there is a significant increase in nitrogen levels in the Arapahoe Aquifer but no increase in chloride levels, then this could indicate that the nitrogen present is originating from a source other than ISDS.

Total coliform is a measure of the bacteria that are used as indicators of fecal contaminants in a water sample. This measurement is a way to assess how bacteria are transported in the subsurface. TDS and DO are constituents which, if monitored, may be indicators that wastewater from ISDS is reaching the aquifer. A significant increase in TDS and a significant decrease in DO are signals that could be precursors for an increase in nitrate levels. These events would warrant an increase in sampling frequency to a monthly basis.

It is useful to note that the model results suggested that slower application rates at higher concentrations, such as provided by evaporative systems, might mitigate potential impacts. Even though the same mass of nitrogen is introduced to the subsurface (nitrogen in STE is not volatile), nitrogen concentrations reaching the water table could be reduced because infiltration rates are reduced and thus more time is provided for denitrification. If denitrification rates are actually very low, however, then this approach would not be useful. In addition, recent research at CSM suggests that higher loading rates at similar concentrations might improve treatment

performance in some cases, possibly because biomats form more rapidly and contribute to enhanced treatment. This complex mechanism could not be considered in the modeling.

2. INTRODUCTION

2.1 Background

Over 25% of the U.S. population and 37% of all new development utilize ISDS (U.S. EPA, 1997). Traditionally ISDS are comprised of septic tanks for preliminary treatment of raw wastewater followed by percolation through soil to achieve purification prior to groundwater recharge. Due to the high demand for land, development has occurred in areas which may be considered unsuitable for such treatment systems. In addition, in some locations certain pollutants (such as nitrogen and pharmaceutically active compounds) are accumulating in water resources, placing increased demands on the quality of treated ISDS effluents discharged to the environment (Laws, 2005; Lindstrom et al., 2002).

The proposed TCDA, in parts of Sections 2, 3, & 4, Township 1 South, Range 67 West, 6th Prime Meridian, is located approximately one mile west of the South Platte River and directly north of Highway 7 (**Figure 2.1**). The total TCDA occupies approximately 4720 acres which are being developed under several parties. ISDS have been proposed to accommodate all domestic wastewater generated within this proposed residential development.
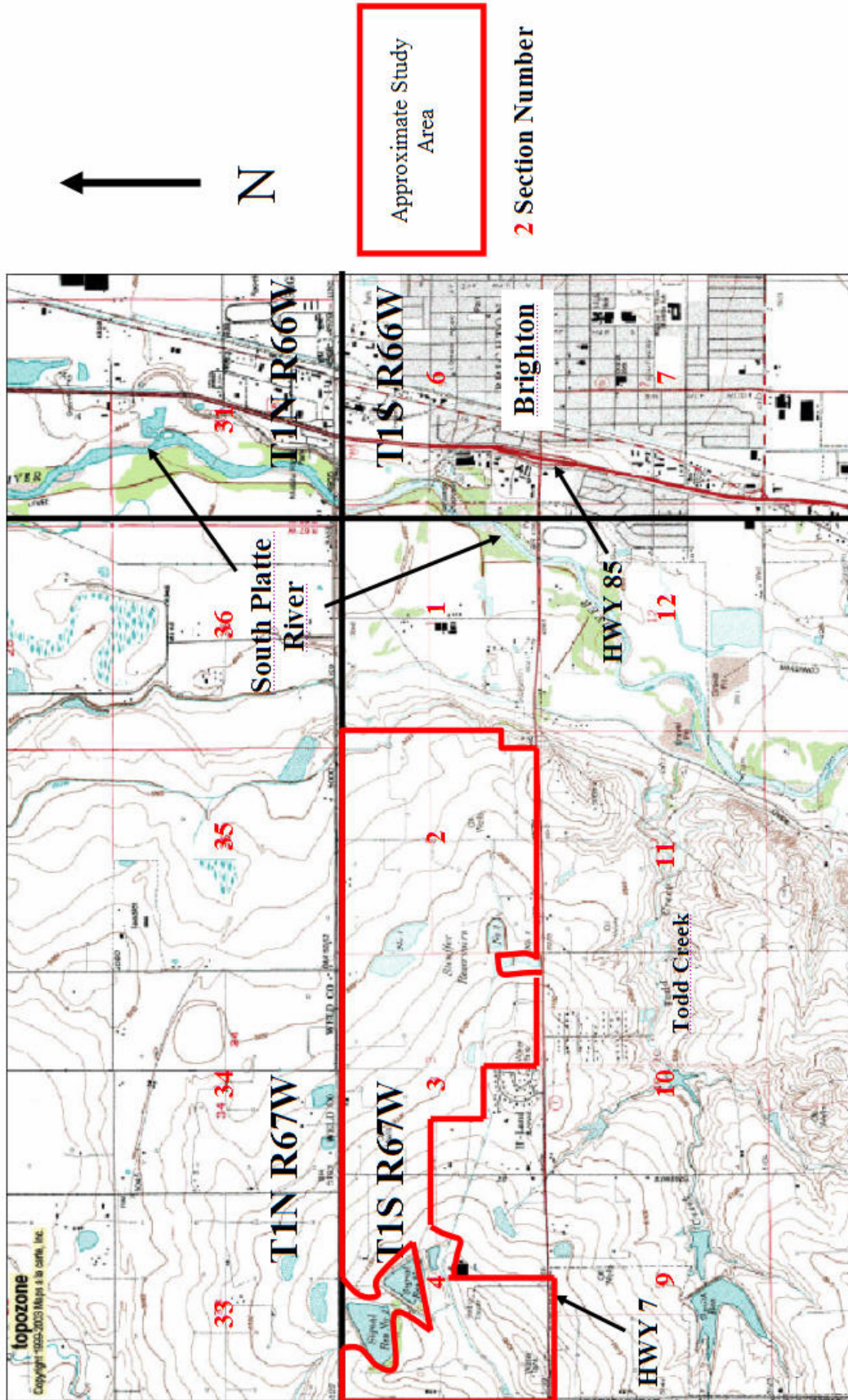
Figure 2.1 Map of the locations of the proposed Todd Creek developments. Base image courtesy of topozone.com.

Conventional ISDS are comprised of four basic components: a wastewater source, a pretreatment unit (septic tank), an effluent delivery system that includes a subsurface infiltration gallery, and a soil absorption field (or leach field) (see **Figure 2.2**).   In this investigation, we focus on ISDS that use septic tanks, where the wastewater source is an individual residence or small businesses. Wastewater generated onsite is collected from the source and piped to a septic tank. Pretreatment processes in this unit include sedimentation of solids, floatation of oils and greases, and anaerobic digestion. Effluent from this tank is then periodically discharged by gravity or pumping to the subsurface through an effluent delivery system. This effluent delivery system is usually comprised of a series of perforated pipes within a number of subsurface trenches or a single subsurface bed.
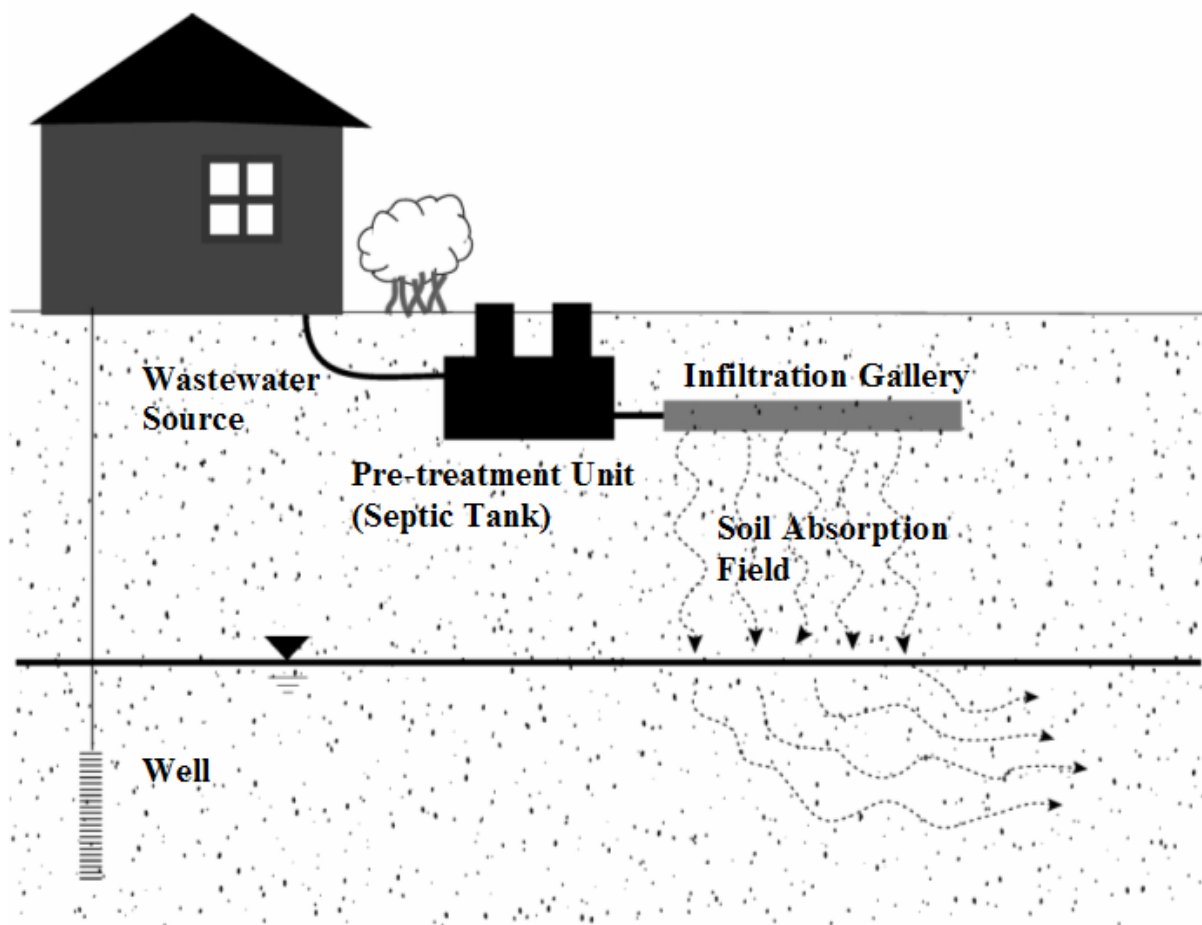
Figure 2.2 Conventional ISDS Delivery System (adopted from McCray et al., 2005).

The effluent from the delivery system infiltrates into the soil absorption field where it percolates through the vadose zone down to the groundwater zone. During percolation through the vadose zone, the effluent receives advanced treatment through pollutant sorption, precipitation as solid phase, transformation, filtration, chemical degradation, and biodegradation. However, conditions in the subsurface such as a high water table, thin soil layer, or shallow fractured or karst bedrock may exist, and contaminants such as nutrients and pathogens may not be treated thoroughly

before recharge into the underlying groundwater. In addition, contaminants reaching the groundwater may then exfiltrate to nearby surface waters through base flow or seepage and runoff, thereby contributing to the contaminant load in those surface waters. Under these conditions, ISDS are clearly potential contributors to surface water and groundwater contaminant loading. With the increasing emphasis on watershed management and nonpoint-source control, there is a need to develop quantitative approaches to assess ISDS-pollutant fate and transport (McCray et al., 2005).

ISDS could potentially impact both surface water and groundwater in the TCDA. The South Platte River and Todd Creek are possible surface water receptors due to their proximity. Discharges to the South Platte River have strict regulations regarding Total Maximum Daily Loads (TMDLs) for nutrients, which are set by the U.S. EPA, and include non-point sources such as agriculture and ISDS. The U.S. EPA (2000) has also set a drinking water MCL for a number of nutrients such as nitrogen.   Additionally, shallow groundwater resources have potential to be contaminated by ISDS. The Arapahoe Formation, which is not fully saturated at this location, is present in the TCDA beneath 10 to 20 feet of unconsolidated sediment and is a possible groundwater receptor. The Arapahoe Aquifer is the source for drinking water for a number of residential wells in the area and already has small amounts of nitrate detected, likely the result of agricultural land-use in the area, but potentially due to existing ISDS. While ISDS are associated with a whole suite of contaminants, the limited scope of this project will focus the investigation on potential nitrogen transport to local water resources.

Nitrogen present in groundwater is usually in the form of nitrate in most natural groundwater. Nitrate is a known carcinogen which may cause a condition known as blue baby syndrome in infants. Current background levels of nitrate in the Arapahoe Aquifer are well below the U.S. EPA MCL of 10 mg-N/L.

2.2 Objective

Research was initiated in the Environmental Science and Engineering Division at the Colorado School of Mines (CSM) to study the potential impacts of ISDS near Todd Creek in Adams County, Colorado. The goals of this investigation were to: 1) perform an area-specific site characterization and assess the vulnerability of local water-resources to contamination from ISDS, 2) develop a monitoring program to detect any possible impacts and ensure local water quality is protected and, 3) model the vulnerability of the Arapahoe Aquifer to nitrate contamination from ISDS.

3. SITE DESCRIPTION

3.1. Overview

A good three-dimensional picture of subsurface geology is necessary to gain understanding of the main controls and important processes affecting potential transport of contaminants originating from ISDS. A wide array of sources has been consulted to help characterize the geology and hydrology of the TCDA, of specific interest were the hydrologic atlases and well logs. Hydrologic Atlases (Robson, 1981, 1983, 1996) published by the USGS, were an invaluable resource of Denver Basin scale information. Several dozen wells logs, obtained from the Colorado State Engineer's Office (CSEO) public records were used to find the most detailed local geologic information.

The proposed TCDA is located on the northwestern margin of the Denver Basin, a large sedimentary basin centered east of Denver. According to **Figure 3.1**, the Arapahoe Aquifer outcrops in the TCDA; however several smaller scale maps, as well as GIS modeling of the Denver Basin indicate that the Denver Aquifer may be present in small thickness in this area. Between 10 and 20 feet of Quaternary loamy soils are typically seen at the surface in the TCDA.
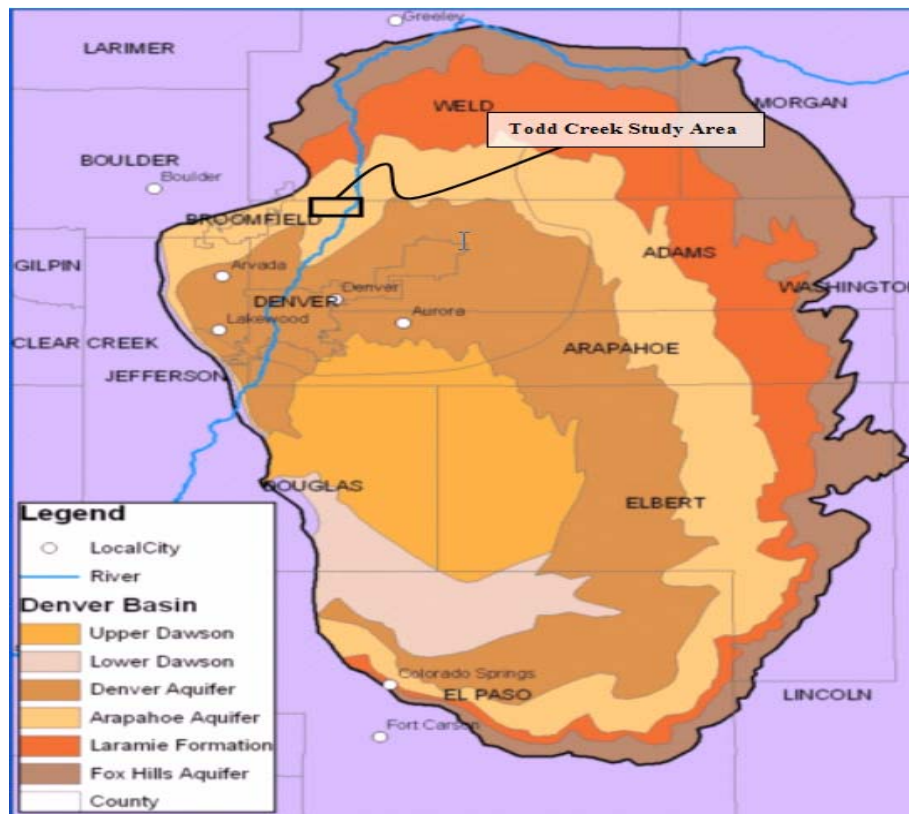
Figure 3.1 Geologic map of the Denver Basin.
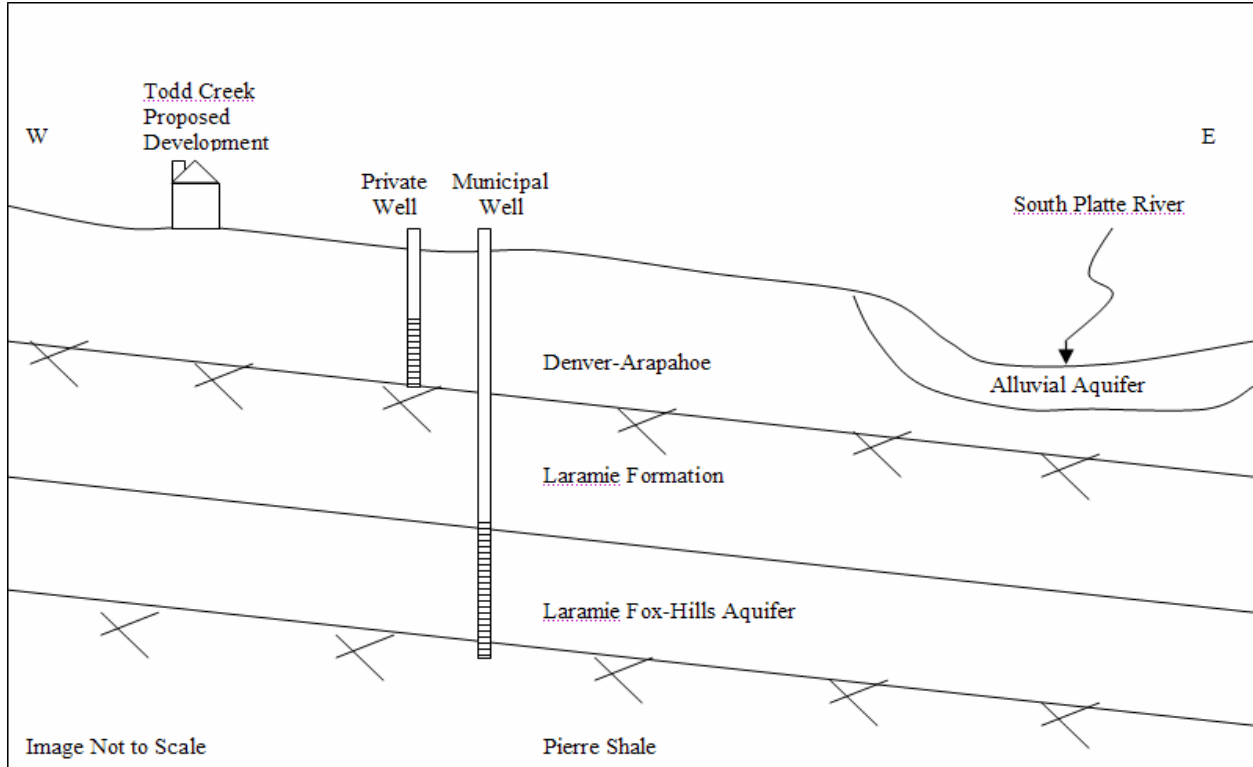
Figure 3.2 Cross-section of major bedrock units in the TCDA.

3.2. Stratigraphy

The stratigraphy within the study area can be characterized by layered sedimentary bedrock units of the Denver Basin with 10-20 feet of Quaternary soils present at the surface. The Alluvial Aquifer is present east of the TCDA, near the South Platte River. **Figure 3.2** shows a W-E cross section of the major bedrock units in the TCDA. A subsurface imaging program, RockWorks$_{TM}$ 2004, was used to generate a three-dimensional model of subsurface geology in the TCDA. RockWorks$_{TM}$ uses data input from 15 well logs within the TCDA to generate a subsurface stratigraphical profile. The program then spatially correlates the subsurface profiles to create a three-dimensional picture of the subsurface. **Appendix A** contains a summary of the RockWorks$_{TM}$ model output. A description of the major geologic units present is given below.

3.2.1. Alluvial Aquifer

The Alluvial Aquifer is not directly beneath the TCDA. This shallow aquifer system is found farther to the east towards the South Platte River, and reaches a thickness of 40 feet towards its center. The Alluvial Aquifer is associated with alluvial deposits from the South Platte River and its major tributaries. The aquifer is made up of mostly sands, while some fine-grained silt and clay deposits are less common. The base of the Alluvial Aquifer just east of the TCDA is between 4920 and 4930 feet above mean sea level.

3.2.2. Unconsolidated Sediments

Unconsolidated soils and sediments range in thickness from 10-20 feet in the TCDA, with an average thickness of approximately 15 feet. Quaternary soil profiles typically extend to a depth

of four to five feet. These mid to fine-grained sediments typically make up the soil units found near the surface. The composition of these near surface soils is primarily loam and clay loam soils with some sands primarily comprised of over-bank deposits associated with Quaternary alluvial systems and eolian (wind-blown) deposits. The structure of the sediments exhibit site-scale heterogeneities, with sandy lenses common. In general, these sediments have a low hydraulic conductivity.

Two major Quaternary soil units exist in the first few feet in the TCDA according to the Soil Survey of Adams County, Colorado (USDA, 1974). The Platner Loam makes up most of the near-surface soils in the TCDA. This soil is comprised of units of clay, clay loam, and sandy loam which exhibit relatively low permeability and high water capacity making it good for cultivation. These soils typically extend to a depth of 60 inches (152 cm). The Ulm Loam makes up less than one-third of the near-surface soils in the TCDA. Together, the Ulm Loam and the Platner Loam make up more than 90% of the near-surface soil units in the TCDA according to the Soil Survey of Adams County, Colorado. The Ulm Loam is much finer than the Platner, and is comprised of silty clay, clay, and clay loam units. The Ulm Loam also has relatively low permeability and high water capacity, making it good for cultivation. Typical Ulm Loam profiles extend to a depth of 48 inches (122 cm).

Beneath the Quaternary soils, unconsolidated sediments are present above any competent bedrock surface. These sediments are mostly highly compacted clays and silts that have low permeability. Sediments of this type characterize the lower part of the unconsolidated sediment profile in the TCDA.

3.2.3. Arapahoe Aquifer

Both the Denver and Arapahoe Aquifers are comprised of shale and siltstone interbedded with moderately consolidated sandstone. Due to their similar composition and the poor detail of well logs in the TCDA, these units have been lumped together into one equivalent hydrostratigraphic unit. Robson (1981) also notes that in many locations the lower Denver and upper Arapahoe formations are not distinguishable. Several geologic maps show that the Denver formation may be present in this area, but in limited thickness. To simplify the conceptual model we will assume that the Arapahoe Aquifer is present directly beneath the unconsolidated sediments in the TCDA. This assumption will not change any of the subsequent conclusions.

The Arapahoe Aquifer is approximately 300 feet thick in the TCDA. This aquifer is an extremely heterogeneous unit that was formed in a depositional alluvial fan system. The base of the Arapahoe Aquifer dips to the east and is about 4800 feet in the west part of the TCDA, and 4600 feet in the east (CSEO Well Logs).

The typical composition of the Arapahoe Aquifer is approximately 30% sand and 70% shale. **Figure 3.3** shows a conceptual cross-section of the Arapahoe Aquifer. The sand layers are lens-shaped and the degree to which they are connected is not completely known. Sand lenses, that are associated with fluvial deposits, appear then pinch out. In some places lenses are so closely spaced that they form a single hydrologic unit. Although the Arapahoe Aquifer is not considered a highly permeable aquifer like the Alluvial Aquifer, the lower 200 or se feet does sustain a number of private drinking water wells in the TCDA.

Previous studies have suggested the presence of upper and lower Arapahoe units in parts of the aquifer, with the upper unit being separated from the lower unit by a continuous confining shale unit (Robson, 1981). Although significant deposits of shale are prevalent in the Arapahoe in the TCDA, results of the subsurface model show that it is not possible to assess the lateral continuity of any such shale layers. A number of geophysical well logs from the TCDA were also analyzed; the logs were also unable to elucidate any one continuous shale layer. While it is possible that a relatively thick layer of continuous shale (30-60 feet) is present in the TCDA, the Arapahoe Aquifer exhibits site-scale heterogeneity and complexity and cannot necessarily be divided into distinct sand or shale units. Generalizing the Arapahoe Aquifer as having upper and lower units, separated by a continuous shale unit, may be appropriate for mapping on the scale of the Denver Basin. However, when contaminant transport is important, site-scale characterization becomes most important. Although it is likely that the lower Arapahoe is protected from above by shale deposits, the possibility exists that it is not completely protected due to intermingling sand layers.
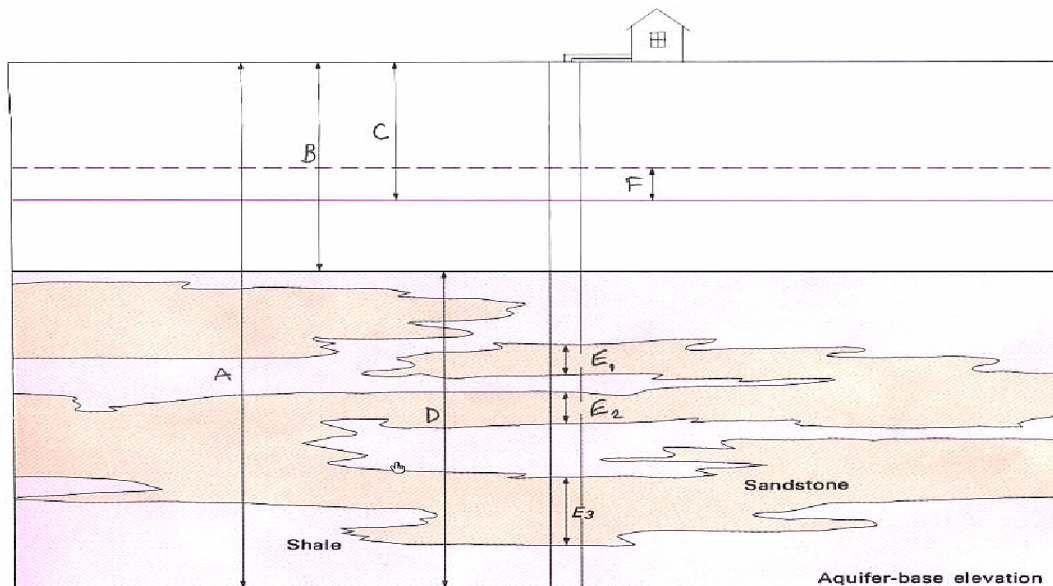
Figure 3.3 Typical cross-section of the Arapahoe Aquifer (Robson, 1981).

3.2.4. Laramie Formation
The Laramie Formation is a massive shale unit over 300 feet thick in the TCDA. This formation is almost entirely shale with a few small coal and sand seams.   The hydraulic conductivity of this unit is small and it acts as a confining layer above the Laramie-Fox Hills Aquifer. The Laramie Formation lies directly beneath the Arapahoe Aquifer, forming an essentially impermeable boundary to any vertical flow.   (Ground Water Atlas of Colorado, 2003)

3.2.5. Laramie-Fox Hills Aquifer
The Laramie-Fox Hills Aquifer lies directly beneath the Laramie Formation and is about 200 feet thick in the TCDA. This aquifer unit is comprised of moderately permeable to highly permeable sands interbedded with a few shales. Another massive shale deposit, the Pierre Shale, forms the lower confining boundary to the Laramie Fox-Hills Aquifer. (CSEO Well Logs; Robson, 1981)

4. FIELD DATA COLLECTION

4.1. Water Quality Sampling

A water sampling program was administered in attempts to characterize the current water quality of the major hydrologic units in the TCDA. The objective of the program was to characterize the spatial and temporal variability in water quality of the major hydrologic units and evaluate their sensitivity to impacts from possible wastewater sources. The program utilized a full hydrochemical analysis which measures for all major ions present in natural waters. The data analyzed for this report will focus on water quality parameters of interest: nitrate (NO_3), ammonium (NH_4), total nitrogen (TN), pH, and alkalinity. All nitrogen species are reported as milligrams of nitrogen per liter (mg-N/L), unless otherwise noted. It is important to note that total nitrogen measurement is a quantification of organic nitrogen in addition to nitrate, nitrite, and ammonia.

Samples were collected in April 2005 and analyzed in laboratory facilities at CSM. The sampling program focused on characterization of the Arapahoe Aquifer, with 6 wells sampled in Sections 9, 10, and 11 directly south of the study area. No Arapahoe wells exist in the proposed development areas for sampling. Samples were also collected from the South Platte River, a reservoir along Todd Creek, and one Alluvial Aquifer Well in Section 1. Standard water sampling techniques were employed for sample collection and preservation. Field and laboratory duplicates and blanks were analyzed for quality assurance purposes. **Appendix B** contains complete results of water quality sampling program including relevant statistics. **Table 4.1** gives a summary of water quality data for the major hydrologic units in the TCDA. Sample ID numbers for aquifer sample correspond to the CSEO Well Permit Number, if available. Discussion of water quality sampling results is provided in **Section 5.3**.

Table 4.1. TCDA water quality summary.

Sample ID	NO_3 (mg-N/L)	NH_4 (mg-N/L)	TN (mg-N/L)	pH	Alkalinity (mg-$CaCO_3$/L)
Arapahoe Aquifer Wells					
228224	<0.3	0.35	3.2	8.55	293
241128	<0.3	0.37	1.5	8.51	326
138926	<0.3	0.35	1.2	8.51	298
69658	0.3	0.69	2.9	8.08	203
46586	<0.3	0.48	0.3	8.65	304
46587	<0.3	0.36	3.5	8.63	271
Alluvial Aquifer Wells					
60966	2.1	0.61	4.7	7.4	136
Surface Water					
South Platte River at Hwy. 7	3.1	1.26	9.5	7.72	100
Todd Creek Reservoir	0.3	0.28	4.3	8.47	190

4.2. Water-Level Monitoring

Water-level monitoring was done in conjunction with water quality sampling in April 2005. The objective of water-level sampling was to determine the orientation of the potentiometric surface in the Arapahoe Aquifer in the TCDA. Mapping of the potentiometric surface helps to determine information about the saturated thickness, groundwater flow direction, and hydraulic gradient in the Arapahoe Aquifer. Water-level measurements were taken in four of the six Arapahoe Aquifer Wells. The remaining two wells were inaccessible with a water-level measuring device.

Table 4.2 contains all relevant measurements and well location information. Results of water-level monitoring will be discussed in a later section in this report.

Table 4.2 Arapahoe Aquifer water-level measurements in the TCDA.

Well Permit #	Date	Time	Depth to Water (ft)	Elevation Top of Casing (ft)	Water Level (ft)	UTM X NAD 27 (m)	UTM Y NAD 27 (m)
241128	4/5/2005	19:15	106.5	4969.3	4862.8	513307.39	4426304.45
138926	4/5/2005	18:00	108.3	5000.6	4892.3	512564.45	4425336.51
46586	4/12/2005	14:15	146.7	5058.1	4911.4	511379.3	4425057.27
46587	4/12/2005	15:30	165.0	5056.0	4891.0	511293.86	4425072.84

4.3. Soil Sampling

The objective of soil sampling was to better characterize the alluvial soils and unconsolidated sediments present in the TCDA. Soil characterization is necessary to assist in estimating the capacity of the soil for natural treatment of wastewater effluent. Physical soil properties are used to predict how solutes will travel through the soil profile. Chemical soil properties are used to observe how certain chemical species exist spatially in the soil profile. Soil samples were collected from three test holes drilled in Section 2 in April 2005. It is important to note that the current (and historical) land-use of the soil sampling locations is agricultural. Based on the Soil Survey of Adams County, Colorado (USDA, 1974), two test holes were drilled in the Platner Loam and one test hole was drilled in the Ulm Loam. Soil core samples were collected using a hollow-stem auger split-spoon sampling method. Samples were taken at two foot intervals in the field and preserved for later analysis. Test holes were completed to a depth where competent bedrock material was encountered. Test Holes 1 and 2 were completed to a depth of 22 feet and Test Hole 3 was completed to a depth of 16 feet.
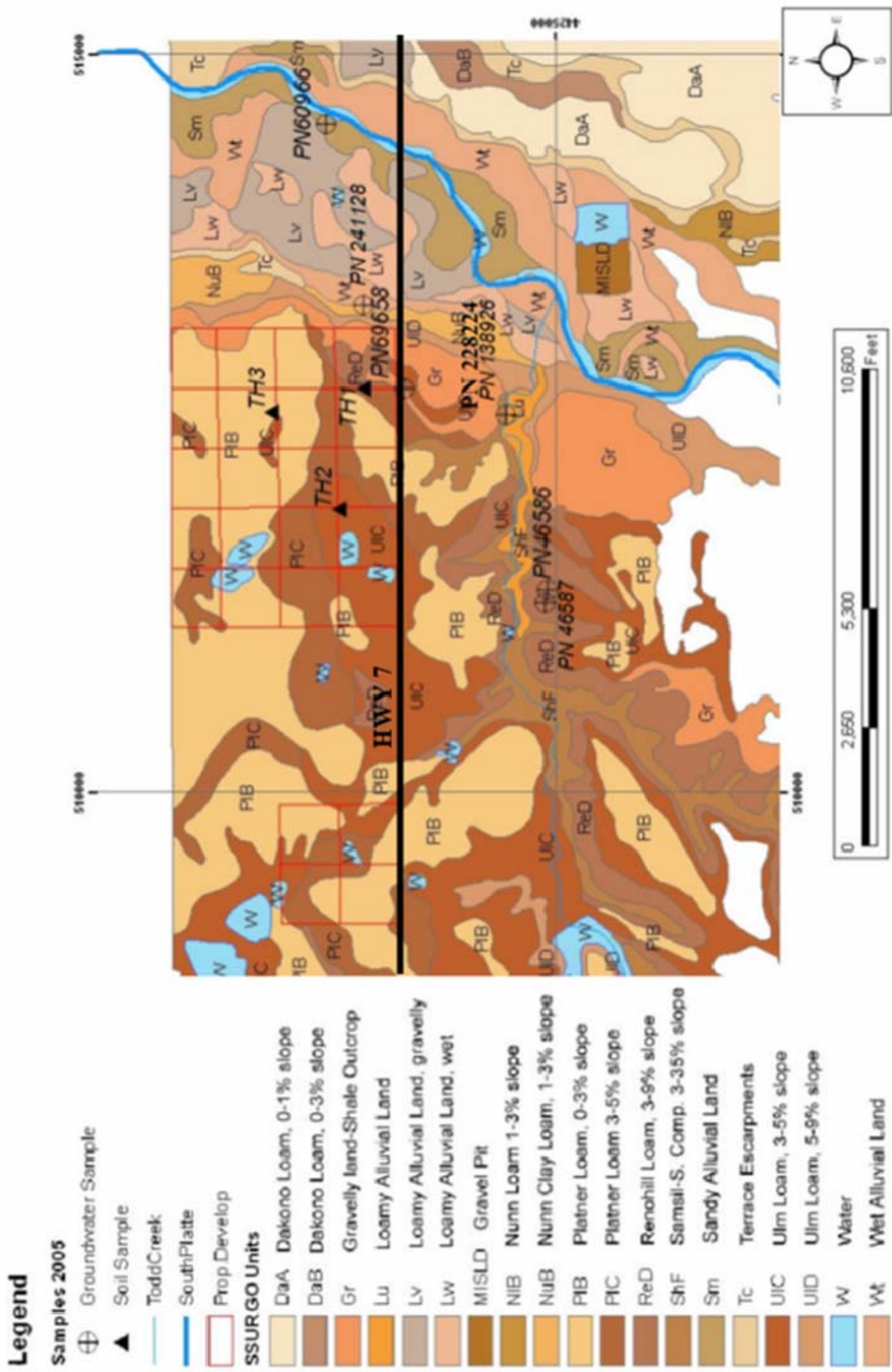
Figure 4.1 Site map including locations of groundwater and soil samples and major soil units

Soil samples were analyzed for physical and chemical properties of interest. **Table 4.3** and **Table 4.4** summarize results for soil physical and chemical sampling respectively. Physical sample analyses were conducted by Church and Associates in their soils laboratory. Samples were analyzed for dry bulk density, moisture content, and percent gravel, sand, and fines. Soil sample chemical analyses were conducted at Evergreen Analytical, Inc. Samples were analyzed for major anions: chloride (Cl), nitrate (NO_3), nitrite (NO_2), and ortho-phosphate (PO_4). Samples were also analyzed for ammonia (NH_3) and total organic carbon (TOC). Due to budget constraints, not all samples were analyzed for the full suite of physical and chemical parameters of interest.

Table 4.3 Results of soil physical property sampling.

Test Hole	Label	Depth (ft)	Moisture Content (% weight)	Dry Density (pcf)	% Fines	% Sand	% Gravel	Field Classification
1	1-2	2-4	24.4	109	72	28	0	loam
1	1-4	4-6	18.2	93	41	59	0	loam
1	1-6	6-8	24.4	--		--	--	loam
1	1-8	8-10	26.1	86	76	24	0	loam
1	1-10	10-12	26.1	--	--	--	--	loam
1	1-12	12-14	29.3	94	--	--	--	clay/claystone
1	1-14	14-16	19.9	--	--	--	--	clay/claystone
1	1-16	16-18	25.5	--	--	--	--	clay/claystone
1	1-18	18-20	26.1	--	--	--	--	clay/claystone
1	1-20	20-22	20.4	107	--	--	--	clay/claystone
2	2-2	2-4	8.5	81	74	26	0	loam
2	2-4	4-6	8.4	--	--	--	--	loam
2	2-6	6-8	8.4	98	55	45	0	loam
2	2-8	8-10	13.2	--	--	--	--	loam
2	2-10	10-12	22.2	98	--	--	--	clay/claystone
2	2-12	12-14	16.8	--	--	--	--	clay/claystone
2	2-14	14-16	24.6	110	--	--	--	clay/claystone
2	2-16	16-18	22.1	--	--	--	--	clay/claystone
2	2-18	18-20	24.4	104	--	--	--	clay/claystone
2	2-20	20-22	22.8	--	--	--	--	clay/claystone
3	3-2	2-4	18.4	--	--	--	--	loam
3	3-4	4-6	21.4	108	61	39	0	loam
3	3-6	6-8	23.5	--	--	--	--	loam
3	3-8	8-10	28.0	106	55	45	0	loam
3	3-10	10-12	27.6	98	30	70	0	loam
3	3-12	12-14	26.0	105	43	57	0	loam
3	3-14	14-16	20.4	86	--	--	--	shale/sandstone

Table 4.4 Results of soil chemical property sampling.

| Hole | Label | Depth (ft) | Soil Carbon Analysis | | | Anions by IC (mg/kg of soil) | | | | | NH$_3$-N |
			Total Carbon (%)	CO$_2$ Carbon (%)	Organic Carbon (%)	Cl	NO$_3$-N	NO$_2$-N	NO$_3$+NO$_2$-N	o-Phosphate	(mg/kg of soil)
1	1-2	2-4	0.18	0.07	0.11	255.0	<0.56	<0.76	<0.76	<0.82	<8.0
1	1-4	4-6	0.10	0.03	0.07	65.2	1.08	<0.76	1.08	<0.82	<8.0
1	1-8	8-10	0.09	<0.02	0.09	9.8	3.8	<0.76	3.8	<0.82	<8.0
1	1-12	12-14	0.15	<0.02	0.15	29.9	4.41	<0.76	4.41	<0.82	<8.0
1	1-20	20-22	0.06	<0.02	0.06	55.3	2.73	<0.76	2.73	<0.82	<8.0
2	2-2	2-4	4.74	4.74	<0.05	<5.0	0.70	<0.76	<0.76	<0.82	<8.0
2	2-6	6-8	0.99	0.99	<0.05	11.0	<0.56	<0.76	<0.76	<0.82	<8.0
2	2-10	10-12	0.32	0.23	0.09	9.4	<0.56	<0.76	<0.76	<0.82	<8.0
2	2-14	14-16	0.14	0.02	0.12	9.2	<0.56	<0.76	<0.76	<0.82	<8.0
2	2-18	18-20	0.19	<0.02	0.19	15.8	0.990	<0.76	0.990	<0.82	<8.0
3	3-4	4-6	2.67	2.67	<0.05	76.1	3.86	<0.76	3.86	<0.82	<8.0
3	3-8	8-10	1.71	1.39	0.32	59.1	5.20	<0.76	5.20	<0.82	<8.0
3	3-10	10-12	0.08	0.04	<0.05	26.5	2.82	<0.76	2.82	<0.82	<8.0
3	3-12	12-14	0.08	0.04	<0.05	25.4	2.71	<0.76	2.71	<0.82	<8.0
3	3-14	14-16	0.17	0.11	0.06	26.1	2.76	<0.76	2.76	<0.82	<8.0

5. SITE CHARACTERIZATION

5.1. Hydrology

5.1.1. Alluvial Aquifer and South Platte River
The Alluvial Aquifer is generally a high conductivity aquifer system, with water levels in the aquifer closely resembling those of the South Platter River. The Alluvial Aquifer and South Platte River are hydraulically connected and have similar water levels. This aquifer system supplies a number of irrigation wells in the TCDA and for the city of Brighton. The elevation of the water table in this area is approximately 4950 feet (CSEO Well Logs and Water Level Database; Robson, 1996).

5.1.2. Vadose Zone
The vadose zone in the study area includes the 10-20 feet of Quaternary alluvial soils and unconsolidated material in the unsaturated portion of the Arapahoe Formation. The near-surface alluvial soil system is the most important hydrologic unit in this study. Effluent discharged from ISDS will percolate through the vadose zone, including these alluvial soils before it reaches groundwater. These soils are capable of natural treatment of effluent, greatly improving water quality of soil-water ultimately recharging groundwater. Microbial processes, namely nitrification and denitrification, are the central mechanisms which can remove nitrate from the subsurface and prevent it from being transported to lower aquifer units. These microbial processes predominantly take place in near-surface soils, and require an organic carbon source. A small amount of denitrification can take place in some aquifers, but the near-surface soils will be the principal location for nitrogen transformation and removal. An in-depth characterization of the Quaternary soils is necessary to better characterize the potential for nitrogen removal.

5.1.3. Arapahoe Aquifer
Presently the water table is below the top of the Arapahoe Aquifer in the TCDA, indicating it is partially saturated. The saturated thickness is estimated to be between 150 feet in the western part of the TCDA and 250 feet in the eastern part. Groundwater flow in the Arapahoe Aquifer is likely near horizontal in the study area. The Laramie Formation effectively cuts off any vertical flow between the Arapahoe and Laramie Fox-Hills aquifer. Regional gradients for the Arapahoe Aquifer indicate a groundwater flow direction of east-southeast.

Potentiometric surface maps of Arapahoe Aquifer indicate a large trough beneath the Alluvial Aquifer (Robson, 1981). Robson suggests that this trough was once smaller, but has become deeper with time due to heavy pumping in the area. Today the water level in the Arapahoe is at an elevation less than 4900 feet above mean sea-level (AMSL) east of the TCDA where Alluvial Aquifer is present. Water-levels in four wells in the Arapahoe Aquifer were measured in April of 2005. These wells, along with historic water levels in the Arapahoe Aquifer were used to generate a potentiometric surface map of the Arapahoe Aquifer in the TCDA (**Figure 5.1**). The local direction of groundwater flow appears to be east-southeast, and water-levels indicate a local hydraulic gradient of approximately 0.004.
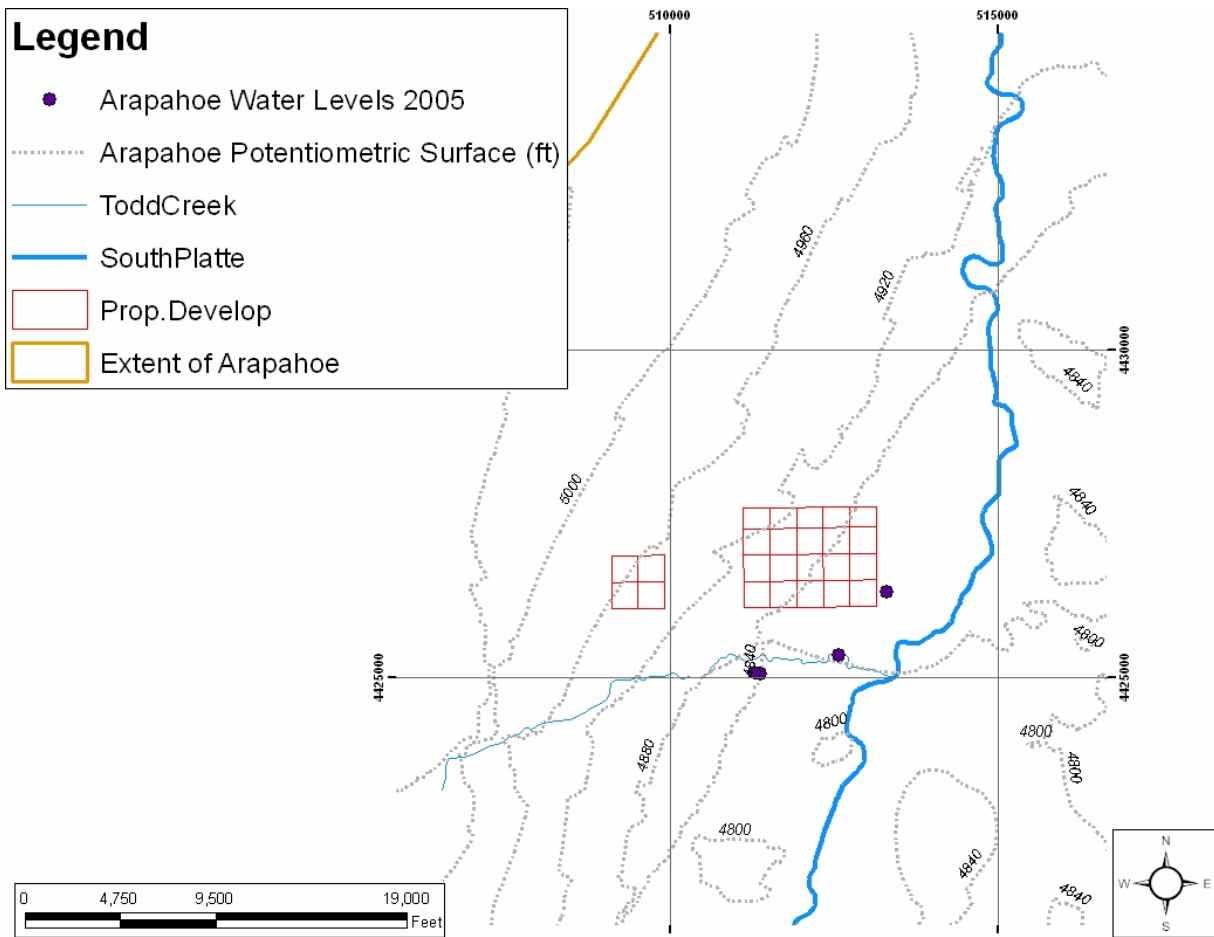
Figure 5.1 Potentiometric Surface map of the Arapahoe Aquifer in the TCDA.

Water-level measurements in the TCDA confirm the potentiometric surface of the Arapahoe Aquifer is clearly below the bottom of the Alluvial Aquifer east of the study area. As a result the water from the Alluvial Aquifer may enter the Arapahoe Aquifer in this area through leakage. Even with leakage from the Alluvial Aquifer, groundwater flow direction is away from the TCDA. Water that enters the Arapahoe through leakage is likely removed from the Arapahoe Aquifer through pumping (CSEO Water Level Database; Robson, 1981). More importantly, there is no pathway for ISDS contaminant transport to the Alluvial Aquifer or South Platte River in the TCDA. A conceptual model for the local hydrologic system is presented in **Figure 5.2**.

5.1.4. Laramie-Fox Hills Aquifer
The Laramie-Fox Hills unit is confined at this location. The hydraulic conductivity is moderately high and a number of municipal wells in the TCDA are screened in this unit. Separated from the overlying aquifers by the Laramie Formation, the Laramie-Fox Hills Aquifer essentially does not communicate with the Arapahoe Aquifer in the TCDA. Regional gradients suggest horizontal groundwater flow to the east-southeast (Robson, 1981).
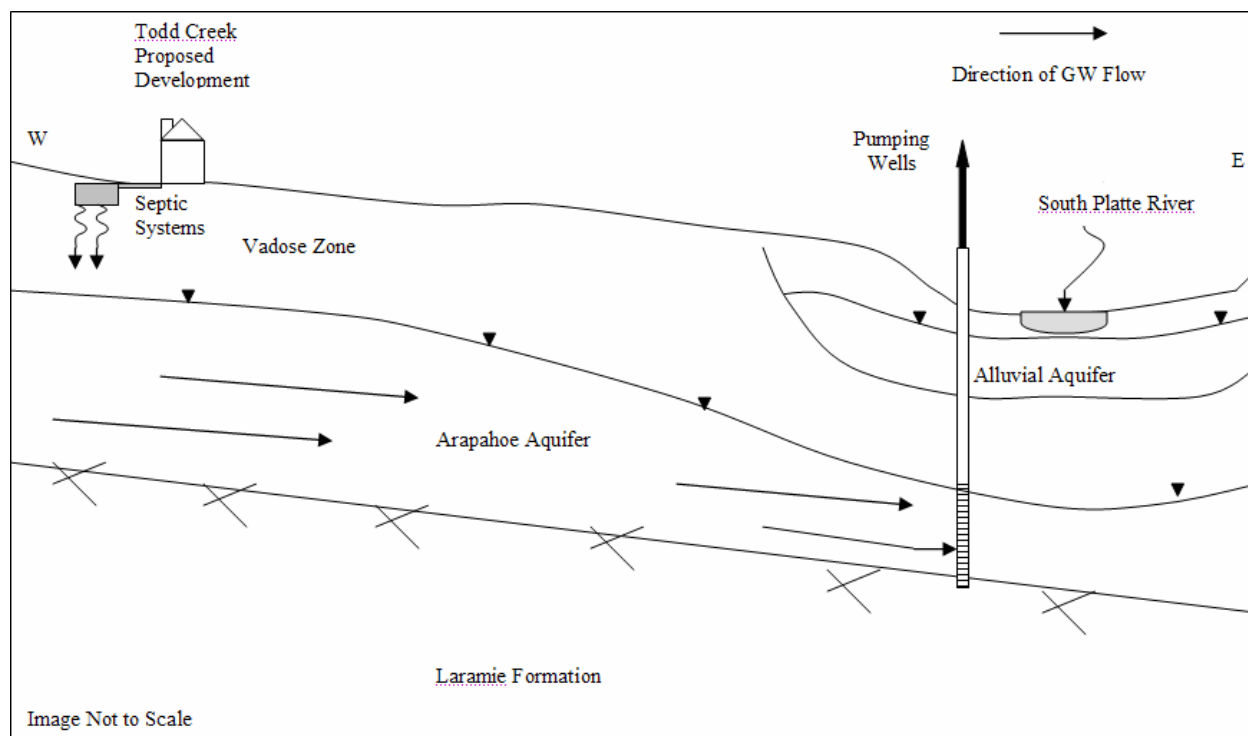
Figure 5.2 Conceptual model for the hydrologic system in the TCDA.

5.2 Water Quality

Table 5.1 summarizes the inorganic nitrogen levels ($NO_3+NO_2+NH_4$) found in the major hydrologic units in the Brighton area according to previous studies and sampling efforts. Nitrogen levels in the Alluvial Aquifer and South Platte River are significant in comparison to the Arapahoe and Laramie-Fox Hills Aquifers. Samples taken from the Alluvial Aquifer and the South Platte River have exceeded the USEPA MCL of 10 mg NO_3-N/L on multiple occasions. The Alluvial Aquifer has the highest concentration of nitrates. This is likely due to the aquifer's location at or near ground surface, high permeability, and recharge with water associated with agricultural practices in the area. The South Platte River similarly sees significant levels of nitrates due to runoff associated with upstream agricultural practices and discharge from municipal wastewater treatment plants. Previous investigations show that no nitrogen species are detected within the Laramie Fox Hills Aquifer. No Laramie-Fox Hills wells were sampled for this investigation and it is not anticipated to be vulnerable to nitrate contamination from ISDS. The Arapahoe Aquifer shows very low levels of inorganic nitrogen, with no samples greater than 1 mg-N/L. **Appendix C** contains a detailed inventory of water quality data for the TCDA.

Table 5.1 Inorganic nitrogen levels of major hydrologic units in the Brighton area.

Unit	Range for NO$_3$ + NO$_2$ + NH$_4$ (mg-N/L)	Data Source
South Platte River	4-12	USGS Henderson Gauging Station
Alluvial Aquifer	9-20	NAQWA Database and Brighton Irrigation Wells
Arapahoe Aquifer	Non Detect-0.7	Water Samples take by Wheeler and Associates in TCDA
Laramie-Fox Hills Aquifer	Non Detect	Highland Acres & Todd Creek Metro District Municipal Wells

Results of water quality sampling are summarized by hydrologic unit in **Table 5.2**. Results of the sampling show that inorganic nitrogen levels in the TCDA fall within the range found in previous investigations in the Brighton area. Results confirm that the Arapahoe Aquifer has very low nitrate levels, below detection limit for most samples. Arapahoe Aquifer water samples have a much different hydrochemical signature in comparison to the other units sampled. Nitrogen levels are much lower in the Arapahoe than other units, while pH and alkalinity average 8.5 and 283 respectively. Alluvial Aquifer and surface water samples indicate greater nitrogen levels and exhibit a lower pH and alkalinity. Wastewater samples were collected from conventional septic systems in Todd Creek from 1999 to 2001 for a previous study at CSM, and this data indicates that STE has much higher levels of inorganic nitrogen than any aquifer or surface water body in the TCDA.

Table 5.2 Water quality results by hydrologic unit.

Sample ID	NO$_3$ (mg-N/L)	NH$_4$ (mg-N/L)	TN (mg-N/L)	pH	Alkalinity (mg-CaCO$_3$/L)
Arapahoe Aquifer Wells					
228224	<0.3	0.35	3.2	8.55	293
241128	<0.3	0.37	1.5	8.51	326
138926	<0.3	0.35	1.2	8.51	298
69658	0.3	0.69	2.9	8.08	203
46586	<0.3	0.48	0.3	8.65	304
46587	<0.3	0.36	3.5	8.63	271
Alluvial Aquifer Wells					
60966	2.1	0.61	4.7	7.4	136
Surface Water					
South Platte River at Hwy. 7	3.1	1.26	9.5	7.72	100
Todd Creek Reservoir	0.3	0.28	4.3	8.47	190
Wastewater					
Todd Creek Conventional ISDS	46.7	0.69	55.46	7.59	542

Results of water quality sampling are consistent with the results of previous sampling done by Wheeler & Associates. Arapahoe wells in the sample area are located in areas of mixed agricultural and low-density residential land-use with ISDS. Current data suggests that the Arapahoe Aquifer has not exhibited significant nitrogen contamination to date. Evident

ammonium levels in the Arapahoe suggest that nitrogen may reach the aquifer having not been fully reduced to nitrate. This is indicative of an anoxic (low-oxygen) environment, where ammonium cannot be nitrified. Additional nitrogen sources may be of concern to this aquifer.

5.3. Wastewater Characterization

Efforts have been made to characterize wastewater generated from ISDS in the TCDA. Septic tank effluent (STE) composition has been analyzed in four different systems within the Todd Creek Metro District in previous studies at CSM. The Todd Creek Metro District has also provided water-use data which can be used to estimate ISDS flowrates. Detailed wastewater characterization and water-use data for ISDS in the TCDA can be found in **Appendix D**.

5.3.1. Wastewater Composition

Table 5.3 summarizes average STE composition in four conventional ISDS monitored in the Todd Creek Metro District from 1999-2001. This data indicates that STE composition from Todd Creek systems falls within typical ranges presented in published literature. It also confirms significant levels of nitrogen are present in STE. Most nitrogen contained in STE is in the form of ammonia (NH_4) which is converted to nitrate (NO_3) in the soils beneath the ISDS.

Table 5.3 STE composition from conventional septic systems in the Todd Creek Metro District and published literature values.

Chemical Constituent	Todd Creek Conventional Systems (Siegrist et al., 2000; Lowe et al., 2001)		Crites and Tchobanoglous (1998)		McCray et al. (2005)	
(units)	Average	Range	Average	Range	Median	Range
Total N (mg-N/L)	57.8	32-84	70.4	50-90	44	12-453
NH_4 (mg-N/L)	50	28.8-75.0	41	30-50	60	17-178
NO_3 (mg-N/L)	0.84	0.5-1.1	--	--	0.2	0-1.94
BOD_5 (mg/L)	166	37-385	185	150-250	--	--

5.3.2. ISDS Flowrate

Water-usage data was provided by the Todd Creek Metro District from 2002-2005. Todd Creek Metro District monitors the water-usage for both potable and irrigation lines separately. Potable water-use was used to estimate average ISDS flowrates in the area. **Table 5.4** shows that flowrates calculated from Todd Creek Metro District water-use data is very close to the estimate calculated using the 50% cumulative frequency value provided by Kirkland (2001). An average household size of 3.08 people was used to convert per capita estimates (Todd Creek Demographic Data).

Table 5.4 Estimates for average ISDS flowrates.

Todd Creek Metro District Water Usage for ISDS		
(gallons/day/capita)	(gallons/day)	(ft^3/day)
56	171	22.7
Estimates From Literature		
Kirkland (2001) 50% CFD		
(gallons/day/capita)	(gallons/day)	(ft^3/day)
60	185	24.7

5.4. Soil Characterization

5.4.1. Soil Physical Properties Characterization

Physical properties of the soils have a direct effect on how fluids are transported through the soil. Soil profiles in each of the test holes have been characterized by their hydraulic properties. The van Genuchten (1980) pore-size distribution relationship is used to describe soil hydraulic properties. This relationship describes soil moisture content (θ) as a function of hydraulic head (h) and is given by **Equation 5.1** as:

$$\theta(h) = \begin{cases} \theta_r + \left| \dfrac{\theta_s - \theta_r}{[1 + |\alpha h|^n]^m} \right| & h < 0 \\ \\ \theta_s & h \geq 0 \end{cases}$$

[5.1]

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

[5.2]

$$K(h) = K_s S_e^l \left[1 - (1 - S_e^{1/m})^m \right]^2$$

[5.3]

$$m = 1 - 1/n \, , \quad n > 1$$

[5.3]

where α, n, and l are empirical constants related to the shape of the soil-water characteristic curve and are a related to soil capillary properties. θ_r and θ_s are the residual and saturated water contents, respectively. K(h) is the soil hydraulic conductivity and S_e is the effective soil saturation given by **Equations 5.2 & 5.3** respectively. K_s is the soil saturated hydraulic conductivity.

A program called Rosetta DLL was used to predict the constants needed for the van Genuchten model. This program uses an extensive soil database, calibrated to hundreds of different soil

samples, to predict van Genuchten constants for each soil type. Rosetta DLL can make predictions with an input of bulk density, and % sand, silt, and clay for a given soil. Rosetta can also assign necessary constants given the appropriate U.S. Department of Agriculture (USDA) soil textural class.

Test hole samples which were analyzed for bulk density and % fines, were input into the Rosetta program as a sample with known bulk density, % sand, silt, and clay. In this case, % fines were assumed to be 50% silt, 50% clay. This assumption was made because the Soil Survey of Adams County classifies soils in this area as loams, which have near equal parts of sand, silt, and clay. Although not ideal, this assumption is necessary to predict soil hydraulic properties. This provides a conservative assumption because, in reality, soils are likely to have a higher percentage of clay. For the case where only a bulk density is reported and the soil was given a field classification of clay, the soil was input into Rosetta as a clay soil; appropriate van Genuchten constants were then assigned. Test hole samples which were not analyzed were input into Rosetta according to a linear interpolation with surrounding analyzed samples. **Table 5.5** gives the results for soil hydraulic properties characterization for the three test holes.

Table 5.5 Summary of soil hydraulic properties for test holes in the TCDA.

Test Hole	Sample	θ_r	θ_s	α	n	K_s (cm/day)	l	Field Classification
1	1-2	0.0699	0.3518	0.016	1.2591	1.63	0.5	loam
1	1-4	0.0602	0.401	0.0213	1.3997	21.79	0.5	loam
1	1-6	0.0756	0.4246	0.0137	1.4194	10.12	0.5	loam
1	1-8	0.0893	0.4567	0.0119	1.4187	10.8	0.5	loam
1	1-10	0.0893	0.4567	0.0119	1.4187	10.8	0.5	loam
1	1-12	0.068	0.38	0.008	1.09	4.8	0.5	clay
1	1-14	0.068	0.38	0.008	1.09	4.8	0.5	clay
1	1-16	0.068	0.38	0.008	1.09	4.8	0.5	clay
1	1-18	0.068	0.38	0.008	1.09	4.8	0.5	clay
1	1-20	0.068	0.38	0.008	1.09	4.8	0.5	clay
2	2-2	0.0906	0.4758	0.012	1.4326	17.06	0.5	loam
2	2-4	0.0798	0.4295	0.0128	1.42	8.65	0.5	loam
2	2-6	0.067	0.3864	0.0165	1.3487	6.48	0.5	loam
2	2-8	0.067	0.3864	0.0165	1.3487	6.48	0.5	loam
2	2-10	0.068	0.38	0.008	1.09	4.8	0.5	clay
2	2-12	0.068	0.38	0.008	1.09	4.8	0.5	clay
2	2-14	0.068	0.38	0.008	1.09	4.8	0.5	clay
2	2-16	0.068	0.38	0.008	1.09	4.8	0.5	clay
2	2-18	0.068	0.38	0.008	1.09	4.8	0.5	clay
2	2-20	0.068	0.38	0.008	1.09	4.8	0.5	clay
3	3-2	0.0628	0.3478	0.0189	1.2516	2.33	0.5	loam
3	3-4	0.0628	0.3478	0.0189	1.2516	2.33	0.5	loam
3	3-6	0.0617	0.351	0.0194	1.259	2.96	0.5	loam
3	3-8	0.06	0.3518	0.0205	1.2613	3.66	0.5	loam
3	3-10	0.0512	0.3768	0.0304	1.4323	31.47	0.5	loam
3	3-12	0.053	0.3509	0.0267	1.2752	8.23	0.5	loam
3	3-14	0.0648	0.4291	0.0185	1.4301	30.53	0.5	sand/sandstone

Soil profiles of hydraulic properties were also generated for the Platner Loam and Ulm Loam based on soil texture classifications assigned by the Soil Survey of Adams County. The Platner Loam and Ulm Loam typically exist to depths of 60 and 48 inches respectively (USDA, 1974). Depths given in **Table 5.6** have been converted to centimeters and normalized to zero-depth datum located at 60 cm below ground surface. This datum corresponds to a two foot depth which is the typical location of the infiltrative surface for conventional ISDS. Material beneath each soil profile is assumed to be clay to a depth of 400 cm.

Table 5.6 Summary of soil hydraulic properties for the Platner Loam and Ulm Loam.

Soil	Depth (cm)	θ_r	θ_s	α	n	K_s (cm/day)	l	Field Classification
Platner Loam	0-12	0.095	0.41	0.019	1.31	6.24	0.5	clay
Platner Loam	12-64	0.078	0.43	0.036	1.56	24.96	0.5	clay loam
Platner Loam	64-92	0.065	0.41	0.075	1.89	106.1	0.5	sandy loam
Platner Loam	92-400	0.068	0.38	0.008	1.09	4.8	0.5	clay
Ulm Loam	0-16	0.068	0.38	0.008	1.09	4.8	0.5	clay
Ulm Loam	16-60	0.095	0.41	0.019	1.31	6.24	0.5	clay loam
Ulm Loam	60-400	0.068	0.38	0.008	1.09	4.8	0.5	clay

Hydraulic properties for the soil profiles are used in subsequent vadose zone modeling discussed in **Section 7**. Each of the three test holes and the Platner Loam and Ulm Loam soils will be modeled as separate cases.

5.4.2. Soil Chemical Properties Characterization
Results from soil chemical sampling conducted on samples from the three test holes in the TCDA give important information about how chemicals are distributed in the soil profile. Please refer to **Table 4.4** for results of chemical sampling. **Figure 5.3** gives results of major chemical species with depth. Calculations for pore-water chloride and nitrate content assume that all mass present in samples is in the soil pore-water.

a. Chloride vs. Depth

b. Nitrate vs. Depth

c. Total Organic Carbon vs. Depth
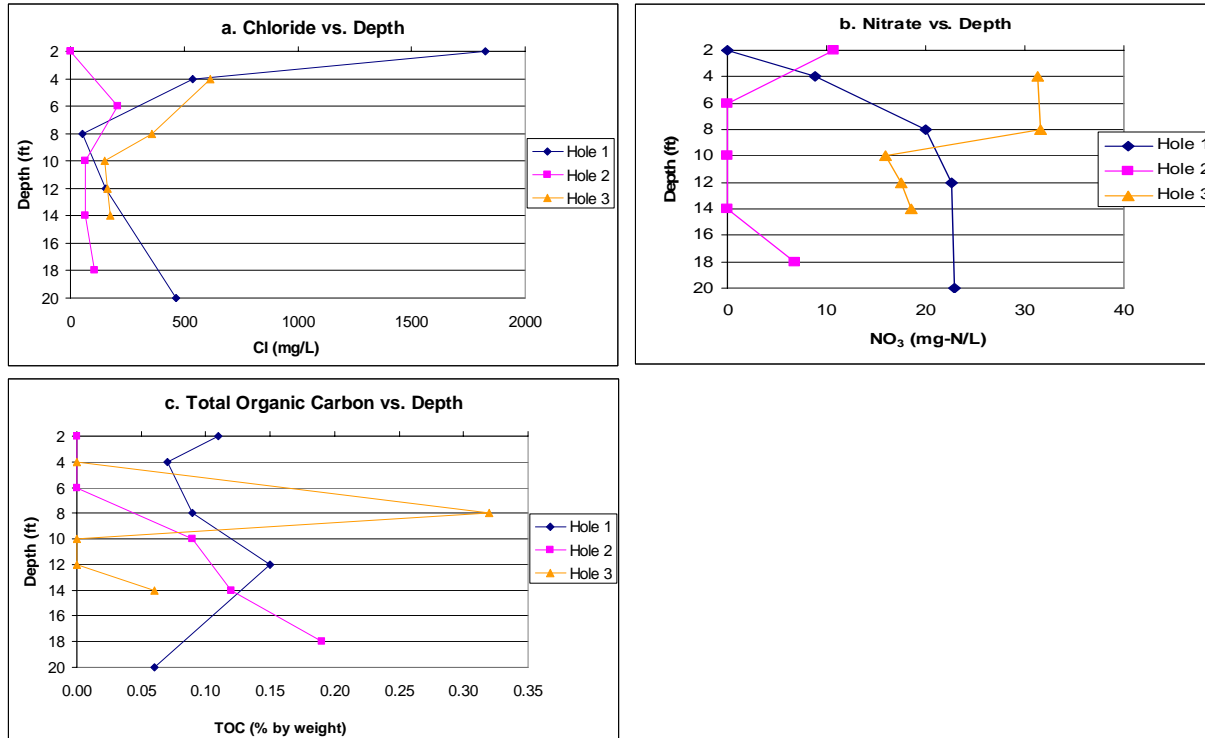
Figure 5.3 Soil profiles of **a**. chloride, **b**. nitrate, and **c**. organic carbon with depth.

Chloride

Chloride is generally a conservative chemical species in soil and groundwater. It can be used to describe conservative transport due solely to advection and dispersion. Chloride is highly soluble; soil sample concentrations are likely a reflection of the composition in soil pore-water. There is no clear pattern of chloride distribution in the vertical soil profile. In two of the test holes (**Figure 5.3 a**) high chloride levels are present in shallow samples, followed by lower chloride levels in deeper soils, and finally higher chloride levels are seen again in the deepest soil samples. Sources of chloride include fertilizer and animal waste, both of which may have been applied in this area. ISDS can also be a source of chloride in soil and groundwater; however, the sample locations are in an agricultural setting. Elevated chloride levels at greater depth may reflect leaching of chloride as a result of soil-water recharge which commonly occurs during the time at which soils were sampled. Elevated chloride levels at depth may also indicate the current vertical limits of recharge under current agricultural conditions.

Inorganic Nitrogen

Inorganic nitrogen species include ammonia, nitrate, and nitrite. Ammonia present in soil samples may be solid-phase ammonia which has been adsorbed to the soil or as liquid-phase ammonium present is soil pore-water. Nitrate and nitrite are highly soluble chemical species in water; soil concentrations are likely a reflection of the composition of soil pore-water. Sources of inorganic nitrogen are fertilizers, animal wastes, irrigation water, and ISDS (where present). Ammonia was not detected in any of the soil samples; however the laboratory detection limit for ammonia is 8 mg-NH_4-N/kg soil. This detection limit precludes evaluation of this species because lower levels of ammonia likely exist. No nitrite was detected in any of the soil samples. Nitrite levels in soil and groundwater are usually very small in comparison to nitrate. Nitrate

levels (**Figure 5.3 b**) show no general trend with depth. Significant nitrate levels do appear to exist below 14 feet in two of the test holes. Deeper samples with high nitrate levels may again reflect leaching as soil water recharge occurs.

Phosphate
Results of soil chemical sampling show that no phosphate was detected at any depths. Sources of phosphate may be fertilizers, irrigation water, decaying plant matter, and ISDS where present. Phosphate is typically absorbed in soil and soil phosphate levels may be affected by plant uptake. The absence of phosphate in soil samples may be due to near-complete absorption in the first two feet of soil which was not sampled, and natural plant recycling of phosphorous.

Total Organic Carbon
Denitrification requires a source of organic carbon for the reaction to take place. Higher denitrification rates are correlated with higher organic carbon levels. Organic carbon is mainly present in the solid-phase in soils; some may be in the dissolved form but is likely low due to the low solubility of organic carbon. Organic carbon may also be present in STE.   Total organic carbon levels range from <0.05 to 0.32 percent by weight in all samples collected. **Figure 5.3 c** shows that there does not appear to be any trend in organic carbon content in soil with depth. Additionally, three of the five samples which were below detection limit (<0.05) had very high CO_2 readings. Because organic carbon content is calculated as difference between total carbon and CO_2 carbon, the three samples with high CO_2 may yield inaccurate readings of organic carbon.   The average organic carbon content is 0.08 and 0.13 without the three questionable samples.

Sampling of soils beneath ISDS in Todd Creek
During a previous study at CSM soil samples beneath septic systems in Todd Creek were chemically analyzed (Lowe et al., 2001). Sampling was done from depths of 0-60 cm (0-2 feet) beneath the infiltrative surface which analyzed soil composition and composition of mobile pore-water. Soil composition beneath the infiltrative surface shows considerable concentrations of ammonium and nitrate beneath the infiltrative surface. **Table 5.7** gives a comparison between samples from 0-60 cm (0-2 feet) beneath conventional septic systems drainfield infiltrative surface (equivalent 2-4 feet below ground surface) and soil samples collected for this study at a depth of 2-4 feet.

Table 5.7 Inorganic nitrogen levels for agricultural soils and ISDS soils in TCDA.

Sample	NH_4 mg-N/kg Soil	NO_3 mg-N/kg Soil	NO_3 mg-N/L
Todd Creek Ag. Soils			
1-2 (2-4 ft depth)	Non-detect	<0.56	0
2-2 (2-4 ft depth)	Non-detect	0.7	10.72
Average (2-4 ft. depth)	*Non-detect*	*0.35*	*5.36*
Todd Creek ISDS Soils			
5 cm below IS	95.3	3.7	71.94
15 cm below IS	20.4	4.0	68.00
30 cm beolow IS	19.1	4.4	79.45
60 cm below IS	15.9	5.7	69.36
Average (2-4 ft depth)	*37.7*	*4.5*	*72.19*

Results show that inorganic nitrogen levels are much greater in soils beneath conventional septic systems than in agricultural soils at comparable depths. In estimating aqueous concentrations, all nitrates in the soil sample are assumed to exist in soil-pore water. Nitrate levels in soil and soil-pore water are more than 10 times greater in soils beneath ISDS than agricultural soils. This suggests that there is more potential for nitrogen loading to groundwater from residential land-use with ISDS than from agricultural land-use. The complete set of soil sampling data collected beneath ISDS in Todd Creek is included in **Appendix D**.

6. QUANTITATIVE SCREENING MODELS

Several modeling strategies were employed in order to determine if additional, more complex modeling was needed. This approach allowed the use of much simpler models to obtain approximate screening of results before developing a more complicated model, and can save much unneeded work. Two models were employed to provide information about ISDS impacts to water-resources. The first model (**Section 6.1**) compares nitrogen mass loading through residential and agricultural land-use practices. The second model (**Section 6.2**) uses an aquifer mass balance to determine if the Arapahoe Aquifer is susceptible to nitrate contamination.

6.1. Mass-Loading Model

The mass-loading model simply calculates the nitrogen mass flux for a given land-use. The flux in this model is calculated as kg of nitrogen per square meter per year (kg-N/m^{2}yr). Model simulations considered either purely agricultural land use or purely residential (with ISDS) land-use. The objective of the mass-loading model is to compare the flux between the different land-uses. This model does not account for several processes that can affect long term nitrogen levels in the system, such as fertilizer application, plant nitrogen uptake, and nitrogen transformation (nitrification and denitrification). These processes are very difficult to model and are not within the objective of this simple screening model. The model shows that the agricultural flux and residential flux are very similar and that evaluation of potential ISDS impacts cannot be disregarded. Complete output of the model simulations is included in **Appendix E**.

A summary of model calculations is shown in **Table 6.1.** This figure summarizes a best estimate for nitrogen mass loading rates. The best estimate simulation uses median (or known) parameter values, and shows that the ratio of residential flux to agricultural flux is 0.8. The model shows that the fluxes due to residential land use, including ISDS, and agricultural land-use are within 20 percent.

Table 6.1 Mass-loading model output for best estimate parameter values

Ratio of Residential Flux to Agricultural Flux		Total Nitrogen Concentration in STE[1] (mg/L)	Total Nitrogen Concentration in Septic Tank Effluent (kg/m^3)	Average Lot Size[2] (acres)	Average Lot Size (m^2)	ISDS Discharge Rate[3] (gal/day/capita)	Average Household Size[4]	ISDS Discharge Rate (gal/day)	ISDS Discharge Rate (m^3/yr)	Mass Flux ISDS (kg/m^2*yr)	
0.8		47.4	0.047	1.5	6070	60	3.04	182	252	0.0020	
Domestic Irrigation Rate[5] (gal/day)	Domestic Irrigation Rate (m^3/yr)	Nitrogen Concentration of Irrigation Water5[6] (mg/L)	Nitrogen Concentration of Irrigation Water (kg/m^3)	Mass Flux Domestic Irrigation (kg/m^2*yr)	Total Domestic Mass Flux (kg/m^2*yr)		Total Nitrogen Concentration in Irrigated Water[5] (mg/L)	Total Nitrogen Concentration in Irrigated Water (kg/m^3)	Irrigation Rate[7] (ft/yr)	Irrigation Rate (m/yr)	Agricultural Mass Flux (kg/m^2*yr)
426	589	5.6	0.0056	0.0005	0.0025		5.6	0.0056	1.8	0.554	0.0031

1 Total Nitrogen Concentrations in Septic Effluent from Conventional Systems in Todd Creek (Lowe et. al., 2001)
2 Average Lot Size in Todd Creek Metro District
3 Typical ISDS discharge rate taken as 50% value from ISDS cumulative distribution curve (McCray, 2005)
4 Household size calculated from Todd Creek District demographic data (http://www.city-data.com/housing/houses-Todd-Creek-Colorado.html, 2000)
5 Average Domestic Irrigation Rate from Todd Creek Metro District Water Usage Data (2003-2005)
6 Average total Nitrate+Nitrite+Ammonium concentration April-Oct at Henderson Gaging Station, South Platte River, CO (USGS NAQWA Database)
7 Average irrigation rate for South Platte River Basin (Colorado Division of Water Resources, 1998)

The basic conclusion of this assessment is that the simple mass loading model cannot rule out potential impacts from ISDS from a mass loading basis. The model shows that calculated nitrogen fluxes from each land-use are within 20% and this cannot account for the uncertainty

and variability of nitrogen transport through the vadose zone. In fact, chemical soil sampling suggests that nitrogen levels in soils of the TCDA are higher for residential land-use. While the mass-loading model predicts nitrogen mass flux based on each land use, this does not, however, necessarily translate to the actual amount of nitrogen seen in soils or transported to groundwater. Agricultural land-use may have a greater mass load per square meter, but in this case the nitrogen is applied evenly over the land surface and the entire area of soil in a given area will have the opportunity for nitrogen removal. In the case of residential land use, the mass load per square meter may be lower, but this flux is based on normalizing STE over the entire land surface in the TCDA rather than just under the ISDS. If we consider the mass flux under a single ISDS drainfield the mass load would be much greater than agricultural land-use. In reality the effluent from ISDS is applied over a much smaller area at much higher nitrogen concentrations. Thus, the actual mass flux is much greater but it is applied to smaller areas, and a smaller area of soil is capable of treating the effluent. This requires much greater treatment from the soil, and is the reason that there is higher potential for nitrogen from ISDS to reach groundwater. Results of the chemical soil sampling confirm this concept as nitrogen levels in soils beneath ISDS are much greater than levels found in the agricultural soils sampled for this study.

6.2. Arapahoe Aquifer Mixing Model
The conceptual model for the Arapahoe Aquifer mixing model is shown in **Figure 6.1**. This model considers a volume of the Arapahoe Aquifer beneath the TCDA. The model also considers a typical cross section of the Arapahoe Aquifer using the average saturated thickness (Hsat) and percent sand (% sand). These values were estimated using results of the RockWorks$_{TM}$ program for the Arapahoe Aquifer and using average water-levels measured in the TCDA. The model assumes the Arapahoe Aquifer behaves as a well-mixed system with flow coming in and out, meaning any nitrogen added will be evenly mixed throughout the aquifer. In reality, this will not be the case, especially in a heterogeneous layered aquifer. As a result, higher concentrations of nitrogen will be present near the water table. This model assumes that a given percent of nitrogen discharged from ISDS is removed in the soil absorption system. It also assumes that all nitrogen reaching groundwater will be in the form of nitrate, which is a conservative assumption from the perspective of aquifer protection. Model simulations were run using a 30, 50, and 70% total nitrogen removal rate in the soil absorption system. If the Arapahoe Aquifer shows impact through this simpler mixing, further modeling which accounts for removal of nitrogen in the vadose zone is required.
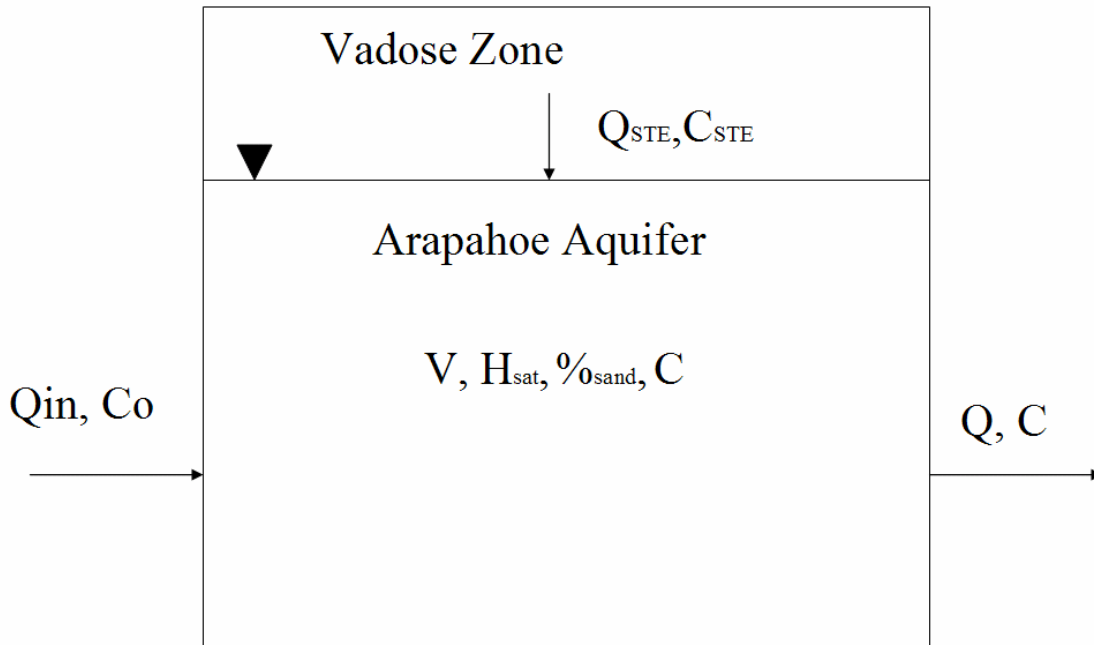
Figure 6.1 Conceptual model for Arapahoe Aquifer mixing model.

This model uses the laws of mass balance on the Arapahoe Aquifer beneath the proposed development.

Key assumptions are:
- the Aquifer is a well mixed system
- the Shale layers are immobile domain
- the Sands are interconnected
- there is no decay of nitrogen in the aquifer

The mass balance equation is shown below (**[6.1]**).

$$\frac{\delta M}{\delta t} = V \frac{\delta C}{\delta t} = Qin * Co + Q_{Vadose} * C_{Vadose} - Q * C \qquad \text{[6.1]}$$

At steady state $\frac{\delta C}{\delta t} \to 0$ and the mass balance equation becomes:

$$Qin * Co + Q_{Vadose} * C_{Vadose} = Q * C \qquad \text{[6.2]}$$

Solving for steady state concentration, C:

$$C = \frac{Qin * Co + Q_{Vadose} * C_{Vadose}}{Q}$$

[6.3]

and Qin can be calculated by Darcy's Law as:

$$Qin = K * I * (H_{sat} * \%_{SANDS} * W)$$

[6.4]

where W is width of the proposed development.

The results for modeling simulations with 50% total nitrogen removal in the soil absorption system are given in **Table 6.2**. Full model output including different removal rate scenarios can be found in **Appendix F**. The most uncertain model parameter in this approach was hydraulic conductivity. The model was accordingly run under a range of possible hydraulic conductivity values. Ranges of hydraulic conductivity were estimated from information given in the USGS Hydrologic Atlas for the Arapahoe Aquifer (Robson, 1981).

Table 6.2 Arapahoe Aquifer mixing model results for 50% nitrogen removal.

Aquifer Properties										ISDS Properties						Steady-State Arapahoe Aquifer Concentration (mg-N/L)
Saturated Aquifer Thickness (m)	% Sand	Equivalent Thickness (m)	Area of Aquifer (acres)	Area of Aquifer (m²)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient	Darcy Flow, q (m/yr)	Aquifer Flowrate, Q (m³/yr)	Background Nitrate Level in Arapahoe (mg-N/L)	Total # of ISDS	Typical Single ISDS Flowrate (m³/yr)	Total ISDS Flowrate (m³/yr)	Total Nitrogen Concentration in Septic Tank Effluent (mg/L)	Soil Absorbtion System Nitrogen Removal Efficieny (%)	Total Nitrate Concentration Reaching Groundwater (mg-N/L)	
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	1100	2.5E+02	2.77E+05	47.4	50.0	23.7	22.52
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	1100	2.5E+02	2.77E+05	47.4	50.0	23.7	18.76
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	1100	2.5E+02	2.77E+05	47.4	50.0	23.7	15.53
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	1100	2.5E+02	2.77E+05	47.4	50.0	23.7	6.53
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	800	2.5E+02	2.02E+05	47.4	50.0	23.7	22.10
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	800	2.5E+02	2.02E+05	47.4	50.0	23.7	17.41
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	800	2.5E+02	2.02E+05	47.4	50.0	23.7	13.75
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	800	2.5E+02	2.02E+05	47.4	50.0	23.7	5.13
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	400	2.5E+02	1.01E+05	47.4	50.0	23.7	20.70
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	400	2.5E+02	1.01E+05	47.4	50.0	23.7	13.75
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	400	2.5E+02	1.01E+05	47.4	50.0	23.7	9.69
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	400	2.5E+02	1.01E+05	47.4	50.0	23.7	2.88
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	200	2.5E+02	5.04E+04	47.4	50.0	23.7	18.38
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	200	2.5E+02	5.04E+04	47.4	50.0	23.7	9.69
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	200	2.5E+02	5.04E+04	47.4	50.0	23.7	6.09
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	200	2.5E+02	5.04E+04	47.4	50.0	23.7	1.53

The model results for 50% nitrogen removal show a range of steady-state nitrate concentrations in the Arapahoe Aquifer from about 1.5-23 mg-N/L. Most simulations are greater than the USEPA MCL of 10 mg/L, which shows a potential impact to water quality of the Arapahoe Aquifer. Results for the model simulations of 30% and 70% nitrogen removed also show that simulations using most parameter inputs yield a nitrate concentration noticeably higher than background levels. For example, the model simulation for 200 ISDS in the TCDA predicts nitrate levels in the Arapahoe Aquifer between 2-18 mg-N/L. This suggests that the Arapahoe Aquifer could be vulnerable to nitrate contamination. The mixing model does not account for certain processes that may be important in nitrogen removal, such as further treatment in deeper

soils and sediment. These results conclude that further hydrologic modeling is needed to account for potential additional loss of nitrogen in the vadose zone.

7. VADOSE ZONE MODELING

Nitrogen loading to the Arapahoe Aquifer, using quantitative screening models, confirms it may be vulnerable to nitrate contamination, if additional nitrate is added to the aquifer. Nitrogen in STE must travel through the vadose zone before it reaches the Arapahoe Aquifer where there is potential for natural attenuation of nitrogen and other nutrients. The objective of vadose zone modeling is to assess the capacity for nitrogen removal and attenuation in the vadose zone. Modeling efforts aim to estimate steady-state concentrations and travel time of nitrogen species passing through the vadose zone.

A numerical modeling program called HYDRUS 1D was used to model nitrogen transport in the vadose zone. HYDRUS 1D assumes one-dimensional vertical water flow and solute transport in the model domain. This program can model 1-D water flow and multiple solute transport in variably saturated media. HYDRUS 1D is capable of simulating advection, dispersion, and zero- and first-order solute transformation and decay.

Nitrogen in STE is primarily in the form of ammonium. Ammonium can be removed from soil water through soil-media absorption and through nitrification. Soil absorption of ammonium will be neglected because modeling efforts focus on steady-state (long-term) solute transport and sorption sites are limited. Ammonium removal will accordingly be simulated using a first order decay rate to represent nitrification. Ammonium is converted to nitrate through the process of nitrification:

$$NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^{2-} \qquad \textbf{[7.1]}$$

Nitrate can also be converted to nitrogen gas through the process of denitrification:

$$NO_3^{2-} \rightarrow N_2O_{(g)} \rightarrow N_{2(g)} \qquad \textbf{[7.2]}$$

Nitrification and denitrification are both microbially facilitated processes that occur under a specific set of conditions. Nitrification is the process of sequential oxidation of nitrogen compounds, usually ammonium, into nitrite, into nitrate. Nitrification takes place under oxidizing conditions, in other words, in the presence of oxygen. Oxidizing conditions are common in most soils at or near the surface. Most nitrification likely takes place in the vadose zone during percolation, within the top meter of soil.

Denitrification takes place under anoxic conditions, or under the absence of dissolved oxygen, and additionally requires a source of organic carbon to transpire. Soil chemical sampling results show that organic carbon is present throughout the soil profile. STE effluent also contains organic matter in the form of biochemical oxygen demand (BOD), which may also be available as an organic source. Denitrification rates are very difficult to predict, and are generally much smaller than nitrification rates. Nitrate removal through denitrification is also simulated using a first-order decay term.

This modeling exercise simulates a two solute system, representing ammonium (C_1) and nitrate (C_2). Solute transformation is simulated by two first-order decay rate coefficients r_1 and r_2, to

calculate the first order rates k_1 and k_2, representing the chain transformation of nitrogen by means of nitrification and denitrification, respectively. The overall sequential first-order decay chain follows the subsequent path:

$$C_1 \xrightarrow{k_1} C_2 \xrightarrow{k_2} \text{Nitrogen Gas} \qquad [7.3]$$
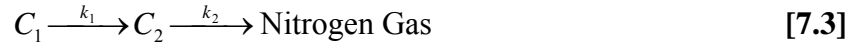
and first order rates are calculated as follows

$$k_{1,2} = r_{1,2} * C_{1,2} \qquad [7.4]$$

The HYDRUS model is capable of generating output of nitrate concentration with depth. Output nitrate flux rates can than be calculated from this output. Nitrate present in water draining out the bottom of the soil profile is assumed to reach the Arapahoe Formation, and has the potential to reach the aquifer by means of vertical transport through interconnected sand layers. The objective of the vadose zone modeling is to quantify the concentration and flux of nitrate (if any) passing through the soil profile and potentially entering the Arapahoe Aquifer.

7.1. Governing Equations

7.1.1. Water Flow Governing Equation
The HYDRUS model solves a modified form of Richard's Equation (**Eq. 7.5**) for one-dimensional water flow in variably saturated media. The equation is given by

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}[K(\frac{\partial h}{\partial x})] \qquad [7.5]$$

where θ is volumetric water content, K is hydraulic conductivity, and h is water pressure head.

HYDRUS discretizes the soil profile into a finite-element mesh, and then solves Richard's Equation [7.5] for each element. The model also utilizes the van Genuchten pore-size distribution model covered in **Section 7.4.1** to describe soil hydraulic conductivity and moisture content as a function of pressure head.

7.1.2. Solute Transport Governing Equations
The partial differential equations governing one-dimensional transport of ammonium and nitrate involved in a sequential first-order decay chain during transient water flow in a variably saturated medium are given by

$$\frac{\partial(\theta C_1)}{\partial t} = \frac{\partial}{\partial x}(\theta D \frac{\partial C_1}{\partial x}) - \frac{\partial q C_1}{\partial x} - k_1 \theta C_1 \qquad [7.6]$$

$$\frac{\partial(\theta C_2)}{\partial t} = \frac{\partial}{\partial x}(\theta D \frac{\partial C_2}{\partial x}) - \frac{\partial q C_2}{\partial x} + k_1 \theta C_1 - k_2 \theta C_2 \qquad [7.7]$$

where q is the Darcy velocity of the soil water with units of length per time, and D is the soil dispersion coefficient. The soil dispersion coefficient is calculated by

$$D = \alpha_l v \qquad \text{[7.8]}$$

where α_1 is longitudinal soil dispersivity, and v is pore-water velocity. Pore-water velocity is calculated by dividing Darcy velocity (q) by effective soil porosity. HYDRUS makes all necessary calculations internally. HYDRUS solves the above convection-dispersion equation with coupled first-order decay for each element in the finite-element mesh.

7.2. Boundary Conditions

Boundary conditions are necessary so HYDRUS can solve the governing equations for water flow and solute transport at the bottom and top of the model domain. Top and bottom boundary conditions need to be specified for water flow and solute transport.

7.2.1. Water Flow Boundary Conditions

The top water flow boundary condition is set as a constant water flux boundary condition which is given by

$$-K \frac{\partial h}{\partial x} = q_o \qquad \text{[7.9]}$$

where q_o is the constant water flux in units of length per time. A constant water flux top boundary condition was chosen to simulate a time-averaged constant discharge from conventional ISDS. The value of q_o is calculated by estimating ISDS flowrates normalized over surface area. This value is an input parameter, STE application rate, and its quantity is discussed in the input parameter section.

The bottom water flow boundary condition is set as a deep drainage boundary which is essentially a zero pressure head gradient boundary condition given by

$$\frac{\partial h}{\partial x} = 0 \qquad \text{[7.10]}$$

where $\frac{\partial h}{\partial x}$ is the pressure head gradient. This bottom boundary condition was chosen to simulate a deep water table and allow free drainage (gravity driven) out of the bottom of the soil profile.

7.2.2. Solute Transport Boundary Conditions

Top and bottom boundary conditions for each solute need to be specified in HYDRUS. The top solute transport boundary condition for *both* solutes is specified as a constant mass flux boundary given by

$$\frac{\partial C_{1,2}}{\partial x} = q_o Co_{1,2} \qquad \text{[7.11]}$$

where $Co_{1,2}$ are the input concentrations of solute 1 (NH_4) and solute 2 (NO_3). A specified mass flux boundary was simulated for each solute to represent time-averaged mass flux from conventional ISDS. The value of q_o is the same value that will be used for the water flow top boundary condition. C_o values will reflect STE concentrations.

The bottom solute transport boundary condition for *both* solutes is a second-type (or Neumann type) boundary condition given by

$$\theta D \frac{\partial C_{1,2}}{\partial x} = 0 \qquad \text{[7.12]}$$

This boundary condition was chosen to represent a zero concentration gradient at the lower boundary (bottom of the soil profile). This boundary condition is not ideal, but some sort of boundary condition needs to be specified. The other possible boundary conditions would be a constant concentration or constant mass flux, neither of which is appropriate in this case. The zero concentration gradient boundary condition is valid if the solute concentration is at or near zero as it approaches the lower boundary. If solute concentration does not approach zero as the solute approaches the boundary, then the model will force the concentration gradient equal to zero, and the model will over-predict solute concentration near the boundary. Thus this boundary condition, when not strictly met, causes the model predictions to be conservative with respect to aquifer protection.

7.3. Initial Conditions

Initial conditions are needed so that HYDRUS can solve the governing equations, which are transient. Like boundary conditions, initial conditions must also be specified for water flow and solute transport for *both* solutes. However, the focus of this modeling is on long-term, steady state nitrogen transport. Accordingly, model simulations are run for long times and effects of initial conditions become negligible as time approaches steady-state. The same steady-state solution is obtained regardless of any specified initial condition.

Regardless, HYDRUS requires user specified initial conditions so it can solve the transient governing equations. The water flow initial condition may be specified in terms of water content or pressure head. An initial condition in the pressure head (**Eq. 7.13**) was specified for all simulations, and a value of -100 cm was assigned. Specifying a negative pressure head of -100 cm translates to initial soil moisture contents near its residual value, and causes the soil to behave in early time as it would during low-moisture conditions. The solute transport initial condition is specified in terms of initial concentration. The initial concentration for both solutes (**Eq. 7.14**) was specified as zero. This will begin the model simulation with no initial nitrogen present in the soil profile.

$$h(x, t = 0) = -100cm \qquad \text{[7.13]}$$
$$C_{1,2}(x, t = 0) = 0 \qquad \text{[7.14]}$$

By specifying these initial conditions the model is simulating an initially dry soil with no nitrogen present. This is meant to simulate how soils in the TCDA might be before operation of ISDS. Breakthrough curves that will be later analyzed pertain to this set of initial conditions.

7.4. Model Simulations

The HYDRUS model requires information about the soil profiles the user desires to model. Five different soil profiles were simulated using this model, corresponding to the three test holes drilled in the TCDA and the soil profiles for the Platner and Ulm Loam given by the Soil Survey of Adams County, Colorado (USDA, 1974). HYDRUS accepts output from Rosetta DLL (summarized in **Table 5.5**) to describe soil hydraulic properties and soil composition with depth.

HYDRUS requires all data is input into the program using consistent units. Units of mg, cm, and days were selected as units for mass, length, and time respectively. All mass units are in terms of mg-nitrogen (mg-N). A time of 1000 days was selected for duration of modeling simulations. After a few hundred days solute concentration profiles cease to change as time increases. A simulation length of 1000 days ensures that an appropriate steady-state profile is obtained.

7.5. Input Parameters

Without data available for calibration, forward modeling requires that the user estimate all necessary model input parameters. Parameters listed in this section are the major input parameters required to simulate nitrogen transport in the vadose zone. Parameter inputs are estimated as best estimate or mean values obtained from the TCDA site characterization or from values published in literature.

7.5.1. STE Application Rate

Table 7.1 contains calculations for estimating an average STE application rate in the TCDA. Warren Brown of the Tri-County Health Department provided an average drainfield size of 1600 square feet for conventional septic systems. STE application rate was estimated using an average flowrate for Todd Creek conventional systems of 22.7 ft^3/day. The *STE application rate* is the amount of effluent applied per unit area of drainfield per time and was calculated as 0.43 cm/day. This is consistent with typical STE infiltration rates (McCray et al., 2005).

Table 7.1 Estimate for input STE application rate.

Todd Creek ISDS Flowrate (ft^3/day)	Average Drainfield Size for Conventional ISDS (ft^2)	STE Application Rate	
		(ft/day)	(cm/day)
22.7	1600	0.014	0.43

7.5.2. STE Concentration

Concentration of ammonium (C_1) and nitrate (C_2) were estimated using average values from the wastewater characterization completed in Todd Creek in **Section 4.3.1**. Input concentrations for ammonium and nitrate were 0.0467 mg-N/cm^3 (46.7 mg-N/L) and 0.0007 mg-N/cm^3 (0.7 mg-N/L) respectively. Together STE application rate and STE concentration make up the constant mass-flux solute transport boundary condition.

7.5.3. Dispersivity

Scale of transport has a direct effect on observed dispersivity values (Fetter, 1999). Both laboratory and field studies have shown a positive correlation between dispersivity and length of transport. Lallemand-Barres and Peaudecerf (1978) and Neuman and Zhang (1990) both developed empirical relationships describing longitudinal dispersivity as a function of length of

transport. Both relationships employed data that was skewed to shorter transport lengths, similar to lengths of soil profiles in this study. Input longitudinal dispersivity values were calculated by taking an average of the two methods. Results of longitudinal dispersivity inputs are found in **Table 7.2**. Values ranged from 75 to 132 cm.

Table 7.2 Longitudinal dispersivity inputs for HYDRUS simulations.

Simulation	Soil Depth (cm)	Dispersivity Estimates (cm)		
		Lallemand-Barres and Peaudecerf (1978)	Neuman and Zhang (1990)	Average
Test Hole 1	610	61	204	132
Test Hole 2	610	61	204	132
Test Hole 3	427	42.7	121	82
Platner Loam	400	40	110	75
Ulm Loam	400	40	110	75

7.5.4. Nitrification Rate
A CFD was implemented to estimate an input first-order nitrification rate (McCray et al., 2005). The 50 percent CFD value (3.25 day^{-1}) was used as an input nitrification rate. **Appendix D** contains all relevant wastewater characterization data, including CFD's for nitrification and denitrification.

7.5.5. Denitrification Rate
A CFD was also utilized to estimate an input first-order denitrification rate. Similarly, the 50 percent CFD value (0.042 day^{-1}) was used as an input denitrification rate.

7.6. Model Output
Steady-state concentration profiles with depth are the means by which model output was evaluated for nitrogen removal. Breakthrough curves were also analyzed for two of the soil profiles to estimate average solute transport velocity and travel time. Hole by hole profiles of nutrient levels with depth can be found in **Appendix G**.

7.6.1. Concentrations vs. Depth
Plots of steady-state ammonium and nitrate concentration with depth, using best-estimate and 50% CFD parameter values, show near complete removal of nitrogen in all soil profiles. **Figure 7.1** shows steady concentration profiles with depth for ammonium (**a**) and nitrate (**b**). Results of steady state soil profiles show that all ammonium is removed in the first 30 cm (~1 foot) of soil, and all nitrate is removed by a depth of 350 cm (12 ft.). Soil nitrogen removal capacity does not appear to differ greatly for different soils as all concentration profiles exhibit similar shape and values.
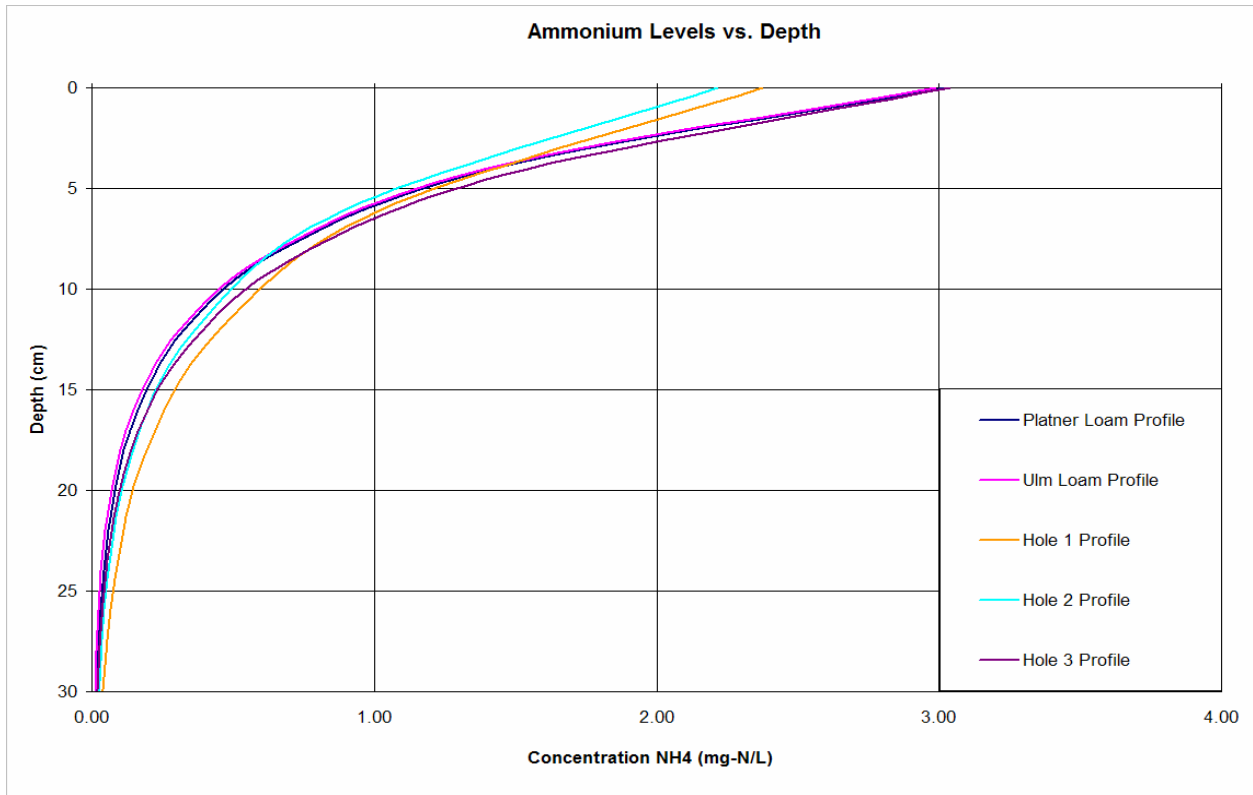
Figure 7.1a Steady-state ammonium profile for all soil profiles.
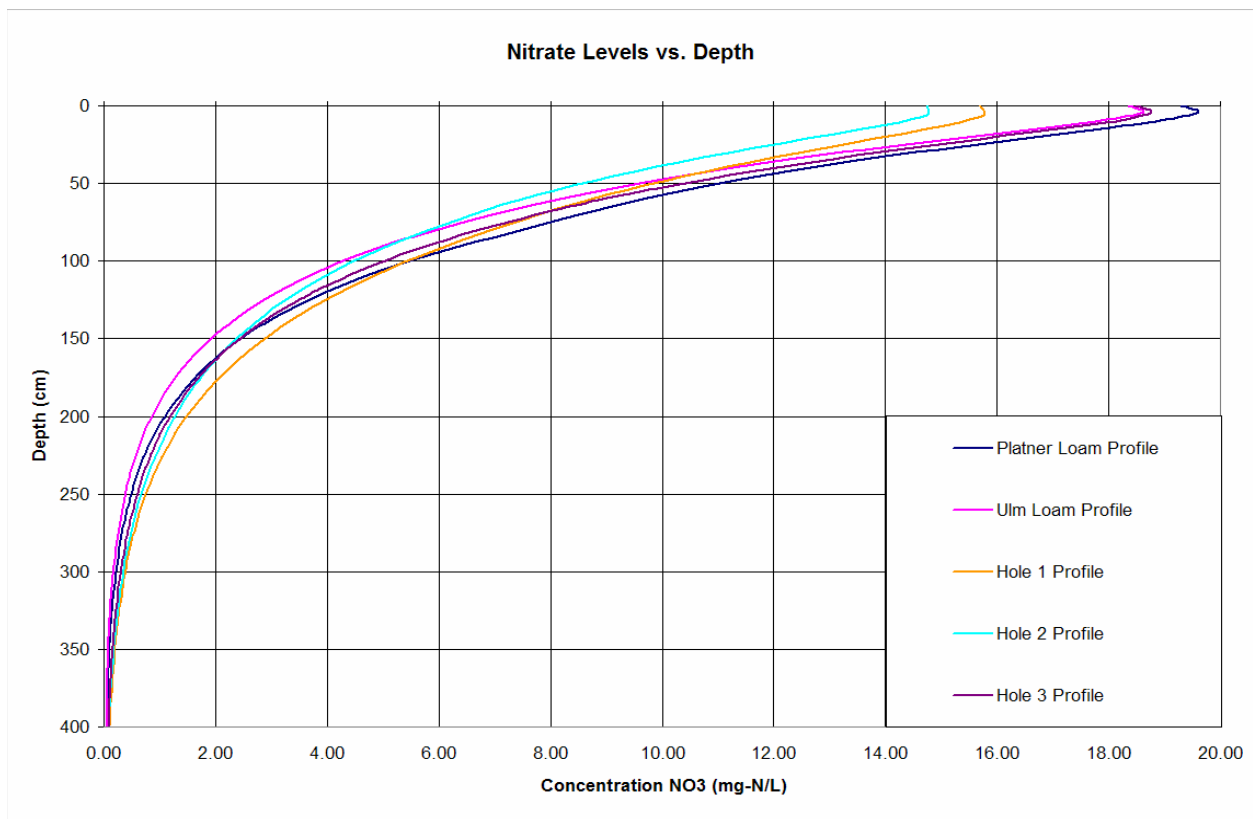
Figure 7.1b Steady-state nitrate profile for all soil profiles.

7.6.2. Breakthrough Curves

Breakthrough curves are plots of relative concentration versus time at a constant location. Information about solute transport velocity and time to steady state may be obtained from a breakthrough curve. Breakthrough curves were constructed for two of the soil profiles using best estimate parameters and nitrate as the solute of interest. Relative concentration is calculated as concentration at a given time divided by the maximum observed concentration (steady-state concentration).

The test hole 1 and Platner Loam soil profiles were monitored for nitrate concentration versus time at the bottom of the soil profile which is 610 cm (20 ft.) for test hole 1 and 400 cm (13 ft.) for the Platner Loam profile. Concentration values were normalized to the maximum (steady-state) concentration observed at those depths, and results were plotted with time. **Figure 7.2** illustrates resulting breakthrough curves of C/C$_{max}$ versus time.
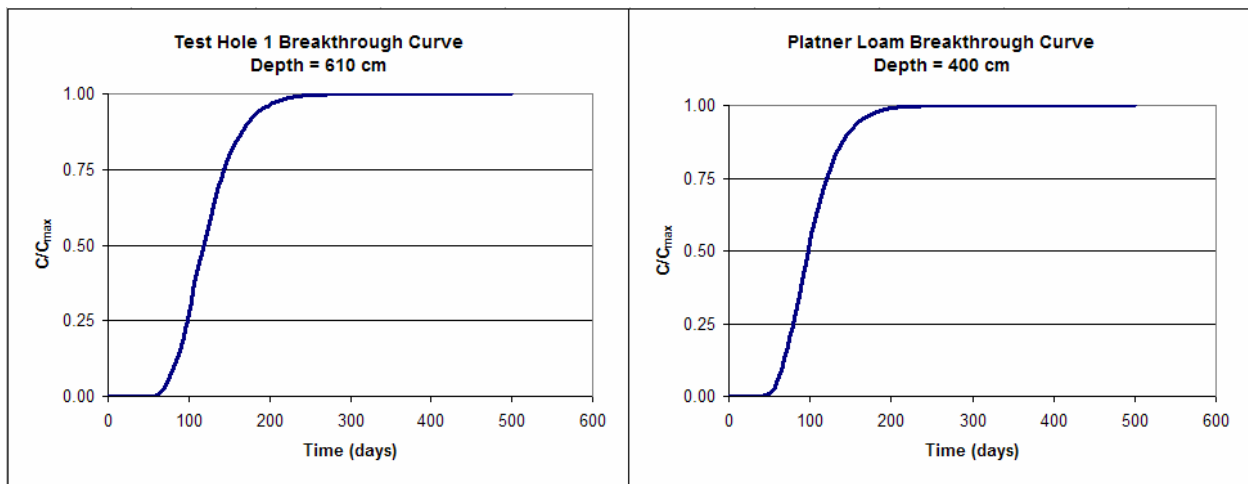
Figure 7.2 Breakthrough Curves for Test Hole 1 and Platner Loam.

The time value corresponding to a C/C$_{max}$ ratio of 0.5 is representative of the breakthrough time for the center of mass. Breakthrough times for the center of mass are a reflection of average solute travel time in the soil profile and can be used to calculate solute velocity. The center of mass travel time for test hole 1 is roughly 120 days and the average calculated velocity is 5.1 cm/day. The Platner Loam has a travel time of approximately 100 days and a solute velocity of 4 cm/day.

7.7. Sensitivity Analysis

During model simulations, site specific values for several key input parameters were not available and were obtained from CFDs (see **Section 7.5** and **Appendix D**). CFDs are a useful tool to estimate the proportion of the members of a population whose measured values exceed or fall short of some stated level. In other words, CFDs show the percentage of reported values that are below a given value. For example, 50% of reported values for constituent A are less than 5 mg/L while 90% of the reported values are less than 22 mg/L, etc. CFDs also illustrate the amount of available data (or lack of) as shown by the individual data points used to generate the distribution curve.

A sensitivity analysis was conducted to evaluate the impact of variability of the input parameters on the model output. The objective of a sensitivity analysis is to show the effect of a change in a model input parameter on model output. If the model is sensitive to the input parameter, a wide range of model outputs may be observed when the input parameter is varied by a small amount. On the other hand, if the model is not sensitive to the input parameter, large differences in the input parameter will result in little difference in the model output.

An observation point at a depth of 200 cm was monitored for model output nitrate concentration for this sensitivity analysis. A depth of 200 cm was selected to observe change in model output nitrate concentration so that changes in input parameters would be noticeable. Selecting an observation point near the bottom of the soil profile might not reflect the full sensitivity of input parameters because all nitrate may be removed by this depth. Sensitivity analyses were run on the test hole 1 and the Platner Loam soil profiles.

The sensitivity analysis was conducted by running the model for separate scenarios changing each input parameter value individually by 25, 10, -10, and -25 percent and then individually measuring the observed change in model output nitrate concentration at the observation point. Results (**Figure 7.3**) were plotted as the percent change in model input parameter values versus the percent change in model output nitrate concentration at a depth of 200 cm.
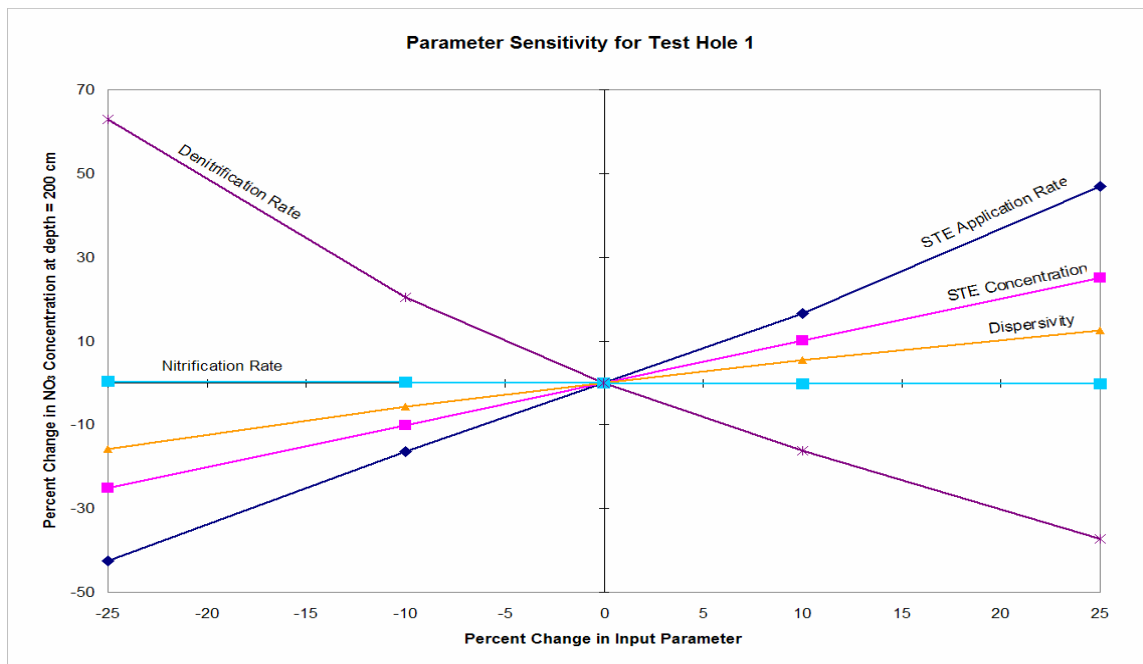
Figure 7.3a Results of sensitivity analysis for test hole 1.
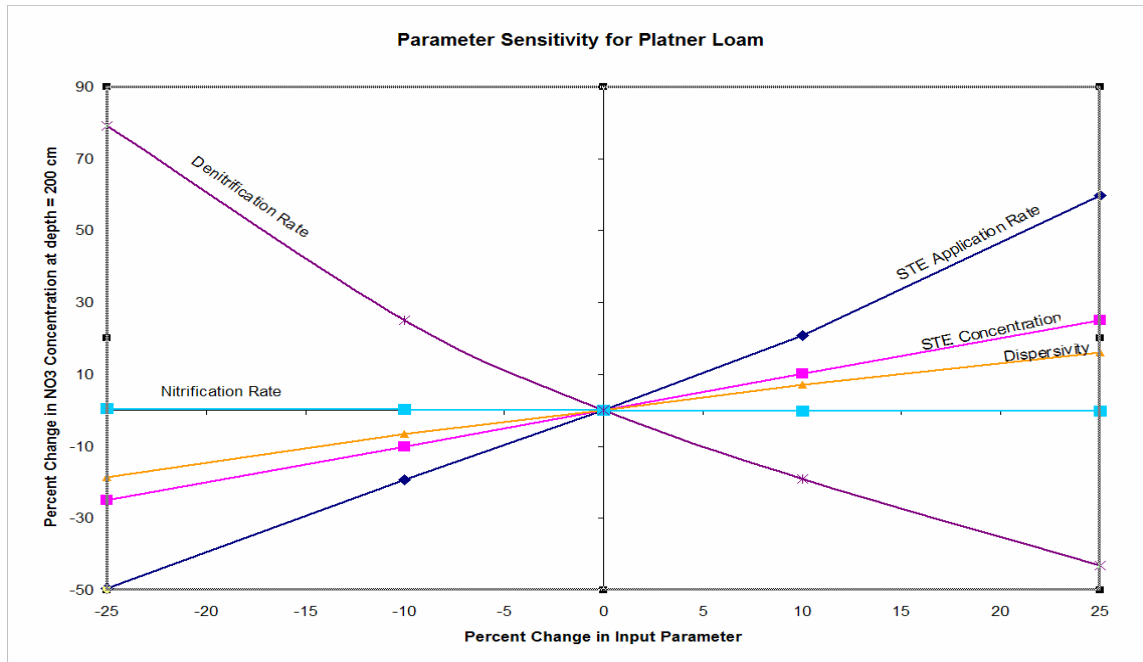
Figure 7.3b Results of sensitivity analysis for Platner Loam.

Results show that denitrification rate and STE application rate are the most sensitive input parameters. Changing the denitrification rate by +/- 25 percent can change the model output nitrate concentration up to 80 percent. Dispersivity and STE concentration have a medium sensitivity and nitrification rate has very low sensitivity. Changing nitrification rate by +/- 25 percent changes the model output by less than 1 percent.

The STE application rate is known with relative certainty, because much data concerning the per-capita generation of household STE has been collected in Todd Creek, and most households generate similar amounts of waste. However, the denitrification rate is a very uncertain parameter because typically rates can vary over orders of magnitude, it varies spatially, and relatively few studies have been conducted to assess this uncertainty or variability.

7.8. Discussion
Results of the modeling simulations show that best-estimate model input parameter values lead to near-complete removal of nitrogen from the soil profile. Best estimates for model parameters that were uncertain (e.g., especially denitrification rate and nitrification rate) were assigned the 50 percentile cumulative frequency values from McCray et al. (2005). These values are the most reasonable in the face of uncertainty. However, because the parameters are uncertain, especially the denitrification rate, there remains some risk that nitrogen contamination of the aquifer could still occur.

Decreasing denitrification rate by an order of magnitude drastically increases the model output nitrate concentration at the bottom of the soil profile. However, under these simulations, nitrate concentrations do not approach zero at the bottom of the soil profile. Consequently, the bottom solute transport zero concentration-gradient boundary condition is violated. This illustrates one of the limitations of the model, as results of simulations of this kind produce output that over-

predicts nitrate concentration. However, using median denitrification input values, or inputs that vary within +/- 50 percent of the median values from the CFD curves, the model output should still be valid.

One process that this modeling approach does not consider is lateral dispersion. This is the horizontal spreading of the solutes as they percolate through the soil. Although the fluid is moving vertically, the solute may spread horizontally by diffusion and dispersion due to soil heterogeneities. The effects of lateral dispersion will be most apparent in the soils located beneath the edges of the drainfield because of the high concentration gradient between unaffected soils and soils with STE applied. Effects of lateral dispersion are likely to not have a large impact in the soils beneath the center of the drainfield. Lateral dispersion is also usually much smaller than longitudinal dispersion and the consequences of not accounting for this process near the edges of the drainfield likely will still be insignificant.

It is also important to note the relative uncertainty of each of the model input parameters in comparison to parameter sensitivity. **Table 7.3** summarizes the relative sensitivity and uncertainty of each input parameter. While STE application rate has high model sensitivity, its relative uncertainty is low. Drainfield size and ISDS flowrates have been well characterized and there are only small variations from average for conventional over long time periods (McCray et al., 2005). On the other hand, denitrification rate has a high relative uncertainty. Nitrification and denitrification are microbially facilitated processes that are poorly understood, highly variable, and have a wide range of recorded values. However, the model output is not sensitive to nitrification rate because it is normally many times greater than denitrification. Denitrification is inarguably the most important input parameter in this study. Like nitrification, denitrification rates are highly variable, but it has high relative uncertainty. Model output is extremely sensitive to denitrification rate. Small changes in denitrification can cause large changes in model output.

Table 7.3 Input parameter sensitivity and uncertainty.

Parameter	Model Sensitivity	Relative Uncertainty
STE Application Rate	High	Low
STE Concentration	Medium	Low
Dispersivity	Medium	Low
Nitrification Rate	Low	High
Denitrification Rate	**High**	**High**

However, when the 50 percent CFD value for denitrification rate is used, the model predicts nearly complete removal of nitrogen from the soil profiles and, and near zero levels of nitrate reaching the Arapahoe Formation. Using a denitrification rate an order of magnitude less than the 50 percent CFD value, the model still predicts a nitrate concentration at the bottom of the soil profile below the MCL of 10 mg-N/L, although there is a noticeable increase in nitrate concentration. Please see **Appendix G** for additional model simulation results.
According to the CFD, in order to be within a 95 percent confidence interval for input denitrification rate, you would need to vary denitrification rate over a range of four orders of magnitude. In order to be within even a 50 percent confidence interval you would still need to vary denitrification rate over 3 orders of magnitude. In other words, to be even 50% confident that the actual denitrification rate was within the range of denitrification rates input into the

model, model simulations would need to be run using denitrification rates that varied by a factor of 1000. Results of these simulations would not be helpful because results would show that nitrate concentrations at the bottom of the profile are either zero or approach STE concentration.

There is always a degree of uncertainty associated with models, as models are a simplification of the real system. This modeling analysis does not provide a risk based decision-support tool for Adams County and Tri-County Health Department. However, a discussion of risk versus uncertainty in the context of this study may be useful.

The sensitivity of the individual input parameters, or combination of parameters, is important as it allows the decision maker to factor in the risk of the certainty of the model output using a common-sense approach. The decision maker's risk implies the willingness to accept the certainty, or uncertainty, of the model output. In the following example, we use denitrification rate for discussion, but any sensitive parameter should be considered. If the model is used to simulate the potential impacts of nitrogen to a sensitive environment (e.g., wetlands, important or limited drinking-water supply, etc.), the decision maker may be willing to accept only a small risk that impact will occur. Thus, the user wants to ensure that the model will not under predict the impact of the nitrogen load to the environment. In this case, the user may select a value from the CFD that represents the 25% value for the denitrification rate (25% of the reported values are below this value). This would result in denitrification that is significantly lower than the median of those reported in the literature. This would minimize the risk that the model would under-predict nitrogen concentrations reaching the receptor. For this case, it is likely but not certain that the model will over-predict the impact. That is, using the 25% CFD value does not guarantee a conservative solution because the system under study may actually be below the 25th percentile with respect to denitrification. If the user wishes to accept no risk that the receiving body would be impacted, then no denitrification could be assumed. However, the selection of an overly conservative value, such as the 0% value for denitrification, is likely to falsely bias the model output to suggest an impact to the environment when a higher nitrogen load might actually still result in no adverse impacts to the receptor.

For STE loading, using a 100 percentile value is conservative with respect to aquifer protection because it will impart the largest load. However, the uncertainty in this parameter is not high as is the case for denitrification. There may only be a factor of two difference in the 50% value and the 90% value. In addition, STE loadings can be measured relatively easily and they have been monitored in Todd Creek. Thus, using the 50% value is reasonable and using a 75 percentile value is probably more than sufficient even if if the user is highly adverse to risks.

Ultimately, only the end-user (planner or regulator) can decide the level of risk they are willing to accept. Then, the model-sensitivity analysis provides insight to the model performance that enables the user or decision maker to evaluate "what if" approaches within the context of acceptable risk and certainty.

Based on the results of this modeling study, using 50 percentile values for the uncertain parameters suggest negligible impact to the aquifer. Measurement of denitrification rates would provide more certainty to this analysis. However, little is known about the spatial variability of this parameter, and thus many measurements at many horizontal and vertical locations in the soil

would be needed to produce acceptable certainty at great cost for such a study.   Instead, if additional ISDS are to be installed, we recommend that a groundwater monitoring program be implemented to ensure that appropriate corrective action can be taken in case any future groundwater contamination is detected. General recommendations for a monitoring program are described in the next section.

It is also useful to note that the model results suggested that slower application rates at higher concentrations, such as provided by evaporative systems, might mitigate potential impacts. Even though the same mass of nitrogen is introduced to the subsurface (nitrogen in STE is not volatile), nitrogen concentrations reaching the water table could be reduced because infiltration rates are reduced and thus more time is provided for denitrification. If denitrification rates are actually very low, however, then this approach would not be useful. In addition, recent research at CSM suggests that higher loading rates at similar concentrations might improve treatment performance in some cases, possibly because biomats form more rapidly and contribute to enhanced treatment. This complex mechanism could not be considered in the modeling.

8. MONITORING PROGRAM

Research completed for this study has given design considerations for the water quality monitoring program. Subsurface geologic mapping and conceptual model development have yielded important information about the local hydrologic system. Water quality monitoring is therefore not necessary in the Laramie-Fox Hills aquifer to assess impacts from ISDS because it is protected from above by the Laramie Formation. The bottom of the Alluvial Aquifer is above the top of the saturated media in the Arapahoe Aquifer in the TCDA. Water quality monitoring is not necessary in the Alluvial Aquifer or the South Platte River to assess impacts from ISDS in the TCDA as there is no physical pathway for transport of contaminants associated with ISDS to reach these water-resources.

The water quality monitoring program should focus on monitoring the Arapahoe Aquifer for possible impacts from ISDS in the study area. The Arapahoe Aquifer may be vulnerable to nitrate contamination if sufficient treatment does not occur in the vadose zone.
A complete water quality monitoring program for the Arapahoe Aquifer should take advantage of all of the existing Arapahoe wells in the TCDA. Six wells were sampled in the immediate area for this study. However, most of the sampled wells are located directly south of the proposed development. In addition, domestic wells provide suspect information because samples must generally be collected from the homes water-distribution system. Thus, it is recommended that at least 6 dedicated monitoring wells be installed.

A complete monitoring program should include one up-gradient monitoring well to assess background water quality and ensure that contamination is not coming from other sources. The program should also include three monitoring wells located near the center but on the south-eastern portion of the development area, and two wells directly down-gradient of the proposed development to assess cumulative impacts.

Three wells are needed within the development area to provide statistically significant results on nitrate-concentration trends in the aquifer. Three wells within the development area will also enable determination of the groundwater hydraulic gradient (i.e., direction and velocity of groundwater flow) below the development, and the hydraulic gradient from these wells can be used to determine the location of the background and down-gradient wells. Three wells would also be useful for conducting pump tests for accurate measurements of hydraulic conductivity for future groundwater modeling if impacts are detected. Two wells are required down-gradient to provide reliable indication of down-gradient impacts and also to enable estimation of modeling parameters such as aquifer dispersion (dispersivity) if future work is required, which can mitigate increasing concentrations down-gradient of the development area.

Two of the wells within the development should be screened above and just below the water table because contamination would occur near the water table. For these two wells, screening 5 feet above and 10 feet below the water table is recommended to account for water table fluctuations due to ISDS input and natural events. One of the wells within the development should be screened below the water table (5 foot screen with the top located 10 feet below the water table) to allow for inexpensive well tests for hydraulic conductivity and dispersivity to be conducted in case future aquifer modeling is needed, or to refine current models. The upstream

well and one of the two downstream wells should be screened over the water table as described above, and one of the downstream wells should be screened below the water table (to allow for an additional measurement of hydraulic parameters, if necessary in the future).

Monthly sampling is recommended at first to establish reliable baseline concentrations. Then, quarterly well sampling is recommended to continually assess water quality in the Arapahoe Aquifer. Increasing nitrate concentrations in a monitoring well within a range that is less than a particular value set by Tri-County Health Department for three consecutive sampling efforts could prompt additional action, such as installing enhanced nitrogen treatment units on ISDS nearest the impacted well. Detection of a single concentration greater than this limit could also warrant specific action. The limit could be set based in part on typical nitrate background levels in agricultural areas (less than 1 mg/L), or could be linked to some multiple of the background nitrate concentration. We recommend 2 mg/L nitrate (as nitrogen) as an action level, which is 20% of the current MCL.

At minimum water samples should be analyzed for nitrate, nitrite, ammonium, chloride, total coliform, TDS and DO. Monitoring for nitrate and ammonium will assess how much nitrogen is in the Arapahoe Aquifer. Currently the average total ammonium + nitrate levels in the aquifer appear to be less than 1 mg-N/L. If levels appear to increase to more than 2 mg-N/L (or another level specified by the health department) then there preventive action procedures may need to be established. Nitrogen levels may vary or oscillate over time so it is important to keep a record of all past samples and to observe the general trend.

Chloride exists in STE at concentrations much higher than in natural groundwater. Chloride is a conservative chemical species that generally does not degrade in natural groundwater, is not removed through natural soil treatment, and that travels faster than other chemicals in vadose-zone and aquifer systems. Thus, chloride measurements can serve as a precursor to contamination from other ISDS constituents (including nitrogen), may help determine if pollutants in monitoring wells originate from ISDS or other sources, and can be used to estimate the relative ratio of ISDS water and aquifer water (mixing factors). Increasing chloride levels may be reason to increase sampling frequency. Current chloride levels in the Arapahoe Aquifer appear to be less than 2 mg/L. If there is a noticeable increase in chloride concentration (greater than 5 mg/L for consecutive sampling events), it likely indicates that water originating from ISDS is recharging the Arapahoe Aquifer in significant volumes. This does not necessarily mean that nitrate pollution is imminent, but could warrant increased sampling frequency (i.e., monthly).

If there is a significant increase in nitrogen levels in the Arapahoe Aquifer but no increase in chloride levels, then this could indicate that the nitrogen present is originating from a different source than ISDS. When analyzing for chloride, it is important to determine if the well sampled has been flushed or disinfected with chlorine based treatments. For example, one of the wells sampled for this study had high chloride levels due to the well owner using chloride tablets.

Total coliform is a measure of the bacteria that are used as indicators of fecal contaminants in a water sample. This measurement is a way to assess how bacteria are transported in the subsurface. TDS and DO are constituents which, if monitored, may be indicators that

wastewater from ISDS is reaching the aquifer. A significant increase in TDS and chloride and a significant decrease in DO are signals that could prelude an increase in nitrate levels. These events would warrant an increase in sampling frequency to a monthly basis.

If after 5 to 10 years following 100% build-out, no impacts are detected, then monitoring frequency could be reduced (e.g., to yearly sampling).   Tri-County health department should set the specific time period after which sampling frequency can be reduced.

9. CONCLUSIONS & RECOMMENDATIONS

The water quality, wastewater sources, hydrologic flow system, and vadose zone have been characterized to the best extent possible in the TCDA given limited time, budget, and resources. Information about the local hydrologic flow system indicates that the Arapahoe Aquifer is the only local water-resource that is potentially vulnerable to contamination from ISDS.

Characterization of the composition and structure of the Arapahoe Aquifer was done using the most appropriate data available. Conceptualization of the Arapahoe Aquifer as an aquifer unit divided into upper and lower formations separated by a continuous shale layer may be appropriate for some Denver Basin scale aquifer characterizations and it is possible that a continuous shale layer 30-60 feet in thickness exists above the lower Arapahoe. However, it is important to consider more site-specific data for characterization of contaminant transport in an area the size of a few square miles. The current conceptual model for the Arapahoe Aquifer in the TCDA still classifies this formation as a complex system of inter-bedded sands and shales associated with alluvial fan system deposits. Although it is likely that the lower Arapahoe is protected from above by shale deposits, the possibility exists that it is not completely protected due to intermingling sand layers. The degree of inter-connectedness of the sand units is not accurately known, and is an important control on how contaminants originating in the vadose zone may be transported throughout the aquifer.

Water quality in the Arapahoe Aquifer currently appears to not be impacted by nitrate contamination. Arapahoe Aquifer wells that were sampled in this study were located in areas that have combined agricultural land-use and low-density residential developments with ISDS. Results of sampling show that most Arapahoe water samples had no nitrate detected and only a few samples had nitrate detected at concentrations less than 1 mg NO_3-N/L. Ammonium levels in the Arapahoe water samples were consistently detected, but at concentrations less than 1 mg NH_4-N/L. While it is not common to detect ammonium without nitrate, it is also not unusual. Current nitrogen levels in the Arapahoe Aquifer are not of concern to public health.

Results of vadose zone modeling, using HYDRUS 1D, show that natural soils in the TCDA remove nearly all of ammonium and nitrate in soil water originating from STE when using best-estimate parameter inputs and 50% CFD nitrification and denitrification rates. However, results of model sensitivity show that model output is extremely sensitive to denitrification rate. This parameter is also highly uncertain. That is, denitrification rates are highly variable and there is not a high level of certainty in using the 50% CFD denitrification rate. Using a denitrification rate an order of magnitude less than the 50% CFD rate creates model output that results in significant nitrate levels passing through the soil profile (but less than the MCL). However, using lower values for this parameter, which are still within a reasonable range, resulted in simulated nitrate concentrations that exceeded the MCL.

A number of ISDS already exist in the TCDA and some are upgradient of the wells sampled for this study. The current low level of nitrogen in the Arapahoe Aquifer does support the idea that there is adequate treatment of STE in the natural soils, but it does not rule out the potential for impact to this aquifer if additional ISDS are implemented. The modeling suggests a low-to-moderate risk of aquifer contamination from nitrates. The modeling results must be viewed in

context of the risk that Adams County and the Tri-County Health department are willing to accept.   If the planners have a high-adversity to risk, then more conservative modeling parameters would be used that would predict aquifer concentrations exceeding the MCL for nitrate.

Modeling cannot be used to accurately predict aquifer nitrate concentration without more certain values for denitrification rates, which would require an extensive experimental effort. Obtaining actual measurements of denitrification rates, which could be used in vadose zone modeling, would require laboratory column studies using site-specific soils or extensive in-situ field measurements beneath existing ISDS. These tasks would require a great deal of additional time and money, and they are not within the scope of this study.   A more cost-effective approach would be to implement a monitoring program if additional ISDS are installed in the study area.

A monitoring program is recommended that includes at least 6 dedicated monitoring wells that are sampled quarterly. Three wells near the center of the development should be installed before development, and the hydraulic gradient obtained from these wells should be used to site background and downstream wells. The wells should be screened in a manner to increase the chances of detecting potential groundwater contamination, and also to allow future testing for hydraulic parameters if needed. The wells samples should be analyzed for nitrate, nitrite, ammonium, chloride, total coliform, TDS, and DO.   Future action would be implemented if increasing concentrations of nitrate are detected in monitoring wells, or if nitrate concentrations exceed 2 mg-N/L.   If changes in chloride, TDS, or DO levels are detected, then sampling frequency should be increased.

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Appendix A

RockWorks$_{TM}$ 2004 was used to aid in understanding the subsurface geology of the TCDA. This software constructs three-dimensional models of subsurface lithology and stratigraphy, based on data input. 15 well logs from the CSEO were selected in the TCDA to be input into the model. RockWorks$_{TM}$ 2004 was used to create a number of two-dimensional and three dimensional graphics that illustrate the subsurface geology. The figures below are examples of the type of graphics developed.
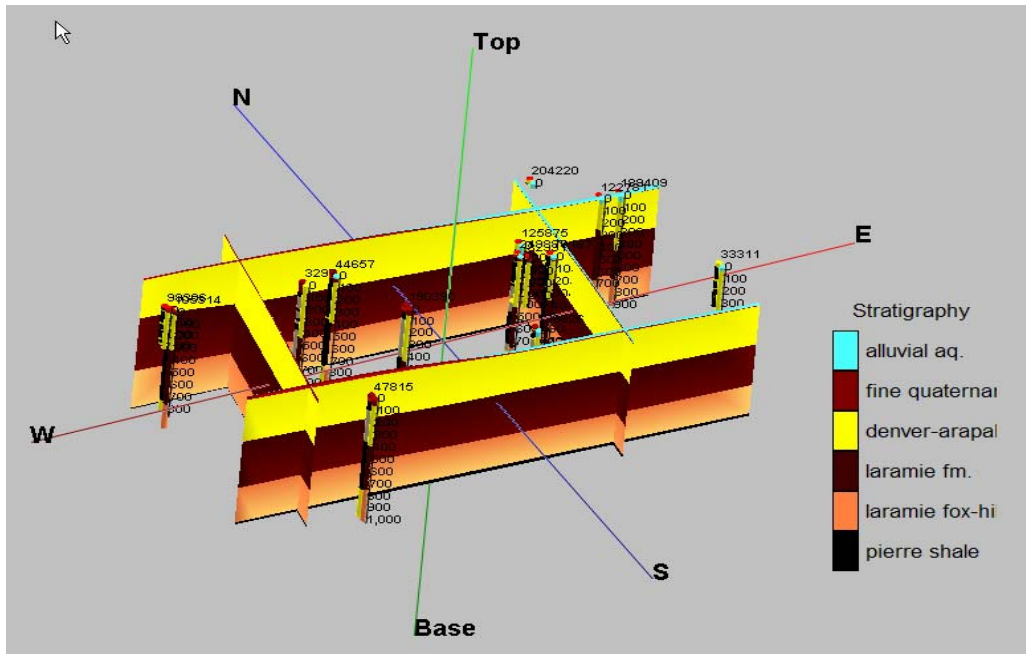
Figure A1. Fence-diagram of subsurface stratigraphy in the TCDA.
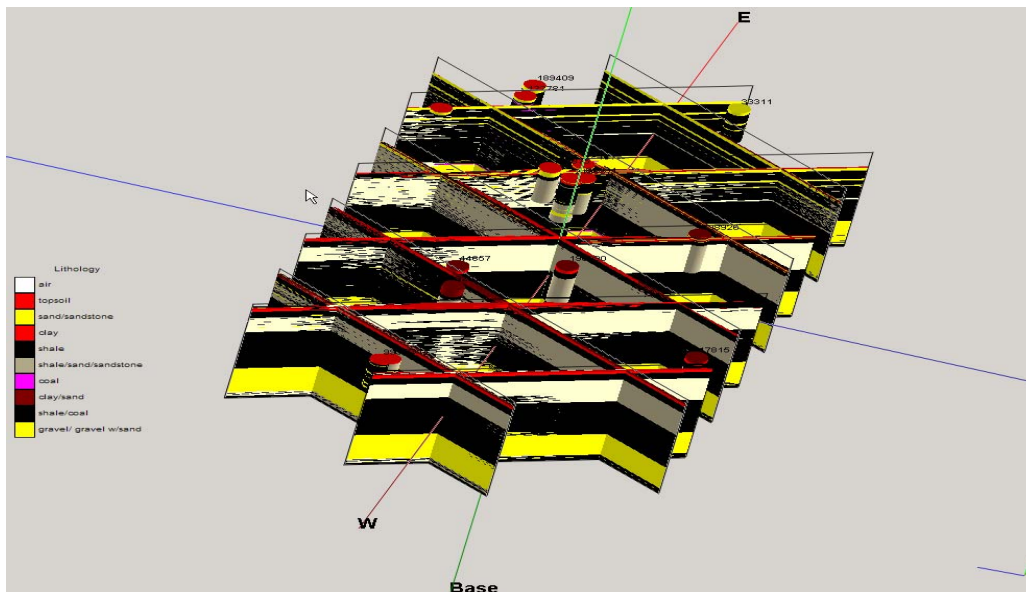
Figure A2. Fence-diagram of subsurface lithology in the TCDA.

Appendix B

Table B1. NH$_4$-N results from CSM water quality sampling.

Name/ Permit #	Date Sampled	Run 1 (mg NH$_4$-N/L)	Run 2 (mg NH$_4$-N/L)	Run 3 (mg NH$_4$-N/L)	Run 4 (mg NH$_4$-N/L)	Average (mg NH$_4$-N/L)	St Dev	Coeff Var
New PH	4/5/2005	0.332	0.357			0.345	0.017678	0.051314
241128	4/5/2005	0.345	0.371	0.389	0.392	0.374	0.021593	0.057696
138926	4/5/2005	0.351	0.357			0.354	0.004243	0.011985
Buller B	4/5/2005	0.302	0.396			0.349	0.066468	0.190453
69658A	4/5/2005	0.669	0.693			0.681	0.016971	0.02492
69658B	4/5/2005	0.696	0.714			0.705	0.012728	0.018054
Lab Blank	--	0.000	0.000	0.003	0.001	0.001	0.001414	1.414214
Field Blank	4/5/2005	0.007	0.000			0.004	0.00495	1.414214
Standard (10 mg/L)	--	>3	>3	>3		--		
Standard (1 mg/L)	--	0.759	0.797	0.704		0.753	0.046758	0.062068
SPR7	4/12/2005	1.260				1.260		
TCL	4/12/2005	0.275				0.275		
46586	4/12/2005	0.479				0.479		
46587	4/12/2005	0.360				0.360		
60966	4/18/2005	0.580	0.632			0.606	0.03677	0.060676

Table B2. NO$_3$-N results from CSM water quality sampling.

Name/ Permit #	Date	Run 1 (mg NO$_3$-N/L)	Run 2 (mg NO$_3$-N/L)	Run 3 (mg NO$_3$-N/L)	Average (mg NO$_3$-N/L)	St Dev	Coeff Var
Lab Blank	--	0.0			0.0	0.00	0.00
Field Blank	4/5/2005	0.0			0.0	0.00	0.00
New PH	4/5/2005	0.0			0.0	0.00	0.00
241128	4/5/2005	0.2	0.1		0.2	0.05	0.33
138926	4/5/2005	0.1			0.1	0.00	0.00
Buller B	4/5/2005	0.1			0.1	0.00	0.00
69658A	4/5/2005	0.3			0.3	0.00	0.00
69658B	4/5/2005	0.2			0.2	0.00	0.00
Standard (10 mg/L)	--	10.3	10.4	10.3	10.3	0.05	0.00
SPR7	4/12/2005	3.1			3.1	0.00	0.00
TCL	4/12/2005	0.3			0.3	0.00	0.00
46586	4/12/2005	0.0			0.0	0.00	
46587	4/12/2005	0.1			0.1	0.00	0.00
60966	4/18/2005	2.0	2.2		2.1	0.10	0.05

Table B3. TN results from CSM water quality sampling.

Name/ Permit #	Date	Run 1 (mg N/L)	Run 2 (mg N/L)	Run 3 (mg N/L)	Run 4 (mg N/L)	Run 5 (mg N/L)	Run 6 (mg N/L)	Average (mg N/L)	ST Dev	Coeff Var
New PH	4/5/2005	3.2	3.1					3.2	0.07	0.02
241128	4/5/2005	1.4	0.7	0.9	3.1			1.5	1.09	0.72
138926	4/5/2005	0.8	1.5					1.2	0.49	0.43
Buller B	4/5/2005	2.4	0.7					1.6	1.20	0.78
69658A	4/5/2005	4.0	4.6					4.3	0.42	0.10
69658B	4/5/2005	1.6	1.7					1.7	0.07	0.04
Lab Blank	--	0.0	0.0	0.1	0.1			0.1	0.06	1.15
Field Blank	4/5/2005	1.4	0.1					0.8	0.92	1.23
Standard (10 mg/L)	--	10.1	11.2	9.5	10.5	13.0	13.9	11.4	1.73	0.15
SPR7	4/12/2005	9.6	9.5	9.4				9.5	0.10	0.01
TCL	4/12/2005	3.9	4.2	4.8				4.3	0.46	0.11
46586	4/12/2005	0.3	0.2	0.4				0.3	0.10	0.33
46587	4/12/2005	3.4	3.9	3.1				3.5	0.40	0.12
60966	4/18/2005	4.7	4.9	4.8	4.7	4.4	4.6	4.7	0.17	0.04

Table B4. pH and Alkalinity results from CSM water quality sampling.

Name/Well Permit #	Date Sampled	pH	Alkalinity (mg CaCO$_3$/L)	mol CO$_3$/L	HCO$_3^-$ (mg/L)
New PH	4/5/2005	8.55	293	0.00293	178.73
Buller B	4/5/2005	8.57	302	0.00302	184.22
241128	4/5/2005	8.51	326	0.00326	198.86
69658	4/5/2005	8.06	202	0.00202	123.22
69658 B	4/5/2005	8.1	203	0.00203	123.83
138926	4/5/2005	8.51	298	0.00298	181.78
46586	4/12/2005	8.65	304	0.00304	185.44
46587	4/12/2005	8.63	271	0.00271	165.31
SPR 7	4/12/2005	7.72	100	0.001	61
TCL	4/12/2005	8.47	190	0.0019	115.9
60966	4/18/2005	7.4	136	0.00136	82.96

** Run Numbers correspond to duplicate laboratory analysis

Table C1. South Platte River water quality obtained from USGS NAWQA monitoring points at Henderson and Kersey Gauging Stations.

Henderson Station

Date	Nitrogen, Ammonia (mg/L as N)	Nitrogen, Nitrite Dissolved (mg/L as N)	Nitrogen, Ammonia + Organic Dissolved (mg/L as N)	Nitrogen, Ammonia + Organic Total (mg/L as N)	Nitrogen, Nitrite + Nitrate Dissolved (mg/L as N)	Total Dissolved Nitrogen (mg/L as N)[1]	Total Nitrate+Nitrite+Ammonia
4/15/1993	3.9	0.24	4.7	6	3.4	8.1	7.3
6/3/1993	2.1	0.26	2.8	3.2	2.1	4.9	4.2
8/6/1993	1.3	0.3	2.1	2.1	2.6	4.7	3.9
9/1/1993	2.3	0.66	3.1	3.2	4.6	7.7	6.9
10/22/1993	5.4	0.32	6.6	7	4.4	11	9.8
11/15/1993	2.3	0.15	3.1	4.1	3.2	6.3	5.5
12/10/1993	3.4	0.25	4.2	5.3	4.8	9	8.2
1/4/1994	3.6	0.31	4.8	5	5.9	10.7	9.5
2/23/1994	6.3	0.46	7.3	7.4	5.4	12.7	11.7
3/10/1994	6.2	0.36	7.8	8.8	5	12.8	11.2
4/13/1994	3	0.34	4.3	5	4.3	8.6	7.3
4/14/1994	3	0.32	3.9	4.7	3.7	7.6	6.7
4/18/1994	2.8	0.44	3.8	4.2	4.5	8.3	7.3
5/9/1994	3.6	0.35	4.8	5.5	4.9	9.7	8.5
5/26/1994	0.76	0.12	1.3	3	1.9	3.2	2.66
5/31/1994	2.2	0.37	2.9	3.7	4.3	7.2	6.5
7/5/1994	1.4	0.5	2.1	2	3.4	5.5	4.8
8/1/1994	2.7	0.86	3.6	3.8	6.3	9.9	9
8/11/1994	0.68	0.16	1.3	3.5	1.7	3	2.38
8/29/1994	2.6	0.93	4	3.8	5.6	9.6	8.2
10/7/1994	2.8	0.65	3.8	3.9	5.1	8.9	7.9
11/15/1994	2.4	0.25	3	3.6	4.1	7.1	6.5
12/8/1994	4.1	0.35	4.9	5.5	5.1	10	9.2
1/10/1995	4.6	0.42	5.7	5.9	4.7	10.4	9.3
2/14/1995	7.2	0.35	8	8.5	4	12	11.2
3/7/1995	3.7	0.4	5.4	5.2	4.4	9.8	8.1
4/17/1995	5.4	0.44	6.2	6.8	4.4	10.6	9.8
5/2/1995	0.67	0.26	4.1	4.2	4.5	8.6	5.17
6/15/1995	0.3	0.02	0.6	1.1	0.72	1.32	1.02
6/21/1995	0.27	0.03	0.5	0.8	0.63	1.13	0.9
6/28/1995	0.26	0.04	0.7	0.8	0.78	1.48	1.04
8/18/1995	0.71	0.28	1.6		3.2	4.8	3.91
8/21/1995	0.5	0.17	1.1	1.6	2.8	3.9	3.3
9/6/1995	0.93	0.32	1.6	1.8	4.3	5.9	5.23
9/29/1995	2.2	0.3	3.2		4.9	8.1	7.1
Average					3.88	7.56	6.61
April-Oct Average					3.56	6.55	5.63
April-Oct St Dev					1.55	3.00	2.73

Kersey Station

Date	Nitrogen, Ammonia Dissolved (mg/L as N)	Nitrogen, Nitrite Dissolved (mg/L as N)	Nitrogen, Ammonia + Organic Dissolved (mg/L as N)	Nitrogen, Ammonia + Organic Total (mg/L as N)	Nitrogen, Nitrite + Nitrate Dissolved (mg/L as N)	Total Dissolved Nitrogen (mg/L as N)[1]
4/17/1993	0.53	0.13	1.1	1.8	6.1	7.2
5/5/1993	0.36	0.09	0.7	1	6.1	6.8
6/9/1993	0.13	0.04	0.5	0.9	3.3	3.8
6/19/1993	0.15	0.03	0.5	0.7	1.5	2
7/9/1993	0.54	0.12	1	1	5.9	6.9
7/15/1993	0.15	0.05	0.5	1.8	2.6	3.1
8/13/1993	0.04	0.07	0.5	1	4.4	4.9
8/31/1993	0.07	0.1	0.5	0.5	5.2	5.7
10/5/1993	0.29	0.1	0.7	1.2	5.9	6.6
11/4/1993	0.39	0.05	0.8	1	5.5	6.3
12/14/1993	0.81	0.12	1.4	2.1	6.6	8
1/21/1994	1	0.15	1.5	2	7.9	9.4
2/24/1994	0.91	0.14	1.5	1.9	5.6	7.1
3/9/1994	0.73	0.08	1.4	1.8	7	8.4
4/16/1994	0.3	0.1	0.8	1.2	6.2	7
4/18/1994	0.53	0.13	1.1	1.6	6.4	7.5
4/19/1994	0.48	0.15	1	1.4	6.6	7.6
5/5/1994	0.09	0.04	0.5	0.9	5.2	5.7
5/11/1994	0.07	0.03	0.4	1.3	3.9	4.3
6/2/1994	0.12	0.03	0.5	1.4	2.4	2.9
6/22/1994	0.06	0.03	0.5	2.1	3	3.5
7/12/1994	0.05	0.1	0.5	0.9	6.5	7
8/10/1994	0.07	0.07	0.5	0.9	10	10.5
8/31/1994	0.15	0.07	0.6	0.6	5.7	6.3
10/6/1994	0.33	0.07	0.8	0.8	5.7	6.5
11/16/1994	0.72	0.05	1.2	1.7	5.6	6.8
12/16/1994	1.4	0.1	2	2.2	6.7	8.7
1/12/1995	1.1	0.12	1.9	1.8	7.1	9
2/13/1995	1.9	0.08	2.7	2.9	7.3	10
3/15/1995	0.4	0.08	0.9	1.3	7.5	8.4
4/13/1995	0.51	0.11	1	1.5	7.1	8.1
5/1/1995	0.19	0.07	0.8	1.7	4.8	5.6
5/31/1995	0.1	0.03	0.6	1.3	0.99	1.59
6/22/1995	0.05	0.02	0.6	0.8	0.75	1.35
7/6/1995	0.04	0.02	0.3	0.8	1.4	1.7
8/9/1995	0.12	0.06	0.5	1.2	4.9	5.4
8/17/1995	0.11	0.06	0.8		4.7	5.5
9/8/1995	0.08	0.05	0.5	1	4.9	5.4
10/10/1995	0.2	0.07	0.7	0.9	6.3	7
11/7/1995	0.36	0.08	0.9	1.1	6.1	7
12/14/1995	0.4	0.05	0.9	1	6.2	7.1

[1] Total Dissolved Nitrogen calcuted as sum of (dissolved nitrite + nitrate) and (dissolved ammonia + organic N)
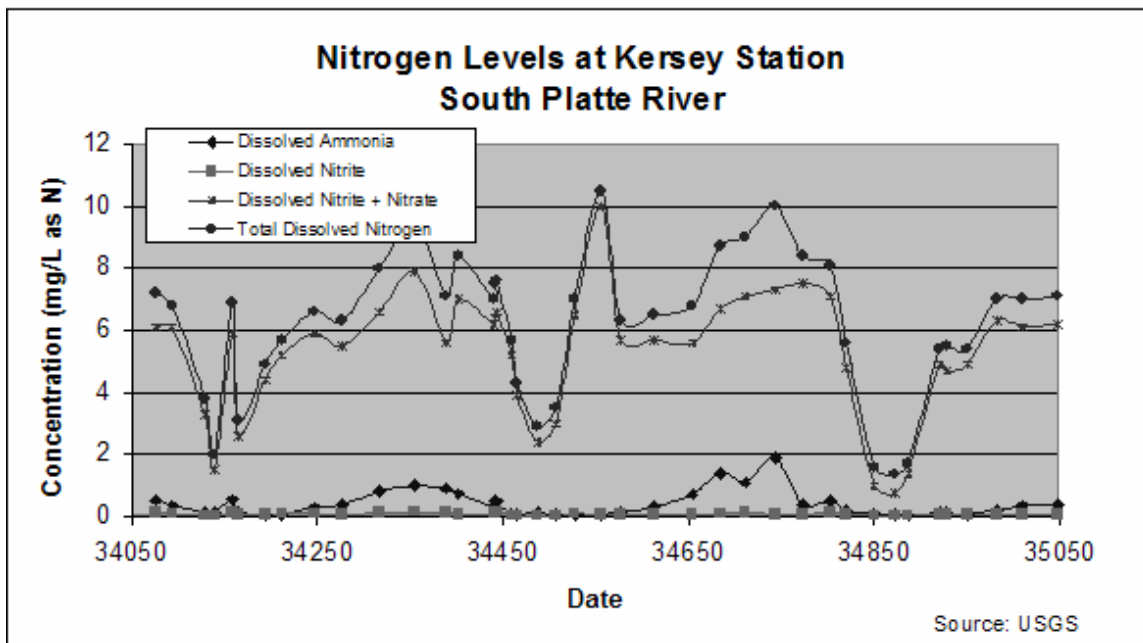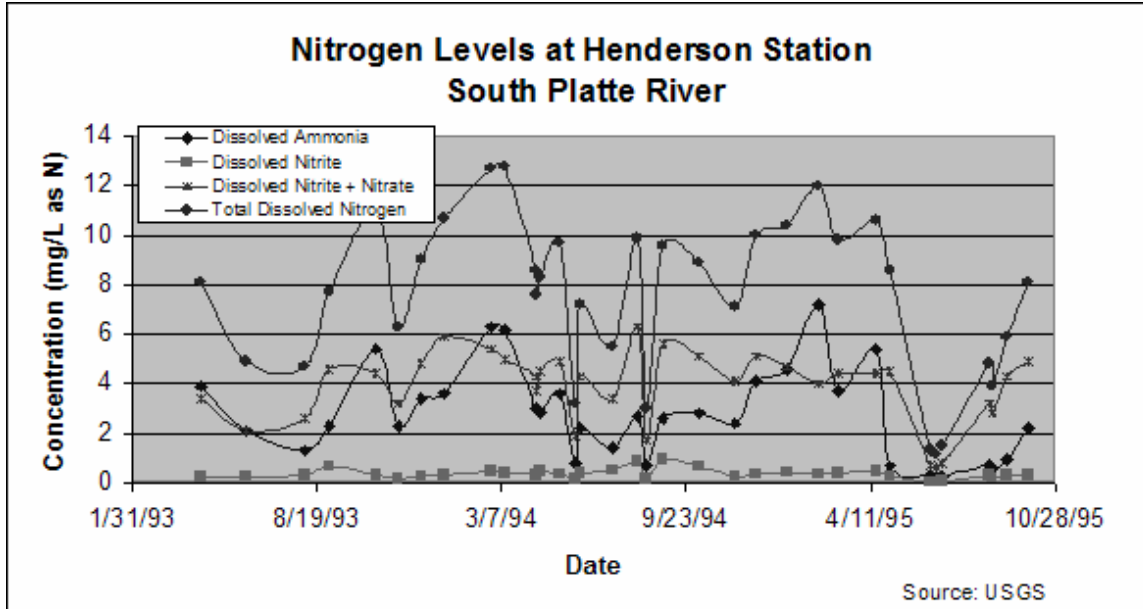
Figure C1. South Platte River nitrogen levels (USGS NAQWA database).

Table C2. Alluvial Aquifer water quality (Brighton Well info provide by Warren Brown, Tri-County Health Department).

Brighton South Platte Alluvial Well Field	Nitrate (mg-N/L)	Date
Brighton Well # 7	19 (ave)	1/5/04-9/20/04
Brighton Well # 26	15.8	4/5/2002
Brighton Well # 31	12.1	4/17/2002
Brighton Mobile Home Park Well	12.6 (ave nitrate+nitrite)	7/10/02-5/8/03

USGS Agricultural Alluvium Study of South Platte Alluvial Aquifer (30 Samples)	Nitrate + Nitrite (mg-N/L)	Date
Maximum	52	1993-1995
Minimum	0.15	1993-1995
90th Percentile	28	1993-1995
75th Percentile	24	1993-1995
25th Percentile	5	1993-1995
10th Percentile	2.5	1993-1995
Median	9.35	1993-1995

USGS NAQWA Database Alluvial Aquifer Wells near Brighton, CO	Nitrate + Nitrite (mg-N/L)	Date
Site # 400237104500301	27	6/8/1994
Site # 400711104481801	18	6/8/1994

Table C3. Arapahoe Aquifer water quality (courtesy of Wheeler & Associates).

Location	Nitrate (mg-N/L)	Nitrite (mg-N/L)	Nitrate + Nitrite (mg-N/L)	Chloride (mg/L)
SE QQ SE Q SEC 2	0.24	<0.38	<0.38	154
NE QQ NE Q SEC 11	<0.056	<0.076	<0.076	3.6
NW QQ SE Q SEC 11	<0.056	<0.076	<0.076	0.44
SE QQ NE Q SEC 10	0.74	<0.38	0.739	154

Average Nitrate	0.245

Table C4. Laramie-Fox Hills Aquifer water quality with source of data.

Source	Year Sampled	Nitrate (mg-N/L)	Nitrite (mg-N/L)	Nitrate + Nitrite (mg-N/L)
Todd Creek Metro District Water Supply Wells (8 Wells) All wells are screened within the Laramie-Fox Hills Aquifer	2003	Non-Detect	Non-Detect	Non-Detect
Highland Acres Water and Sanitation District Water Supply Wells. All Screened Within the Laramie-Fox Hills Aquifer	2002	--	--	Non-Detect

Appendix D
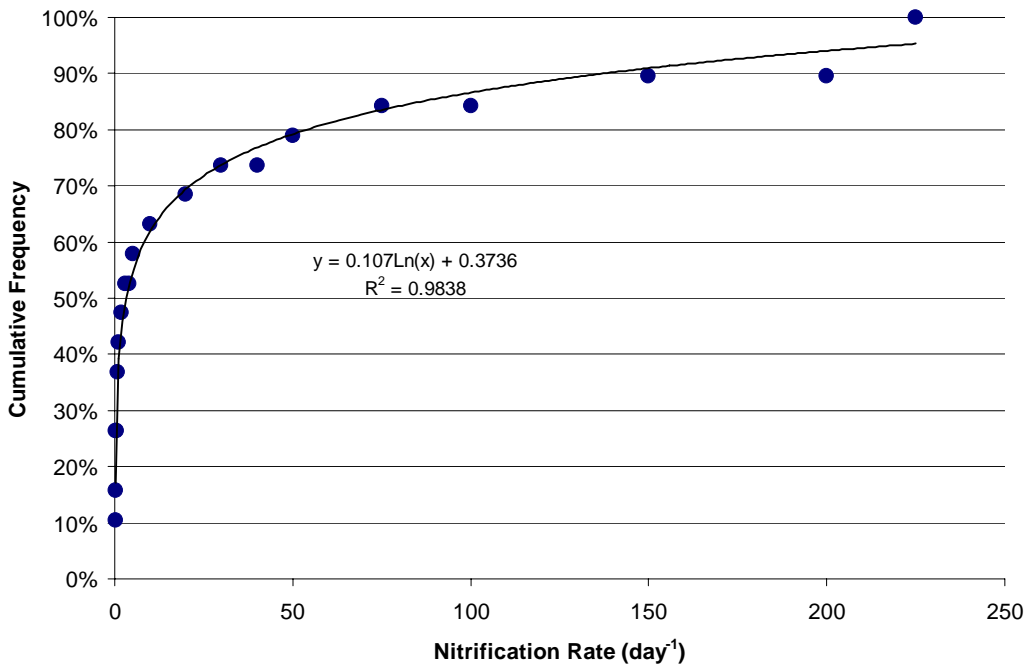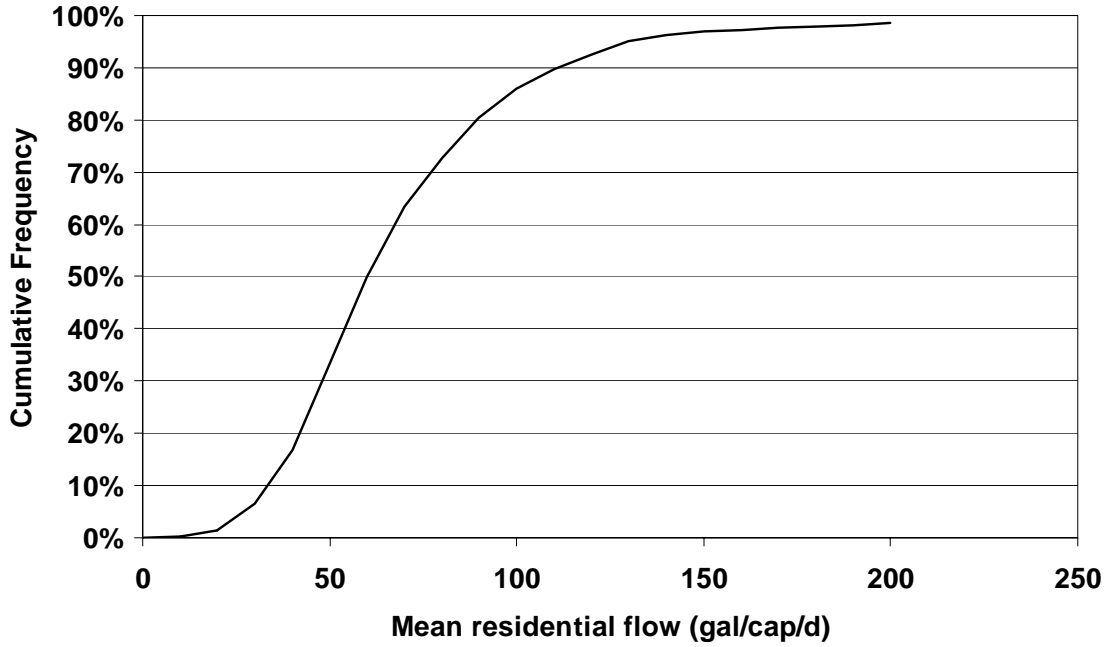
Figure D1. Cumulative Frequency Diagrams for ISDS flowrate, first-order nitrification, first order denitrification (McCray et al., 2005; Kirland, 2001)
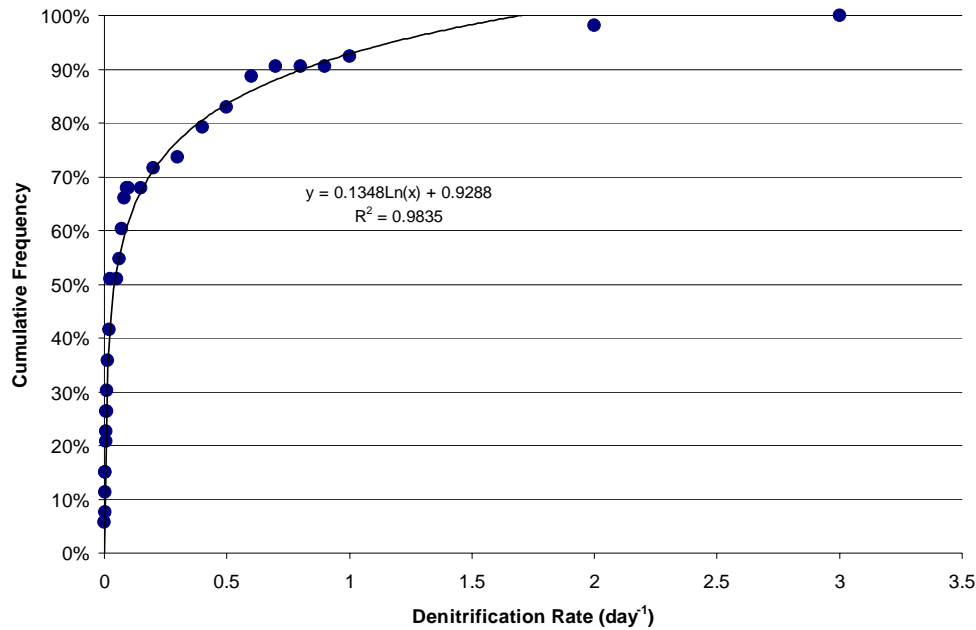
Figure D1 (continued). Cumulative Frequency Diagrams for ISDS flowrate, first-order nitrification, first order denitrification (McCray et al., 2005; Kirland, 2001)

Table D1. STE composition of four conventional systems in Todd Creek (Lowe et al., 2001)

| Location	Q*	Date	pH	Alkalinity	COD	BOD5	TS	TSS	TN	NH4	NO3	TP	FC
				mg/L as CaCO3	mg/L	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as N	mg/L as P	cfu/100 mL
12	1	08/01/99	8.04	726	350			128	84	74.6	1.5	11.95	6.30E+05
12	1d	08/01/99	7.95	658	320				70	70.2	0.9	11.85	
12	1	02/18/01	8.32	476	376		1265	455	40	29.4	0.5	12	4.60E+06
12	1d	02/19/01			372		1255	550	48	28.8	0.5	12.2	
12	2	02/20/01	8.25	506	423		1300	140	72	31.4	0.6	13.2	8.20E+06
12	2d	02/21/01			403		1340	285	64	30.2	0.5	14.6	
12	1	02/28/01	8.55	580	442	42.6	1410	310	32	34.4	1	5.6	1.77E+07
12	1d	03/01/01					1435	375	32	37	nd	6.7	1.91E+07
12	2	03/02/01	8.5	588		37.2	1415	365	32	32	0.8	4.8	2.64E+07
12	2d	03/03/01					1360	480	32	37.2	0.6	13.6	1.38E+07
13	1	08/01/99	7.29	678	815	300		143	56	54.4	1.7	9.25	6.30E+05
14	1	08/01/99	7.05	674	825	310		125	72	73.4	1.1	6.25	1.30E+07
14	1	02/22/01	7.34	540	688		1250	110	76	71	0.7	20.7	7.60E+06
14	1d	02/23/01			674		1190	140	80	68.6	0.6	19.5	
14	2	02/24/01	7.34	546	701		1235	135	76	75	0.5	19.6	7.80E+06
14	2d	02/25/01			703		1225	135	80	71	0.6	23.7	
14	1	03/04/01	6.98	546	786		1170	215	64	63.6	1.1	19.3	1.45E+07
14	1d	03/05/01					1200	190	68	66.4	1.1	9.7	4.30E+06
14	2	03/06/01	7.23	578		67.2	1265	195	71	57.6	0.6	31.2	7.10E+06
14	2d	03/07/01					1255	210	68	59.4	0.7	16.8	2.40E+06
15	1	08/01/99	8.17	320	270	184							
16	1	08/01/99	7.32	692	170	385		115	64	55.6	2.6	8.9	2.50E+05
16	1	02/15/01	7.12	620	657		1245	70	64	42.2	0.6	12.8	5.40E+06
16	1d	02/15/01			653		1250	80	64	42.2	0.6	14.6	
16	2	02/16/01	7.1	464	604		1145	35	40	43.8	0.7	13.2	
16	2d	02/17/01			608		1215	105	40	41.2	0.6	10.8	
16	1	02/24/01	7.18	548	620	49.2	1045	75	40	41.6	0.9	5	5.20E+06
16	1d	02/25/01					1100	85	44	38.4	0.7	8.4	8.60E+06
16	2	02/26/01	7.15	518		120	1225	145	52	39.2	0.6	17.9	6.00E+06
16	2d	02/27/01					1260	155	52	39.2	0.7	21.8	1.17E+07

	pH	Alkalinity	COD	BOD5	TS	TSS	TN	NH4	NO3	TP	FC
		mg/L as CaCO3	mg/L	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as N	mg/L as P	cfu/100 mL
average	7.60	569.89	545.71	166.13	1252.29	198.25	57.83	49.97	0.84	13.65	8.81E+06
SD	0.56	98.32	192.63	134.31	93.48	134.71	16.63	16.09	0.45	6.22	6.72E+06
CV	0.07	0.17	0.35	0.81	0.07	0.68	0.29	0.32	0.54	0.46	0.76
No.	18.00	18.00	21.00	9.00	24.00	28.00	29.00	29.00	28.00	29.00	2.10E+01
min	6.98	320.00	170.00	37.20	1045.00	35.00	32.00	28.80	0.50	4.80	2.50E+05
max	8.55	726.00	825.00	385.00	1435.00	550.00	84.00	75.00	2.60	31.20	2.64E+07

Table D2. Soil composition beneath conventional ISDS in Todd Creek (Lowe et al., 2001)

1	Q·	Depth	Date	pH	WC	Org Mat	TN	NH4	NO3	TP	Avail P	FC
		(cm)			%	%	mg/L as N	mg/kg as N	mg/kg as N	mg/kg as P	mg/kg as P	cfu/g dry soil
16		15	3/5/2001	7.9	24.6	0.8	575.79	54.61	1.11	421.53	4	0.E+00
16	D	15	3/5/2001		23.1							0.E+00
16		15	3/5/2001	8.0	26.0	0.8	568.89	22.15	1.86	311.61	6	0.E+00
12		15	8/25/1999		11.4	1.3		3.96	1.99	1.00		3.E+01
12		15	8/25/1999		13.6	0.9		3.76	2.00	1.00		6.E+00
13		15	8/25/1999		31.1	0.5		5.59	1.89	1.00		0.E+00
14		15	8/25/1999		27.1	1.1		10.13	10.49	1.00		4.E+03
15		15	8/25/1999		25.9	0.6		55.16	1.89	3.00		1.E+03
15		15	8/25/1999		26.1	1.1		35.63	2.21	2.00		4.E+02
16		15	8/25/1999		10.8	1.1		45.20	2.50	2.00		2.E+02
12		30	3/3/2001	9.2	26.0	0.6	382.67	5.73	7.24	569.91	2	4.E+01
12	D	30	3/3/2001		26.0							4.E+01
12		30	3/3/2001	8.9	20.1	0.5	337.83	6.22	4.19	575.52	2	2.E+02
14		30	3/3/2001	8.8	23.7	0.8	496.39	6.32	12.52	446.77	1	0.E+00
14		30	3/3/2001	8.9	24.1	0.7	447.41	6.30	3.27	572.41	1	2.E+01
14	D	30	3/3/2001		23.8							1.E+01
16		30	3/5/2001	8.5	21.8	0.6	410.46	11.90	1.22	466.15	3	0.E+00
16	D	30	3/5/2001		nt							0.E+00
12		30	8/25/1999		11.5	1.1		3.73	2.00	1.00		0.E+00
12		30	8/25/1999		9.5	0.3		3.15	2.34	2.00		0.E+00
13		30	8/25/1999		23.3	0.6		5.99	1.90	5.00		0.E+00
14		30	8/25/1999		25.4	0.8		15.21	10.19	1.00		1.E+04
15		30	8/25/1999		23.9	0.6		62.62	2.01	2.00		1.E+03
15		30	8/25/1999		24.4	1.1		82.52	1.92	6.00		3.E+02
12		60	3/3/2001	9.2	18.1	0.5	305.88	5.98	5.68	447.98	2	0.E+00
12	D	60	3/3/2001		18.1							0.E+00
12		60	3/3/2001	8.6	26.6	0.4	327.10	9.69	10.44	380.04	2	0.E+00
14		60	3/3/2001	9.0	26.8	0.7	401.79	5.69	11.77	436.65	1	0.E+00
14		60	3/3/2001	8.8	22.8	0.7	413.33	6.35	3.62	441.95	2	0.E+00
14	D	60	3/3/2001		22.7							0.E+00
16		60	3/5/2001	8.2	28.5	0.6	387.36	19.55	1.83	292.51	3	0.E+00
16	D	60	3/5/2001		27.7							0.E+00
13		60	8/25/1999		21.6	0.6		6.26	1.85	2.00		0.E+00
14		60	8/25/1999			0.8		8.19	8.44	1.00		3.E+03
15		60	8/25/1999		23.0	0.6		65.75	1.95	5.00		1.E+03

Table D3. Summary statistics for soil chemical sampling beneath conventional ISDS in Todd Creek (Lowe et al., 2001).

15 cm below IS	pH	WC	Org Mat	TN	NH4	NO3	TP	Avail P	FC
average	8.6	23.1	0.8	509.7	20.4	4.0	213.0	6.2	478.1
median	8.8	24.6	0.8	572.3	8.9	2.1	3.0	5.0	52.7
min	7.9	10.8	0.4	298.6	3.8	1.1	1.0	1.0	0.0
max	8.9	31.1	1.3	607.2	55.2	12.9	583.5	17.0	4208.0
sd	0.47	5.86	0.27	128.37	20.02	3.74	246.85	5.78	1063.39
cv	18.27	3.94	3.15	3.97	1.02	1.08	0.86	1.07	0.45

30 cm below IS	pH	WC	Org Mat	TN	NH4	NO3	TP	Avail P	FC
average	8.9	21.8	0.7	415.0	19.1	4.4	240.7	1.8	1136.7
median	8.9	23.8	0.6	410.5	6.3	2.3	6.0	2.0	15.8
min	8.5	9.5	0.3	337.8	3.2	1.2	1.0	1.0	0.0
max	9.2	26.0	1.1	496.4	82.5	12.5	575.5	3.0	14029.0
sd	0.25	5.28	0.24	60.61	27.05	3.83	276.28	0.84	3726.06
cv	35.30	4.13	2.91	6.85	0.70	1.16	0.87	2.15	0.31

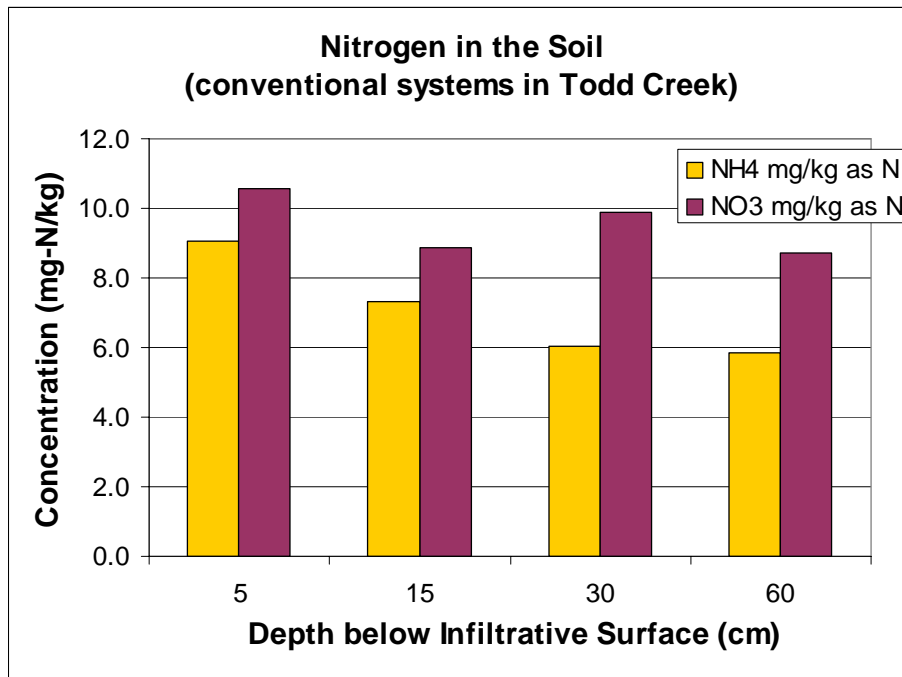| 60 cm below IS	pH	WC	Org Mat	TN	NH4	NO3	TP	Avail P	FC
average	8.8	23.6	0.6	367.1	15.9	5.7	250.9	2.0	360.1
median	8.8	22.9	0.6	387.4	7.3	4.7	336.3	2.0	0.0
min	8.2	18.1	0.4	305.9	5.7	1.8	1.0	1.0	0.0
max	9.2	28.5	0.8	413.3	65.8	11.8	448.0	3.0	2853.0
sd	0.38	3.74	0.12	47.69	20.64	4.05	211.50	0.71	891.12
cv	22.77	6.31	4.91	7.70	0.77	1.41	1.19	2.83	0.40

Figure D2. Nitrogen levels in soil below conventional ISDS in Todd Creek (Lowe et al., 2001)

Appendix E

For the initial simulation of agricultural land-use, the source of nitrogen considered for agricultural land-use is agricultural irrigation water. Irrigation rates are difficult to determine and a reasonable range of values were used in the model. Concentration of nitrogen in irrigation water is estimated from typical South Platte River water quality data. Sources not included in the model were fertilizers and livestock. Fertilizers differ greatly in composition and can have highly variable levels of nitrogen. Additionally, the historical use of fertilizers in the TCDA is hard to determine, and compared to the significant quantity of irrigation water applied fertilizers may be insignificant. Finally, from a mass balance point of view, livestock do not add any nitrogen to the system because all nitrogen in feces originates in plant material.

The sources of nitrogen considered for residential land use are ISDS and domestic irrigation water. The model assumes an average lot size of 1.5 acres, which is average for the Todd Creek Metro District. Simulations show that ISDS is the main source of nitrogen for residential land-use. Both irrigation rates and ISDS flowrates were estimated using water-use data provided by the Todd Creek Metro District. Concentration of nitrogen in STE was obtained from wastewater characterization done in the Todd Creek Metro District and nitrogen concentration in irrigation water is estimated from South Platte River water quality data.

Because the calculated flux rates are so close, the model does not show that agricultural flux is clearly much greater than residential flux, nor does it suggest that possible impact from ISDS can be ignored. However, this model gives a rough estimate of nitrogen which might reach the Arapahoe Aquifer. In reality, actual levels of nitrogen that reach the groundwater zone will be much less than that calculated in this model for both land uses. Only a small fraction of nitrogen in irrigation water will likely reach the water table; plant uptake and nitrogen recycling may be as high as 80% (Chen and Harkin, 1998). Water originating from irrigation also has less potential for percolation than ISDS. This is because irrigation water is applied over a more evenly distributed area, which utilizes near-surface soil capacity to retain that moisture. As it is held in the soil, nitrogen can be lost through volatilization, denitrification, and plant uptake processes.

The same processes will affect STE discharging from ISDS; however the STE is applied to a much smaller area, resulting in greater hydraulic loading rates (volume applied per area of soil), and hence increasing depth of infiltration. Conventional ISDS are also designed so that STE is drained through trenches commonly two feet or more below ground surface, yielding less potential for plant uptake. Other types of ISDS that are likely to be used in the TCDA include mound systems and drip irrigation systems, both of which make greater use of evapotranspiration. Chen and Harkin (1998) and Tackett (2004) suggest that between 30-70% of the total nitrogen is removed by treatment in the soil absorption system.

There was a wide range of output from this mass loading model, depending on input parameter values. Some parameters, such as agricultural irrigation rate, are both relatively uncertain and have a high level of sensitivity. For example, a small change in irrigation rate results in a large change in the predicted ratio of nitrogen flux. Due to expected nitrogen transformation and

removal processes not considered and the close flux rates predicted by the model, potential impacts to groundwater from ISDS based on a mass loading perspective cannot be ignored. As a result, model output was highly variable and it was difficult to have a high degree of certainty in the model. Further analysis was needed; therefore, the next step in the modeling approach was to determine if the amount of nitrogen reaching groundwater from ISDS was enough to significantly degrade water quality in the Arapahoe Aquifer.

Table E1. Results of mass-loading model for best estimate inputs of all parameters.

Ratio of Residential Flux to Agricultural Flux		Total Nitrogen Concentration in STE[1] (mg/L)	Total Nitrogen Concentration in Septic Tank Effluent (kg/m³)	Average Lot Size[2] (acres)	Average Lot Size (m²)	ISDS Discharge Rate[3] (gal/day/capita)	Average Household Size[4]	ISDS Discharge Rate (gal/day)	ISDS Discharge Rate (m³/yr)	Mass Flux ISDS (kg/m²*yr)
0.8		47.4	0.047	1.5	6070	60	3.04	182	252	0.0020

Domestic Irrigation Rate[5] (gal/day)	Domestic Irrigation Rate (m³/yr)	Nitrogen Concentration of Irrigation Water[5,6] (mg/L)	Nitrogen Concentration of Irrigation Water (kg/m³)	Mass Flux Domestic Irrigation (kg/m²*yr)	Total Domestic Mass Flux (kg/m²*yr)		Total Nitrogen Concentration in Irrigated Water[5] (mg/L)	Total Nitrogen Concentration in Irrigated Water (kg/m³)	Irrigation Rate[7] (ft/yr)	Irrigation Rate (m/yr)	Agricultural Mass Flux (kg/m²*yr)
426	589	5.6	0.0056	0.0005	0.0025		5.6	0.0056	1.8	0.554	0.0031

1 Total Nitrogen Concentrations in Septic Effluent from Conventional Systems in Todd Creek (Lowe et. al., 2001)
2 Average Lot Size in Todd Creek Metro District
3 Typical ISDS discharge rate taken as 50% value from ISDS cumulative distribution curve (McCray, 2005)
4 Household size calculated from Todd Creek District demographic data (http://www.city-data.com/housing/houses-Todd-Creek-Colorado.html, 2000)
5 Average Domestic Irrigation Rate from Todd Creek Metro District Water Usage Data (2003-2005)
6 Average total Nitrate+Nitrite+Ammonium concentration April-Oct at Henderson Gaging Station, South Platte River, CO (USGS NAQWA Database)
7 Average irrigation rate for South Platte River Basin (Colorado Division of Water Resources, 1998)

Table E2. Results of mass-loading model for several different scenarios of parameter inputs.

	Ratio of Residential Flux to Agricultural Flux	Total Nitrogen Concentration in STE[1] (mg/L)	Total Nitrogen Concentration in Septic Tank Effluent (kg/m³)	Average Lot Size[2] (acres)	Average Lot Size (m²)	ISDS Discharge Rate[2] (gal/day/capita)	Average Household Size[3]	ISDS Discharge Rate (gal/day)	ISDS Discharge Rate (m³/yr)	Mass Flux ISDS (kg/m²*yr)
Best Estimate	0.8	47.4	0.047	1.5	6070	60	3.04	182	252	0.0020
Worst Case	9.2	59.3	0.059	1	4047	75	3.04	228	315	0.0046
Best Case	0.2	35.6	0.036	2	8094	45	3.04	137	189	0.0008

Domestic Irrigation Rate[4] (gal/day)	Domestic Irrigation Rate (m³/yr)	Nitrogen Concentration of Irrigation Water[5] (mg/L)	Nitrogen Concentration of Irrigation Water (kg/m³)	Mass Flux Domestic Irrigation (kg/m²*yr)	Total Domestic Mass Flux (kg/m²*yr)		Total Nitrogen Concentration in Irrigated Water[4] (mg/L)	Total Nitrogen Concentration in Irrigated Water (kg/m³)	Irrigation Rate[6] (ft/yr)	Irrigation Rate (m/yr)	Agricultural Mass Flux (kg/m²*yr)
426	589	5.6	0.0056	0.0005	0.0025		5.6	0.0056	1.8	0.554	0.0031
533	736	7.0	0.0070	0.0013	0.0059		4.2	0.0042	0.5	0.152	0.0006
320	442	4.2	0.0042	0.0002	0.0011		7.0	0.0070	3.0	0.914	0.0064

1 Total Nitrogen Concentrations in Septic Effluent from Conventional Systems in Todd Creek (Lowe et. al., 2001)
2 Average Lot Size in Todd Creek Metro District
3 Typical ISDS discharge rate taken as 50% value from ISDS cumulative distribution curve (McCray, 2005)
4 Household size calculated from Todd Creek District demographic data (http://www.city-data.com/housing/houses-Todd-Creek-Colorado.html, 2000)
5 Average Domestic Irrigation Rate from Todd Creek Metro District Water Usage Data (2003-2005)
6 Average total Nitrate+Nitrite+Ammonium concentration April-Oct at Henderson Gaging Station, South Platte River, CO (USGS NAQWA Database)
7 Average irrigation rate for South Platte River Basin (Colorado Division of Water Resources, 1998)

Table E3. Mass-loading model results for variation of each input parameter.

	Total Nitrogen Concentration in Septic Tank Effluent[1] (mg/L)	Total Nitrogen Concentration in Septic Tank Effluent (kg/m³)	Average Lot Size[2] (acres)	Acre Area (m²)	ISDS Discharge Rate[2] (gal/day/cap)	Average Household Size[2] (m³)	ISDS Discharge Rate (gal/day)	ISDS Discharge Rate (m³/yr)	Mass Flux ISDS (kg/m²·yr)	Domestic Irrigation Rate[4] (gal/day)	Domestic Irrigation Rate (m³/yr)	Nitrogen Concent. of Irrigation Water[1] (mg/L as)	Nitrogen Concent. of Irrigation Water (kg/m³ as)	Mass Flux Domestic Irrigation (kg/m²·yr)	Total Domestic Mass Flux (kg/m²·yr)	Total Nitrogen Concentration in Irrigated Water[4] (mg/L)	Total Nitrogen Concentration in Irrigated Water (kg/m³)	Irrigation Rate[6] (ft/yr)	Irrigation Rate (m/yr)	Agricultural Mass Flux (kg/m²·yr)	Ratio of Residential Flux to Agricultural Flux
	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	5.6324	0.0056324	0.000546	0.002515	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.81
50%	23.7	0.0237	1.5	6070	60	3.041002	182.4601	252.0989	0.000984	426.1238	588.763	5.6324	0.0056324	0.000546	0.001531	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.48
75%	35.55	0.03555	1.5	6070	60	3.041002	182.4601	252.0989	0.001476	426.1238	588.763	5.6324	0.0056324	0.000546	0.002023	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.63
100%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	5.6324	0.0056324	0.000546	0.002515	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.81
125%	59.25	0.05925	1.5	6070	60	3.041002	182.4601	252.0989	0.002461	426.1238	588.763	5.6324	0.0056324	0.000546	0.003007	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.95
150%	71.1	0.0711	1.5	6070	60	3.041002	182.4601	252.0989	0.002953	426.1238	588.763	5.6324	0.0056324	0.000546	0.003499	5.6324	0.0056324	1.818181	0.5541818	0.003214	1.12
50%	47.4	0.0474	1.5	6070	30	3.041002	91.2307	126.0499	0.000984	426.1238	588.763	5.6324	0.0056324	0.000546	0.001531	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.48
75%	47.4	0.0474	1.5	6070	45	3.041002	136.8451	189.0749	0.001476	426.1238	588.763	5.6324	0.0056324	0.000546	0.002023	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.63
100%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	5.6324	0.0056324	0.000546	0.002515	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.81
125%	47.4	0.0474	1.5	6070	75	3.041002	228.0752	315.1248	0.002461	426.1238	588.763	5.6324	0.0056324	0.000546	0.003007	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.95
150%	47.4	0.0474	1.5	6070	90	3.041002	273.6902	378.1488	0.002953	426.1238	588.763	5.6324	0.0056324	0.000546	0.003499	5.6324	0.0056324	1.818181	0.5541818	0.003214	1.12
50%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	213.0619	294.381	5.6324	0.0056324	0.000273	0.002242	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.72
75%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	319.5928	441.572	5.6324	0.0056324	0.00041	0.002378	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.76
100%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	5.6324	0.0056324	0.000546	0.002515	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.81
125%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	532.6547	735.954	5.6324	0.0056324	0.000683	0.002651	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.85
150%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	639.1857	883.144	5.6324	0.0056324	0.000819	0.002788	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.89
50%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	2.8162	0.0028162	0.000273	0.002242	2.8162	0.0028162	1.818181	0.5541818	0.0015607	1.61
75%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	4.2243	0.0042243	0.00041	0.002378	4.2243	0.0042243	1.818181	0.5541818	0.002341	1.07
100%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	5.6324	0.0056324	0.000546	0.002515	5.6324	0.0056324	1.818181	0.5541818	0.003214	0.81
125%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	7.0405	0.0070405	0.000683	0.002651	7.0405	0.0070405	1.818181	0.5541818	0.0038017	0.64
150%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	8.4486	0.0084486	0.000819	0.002788	8.4486	0.0084486	1.818181	0.5541818	0.0046821	0.54
50%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	5.6324	0.0056324	0.000546	0.002515	5.6324	0.0056324	0.25	0.0762	0.0004292	5.86
75%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	5.6324	0.0056324	0.000546	0.002515	5.6324	0.0056324	0.5	0.1524	0.0008584	2.93
100%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	5.6324	0.0056324	0.000546	0.002515	5.6324	0.0056324	1.82	0.5541818	0.003214	0.81
125%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	5.6324	0.0056324	0.000546	0.002515	5.6324	0.0056324	2	0.6096	0.0034335	0.73
150%	47.4	0.0474	1.5	6070	60	3.041002	182.4601	252.0989	0.001989	426.1238	588.763	5.6324	0.0056324	0.000546	0.002515	5.6324	0.0056324	3	0.9144	0.0051503	0.48

Table F1. Arapahoe Aquifer mixing model results with 30% nitrorgen removal.

	Aquifer Properties										ISDS Properties							Steady-State Arapahoe Aquifer Concentration (mg-N/L)
Saturated Aquifer Thickness (m)	% Sand	Equivalent Thickness (m)	Area of Aquifer (acres)	Area of Aquifer (m²)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient	Darcy Flow, q (m/yr)	Aquifer Flowrate, Q (m³/yr)	Background Nitrate Level in Arapahoe (mg-N/L)	Total # of ISDS	Typical Single ISDS Flowrate (m³/yr)	Total ISDS Flowrate (m³/yr)	Total Nitrogen Concentration in Septic Tank Effluent (mg/L)	Soil Absorbtion System Nitrogen Removal Efficieny (%)	Total Nitrate Concentration Reaching Groundwater (mg-N/L)	
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	1100	2.5E-02	2.77E+05	47.4	30.0	33.2	31.52
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	1100	2.5E-02	2.77E+05	47.4	30.0	33.2	26.27
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	1100	2.5E-02	2.77E+05	47.4	30.0	33.2	21.74
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	1100	2.5E-02	2.77E+05	47.4	30.0	33.2	9.14
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	800	2.5E-02	2.02E+05	47.4	30.0	33.2	30.94
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	800	2.5E-02	2.02E+05	47.4	30.0	33.2	24.37
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	800	2.5E-02	2.02E+05	47.4	30.0	33.2	19.25
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	800	2.5E-02	2.02E+05	47.4	30.0	33.2	7.19
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	400	2.5E-02	1.01E+05	47.4	30.0	33.2	28.99
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	400	2.5E-02	1.01E+05	47.4	30.0	33.2	19.25
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	400	2.5E-02	1.01E+05	47.4	30.0	33.2	13.56
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	400	2.5E-02	1.01E+05	47.4	30.0	33.2	4.03
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	200	2.5E-02	5.04E+04	47.4	30.0	33.2	25.73
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	200	2.5E-02	5.04E+04	47.4	30.0	33.2	13.56
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	200	2.5E-02	5.04E+04	47.4	30.0	33.2	8.52
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	200	2.5E-02	5.04E+04	47.4	30.0	33.2	2.15

Table F2. Arapahoe Aquifer mixing model results with 50% nitrorgen removal.

Saturated Aquifer Thickness (m)	% Sand	Equivalent Thickness (m)	Area of Aquifer (acres)	Area of Aquifer (m²)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient	Darcy Flow, q (m/yr)	Aquifer Flowrate, Q (m³/yr)	Background Nitrate Level, in Arapahoe (mg-N/L)	Total # of ISDS	Typical Single ISDS Flowrate (m³/yr)	Total ISDS Flowrate (m³/yr)	Total Nitrogen Concentration in Septic Tank Effluent (mg/L)	Soil Absorbtion System Nitrogen Removal Efficieny (%)	Total Nitrate Concentration Reaching Groundwater (mg-N/L)	Steady-State Arapahoe Aquifer Concentration (mg-N/L)
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	1100	2.5E+02	2.77E+05	47.4	50.0	23.7	22.52
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	1100	2.5E+02	2.77E+05	47.4	50.0	23.7	18.76
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	1100	2.5E+02	2.77E+05	47.4	50.0	23.7	15.53
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	1100	2.5E+02	2.77E+05	47.4	50.0	23.7	6.53
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	800	2.5E+02	2.02E+05	47.4	50.0	23.7	22.10
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	800	2.5E+02	2.02E+05	47.4	50.0	23.7	17.41
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	800	2.5E+02	2.02E+05	47.4	50.0	23.7	13.75
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	800	2.5E+02	2.02E+05	47.4	50.0	23.7	5.13
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	400	2.5E+02	1.01E+05	47.4	50.0	23.7	20.70
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	400	2.5E+02	1.01E+05	47.4	50.0	23.7	13.75
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	400	2.5E+02	1.01E+05	47.4	50.0	23.7	9.69
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	400	2.5E+02	1.01E+05	47.4	50.0	23.7	2.88
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	200	2.5E+02	5.04E+04	47.4	50.0	23.7	18.38
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	200	2.5E+02	5.04E+04	47.4	50.0	23.7	9.69
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	200	2.5E+02	5.04E+04	47.4	50.0	23.7	6.09
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	200	2.5E+02	5.04E+04	47.4	50.0	23.7	1.53

Table F3. Arapahoe Aquifer mixing model results with 70% nitrorgen removal.

Saturated Aquifer Thickness (m)	% Sand	Equivalent Thickness (m)	Area of Aquifer (acres)	Area of Aquifer (m²)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient	Darcy Flow, q (m/yr)	Aquifer Flowrate, Q (m³/yr)	Background Nitrate Level in Arapahoe (mg-N/L)	Total # of ISDS	Typical Single ISDS Flowrate (m³/yr)	Total ISDS Flowrate (m³/yr)	Total Nitrogen Concentration in Septic Tank Effluent (mg/L)	Soil Absorbtion System Nitrogen Removal Efficieny (%)	Total Nitrate Concentration Reaching Groundwater (mg-N/L)	Steady-State Arapahoe Aquifer Concentration (mg-N/L)
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	1100	2.5E+02	2.77E+05	47.4	70.0	14.2	13.51
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	1100	2.5E+02	2.77E+05	47.4	70.0	14.2	11.26
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	1100	2.5E+02	2.77E+05	47.4	70.0	14.2	9.32
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	1100	2.5E+02	2.77E+05	47.4	70.0	14.2	3.92
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	800	2.5E+02	2.02E+05	47.4	70.0	14.2	13.26
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	800	2.5E+02	2.02E+05	47.4	70.0	14.2	10.44
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	800	2.5E+02	2.02E+05	47.4	70.0	14.2	8.25
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	800	2.5E+02	2.02E+05	47.4	70.0	14.2	3.08
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	400	2.5E+02	1.01E+05	47.4	70.0	14.2	12.42
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	400	2.5E+02	1.01E+05	47.4	70.0	14.2	8.25
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	400	2.5E+02	1.01E+05	47.4	70.0	14.2	5.81
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	400	2.5E+02	1.01E+05	47.4	70.0	14.2	1.73
250	30	75	4720	1.9E+07	0.1	11.1252	0.004	4.5E-02	1.5E+04	0	200	2.5E+02	5.04E+04	47.4	70.0	14.2	11.03
250	30	75	4720	1.9E+07	0.5	55.626	0.004	2.2E-01	7.3E+04	0	200	2.5E+02	5.04E+04	47.4	70.0	14.2	5.81
250	30	75	4720	1.9E+07	1	111.252	0.004	4.5E-01	1.5E+05	0	200	2.5E+02	5.04E+04	47.4	70.0	14.2	3.65
250	30	75	4720	1.9E+07	5	556.26	0.004	2.2E+00	7.3E+05	0	200	2.5E+02	5.04E+04	47.4	70.0	14.2	0.92

Appendix G

Figure G1. Modeling Simulations using best-estimate and 50% CFD input parameters.

Test Hole 3
Nutrient Levels vs. Depth

Platner Loam
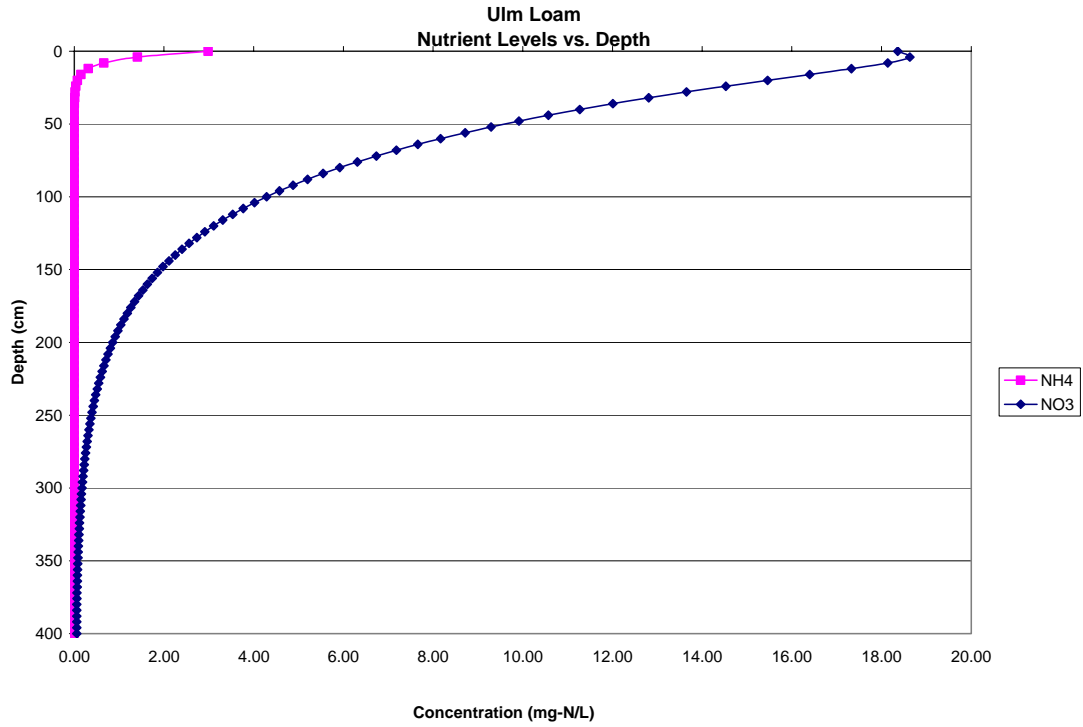**Nutrient Levels vs. Depth**
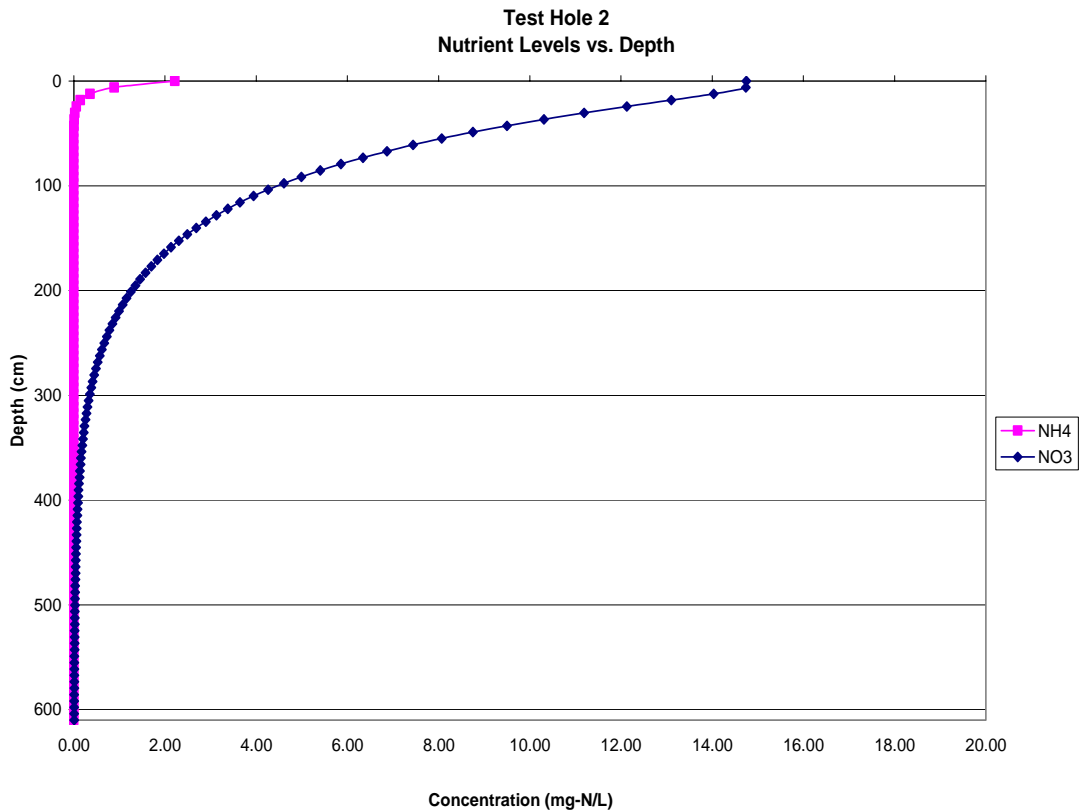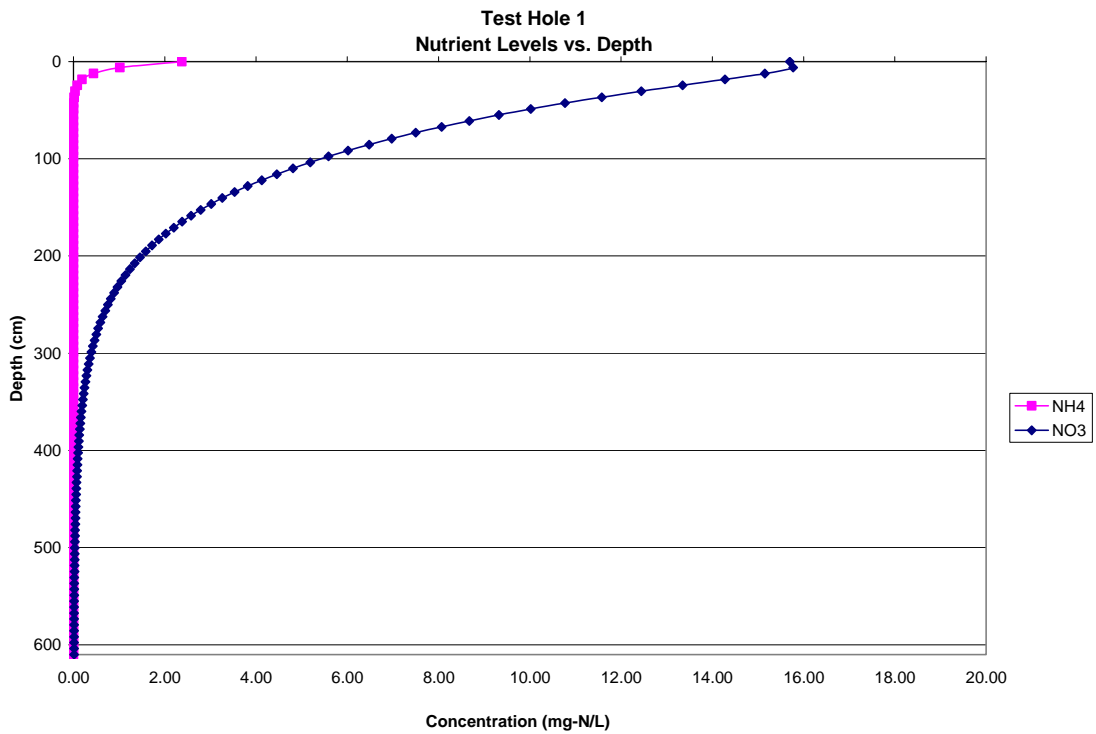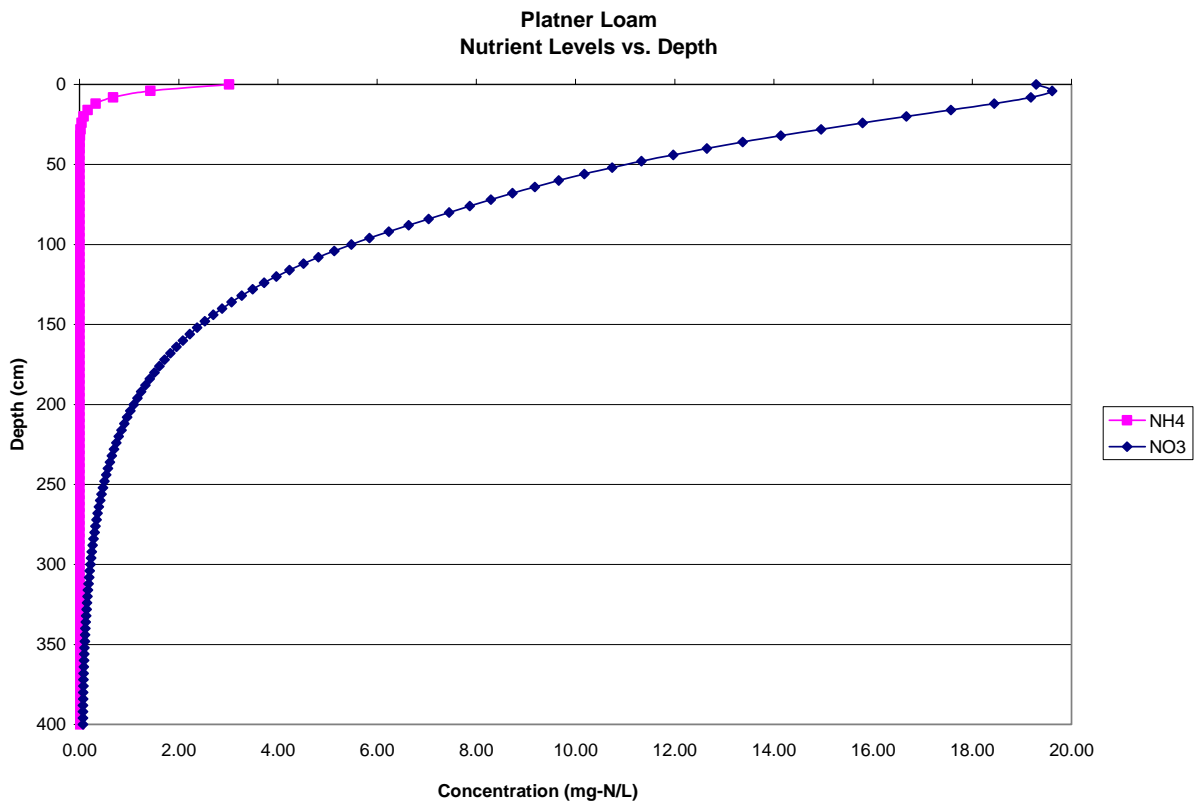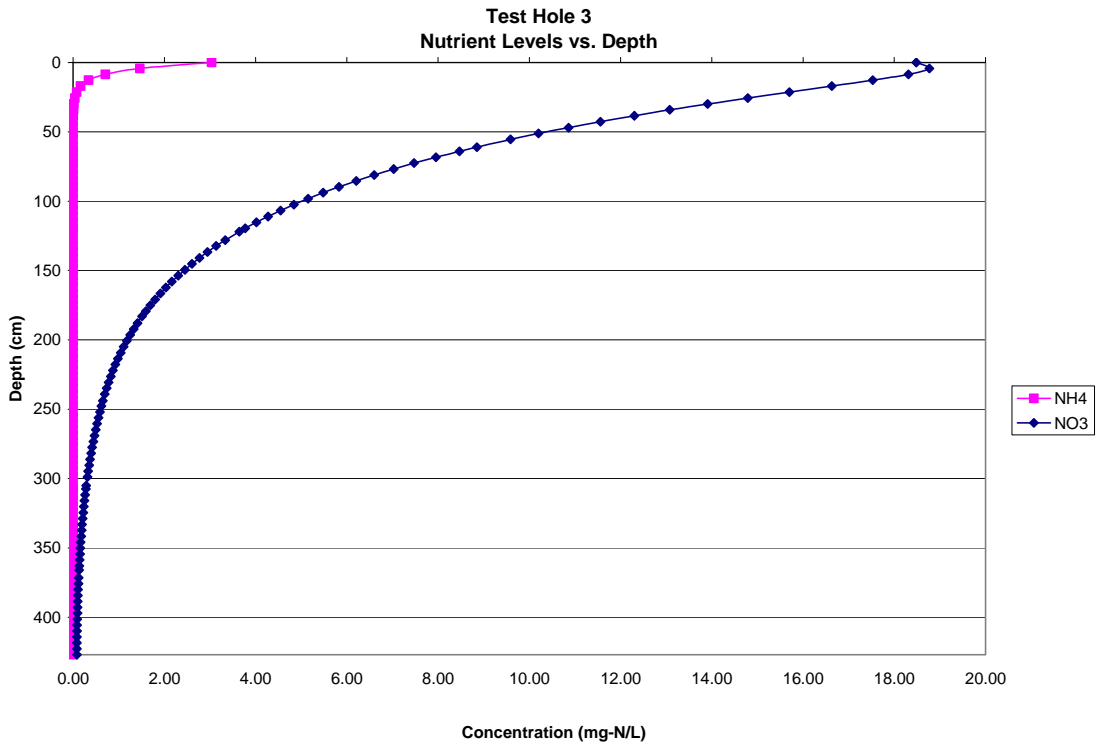
Figure G2. Simulation using -25% nitrification and denitrification rates and +25% dispersion, STE concentration, and STE application rate (note: bottom solute transport boundary condition is violated).
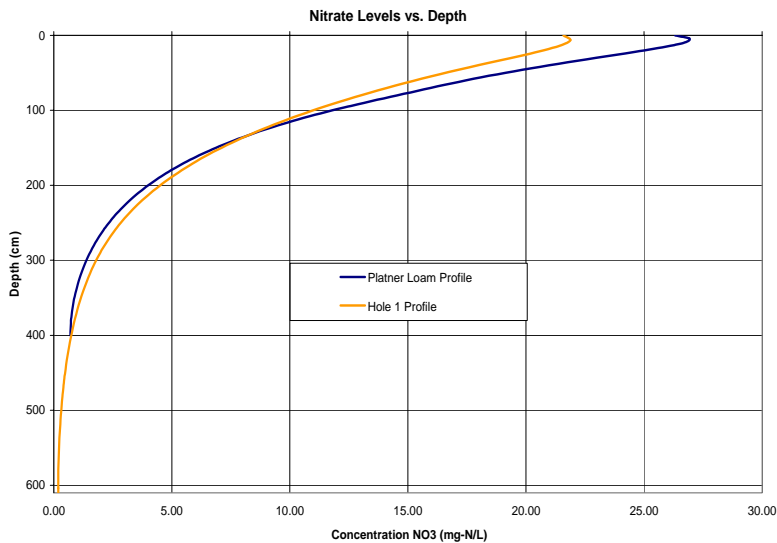
Figure G3. Simulation using denitrification rate an order of magnitude less than 50% CFD value. (note: The bottom solute transport boundary condition is violated. The model will over-predict concentrations. Nitrate concentration is still less than 10 mg-N/Lat bottom of profile.)