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Development of Soil Screening Levels and Site-Specific Dilution Attenuation Factors for the Fort Wingate Depot Activity

David W. Henry, Mansour Zakikhani, Heather J. Theel, Warren P. Lorentz, Danny W. Harrelson, and M. Saqib Khan

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Final report

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Abstract

This investigation was conducted as part of the overall Base Realignment and Closure (BRAC) program for the Fort Wingate Depot Activity (FWDA). Groundwater protection soil screening levels (SSL) can be calculated using various approaches including the Dilution Attenuation Factor (DAF) as defined in the New Mexico risk guidance documents (NMED, 2015). The purpose of this task was to estimate the DAF that may be used in SSL calculations for protection of the groundwater from potential soil contamination. SSL estimates may be utilized during remedial activities. The Chloride Mass Balance (CMB) method was used to determine the annual recharge rate for topographically flat areas at the FDWA and used as the infiltration rate as justified in the report. A site-specific DAF of 529 was calculated for the northern areas at FWDA that are flat and do not collect water.

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Preface

As part of an environmental investigation at the Fort Wingate Depot Activity, New Mexico, the U.S. Army Engineer Research and Development Center (ERDC), in cooperation with the U.S Army Corps of Engineers, Albuquerque District, Fort Worth and Tulsa- Districts, prepared this report.

The initial data and field information were provided by Mr. David Henry from the US Army Corps of Engineers, Albuquerque, New Mexico. The work was performed by the Environmental Modeling Branch (EMB) of the Environmental Processes and Engineering Division (EPED), US Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL), Vicksburg, Mississippi. At the time of publication, Dorothy Tillman was Branch Chief, CEERD-EL-EMB; Warren P. Lorentz was Division Chief, CEERD-EPED. The Deputy Director of ERDC-EL was Dr. Jack Davis and the Director was Dr. Beth Fleming.

Colonel Bryan S. Green was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

List of Acronym and Abbreviation

ERDC	Army Engineer Research and Development Center
Bgs	below ground surface
CMB	Chloride Mass Balance
CF	Cubic Feet
CY	Cubic Yards
DAF	Dilution Attenuation Factor
DoD	Department of Defense
ft.	foot and/or feet
FWDA	Fort Wingate Depot Activity
g/g	grams/gram
GMS	Groundwater Modeling System Software
HWB	Hazardous Waste Bureau
m/yr.	Meters per Year
µg/Kg	Micrograms per Kilogram
mg/Kg	Milligram per Kilogram
mm/yr.	Millimeter per Year
SSL	NMED Soil Screening Level
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

1 Introduction

The Fort Wingate Depot Activity (FWDA) is located approximately 7 miles east of the city of Gallup, New Mexico (Figure 1). The US Army Corps of Engineers (USACE) conducted this non-permit required, Army initiated, data analysis and report to determine the site specific DAF for all COPCs at the FWDA where applicable.

The purpose of this effort was to develop the site-specific Dilation Attenuation Factor (DAF) for the northern areas in FWDA excluding the former TNT leaching beds that will be used in soil screening levels (SSLs) calculation for the protection of potential contamination migration from soil into groundwater.

In regard to the northern areas at FWDA, in October 2014, Army submitted a separate report titled, “TNT leaching bed soil boring test results and development of Site-Specific DAF for Fort Wingate Depot Activity”. NMED provided comments on that report in their letter dated April 15, 2015. Based upon the comments received and follow up conversation with NMED, the Army developed a new task to separate the TNT leaching beds SSL calculation from the other areas in the northern FWDA due to the unique disturbed surface characteristics of the TNT beds compared to the other northern areas. Army estimated a new groundwater protection SSL for the TNT Leaching beds located in Parcel 21 using the Department of Defense (DoD) groundwater modeling system (GMS) (Zakikhani, et al. 2015). Based upon the model results, Army will remove an additional 20,000 cubic yards of soil around the former TNT leaching beds up to a depth of 35 feet where needed. Any remaining issues regarding the former TNT leaching beds are being addressed separately in the forthcoming revised TNT Removal Work Plan.

This report provides the DAF estimation used for developing SSL for the reminder of the “flat areas” in the northern FWDA facility excluding the TNT leaching beds. The northern FWDA flat areas are those areas that do not have visible indications of surface water or disturbed areas. The Army will use these SSL numbers during the remedial activities.

These Flat Areas are mainly located in the northern part of the Wingate. In general these do not collect water and do not have visible indications of surface water or disturbed areas. The areas with outcropping formations and disturbed areas such as the former TNT leaching beds (Figure 2 and Figure 3) are not part of this study. Typical field indicators of the presence of surface water would include direct evidence such as standing or flowing water or indirect evidence such as scouring, water-borne sediment or debris deposits, water staining or visible drainage patterns (USACE-WES, 1987). The northern FWDA flat areas are easily identified in the Google image titled "overhead" (Figure 2). Figure 2 and 3 clearly document the relatively flat surface elevations in the northern FWDA.

USACE and ERDC (Zakikhani at el., 2014) calculated the subsurface recharge rates for the northern flat areas using the data provided by the USGS report (Robertson et al., 2013). The recharge rate was used to develop site-specific Dilution Attenuation Factors (DAF) as described in this report. The former TNT leaching beds are excluded from this calculation because the site has been disturbed and the approach used to calculate the recharge rate (Zakikhani et al. 2014) cannot be applied to disturbed areas.

Figure 1. FWDA location and study site.

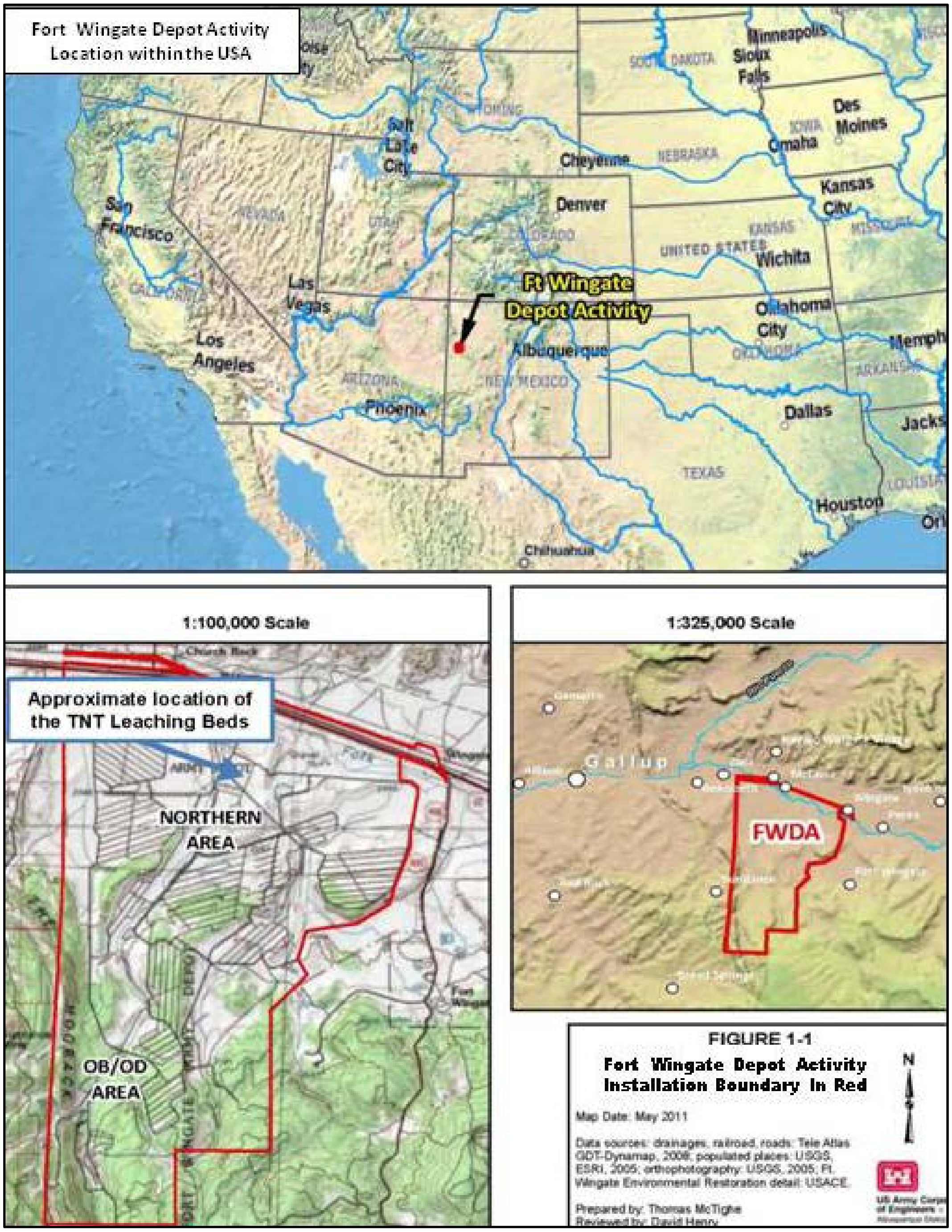
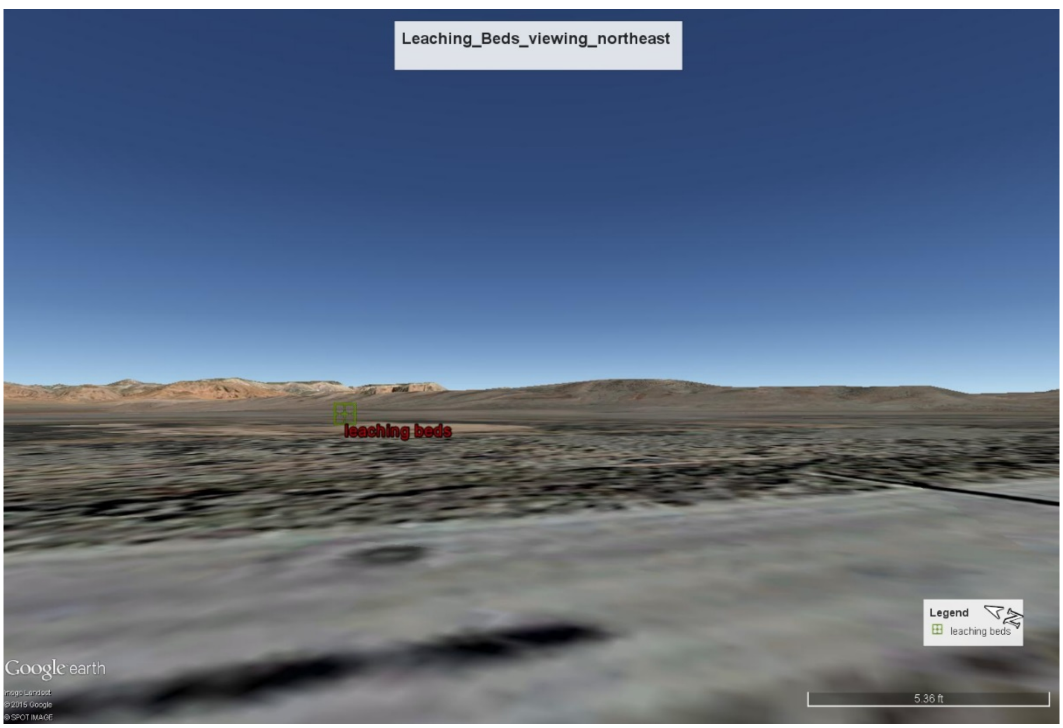


Figure 2. Map of FDWA flat areas.

Figure 3. Image of FWDA flat areas looking northeast.



2 Site-Specific Dilution-Attention-Factor (DAF)

A site-specific DAF is developed to evaluate the potential impacts to groundwater from chemical constituents in soil. A DAF is defined as dilution-attention-factor (Equation 2; Equation 56, NMED 2015).

Equation 1. DAF Equation (NMED, 2015).

Equation 56
Dilution/Attenuation Factor (DAF)

$$DAF = 1 + \left(\frac{K \times i \times D}{I \times L}\right)$$

Where:

$$D = \left(0.0112 \times L^2\right)^{0.5} + D_a\left(1 - \exp\left[\frac{-L \times I}{K \times i \times D_a}\right]\right)$$

Parameter	Definition (units)	Default
DAF	Dilution/attenuation factor (unitless)	Site-Specific
K	Aquifer hydraulic conductivity (m/yr)	Site-Specific
i	Hydraulic gradient (m/m)	Site-Specific
D	Mixing zone depth (m)	Site-Specific
I	Infiltration rate (m/yr)	Site-Specific
L	Source length parallel to groundwater flow (m)	Site-Specific
D_a	Aquifer thickness (m)	Site-Specific

The site infiltration rate is a critical parameter of the DAF equation. To determine a site-specific DAF, a site-specific annual average infiltration rate was estimated for the flat areas in the northern FWDA using the Chloride Mass Balance (CMB) method. Appendix A provides a copy of the CMB report.

Groundwater recharge and its spatial distribution are an important part of this effort, yet difficult to quantify. This is especially true in arid and semi-arid environments such as at the FWDA. In 2009, the U.S. Geologic Survey (USGS) collected subsurface soil samples that were tested for chloride concentrations, soil moisture content, and bulk density (Robertson et al., 2013). The majority of subsurface soil is fine-grained and were classified as silty clay. These data were used to estimate the rate of recharge to groundwater using the CMB method. The CMB method is a well-established method for estimating recharge rates in arid and semi-arid environments. ERDC and USACE used the USGS data to estimate an average annual recharge rate for flat areas at FWDA (Zakikhani et al., 2014; Appendix A). In general, arid and semi-arid environments potentially have higher annually averaged evapotranspiration rates than precipitation rates, which is evident at FWDA (Zakikhani et al., 2014). Based on the CMB method, an estimate of a site-specific recharge rate through the unsaturated zone, where the land surface is flat was calculated. The recharge rate for flat areas is estimated at approximately 0.0178 millimeters/year (mm/yr.) or 1.778E-05 meters/year (m/yr.).

A portion of the water that falls as rain and snow and infiltrates into the subsurface soil and rock is defined as the infiltration rate (used in DAF Equation). Some water that infiltrates may remain in the shallow soil layer, where it will gradually move vertically and horizontally through the soil and subsurface material. All or some of the water may infiltrate deeper, recharging groundwater aquifers, which may be quantified by recharge rate.

The DAF equation (Equations 1 and 3) uses the infiltration rate (I). However, the CMB provides the recharge rate. We are assuming the difference between the infiltration rate and the recharge rate for the FWDA site is negligible. For the purpose of this report, we used the recharge rate cited in the CMB report as the infiltration rate in DAF equation.

2.1 Estimation of SSL and DAF for FWDA flat areas

Groundwater protection soil screening levels (SSL) can be calculated using various approaches including the Dilution Attenuation Factor (DAF) as defined in the New Mexico risk guidance documents (NMED, 2015). The DAF formulation provided in Equation 1 (NMED 2015, Equation 56) required some site-specific input parameters as described below.

The site-specific input parameters used in DAF calculation for FWDA flat areas are given as:

K = 0.0225 meters/day (m/d) = 8.2125 m/yr. (hydraulic conductivity for silty clay soil that represents common soil at the site)

i = 0.014377 (Hydraulic gradient) (calculated (Equation 2) based on the site groundwater monitoring contour map and GW elevation data;

groundwater elevation drops 25 feet (6670-6645) over 1739 ft. distance (530 meters) ; GW Elevations: 6670 and 6645 ft.)

$$\mathbf{i} = \frac{(6670-6645)}{1739} = \mathbf{0.01437} \quad (2)$$

I = 1.78E-05 m/yr. (infiltration rate, based on the USGS chloride work; Appendix A; Zakikhani, et al. 2014)

L = 115 m (source length parallel to groundwater flow, measured in Google Earth - length of a site in FWDA flat areas that was used for DAF calculation)

Da = 9.114 m (mixing zone depth, about 30 ft. (9.114 m) from the water table to the basal confining unit)

D(m) = 9.114 m (aquifer thickness, calculated D as the formulation provided in Equation 1 as 12.187 m; according to DAF rules (NMED, 2015), because D>Da, value of Da should be used for D in DAF Equation)

Substituting all the above parameters in Equation 1 for DAF:

$$\boldsymbol{DAF} = \mathbf{1} + \left(\frac{\boldsymbol{K \times i \times D}}{\boldsymbol{I \times L}}\right) = \mathbf{529.03} \quad (3)$$

Therefore, the resulting site-specific DAF is 529.03. Equation 4 (NMED 2015; Equation 54) below can be used to calculate site-specific screening levels (SSLs) for the protection of groundwater based on the site-specific DAF of 529.03. Equation 4 requires a target soil leachate concentration (C_w in mg/L) for each constituent being evaluated. C_w is equal to the chemical constituent tap water SSL (NMED, 2015, Table A-1) multiplied by the site-specific DAF of 529.03 (Equation 3). The C_w then may be used to calculate the site-specific SSL for the protection of groundwater using Equation 4 below.

Equation 4. Generic SSL for Groundwater protection (NMED, 2015).

Equation 54
Soil Screening Level For Leaching To Groundwater Pathway

$$SSL = C_w \ x \left[K_d + \left(\frac{\theta_w + \theta_a H'}{\rho_b} \right) \right]$$

Parameter	Definition (units)	Default
SSL	Soil Screening Level for migration to groundwater pathway (mg/kg)	Chemical-Specific
C_w	Target soil leachate concentration (mg/L)	Chemical-Specific
K_d	Soil /water partition coefficient (L/kg)	Chemical-Specific
θ_w	Water-filled soil porosity (L_{water}/L_{soil})	0.26
θ_a	Air-filled soil porosity (L_{air}/L_{soil}), n - θ_w	0.17
n	Total soil porosity (L_{pore}/L_{soil}), 1 - (ρ_b/ρ_s)	0.43
ρ_s	Soil particle density (kg/L)	2.65
ρ_b	Dry soil bulk density (kg/L)	1.5
H´	Dimensionless Henry's Law constant	Chemical-Specific

Source – NMED 2015

3 Summary

The CMB method was used to determine the annual recharge rate for topographically flat areas in the northern FWDA, which excludes the former TNT leaching beds because of its disturbed and unique surface characteristics. The recharge rate used as the infiltration rate in the DAF equation to calculate a conservative DAF number as justified in the report. A site-specific DAF of 529 was calculated for the northern FWDA areas excluding the areas that are not flat, or disturbed and do collect waters. The flat areas includes the most part of the northern FWDA excluding the former TNT leaching beds. Army estimated a new groundwater protection SSL for the TNT Leaching beds located in Parcel 21 using the DOD groundwater modeling system (GMS) (Zakikhani, et al. 2015). Based upon the model results, Army will remove an additional 20,000 cubic yards of soil around the former TNT leaching beds up to a depth of 35 feet where needed. The northern FWDA flat areas are those areas that do not have visible indications of surface water or disturbed areas. Typical field indicators of the presence of surface water would include direct evidence such as standing or flowing water or indirect evidence such as scouring, waterborne sediment or debris deposits, water staining or visible drainage patterns (USACE-WES, 1987). Using this site-specific DAF of 529, the site-specific screening levels (SSLs) for groundwater protection can be calculated.

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Zakikhani, M., D. W. Henry, W. P. Lorenz, and H. J. Theel. 2015. Numerical modeling of explosives at the former TNT leaching beds, Fort Wingate Depot Activity, NM. May 2015. Engineer Research & Development Center (ERDC), Draft Technical Report.

Appendix A: Estimation of Recharge Rates Using Chloride Mass Balance

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Estimation of Recharge Rates Using Chloride Mass Balance

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August 2014

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Estimation of Recharge Rates Using Chloride Mass Balance

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Final report

Abstract

This study was conducted as part of an environmental investigation at Fort Wingate Depot Activity, New Mexico to better understand the mechanisms of groundwater recharge and to estimate the recharge rates to the alluvial aquifer underlying the study area. The purpose of this study was to estimate groundwater recharge using two approaches: (1) chloride mass balance in groundwater, and (2) chloride mass balance in the unsaturated zone. The average concentration of meteoric chloride in precipitation was calculated from data records at the Cuba, Bandelier, Painted Desert, Mesa Verde and Canyon lands National Atmospheric Deposition Program (NADP) sites over their respective periods of record. The average chloride wet deposition concentration in the annual precipitation was determined to be 0.11 mg/L. The 2009 chloride concentrations in groundwater samples were collected from wells along the TNT flow path and the FUH flow path. The recharge rate calculated using data from well along the TNT flow path was between 0.012 and 0.015 inches per year, with an average of 0.013 in/yr. The recharge rates from wells along the FUH flow path vary from 0.025 to 0.045 inches per year, with an average of 0.033 in/yr. Data from the unsaturated zone were used to graphically identify three rates of recharge for the unsaturated zone. The first estimate of recharge was of 0.0007 inches per year, the second estimate was 0.0022 inches per year, and the third estimate was 0.0081 inches per year.

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Preface

As part of an environmental investigation at Fort Wingate Depot Activity, New Mexico, the U.S. Army Engineer Research and Development Center (ERDC), in cooperation with the U.S Army Corps of Engineers, Albuquerque District, and the U.S. Geological Survey, conducted this study.

The initial data and field information were provided by Mr. Andrew Robertson from the USGS New Mexico Water Science Center in Albuquerque, New Mexico. The work was performed by the Environmental Modeling Branch (EMB) of the Environmental Processes and Engineering Division (EPED), US Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL). At the time of publication, Dorothy Tillman was Chief, CEERD-EL-EMB; Warren P. Lorentz was Chief, CEERD-EP. The Deputy Director of ERDC-EL was Dr. Jack Davis and the Director was Dr. Beth Fleming.

COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
foot-pounds force	1.355818	joules
gallons (US liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
pounds (force) per inch	175.1268	newtons per meter
slugs	14.59390	kilograms
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters

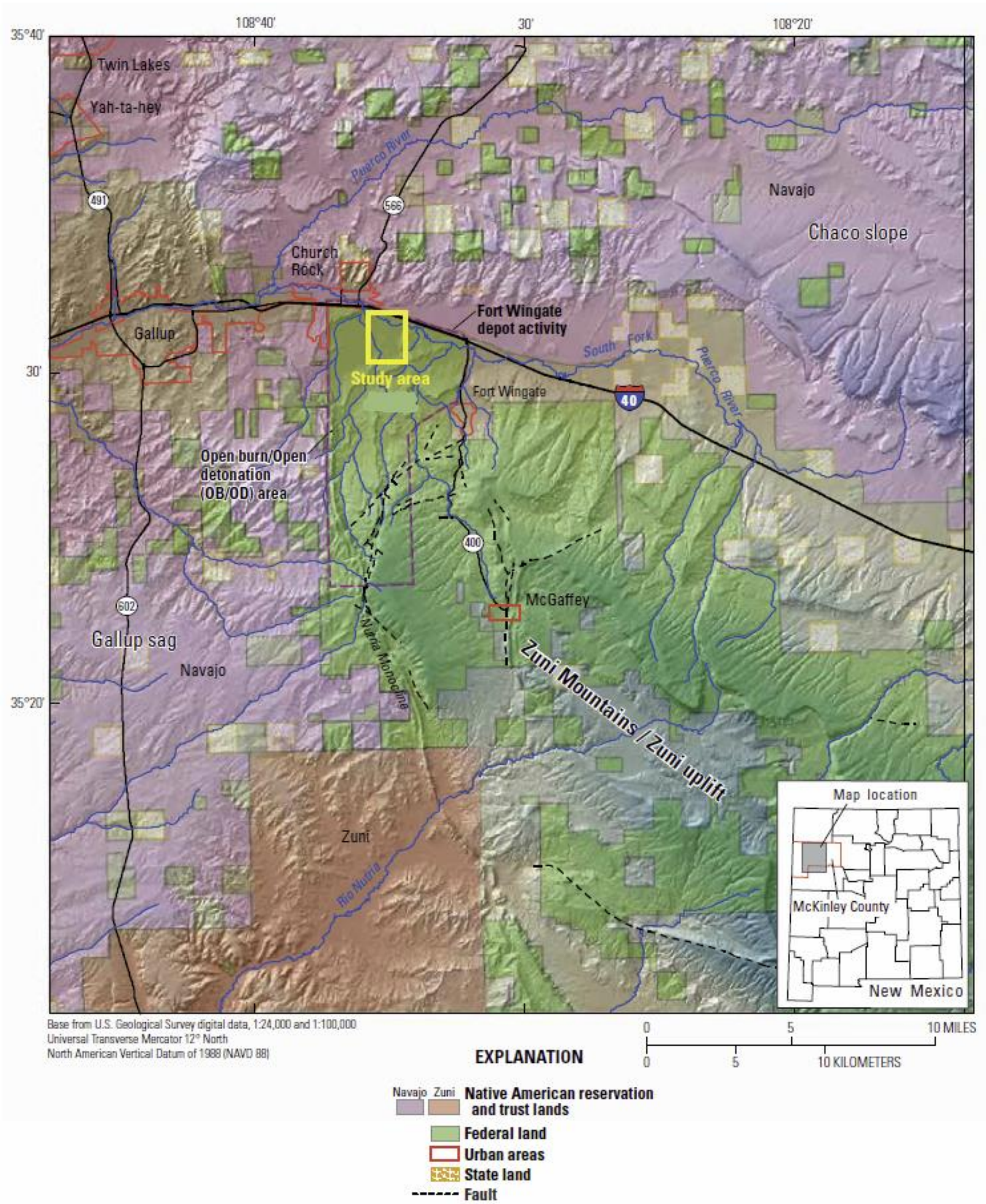
1 Introduction

1.1 Background and purpose

As part of an environmental investigation at Fort Wingate Depot Activity, New Mexico, the U.S. Army Engineer Research and Development Center (ERDC), in cooperation with the U.S. Army Corps of Engineers, Albuquerque District, and the U.S. Geological Survey, conducted this study to better understand groundwater recharge that is needed for characterizing the groundwater flow paths and the fate and transport of constituents of concern in the alluvial aquifer underlying the study area. The fine-grained nature of the alluvial matrix creates a highly heterogeneous environment, which adds to the difficulty of characterizing the flow of groundwater and the fate of aqueous constituents of concern.

Fort Wingate Depot Activity (hereafter referred to as the Depot) in northwestern New Mexico occupies approximately 24 square miles in McKinley County (Figure 1). It is located about 7 miles east of Gallup, New Mexico. The Depot is contained within a small basin defined by the Zuni Mountains to the south and east, the Nutria Monocline to the west, and the South Fork of the Puerco River Valley to the north. Elevations range from about 6,700 feet along the Puerco River to near 8,000 feet in the Zuni Mountains in the southern part of the Depot. The majority of Depot activities took place on the Quaternary alluvial fill valleys and on the moderately incised dip slopes of the Late Triassic Painted Desert Member of the Petrified Forest Formation.

Figure 1. Location of Fort Wingate Depot Activity, New Mexico.



Source: USGS-File Report 2013-5098: Geochemical Evidence of Groundwater Flow Paths and the Fate and Transport of Constituents of Concern in the Alluvial Aquifer at Fort Wingate Depot Activity, New Mexico, 2009

Understanding the recharge mechanisms and quantifying groundwater recharge is important for developing strategies to optimally manage groundwater resources and to assess the fate and transport of constituents at the site. Previous work at the site identified groundwater flow paths originating from four areas of groundwater recharge to the study area. The flow paths were identified based on groundwater elevations, hydrogeologic characteristics, and geochemical and isotopic evidence (Robertson et al., 2013). One source of recharge enters the study area from the saturated alluvial deposits underlying the South Fork of the Puerco River to the north of the study area. A second source of recharge was shown to originate from a leaky cistern containing production water from the San Andres-Glorieta aquifer (this cistern was decommissioned in 2012). The other two sources of recharge are reported to enter the study area from the south: one from the Fenced-Up Horse (FUH) Canyon, an arroyo valley draining an area to the south, and referred to as FUH flow path, and one from hill-front recharge that passes under the reported release of perchlorate and explosive constituents, referred to as the Trinitrotoluene (TNT) flow path. Additional information related to various flow paths on the Post can be found in the U.S. *Geological Survey Scientific Investigation Report, titled Geochemical evidence of groundwater flow paths and the fate and transport of constituents of concern in the alluvial aquifer at Fort Wingate Depot Activity, New Mexico, 2009* (Robertson et al., 2013).

The purpose of this study was to investigate the mechanism of recharge to the shallow aquifer and to estimate the amount of groundwater recharge using a tracer-based approach. The chloride mass balance estimation was performed with chloride concentrations in the (1) groundwater, and (2) the soil water of the unsaturated zone. Chloride concentrations in groundwater samples were used to estimate disperse recharge rates to a portion of the aquifer at a given groundwater flow path. The chloride mass balance approach was also applied to the unsaturated zone to provide point recharge estimates in different land use settings and confirm the conceptual model of focused recharge of precipitation. Recharge occurred from the surface of flat areas through the unsaturated zone and into the groundwater. The prevailing hypothesis is that nearly all recharge on the post occurs through streams (the Rio Puerco), arroyos (such as the FUH path way) and areas, where bedrock outcrops.

This report describes the techniques used to measure and calculate recharge rates both in groundwater, along the FUH (arroyo) and TNT flow paths (bedrock outcrop), and the unsaturated zone (flat areas on the Post). The results are accurate within the limitations of assumptions used.

2 Study Methods

2.1 Recharge

Recharge is defined as the addition of water to an aquifer, generally from precipitation that infiltrates downward through the subsurface. Direct recharge is the infiltration of precipitation directly from the unsaturated zone to the saturated zone over most of the areal extent of the aquifer (Anderholm et al., 1994). However, in many arid and semi-arid environments where the thickness of the unsaturated zone is large, much of the precipitation does not reach the water table. In these settings recharge to the aquifer may be limited to focused recharge, where recharge may occur only under surface depressions (e.g. Lake Knudson) or channels (the FUH flow path and Rio Puerco) that accumulate and pond water, or along the contact of outcropping bedrock such as noted for TNT flow path.

2.2 Meteoric chloride

Ambient chloride is continuously deposited on the land surface from the atmosphere, both dissolved in precipitation and dry fallout. This meteoric chloride then moves into the soil profile along with infiltrating precipitation. The chloride is retained in soil when the water is abstracted by evaporation or transpiration. The chloride mass balance then can be used to estimate recharge (residual moisture flux).

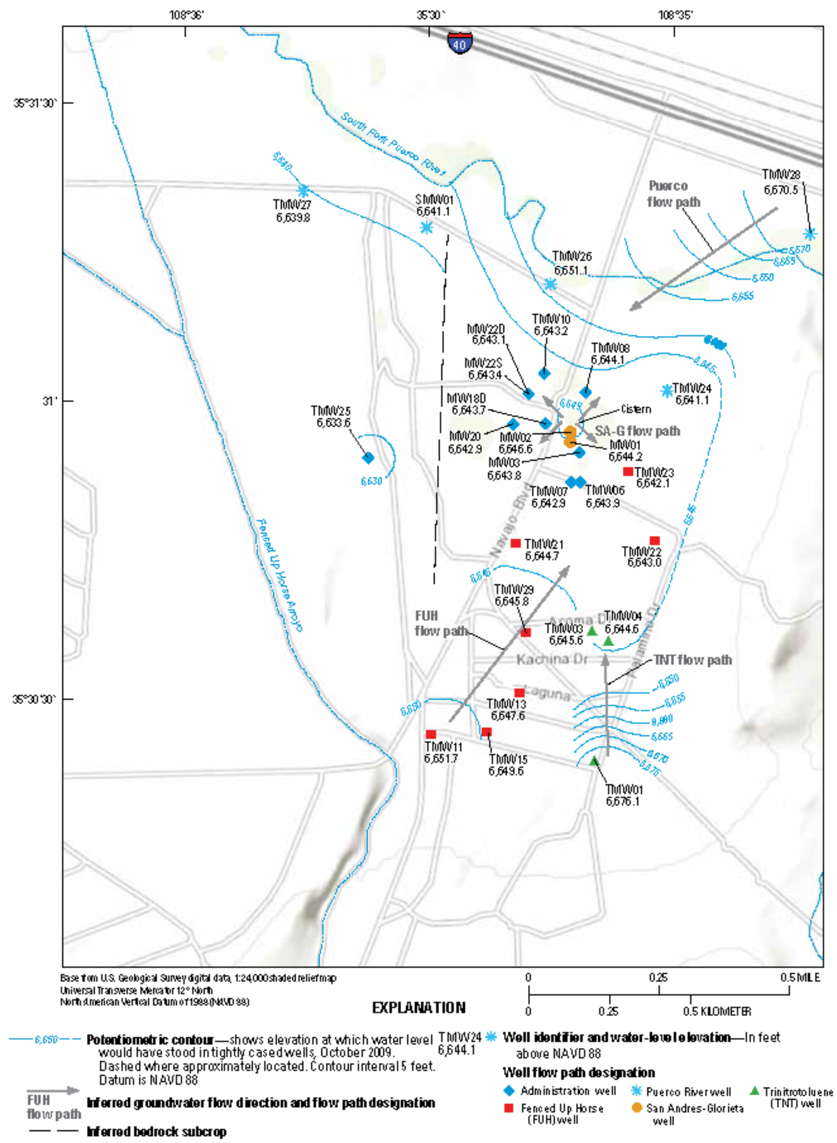
2.3 Groundwater chloride mass balance (CMB)

Chloride concentrations in groundwater or in unsaturated zone pore water may be used to estimate recharge (Murphy et al., 1996). This technique is based on the use of environmental tracers and has been described as the most ***successful*** method for estimating recharge in arid regions (Allison, 1988 and Allison et al. 1994). The estimates obtained by this method accurately describe moisture flux that occurs below the root zone. The assumptions made for this estimate are (1) the chloride in the groundwater or unsaturated zone originates from precipitation, (2) chloride is conservative in the system, and (3) the chloride-mass flux has not changed over time (Wood, 1999). The chloride mass balance approach can be applied to chloride concentrations in groundwater using the following formulation:

$$Q = P\left(\frac{[Cl_p]}{[Cl_{gw}]}\right) \qquad (1)$$

where Q is the recharge (in/yr), P is the average annual precipitation rate (in/yr), $[Cl_p]$ is the average concentration of meteoric chloride in precipitation (mg/L), and $[Cl_{gw}]$ is the chloride concentrations (mg/L) in groundwater samples collected from the wells along the TNT flow path and wells along the FUH flow path. Wells and flow paths are shown in Figure 2.

Figure 2. Location of alluvial wells on the Depot and their associated flow paths.



Source: USGS-File Report 2013-5098: Geochemical Evidence of Groundwater Flow Paths and the Fate and Transport of Constituents of Concern in the Alluvial Aquifer at Fort Wingate Depot Activity, New Mexico, 2009

The average concentration of meteoric chloride in precipitation, $[Cl_p]$ was calculated from data records at several gauge stations located in different states. These include the Cuba, NM, Bandelier, NM, Painted Desert, AZ, Mesa Verde, CO, and Canyonlands, UT, National Atmospheric Deposition Program (NADP) sites over their respective periods of record (National Atmospheric Deposition Program, 2014). The average chloride wet deposition concentration in the annual precipitation was determined to be 0.11 mg/L.

Due to the controversy surrounding its measurement, dry deposition is not reported at NADP sites and is no longer measured. Dry deposition contribution to the total chloride deposition is often estimated or not addressed. For this study, the dry component estimate of the chloride deposition was chosen based on an analysis by Sterling (2000). In that work, the dry fraction ranged between 30 to 50 percent of the total chloride deposition for Northwest New Mexico. The dry deposition was estimated to be 67% of the calculated wet deposition (equivalent to 40% of the total).

2.4 Unsaturated zone chloride mass balance

To further investigate the mechanism of recharge, the chloride mass balance approach was extended to the unsaturated zone by determining the chloride concentrations of pore water from two soil cores; one core was collected from a relatively flat area that has no observable features of runoff and the other collected from an area that is designed to collect and divert water. The conceptual model suggests that the recharge occurs in surface features that collect water. Recharge from direct precipitation on the land surface that are not collecting water, in this conceptual model, assumed to be negligible. The extension of this model is that there should be a large difference in chloride concentrations of the pore water in the unsaturated zone underlying a topographic flat site and in the soils underlying a surficial depression or other hydrologic surface feature. Other assumptions used in the model were that dispersion and preferential vadose zone fluxes are negligible. No large fissures, root tubes, or animal burrows were observed that would indicate preferential flow. Phillips (1994) provides evidence that these two assumptions are generally valid in the southwest.

The estimated recharge rate at a point in the unsaturated zone uses the same fundamental relationship as Equation 1.

$$Q = P\left(\frac{[Cl_p]}{[Cl_{sw}]}\right) \qquad (2)$$

where $[Cl_{sw}]$ represents the chloride concentration in the soil water (pore water) of the unsaturated zone (mg/L). The other variables are as defined in Equation 1. This approach assumes that no chloride has been added or removed from the site through surface water flows.

2.5 Field methods

Groundwater samples were collected in October 2009. A summary of the collection techniques and data validation can be found in the Fort Wingate geochemical report by Robertson et al. (2013).

Soil samples for pore water chloride concentration measurements were obtained through the use of direct push technologies (DPT). Samples were collected from two locations; one site was topographically flat with no evidence of surface water features, while the second site was located in a small depression in a ditch designed to collect and divert water. Soil cores were collected in 1.75 inch diameter polyethylene sleeves inside the 5 foot steel core-sampler. Samples were taken from the cores at 1 ft intervals from land surface to a depth of 40 ft below land surface (bls), then at 2 ft intervals until soil saturation, where recovery allowed.

The desired depths were extracted from the core-tubes by cutting out 3.5 inch long sections. The length of the section was measured and the soil was transferred to a pre-weighed sample jar. The sample weight was determined by calculating the difference between the jar weight and the total weight with a scale that has a reported accuracy of 0.01g. The scale was calibrated daily using 200g reference weights. Bulk density was determined by dividing the weight of the sample by the computed volume (the product of the measured length and area, which was calculated from the reported inner diameter of the core tubes).

Soil samples were sent to the USGS contract laboratory for gravimetric percent moisture analysis using American Society for Testing and Materials (ASTM) method D2216-90. Water-soluble anions leached from these samples were analyzed using U.S. Environmental Protection Agency (EPA) method SW846 9056. The results of the anion analysis are reported as mg/kg on a dry weight basis. No field duplicates were collected at the site, but 2 MS/MSD and laboratory split samples were performed for each site.

2.6 Analysis Methods

To calculate the volumetric moisture content of the soil sample, the percent mass moisture were converted to percent volume moisture using the bulk density calculated for each sample and the density of water by the following equation:

$$\boldsymbol{\theta} = \boldsymbol{u}(\boldsymbol{\rho_s}/\boldsymbol{\rho_w}) \quad (3)$$

where θ is the volumetric soil moisture in cubic centimeters per cubic centimeter, *u* is the gravimetric soil moisture in grams per grams, ρ_s is the bulk density of the sample in grams per cubic centimeter, and ρ_w is the density of water in grams per cubic centimeter (assumed to be 1 for this study).

The measured bulk density of the soil samples ranged from 1.2 to 2.4 g/cm^3, and the mean (and median) bulk density was calculated to be 1.8 g/cm^3. The percent moisture of the samples ranged from 2 to 21 % with an average of about 8%. The average annual wet chloride deposition rate computed for the site was determined to be 55.5 mg/m^2/yr. This rate is less than the values reported by Phillips (1994) (75 to 150) for sites in Nevada, Arizona, New Mexico, and Texas.

The concentration of the chloride in the soil water of the sample is calculated from the measured dry weight concentration of chloride in the sample as:

$$[\boldsymbol{Cl_{sw}}] = [\boldsymbol{Cl_{sample}}]\left(\frac{\boldsymbol{\rho_w}}{\boldsymbol{u}}\right) \quad (4)$$

where $[Cl_{sw}]$ is the chloride concentration in the soil water (mg/L), $[Cl_{sample}]$ is the dry weight concentration of chloride in the sample (mg/kg), *u* is the gravimetric soil moisture (g/g), and ρ_w is the density of water (g/mL) (assumed to be 1 for this study).

The time that is required to accumulate the mass of chloride (sum of chloride mass above specified depth), at a given annual rate of precipitation and chloride deposition, can be calculated using the following equation:

$$\boldsymbol{T} = \boldsymbol{M_{Cl}}/(\boldsymbol{P}[\boldsymbol{Cl_P}]) \quad (5)$$

where T (years) is the time required to accumulate the mass of chloride above a certain depth, M_{Cl} (g/m^2) is the mass of chloride summed over the depth interval, P ($L/m^2/yr$) is the average annual precipitation rate, [Cl_p] (g/L) is the average concentration of meteoric chloride in precipitation.

3 Results

Recharge in arid and semiarid regions is generally extremely low, typically ranging from 2 to 4% of average precipitation and often is focused in playas, arroyos basins and topographic depressions (Wood, 1999). Evaporation/evapotranspiration typically exceeds average precipitation.

This is in part due to the fact that the xeric plants and vegetation are extremely efficient at removing water from the soil. The plant community has been suggested to control the moisture regimes in these environments (Phillips, 1994). Figure 3 shows photo of roots exposed in a 20 foot arroyo wall.

Figure 3. Photo of roots exposed in 20 foot arroyo wall.

3.1 Groundwater chloride mass balance

The 2009 chloride concentrations were measured in groundwater samples collected from wells along the FUH and TNT flow paths (Figure 2). Samples collected from wells along the TNT flow path (Figure 2) contained chloride concentrations ranging from 150 to 180 mg/L with an average concentration of 167 mg/L. The recharge calculated by Equation 1 is between 0.012 and 0.015 inches per year, with an average of 0.013 in/yr. Samples collected from wells along the FUH flow path (Figure 2) contained chloride concentrations ranging between 49 to 86 mg/L with an average concentration of 66 mg/L indicating more variability in recharge than the TNT flow path. This result is expected with multiple drainages crossing the surface. The calculated recharge rates from FUH flow path wells vary from 0.025 to 0.045 inches per year, with an average of 0.033 in/yr. It is also reasonable that the recharge would be higher in the contributing area of FUH flow path than the contributing area of the TNT flow path given the larger number of surficial features that would collect and retain water and the existence of an ephemeral arroyo. The estimate for the FUH flow path should be used with caution as the presence of the Fenced-Up Horse arroyo may violate the assumption of chloride being transported by the stream biasing the estimate high. Estimates of recharge from wells along the San Andres-Glorieta (SAG) and Puerco River (Figure 2) flow paths are not considered due the violations of assumptions used in the CMB recharge calculations. Table 1 provides summary of groundwater chloride estimates and the recharge rates.

Table 1. Summary of estimated chloride concentration and recharge rates in the groundwater.

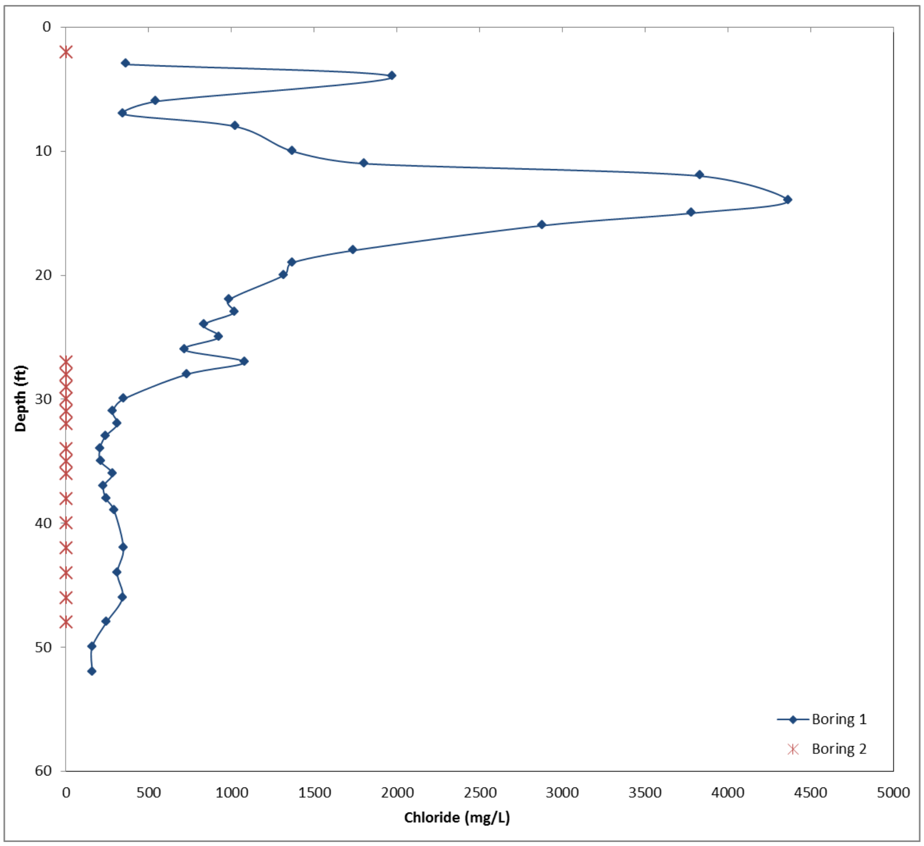
Precipitation Rate (in/yr)	Total [Cl_p] (mg/L)	Groundwater Well	Stats for [Cl_{gw}]	[Cl_{gw}] (mg/L)	Stats for Recharge	Q (in/yr)
11.9*	0.1837#	TNT Well	Average	167	Average	0.013
			Minimum	150	Maximum	0.015
			Maximum	180	Minimum	0.012
		FUH Well	Average	66	Average	0.033
			Minimum	49	Maximum	0.045
			Maximum	86	Minimum	0.025

*Average Annual Precipitation rate (P) at Depot (1940-1966)
Total [Cl_p] = Wet deposition rate + Dry deposition rate = Wet + (67/100)*Wet

3.2 Unsaturated zone chloride mass balance

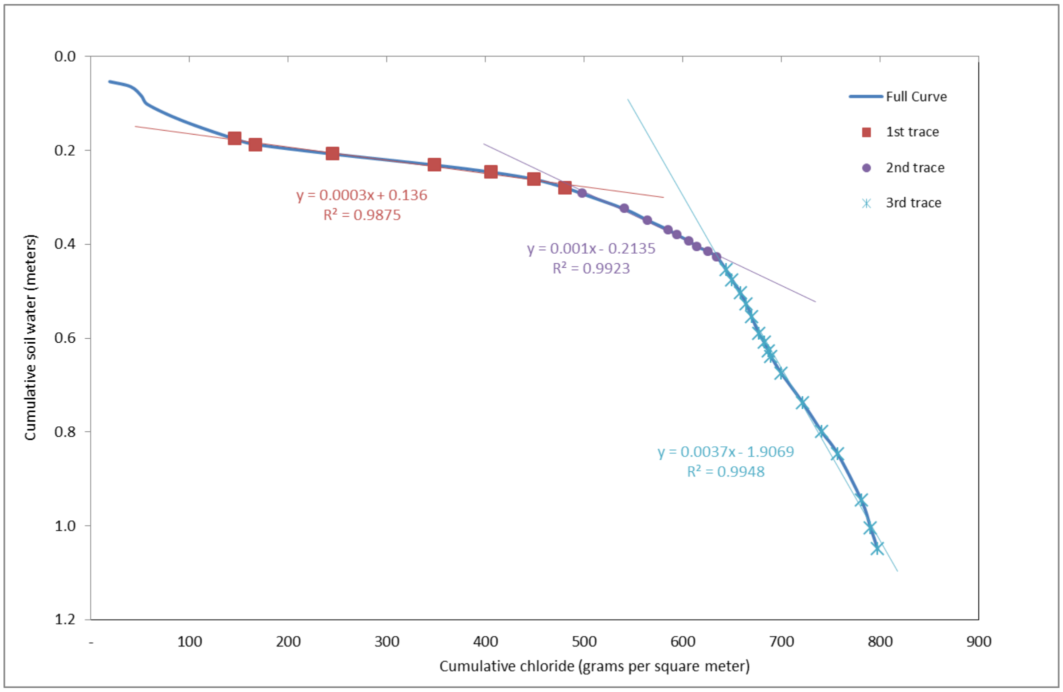
The chloride mass balance method was used to estimate recharge from soil samples collected from the unsaturated zone. The chloride concentrations in the soil samples from Boring 1 show a characteristic of arid and semi-arid "chloride bulge" delineating the active root zone (Figure 4) (Phillips, 1994). The soil water chloride concentrations rise rapidly to 4363.6 mg/L at 14 ft below ground surface (bgs) and fall nearly as fast to a range of about 150 to 300 mg/L below 30 feet. Thirty-eight soil samples were collected from Boring 2. Twenty-two of these samples had dry weight chloride concentrations below the detection limit of 2.2 mg/kg. All of the measured chloride soil concentrations in Boring 2 were below the reporting limit (Figure 4).

Figure 4. Chloride soil water concentrations in two borings to groundwater as a function of depth below ground surface.



The cumulative chloride mass per square meter (g/m^2) in samples from Boring 1 is plotted as a function of cumulative water volume per square meter (m^3/m^2) (Figure 5). According to Allison (1985) this graph can be used to remove the effect of variations in water content in the soil profile. The slopes of the graphs (referred to as traces in this report) are used to determine graphically the intervals of differing recharge rates (Phillips, 1994). A graph of the cumulative chloride and water content for Boring 2 was not generated due the large number of non-detects data in the data. The lack of chloride in the Boring 2 suggests that water is able to move through the unsaturated zone to the aquifer, carrying the meteoric chloride with it.

Figure 5. Plot of cumulative chloride versus cumulative water in the soil profile of Boring 1 (Equations represent least squares analysis on observable straight line segments and the associated R^2 fit).



The soil water in the unsaturated zone, $[Cl_{SW}]$, is determined at each trace as the inverse of the slope (slope of lines in Figure 5). The data from the first 7 feet of the soil profile is ignored because much of the water will be subsequently used by vegetation (Allison, 1985). The straight line segments represent a consistent recharge rate over a period of time. The 1st trace represents the shallower depths and the most recent deposition environment. The estimated recharge rate calculated from the 1st trace (upper part of the soil profile) is 0.0007 inches per year (0.0179 millimeters per year). The chloride mass per square meter at the 18 ft bgs is 854 g/m^2, which corresponds to about 15,400 years of deposition at current precipitation and chloride deposition rates. The 2nd trace has an estimated recharge rate of 0.0022 inches per year (0.0559 millimeter per year) and the total chloride mass from the surface to 28 ft bgs summed to 1,128 g/m2, which corresponds to about 20,300 years of accumulation. The recharge rate for the 3rd trace is calculated to be 0.0081 inches per year (0.2057 millimeter per year) going beyond 25,500 years. Table 2 provides a summary of the estimated recharge rates for unsaturated zone.

Table 2. Summary of estimated chloride concentration and recharge rates in the unsaturated zone.

Total [Cl_p] (mg/L)	[Cl_{sw}] (mg/L)	Precipitation (in/yr)	Q (in/yr)	Q (mm/yr)
0.1837	3333.33	11.9	0.0007	0.0179
0.1837	1000.00	11.9	0.0022	0.0559
0.1837	270.27	11.9	0.0081	0.2057

The estimated recharge rate calculated from chloride concentrations in soil samples from Boring 1 indicate a rate reduction of approximately 30% at the depth climatic epoch change from the Pleistocene to the Holocene about 15,000 years ago. This inflection point is similar to inflection points observed in plots of cumulative chloride versus cumulative water reported by Phillips (1994) for six sites in the southwest U.S. A similar change in recharge rates at the site occurs between the 3rd and 2nd trace at around 20,300 years before present. This estimated recharge record corresponds to the last glacial maximum (Clark et al., 2009). For the fate and transport calculations, the recharge rate of 0.0007 in/yr (0.0179 mm/yr) has been recommended.

4 Summary and Conclusion

As part of an environmental investigation at Fort Wingate Depot Activity, New Mexico, this study was conducted to better understand the mechanisms of groundwater recharge and to estimate the recharge rates to the alluvial aquifer underlying the study area.

Fort Wingate Depot Activity in northwestern New Mexico occupies approximately 24 square miles in McKinley County. It is located about 6 miles east of Gallup, New Mexico, where there is a station to measure precipitation. The majority of Depot activities took place on the Quaternary alluvial fill valleys and on the moderately incised dip slopes of the Late Triassic Painted Desert Member of the Petrified Forest Formation.

Chloride concentrations in groundwater and in unsaturated zone pore water were used to assess recharge mechanisms and estimate recharge rates. The technique is based on the use of environmental tracers and has been the most successful method for estimating recharge in arid regions. The estimates obtained by this method describe moisture flux that occurs below the root zone.

The average concentration of meteoric chloride in precipitation was calculated from data records at the Cuba, Bandelier, Painted Desert, Mesa Verde, in the state of New Mexico and Canyon lands National Atmospheric Deposition Program (NADP) sites over their respective periods of record. The average chloride wet deposition concentration in the annual precipitation was determined to be 0.11 mg/L.

Due to the controversy surrounding its measurement, dry deposition is not reported at NADP sites and is no longer measured. Dry deposition contribution to the total chloride deposition is often estimated or not addressed. The dry deposition for this study was estimated to be 67% of the calculated wet deposition (equivalent to 40% of the total). The sum of the wet deposition and the estimated dry deposition result in a chloride concentration in annual precipitation to be 0.18 mg/L.

The 2009 chloride concentrations in groundwater samples collected from wells along the TNT flow path contained a chloride concentration ranging from 150 to 180 mg/L with an average concentration of 167 mg/L. The recharge calculated by Equation 1 is between 0.012 and 0.015 inches per year, with an average of 0.013 in/yr. The chloride concentrations in groundwater samples also collected from wells along the FUH flow path contained a chloride concentrations ranging between 49 to 86 mg/L with an average concentration of 65.80 mg/L indicating more variability in recharge than the calculated recharge from the TNT flow path. This result is expected with multiple drainages crossing the surface. The recharge rates from FUH flow path vary from 0.025 to 0.045 inches per year, with an average of 0.033 in/yr. It is also reasonable that the recharge would be higher in the contributing area of FUH flow path than the contributing area of the TNT flow path given the larger number of surficial features that would pond water and the existence of an ephemeral arroyo. The estimate for the FUH flow path should be used with caution as the presence of the Fenced-Up Horse arroyo may violate the assumption of chloride being transported by the stream biasing the estimate high. Estimates of recharge from the San Andres-Glorieta (SAG) and Puerco River wells flow paths are not considered due the violations of assumptions used in the CMB recharge calculations.

The chloride mass balance approach was extended to unsaturated zone by determining the chloride concentrations of pore water from two soil cores; one core was collected from an area that has no observable features of runoff and the other collected from an area that is designed to collect and divert water. The conceptual model for the unsaturated zone suggests that the recharge occurs in surface areas that collect water. Conversely, areas where the surface topography is flat, there is substantially less recharge to the unsaturated zone.

The chloride concentrations in the soil samples from Boring 1 show a characteristic of arid and semi-arid “chloride bulge” delineating the active root zone. The soil water chloride concentrations rise rapidly to 4363.6 mg/L at 14 ft below ground surface (bgs) and fall nearly as fast to a range of about 150 to 300 mg/L below 30 feet. Thirty-eight soil samples were collected from Boring 2. Twenty-two of these samples had dry weight chloride concentrations below the detection limit of 2.2 mg/kg. All of the calculated chloride soil water concentrations were below the reporting limit.

The graph of cumulative chloride mass as a function of cumulative water volume was used to calculate recharge rates in the unsaturated zone. The data points were used in a statistical calculation to create three straight line segments representing a consistent recharge rate over a period of time. The 1st trace (graphic line) represents the most recent deposition environment and corresponds to an estimated recharge rate of 0.0007 inches per year (0.0179 millimeter per year). The chloride mass per square meter at the 18 ft bgs is 854 g/m2, which corresponds to about 15,400 years of deposition at current rates. The 2nd trace has an estimated recharge rate of 0.0022 inches per year (0.0559 millimeters per year) and the total chloride from surface to 28 ft bgs is 1,128 g/m2, which corresponds to about 20,300 years. The recharge rate for the 3rd trace is calculated to be 0.0081 inches per year (0.2057 millimeters per year) going beyond 25,500 years. The estimated recharge rate using the CMB analysis is very low, ranging from 0.0007 to 0.0081 in/yr (0.0179 to 0.2057 mm/yr). The USACE Albuquerque District and ERDC has recommended 0.0007 in/yr (0.0179 mm/yr) to be used for other parts of the studies at the Post.

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Appendix: Field Data and Recharge Calculations

This appendix provides copies of some page of an excel file, which contains measured soil data, precipitation data, chloride data, and calculated recharge rates.

Figure A1. Recharge calculations.

Unsaturated Zone

Q = P (Clp) / (Clsw)

Precipitation				
in/yr	*L/m2/yr*			*Source*
11.9	302.26	Depot (1940-1966)	0.16729	1
11.3	287.02	Gallup (1921-2005)	0.17618	1
18.7	474.98	McGaffey (1923-2005)	0.10646	1
11.6	294.64	Gallup (?-?)	0.17162	2
7.4	187.96		0.26903	

Data Source

1 Western Regional Climate Center, 2010

2 weather channel .com

	Clp		Clsw	
	mg/L	*g/m3*	*g/m3*	
wet	0.1100	0.1100	769.23	1st trace
dry	0.0737	0.0737	3333.33	2nd trace
total	0.1837	0.1837	1000.00	3rd trace
			270.27	4th trace

		Q (in/yr)	Clp		Precip				
			0.110	**0.1837**	**11**	**12**	**Mcl**	**time (yrs)**	
		454.55	0.0029	0.0048	0.0044	0.0048	166.40	2,997	
		3333.33	0.0004	0.0007	0.0006	0.0007	853.72	15,375	30.0%
min	0.0004	1000.00	0.0013	0.0022	0.0020	0.0022	1127.90	20,313	27.0%
max	0.0081	270.27	0.0048	0.0081	0.0075	0.0082	1417.51	25,529	

Water | Put dry depo into rain

1 g/ cm3 | 0.073

0.183

		Q (mm/yr)	Clp		Precip		
			0.11	**0.2**	**11**	**12**	
		769.23	0.07	0.12	0.11	0.12	
		3333.33	0.01	0.02	0.02	0.02	
min	0.0100	1000.00	0.03	0.06	0.05	0.06	
max	0.2054	270.27	0.12	0.21	0.19	0.21	4.05
							1.1
		Deposition Rate		55.525			0.0035
				50.629			

Groundwater

Flowpath	*Stats*	*[Cl] mg/L*	*Q (in/yr)*	*Q (mm/yr)*					
						33.249	55.525		
TNT	ave Cl	167.00	0.013	0.33					
	min	150	0.015	0.37			22.28		0.32%
	max	180	0.012	0.31			#####		
FUH	ave Cl	65.80	0.033	0.84					
	min	49.00	0.045	1.13			1.670		
	max	86.00	0.025	0.65			0.074	0.401	
					0.110				

Precip weighted means in mg/L					
	Cuba	Bandelier	PD	MV	CL
1981				0.16	
1982	0.18	0.10		0.09	
1983	0.12	0.15		0.09	
1984	0.18	0.14		0.14	
1985	0.11	0.12		0.09	
1986	0.12	0.08		0.08	
1987	0.10	0.11		0.09	
1988	0.10	0.08		0.10	
1989	0.10	0.09		0.13	
1990	0.12	0.09		0.15	
1991	0.08	0.08		0.08	
1992	0.08	0.06		0.07	
1993	0.08	0.07		0.06	
1994	0.08	0.08		0.10	
1995	0.09	0.08		0.08	
1996	0.13	0.10		0.12	
1997	0.10	0.08		0.08	0.06
1998	0.06	0.05		0.07	0.07
1999	0.10	0.07		0.08	0.19
2000	0.07	0.05		0.08	0.07
2001		0.09		0.08	0.08
2002		0.08		0.09	0.16
2003		0.05	0.07	0.06	0.07
2004		0.05	0.09	0.07	0.13
2005		0.04	0.08	0.05	0.06
2006		0.05	0.16	0.07	0.08
2007		0.07	0.33	0.08	0.07
2008		0.07	0.09	0.07	0.08
2009		0.06	0.53	0.10	0.17
2010		0.07	0.11	0.06	0.06
2011		0.07	0.19	0.07	0.07
2012		0.068	0.14	0.08	0.07
2013		0.053	0.09	0.1	0.07
min	*0.06*	*0.04*	*0.07*	*0.05*	*0.06*
max	*0.18*	*0.15*	*0.53*	*0.16*	*0.19*
ave	*0.11*	*0.08*	*0.17*	*0.09*	*0.09*
min	*0.06*	*0.04*	*0.07*	*0.05*	*0.06*
max	*0.18*	*0.15*	*0.53*	*0.16*	*0.19*
ave	*0.11*	*0.08*	*0.18*	*0.09*	*0.09*

Cl Accumulation Rate in mg/m2/year					
	Cuba	Bandelier	PD	MV	CL
1981				50.00	
1982		35		58.00	
1983		54		49.00	
1984		52		56.00	
1985		67		47.00	
1986		43		51.00	
1987		42		44.00	
1988		43		40.00	
1989		33		33.00	
1990		35		64.00	
1991		45		37.00	
1992		22		37.00	
1993		33		33.00	
1994		34		45.00	
1995		28		33.00	
1996		36		53.00	
1997		41		38.00	1
1998		15		28.00	15
1999		30		23.00	48
2000		19		24.00	13
2001		24		23.00	17
2002		15		19.00	26
2003		12	6.00	18.00	13
2004		17	23.00	24.00	31
2005		19	19.00	25.00	18
2006		19	24.00	23.00	25
2007		23	76.00	31.00	18
2008		25	15.00	30.00	16
2009		20	73.00	35.00	26
2010		21	33.00	30.00	16
2011		15	39.00	29.00	19
min	*0.00*	*12.00*	*6.00*	*18.00*	*1.00*
max	*0.00*	*67.00*	*76.00*	*64.00*	*48.00*
ave	*#DIV/0!*	*30.57*	*34.22*	*36.45*	*20.13*
min	*0.00*	*12.00*	*6.00*	*18.00*	*1.00*
max	*0.00*	*67.00*	*76.00*	*64.00*	*48.00*
ave	*#DIV/0!*	*30.57*	*34.22*	*36.45*	*20.13*

Figure A2. Subsurface soil data.

Sample Depth		Smpl Int	Sample Wt	Sample Vol	Density	%Moisture	% Vol soil moisture	Cum soil moisture		Cl dry conc	Cl bulk conc	Cl per Soil H2O vol		[Cl]/depth		Time
Field			Field	Field	Calc	Lab data	V = %mois * bulk/water density	Vol soil moisture*depth	Sum	reported [Cl]	[Cl] -([Cl]* %mois)	see Anderholm or murphey		[Cl]sw *D* %vol	Sum	[Cl]/(precip*([Cl]sw/1000)
(ft bgs)	(m bgs)	m	(g)	(cm3)	(g/cm3)	(g/g)	(cm3/cm3)	(m)	(m)	(mg/kg)	(mg/kg)	mg/L	g/m3	g/m2		years
3	0.914	0.91	216.67	173.75	1.25	8.30%	10.35%	0.09	0.095	30	27.51	361.4	361.4	34.19	34.19	616
4	1.219	0.46	209.06	173.75	1.20	3.50%	4.21%	0.02	0.114	69	66.59	1971.4	1971.4	37.96	72.15	1299
6	1.829	0.46	170.63	102.51	1.66	4.80%	7.99%	0.04	0.150	26	24.75	541.7	541.7	19.79	91.94	1656
7	2.134	0.30	173.72	104.25	1.67	6.10%	10.16%	0.03	0.181	21	19.72	344.3	344.3	10.67	102.60	1848
8	2.438	0.46	193.97	139.00	1.40	9.80%	13.68%	0.06	0.244	100	90.20	1020.4	1020.4	63.80	166.40	2997
10	3.048	0.46	159.27	102.51	1.55	9.50%	14.76%	0.07	0.311	130	117.65	1368.4	1368.4	92.34	258.75	4660
11	3.353	0.30	179.00	102.51	1.75	4.00%	6.98%	0.02	0.333	72	69.12	1800.0	1800.0	38.32	297.07	5350
12	3.658	0.46	166.08	99.04	1.68	4.70%	7.88%	0.04	0.369	180	171.54	3829.8	3829.8	138.01	435.07	7836
14	4.267	0.46	172.62	102.51	1.68	5.50%	9.26%	0.04	0.411	240	226.80	4363.6	4363.6	184.77	619.84	11163
15	4.572	0.30	203.86	104.25	1.96	4.50%	8.80%	0.03	0.438	170	162.35	3777.8	3777.8	101.33	721.17	12988
16	4.877	0.46	189.44	102.51	1.85	3.20%	5.91%	0.03	0.465	92	89.06	2875.0	2875.0	77.73	798.90	14388
18	5.486	0.46	189.41	104.25	1.82	3.80%	6.90%	0.03	0.497	66	63.49	1736.8	1736.8	54.82	853.72	15375
19	5.791	0.30	190.72	102.51	1.86	4.10%	7.63%	0.02	0.520	56	53.70	1365.9	1365.9	31.76	885.48	15947
20	6.096	0.46	175.29	105.99	1.65	7.60%	12.57%	0.06	0.577	100	92.40	1315.8	1315.8	75.62	961.09	17309
22	6.706	0.46	168.33	104.25	1.61	5.80%	9.37%	0.04	0.620	57	53.69	982.8	982.8	42.08	1,003.17	18067
23	7.010	0.30	213.21	104.25	2.05	5.80%	11.86%	0.04	0.656	59	55.58	1017.2	1017.2	36.78	1,039.95	18729
24	7.315	0.30	186.46	104.25	1.79	3.60%	6.44%	0.02	0.676	30	28.92	833.3	833.3	16.35	1,056.31	19024
25	7.620	0.30	196.95	104.25	1.89	4.00%	7.56%	0.02	0.699	37	35.52	925.0	925.0	21.31	1,077.61	19408
26	7.925	0.30	214.50	107.72	1.99	3.50%	6.97%	0.02	0.720	25	24.13	714.3	714.3	15.17	1,092.79	19681
27	8.230	0.30	205.88	92.09	2.24	2.60%	5.81%	0.02	0.738	28	27.27	1076.9	1076.9	19.08	1,111.87	20025
28	8.534	0.46	224.75	102.51	2.19	2.20%	4.82%	0.02	0.760	16	15.65	727.3	727.3	16.04	1,127.90	20313
30	9.144	0.46	196.41	107.72	1.82	5.80%	10.57%	0.05	0.808	20	18.84	344.8	344.8	16.67	1,144.58	20614
31	9.449	0.30	157.86	105.99	1.49	8.50%	12.66%	0.04	0.847	24	21.96	282.4	282.4	10.90	1,155.47	20810
32	9.754	0.30	162.81	100.77	1.62	10.00%	16.16%	0.05	0.896	31	27.90	310.0	310.0	15.27	1,170.74	21085
33	10.058	0.30	189.84	104.25	1.82	7.60%	13.84%	0.04	0.938	18	16.63	236.8	236.8	9.99	1,180.73	21265
34	10.363	0.30	184.23	104.25	1.77	8.80%	15.55%	0.05	0.986	18	16.42	204.5	204.5	9.70	1,190.42	21439
35	10.668	0.30	175.08	100.77	1.74	12.00%	20.85%	0.06	1.049	25	22.00	208.3	208.3	13.24	1,203.66	21678
36	10.973	0.30	193.85	97.30	1.99	5.70%	11.36%	0.03	1.084	16	15.09	280.7	280.7	9.72	1,213.38	21853
37	11.278	0.30	211.28	100.77	2.10	5.30%	11.11%	0.03	1.118	12	11.36	226.4	226.4	7.67	1,221.05	21991
38	11.582	0.30	221.10	105.99	2.09	3.10%	6.47%	0.02	1.137	7.5	7.27	241.9	241.9	4.77	1,225.81	22077
39	11.887	0.61	222.87	104.25	2.14	4.80%	10.26%	0.06	1.200	14	13.33	291.7	291.7	18.25	1,244.06	22405
42	12.802	0.76	204.78	104.25	1.96	7.50%	14.73%	0.11	1.312	26	24.05	346.7	346.7	38.92	1,282.98	23106
44	13.411	0.61	177.14	99.04	1.79	10.00%	17.89%	0.11	1.421	31	27.90	310.0	310.0	33.80	1,316.78	23715
46	14.021	0.61	178.44	104.25	1.71	8.20%	14.04%	0.09	1.507	28	25.70	341.5	341.5	29.22	1,345.99	24241
48	14.630	0.61	214.60	104.25	2.06	14.00%	28.82%	0.18	1.682	34	29.24	242.9	242.9	42.67	1,388.66	25010
50	15.240	0.61	128.65	104.25	1.23	14.00%	17.28%	0.11	1.788	22	18.92	157.1	157.1	16.55	1,405.21	25308
52	15.850	0.46	147.60	104.25	1.42	12.00%	16.99%	0.08	1.865	19	16.72	158.3	158.3	12.30	1,417.51	25529
min			***128.65***	***92.09***	***1.20***	***2.2%***	***0.04***	***0.02***	***0.09***	***7.50***	***7.27***	***157.14***	***157.14***	***4.77***		
max			***224.75***	***173.75***	***2.24***	***14.0%***	***0.29***	***0.18***	***1.87***	***240.00***	***226.80***	***4363.64***	***4363.64***	***184.77***		
mean			***188.28***	***107.87***	***1.77***	***6.6%***	***0.11***	***0.05***	***0.79***	***52.69***	***49.43***	***1003.60***	***1003.60***	***38.31***		
median			***189.44***	***104.25***	***1.79***	***5.8%***	***0.10***	***0.04***	***0.72***	***30.00***	***27.51***	***541.67***	***541.67***	***21.31***		
			Field data			16	0.16									
	0.6096		Anderholm, 1994			11	0.11									**1/slope**
			Lab data			6.5	0.065								**0 trace**	**454.55**
			Murphey etal, 1996			14	0.14								**1st trace**	**3333.33**
			Calculations			14	0.14								**2nd trace**	**1000.00**
						15	0.15								**3rd trace**	**270.27**
						5.2	0.052									
Sample	V (cm3)					10	0.1									
3	308.89					12	0.12									
4	308.89					17	0.17									
6	182.24					16	0.16									
7	185.33					3.7	0.037									
8	247.11					5.4	0.054									
10	182.24					7.0	0.07									
11	182.24					6.0	0.06									
12	176.07					7.0	0.07									
14	182.24					12	0.12									
15	185.33					7.0	0.07									
16	182.24					4.1	0.041									
18	185.33					3.2	0.032									
19	182.24					3.0	0.03									
20	188.42					5.3	0.053									
22	185.33					7.9	0.079									
23	185.33					12	0.12									
24	185.33					15	0.15									
25	185.33					3.6	0.036									
26	191.51					10	0.1									
27	163.71					7.6	0.076									
28	182.24					10	0.1									
30	191.51					5.0	0.05									
31	188.42					13	0.13									
32	179.16					13	0.13									
33	185.33					5.2	0.052									
34	185.33					12	0.12									
35	179.16					10	0.1									
36	172.98					7.2	0.072									
37	179.16					21	0.21									
38	188.42					17	0.17									
39	185.33					3.00										
42	185.33					21.00										
44	176.07					9.73										
46	185.33					10.00	7.20%									
48	185.33															
50	185.33															
52	185.33															