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Potential Release Site Sediment Concentrations Correlated to Storm Water Station Runoff through GIS Modeling

Los Alamos
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Christopher T. McLean

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POTENTIAL RELEASE SITE SEDIMENT CONCENTRATIONS RELATED TO STORM WATER RUNOFF THROUGH GIS MODELING

A THESIS PRESENTED TO
THE DEPARTMENT OF GEOLOGY AND GEOGRAPHY
IN CANDIDACY FOR THE DEGREE OF
MASTER OF SCIENCE

By
Chris Mclean

NORTHWEST MISSOURI STATE UNIVERSITY
MARYVILLE, MISSOURI
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Potential Release Site Sediment Concentrations Related to Storm Water Station Runoff through GIS Modeling

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THESIS APPROVED

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Potential Release Site Sediment Concentrations Related to Storm Water Station Runoff through GIS Modeling

Abstract

This research examined the relationship between sediment sample data taken at Potential Release Sites (PRSs) and storm water samples taken at selected sites in and around Los Alamos National Laboratory (LANL). The PRSs had been evaluated for erosion potential and a matrix scoring system implemented. It was assumed that there would be a stronger relationship between the high erosion PRSs and the storm water samples. To establish the relationship, the research was broken into two areas. The first area was raster-based modeling, and the second area was data analysis utilizing the raster based modeling results and the sediment and storm water sample results.

Two geodatabases were created utilizing raster modeling functions and the Arc Hydro program. The geodatabase created using only Arc Hydro functions contains very fine catchment drainage areas in association with the geometric network and can be used for future contaminant tracking. The second geodatabase contains sub-watersheds for all storm water stations used in the study along with a geometric network.

The second area of the study focused on data analysis. The analytical sediment data table was joined to the PRSs spatial data in ArcMap. All PRSs and PRSs with high erosion potential were joined separately to create two datasets for each of 14 analytes.

Only the PRSs above the background value were retained. The storm water station spatial data were joined to the table of analyte values that were either greater than the National Pollutant Discharge Elimination System (NPDES) Multi-Sector General Permit (MSGP) benchmark value, or the Department of Energy (DOE) Drinking Water Defined Contribution Guideline (DWDCG). Only the storm water stations were retained that had sample values greater than the NPDES MSGP benchmark value or the DOE DWDCG. Separate maps were created for each analyte showing the sub-watersheds, the PRSs over background, and the storm water stations greater than the NPDES MSGP benchmark value or the DOE DWDCG. Tables were then created for each analyte that listed the PRSs average value by storm water station allowing a tabular view of the mapped data. The final table that was created listed the number of high erosion PRSs and regular PRSs over background values that were contained in each watershed.

An overall relationship between the high erosion PRSs or the regular PRSs and the storm water stations was not identified through the methods used in this research. However, the Arc Hydro data models created for this analysis were used to track possible sources of contamination found through sampling at the storm water gaging stations. This geometric network tracing was used to identify possible relationships between the storm water stations and the PRSs. The methods outlined for the geometric network tracing could be used to find other relationships between the sites. A cursory statistical analysis was performed which could be expanded and applied to the data sets generated during this research to establish a broader relationship between the PRSs and storm water stations.

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Acronyms

BV	Background Value
CASE	Computer Aided Software Engineering
DOE	Department of Energy
DCG	Defined Contribution Guideline
DWDCG	Drinking Water Defined Contribution Guideline
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
FFCA	Federal Facility Compliance Act
GIS	Geographic Information System
LANL	Los Alamos National Laboratory
LIDAR	Light Detection And Ranging
MSGP	Multi-Sector General Permit
NMED	New Mexico Environment Department
NPDES	National Pollutant Discharge Elimination System
PRS	Potential Release Site
RCRA	Resource Conservation and Recovery Act
UML	Unified Modeling Language

1 Introduction

Historical practices at LANL have resulted in numerous Potential Release Sites (PRSs) that have received some type of contamination. Sampling has been done at many of these sites. This research will focus on 14 different analytes found through sampling to exist at these sites. These analytes were chosen due to their ability to colloid with sediments. The sediment particle colloid is transported in the storm water as suspended sediment. During storm events the suspended sediments will become entrained in the water column and will be sampled at the storm water stations. A watershed approach will be used to determine the PRSs that could have an impact on a storm water station. The purpose of the study is to compare the results of sediment sampling at PRSs against the storm water station sampling results to determine if a relationship can be defined.

Los Alamos National Laboratory (LANL) is located on a unique mesa-top canyon environment. The canyons have an east-to-west orientation and are cut by intermittent or ephemeral streams. The mesa tops range in elevation from 7800 feet close to the mountains to 6200 feet above the Rio Grande Canyon. Most of the canyon streams are ephemeral in nature. Many of these canyons are over 500 feet deep, while the mountains draining into LANL are over 10000 feet in elevation. The total area of the Laboratory is over 40 square miles. Figure 1 shows an overview of the location of LANL and the east to west orientation of the stream channels.

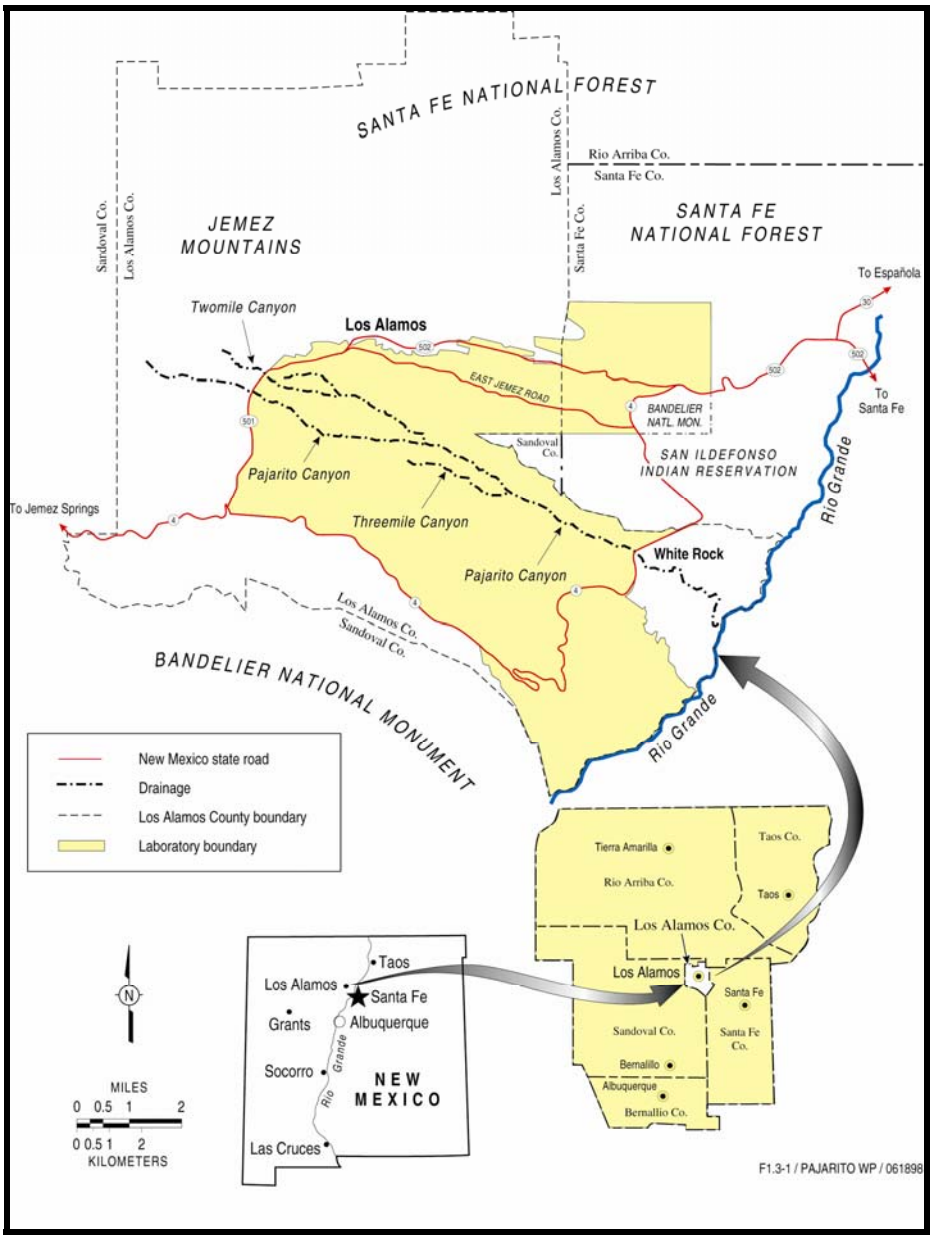


Figure 1 Los Alamos National Laboratory overview map

The Environmental Restoration Project is tasked with characterization and cleanup of the PRSs under the Resource Conservation and Recovery Act. The Environmental Restoration Project has characterized and defined over 2000 of these PRSs. These PRSs are spread out around LANL, both inside and outside the boundary.

Differing types and levels of contamination have been documented by sediment sampling at many of these sites. The PRSs have been scored by erosion potential using a matrix process through site visits. For matrix scoring, each site was visited and slope, run-on, vegetation cover, and evidence of erosion was noted for each site. These observations were given a number for numerical representations which were entered into a database and a report was generated that calculated the erosion potential.

The Water Quality Group at LANL is responsible for the monitoring of storm water from industrial activities under the National Pollutant Discharge Elimination System (NPDES) Multi-Sector General Permit (MSGP). There are over 80 automated storm water stations that measure flow and collect samples during times of high flow due to storm events. It is assumed the storm water will be affected through sediment transport and other chemical and hydrologic processes from the PRSs.

This research was undertaken to determine the PRSs contained in specific storm water monitoring station watersheds. With this knowledge the sediment analyte values for each PRS were correlated to specific storm water station runoff values by watershed. A Geographic Information System (GIS) was used to delineate the watershed for each storm water station. GIS was also used in map creation to visually display the analyte concentrations for the PRSs and the storm water monitoring stations.

The Environmental Systems Research Institute (ESRI) geodatabase format and the Arc Hydro data model were used to create a geometric network. Geometric networks for this model can be defined as an intelligent data type of a stream course with flow direction encoded into the data. This geometric network can be used to track contaminants upstream or downstream of the source due to the flow direction being

captured in the model. This geometric network can be utilized in the future to determine appropriate placement of storm water stations. Presumably, this will mean that storm water stations will be collocated closer to PRSs that have been found, through this research, to have a possible contribution to high storm water runoff values.

2 Research Objectives

The primary research objective is:

To determine if there is a greater impact to storm water station runoff from PRSs with high erosion potential and sediment values over background than from PRSs sites that do not have high erosion potential or high background values.

Two conditions exist that may contribute to elevated analyte values in storm water runoff at monitoring stations. These conditions are:

1. PRSs with high erosion potential have a greater impact on storm water runoff than PRSs with lower erosion potential.
2. PRSs with high erosion potential and sediment values greater than background have the greatest impact on storm water station analyte runoff values.

The term "greater than background" refers to an analyte that has a measured value greater than the calculated background value for that specific area.

Secondary research objectives are:

1. Create a GIS modeling procedure for contaminant analysis.
2. Complete large-scale raster modeling using the ArcGIS personal geodatabase and Arc Hydro data model structure.
3. Create geometric networks for hydrologic analysis.
4. Analyze the relationship between PRSs and storm water stations by watershed.

3 Regulatory Background

The Environmental Protection Agency (EPA) initiated a Federal Facility Compliance Act (FFCA) against LANL in 2004 in relation to compliance with the NPDES MSGP. The compliance act is focused on the possible contribution of PRSs with high erosion potential to storm water runoff. This research hopes to further the investigation of the PRSs as possible contributors of contaminant sources to the storm water stations by reviewing the sediment values. In addition, an individual permit application is being prepared under the NPDES storm water regulations for LANL. This research should allow a better determination of possible source contribution from PRS sites to storm water runoff stations. Once sources have been identified using the methodology developed in the research, an automated storm water station can be installed to sample closer to possible contaminant sources such as a PRS. Also this research could be used to track other possible contaminant sources by watershed for a particular storm water station. If the storm water station samples had values greater than a benchmark value or Department of Energy (DOE) Drinking Water Defined Contribution Guideline (DWDCG), but did not contain PRSs with high erosion or values over background, then other possible sources could be added to the GIS system allowing a relationship to be determined.

The EPA has endorsed using watershed approaches for NPDES storm water program compliance. This study strives to correlate PRS sediment data to storm water analytical data using a watershed approach. In addition, a geometric network was created for the watercourse to locate possible sampling stations on this network. Watersheds could be prioritized through review of analyte levels in PRSs and storm water stations so controls

could be established to eliminate contaminant transport at the PRSs in the prioritized watershed.

4 Research Background

Most of the information related to contaminant transport and watershed analysis is based on modeling approaches. The analytes chosen for this study bind to the sediments thereby impacting storm water through sediment transport during storm events. This will link possible contaminants bound to the sediments that impact storm water by relating the analytical sampling results to each other. This strategy allows source impacts determined from sediment analytical values to be directly linked to analytical values in storm water. The literature on this type of analysis is limited, but the tools required to construct the analysis have been well developed. The current literature contains methods that can be used to further develop this analysis technique. These methods include watershed delineation, geometric networks, sediment data analysis, storm water data analysis, and Light Detection and Ranging (LIDAR) data.

The sediments and storm water were compared against appropriate screening levels. These screening levels included the background values for sediments, the NPDES MSGP benchmark values, and the DOE DWDCG for storm water. Each of these standards is discussed in detail later in the study.

The PRSs were assessed for erosion potential using a documented operating procedure. The surface water site assessment process (Veenis 1998) outlines the steps used to document the erosion potential of the PRSs. The PRS with high erosion potential are a subset all PRSs and are considered as a separate group for all phases of this study.

Osborne (2000) uses a modeling approach to examine non-point source pollution. Her thesis builds on work completed in 1997 by the Center for Research in Water Resources located at The University of Texas at Austin. This model focuses on

calculating the pollutant loadings expected for a watershed. Osborne's technique uses possible pollution source sites termed "Environmental Integrity Sites" to estimate these pollution loads. The research in this paper differs from Osborne's research. The research in this paper uses known analytical sampling values to track and relate the PRSs defined as a non-point source input to a storm water analytical value, while Osborne's paper calculates a possible pollution load based on Environmental Integrity Sites.

4.1 Watershed Delineation

Mason (2000) found that a 90-meter digital elevation model (DEM) did not delineate a watershed accurately. A 30-meter DEM was found to accurately delineate the watershed. Thus, for this research, it is assumed that a four-foot DEM will yield accurate results considering the size of the watersheds that will be delineated. Carey and Cole (2002) described the four-foot DEM that was used to create all Arc Hydro data model GIS layers. Their work presents details regarding the accuracy of the LIDAR data, used to create the DEM, in terms of acquisition and post processing. LIDAR can be described as either Laser-altimetry or light detection and ranging.

Arc Hydro was developed by the Center for Research in Water Resources at the University of Texas at Austin. There are two key components of Arc Hydro: the data model and the tools. The Arc Hydro tools operate on top of the Arc Hydro data model. Both the Arc Hydro tools and data model are used in the research. Maidment's (2002) Arc Hydro book was used as a reference for creation of all layers for the Arc Hydro data model. The Arc Hydro toolset for ArcGIS was used to create these layers including catchments, watersheds, watercourses, and the geometric network. Catchments are a subset or smaller area of a watershed. In other words watersheds contain catchments.

The watershed delineation technique that is most applicable for this application is the sub-watershed utility. The Arc Hydro sub-watershed function allows a watershed to be created for each storm water station. For example, one canyon has three storm water station monitoring stations. For this watershed three sub-watersheds will be created. The second sub-watershed will start where the first sub-watershed ends.

4.2 Geometric Network

ESRI – Canada (2004) outlined the process and functions to perform a network trace over a geodatabase geometric network. The example presented by ESRI – Canada for stream tracing is similar to the usage in this research. Maidment (2002) presented an in-depth coverage of the materials related to this type of application using stream tracing with geometric networks.

Most of the literature on geometric networks is focused on the utilization of the network for upstream or downstream contaminant tracing. This study uses the geometric network in this same manner to track contaminants upstream and downstream from a source. The Arc Hydro data model and the catchments generated can be utilized in association with the geometric network to place sampling sites at the drainage outlet of the catchments. Thus contaminant tracing can be further refined to allow for placement of monitoring sites closer to the source.

4.3 Sediment Data

Background values (BVs) for radionuclides, inorganic and organic analytes in sediments have been calculated for LANL and the surrounding area (Ryti et al. 1998). The BVs were calculated for compliance with the Resource Conservation and Recovery Act (RCRA) Risk-Based Decision Tree, which was developed by the New Mexico

Environment Department (NMED). These background levels are defined as the naturally occurring concentrations of inorganic chemicals in the area upgradient or upwind from a site. This definition fits with the intent of this study, as the PRS sites are upgradient from the storm water monitoring sites. Ryti et al (1998) summarized the data collected from the past five years including the data presented in Longmire (1995). The sampled sediment analyte values were screened against the calculated background values.

4.4 Storm Water Data

DOE order 5400.5 calculates DWDCGs and Defined Contribution Guidelines (DCGs). The DWDCG was used as a screening tool for radionuclides, as there are limited standards developed for radiochemical analytes in water. The DWDCGs are an applicable screening tool for radionuclides, as this study was completed on a DOE facility. This report applies the DWDCGs to storm water radiochemical analytical values. The DWDCG is more conservative than the DCG. Since the DWDCG has a smaller calculated value than the DCG, more values will be returned. This allows a greater chance for a relationship to the analytical storm water values to be determined.

The United States Environmental Protection Agency (EPA) calculated specific analyte benchmark values for the NPDES MSGP. The benchmark values were used as a screening tool storm water runoff for all non-radiochemical analytes from industrial activities. The PRSs located at LANL are considered a treatment, storage, and disposal industrial activity. Thus the benchmark values for applicable analytes are an appropriate screening tool for these PRS sites.

4.5 LIDAR Data

The DEM used for this study was created from LIDAR collected in June of 2000. This LIDAR DEM was compared to photogrammetry derived DEMs (Carey 2002). The photogrammetry derived DEM data was collected in 1992. Both four-foot and one-foot DEMs were created for the 1992 photogrammetry data set and the 2000 LIDAR data set. This allowed a comparison based on equal pixel size. It was determined that there were errors introduced during processing of the LIDAR data. Ninety-six percent of the four-foot DEM elevations were within five feet of the surveyed elevations. On the other hand, 74% of the one-foot DEM elevations were within one foot of the surveyed elevations. The one foot DEM from the 2000 LIDAR was found to contain more errors than the four-foot LIDAR DEM; however, the 2000 LIDAR DEM derived data was found to be consistently more accurate than the 1992 photogrammetry DEM derived data.

5 Description of Data Sources

5.1 PRSs Data

PRSs have historically received a contaminant of some type. Many of these sites have been sampled. Sites that have been sampled and contain elevated contaminant concentrations are utilized in this study. There are a total of 2254 PRSs. These PRS sites were visited and the erosion potential of the sites documented using a systematic process (Veenis 1998). There are 324 PRSs with high erosion potential. Of the total 2254 PRSs, 45% or 1024 sites have been sampled. Of the 324 high erosion PRSs, 72% or 234 have been sampled. The PRS sediment data were screened by the environmental restoration projects background values (Ryti 1998).

5.2 Storm Water Stations Data

Storm water stations have been placed in many of the main watercourses and tributaries. The watercourses are generally ephemeral in nature and only flow during the summer rainy season. There are 86 storm water stations operated by LANL. Many of these storm water stations are used for background measurements and will not be used in this study. Fifty-four storm water stations were used in this study. These stations are listed in Table 2.

NPDES MSGP storm water benchmark values were used to screen storm water station data for all non-radiochemical analytes. The storm water station drainage areas are considerably larger than the PRSs areas. The sediment concentration is diluted in the storm water. The contaminants at the PRSs are transported in the storm water and redeposited in the stream channel system as packets. These packets then take up residency in the channel, banks, or floodplains. The contaminants stay deposited in this

area until they are re-suspended in the water column due to a large storm event that causes a large volume of runoff. Thus the sample measurements that could be attributed to the PRSs at the storm water stations are highly variable due to the complicated nature of the channel dynamics.

5.3 Analytical Data

The 14 analytes used in this study were screened for both sediments and storm water. Only the sampled values greater than the screening levels listed in Table 1 were retained in the dataset. The storm water data is current through July of 2004. The sediment data is current through March of 2003. Table 1 lists the analytes and screening levels.

Table 1 Analytes evaluated

# of Analytes	Analyte	Benchmark value (ug/L)	DOE DWDCG (pCi/L)	Sediment Background
1	Aluminum (Al)	750		29200 (mg/kg)
2	Americium 241 (AM-241)		1	0.013 (pCi/g)
3	Cadmium (Cd)	15.9		0.4 (mg/kg)
4	Copper (Cu)	63.6		14.7 (mg/kg)
5	Iron (Fe)	1		21500 (mg/kg)
6	Magnesium (Mg)	63.6		4610 (mg/kg)
7	Lead (Pb)	81.6		22.3 (mg/kg)
8	Plutonium 238 (Pu-238)		2	0.023 (pCi/g)
9	Plutonium 239 (Pu-239)		1	0.054 (pCi/g)
10	Strontium (Sr-90)		40	1.31 (pCi/g)
11	Uranium 234 (U-234)		20	2.59 (pCi/g)
12	Uranium 235 (U-235)		24	0.20 (pCi/g)
13	Uranium 238 (U-238)		24	2.29 (pCi/g)
14	Zinc (Zn)	117		48.8 (mg/kg)
Analytes not used in the analysis				
15	Selenium			
There were values over the background for sediments but no values over the benchmark values for storm water.				
16	Mercury			
There were values over the background for sediments but only 3 values over the benchmark values for storm water. This is not a large enough sample size for use in this study.				
17	Silver			
There were values over the background for sediments but only 7 values over the benchmark values for storm water. This is not a large enough sample size for use in this study.				
18	Arsenic			
There were values over the background for sediments but only 9 values over the benchmark values for storm water. This is not a large enough sample size for use in this study.				
19	Cyanide			
There were values over the background for sediments but only 6 values over the benchmark values for storm water. This is not a large enough sample size for use in this study.				

5.4 LIDAR Data

The four-foot DEM derived from LIDAR (Carey 2002) flown in June of 2000 was used for all Arc Hydro data modeling. The one-foot DEM created from a separate flyover in July of 2000 contained more errors and would have considerably extended processing time. The four-foot DEM data set extends for 320 square miles, which adequately covers the area for this study. A study area was defined that covered the storm water stations used for all data modeling. A LIDAR tile mosaic was created for

use as one continuous grid for the study area. The study area for the watershed modeling covers a larger area than the catchment modeling study area. A larger area was needed for the watershed modeling to cover all the storm water stations used for the study.

6 Hydrologic Data Modeling

6.1 Arc Hydro Overview

The Arc Hydro data model and functions were built by The University of Texas at Austin Center for Research in Water Resources. For complete functionality of all the Arc Hydro tools, ArcInfo and the Spatial Analyst extension are required. Arc Hydro contains four major areas of functionality (Maidment 2002).

1. Terrain Processing
   These tools allow streams and catchments to be created from a base DEM. These layers become the inputs for the geometric network.
2. Watershed Processing
   This allows watersheds and sub-watersheds to be delineated along with flow path information.
3. Network Tools
   These tools allow creation of the geometric network and storage of flow directions.
4. Attribute Tools
   Utilizing these tools allows a geometric hydro network to be built from existing layers including streams, watersheds, and monitoring points.

All data layers were completed using the four-foot LIDAR DEM. The processing steps for Arc Hydro to complete each dataset are listed below in the order they are implemented (Maidment 2002).

1. Acquire base DEM
2. Fill sinks in DEM
3. Create flow direction grid
4. Create stream definition grid
5. Create stream segmentation grid
6. Delineate catchment grid
7. Create catchment polygon in geodatabase
8. Create drainage line in geodatabase
9. Create adjoint catchment in geodatabase
10. Create drainage point in geodatabase
11. Create hydro network in geodatabase
12. Create node/link schema
13. Store flow direction in geodatabase
14. Set flow direction in geodatabase

Two separate datasets were completed that comply with the Arc Hydro data model. The first followed the sequence of functions 1-14 listed above. This creates all relationships for the Arc Hydro data model as each layer is created. Completing the Arc Hydro model in this manner satisfies all requirement of the Arc Hydro data model. The second Arc Hydro data model was built by importing the layers that make up the data model. This generally includes streams, catchments, watersheds, basins, water bodies, monitoring points, and junctions. Junctions refer to the meeting of two stream segments (Maidment 2002).

These datasets were imported to the geodatabase structure and named according the Arc Hydro data model. The Arc Hydro Universal Modeling Language (UML) schema was applied to the created geodatabase using the Microsoft repository. Applying the Arc Hydro data model to the geodatabase creates all relationships and data sets that are not already present in the geodatabase. This brings the database into compliance with the Arc Hydro data model. When applying the Arc Hydro UML schema, an unused feature class of water body was created. There is one water body that could have been included in the model. This water body, Los Alamos Reservoir, was not considered large enough to include. This data set was deleted from the created Arc Hydro data model geodatabase.

As documented on the ESRI website (ESRI Forums 2003), the Arc Hydro program does not support grids containing over 10000 * 10000 cells. The 37-tile four-foot LIDAR mosaic was 16001 * 18001 cells; therefore, the study area was too large for the terrain processing functions. It was found that the catchments function, which converts the cell-based grids to geodatabase polygon layers, would not populate the HydroID field.

Without the HydroID field being populated, the relationships between the other layers cannot be defined.

Shown below are the model runs used to create the final two Arc Hydro data models.

Arc Hydro function from base LIDAR DEM

1. Four-foot cell size with 37 four-foot LIDAR grid mosaic.
2. Twelve-foot cell size with 53 four-foot LIDAR grid mosaic resample
3. Four-foot cell size with 53 four-foot LIDAR grid mosaic clipped to LANL boundary
4. Eight-foot cell size with 53 four-foot LIDAR grid mosaic resample

Arc Hydro functions with UML model applied

5. Mosaic of 59 four-foot LIDAR grids

6.2 Arc Hydro Large Scale Modeling

All layers were developed using the Arc Hydro toolset. The limitations of the model were explored when utilizing the Arc Hydro toolset to create an Arc Hydro geodatabase. Many different model iterations were explored to generate an Arc Hydro data model with as much detail as possible. The final results of the model were generated after trying different grid cell sizes and varying the stream definition layer. The stream definition layer controls the detail of the model layers created in subsequent steps.

6.2.1 Four-foot cell size large scale model

The modeling was run using the four-foot LIDAR tiles from the 2000 flyover. Each tile contained 2001 X 3001 cells. Originally 37 four-foot tiles were used to create a mosaic. This resulted in a grid size of over 1GB with 18001 X 16001 grid elements. As presented earlier, Arc Hydro is only able to accomplish terrain processing with the number of grid elements below 10000 by 10000. With this knowledge the limitations of the model were tested in regards to grid size.

This analysis was run utilizing server hard drive space over a network. The network is a 100 mega bits per second line. The server is a Dell Poweredge 4400 with four 1.5 GHz processors, two gigabytes of RAM, and storage for up to 680 gigabytes. When running Arc Hydro Tools utilizing the server, jobs would routinely take over 48 hours. The FILL function in Arc Hydro Tools runs consecutive fills of a grid until all sinks are filled. While running the FILL function on the server using Arc Hydro, grids would appear in consecutive order. The last grid that appeared was labeled 29. This meant that this was the 29th pass that the FILL function had completed. It took approximately three days for FILL to complete the 29th grid. The program automatically terminated after the 29th grid pass was finished, before completing the fill successfully. The 29th grid was shown in the folder with the original grid and FILL was started again using this grid. Using the 29th grid FILL finished running in approximately one day. Flow direction and flow accumulation took another three days to finish. Stream definition, stream segmentation, and the catchment grid were all delineated successfully without undue processing time. Creating the catchment polygons in the geodatabase from the catchment grid was still processing after running for a week. The file size of the geodatabase layer was only increasing by 10 megabytes per day. With a projected final file size of 500 megabytes it was deemed that the processing would not be finished in an acceptable amount of time and the process was halted.

Breaking the original 37-tile four-foot grid mosaic into two grids sized below the 10000 X 10000 size limit was considered. This would mean merging the two geodatabases after the modeling process. Keeping the relationships between the data sets could pose a problem during the merge process. It was beneficial to have a single

geodatabase for the contaminant migration analysis utilizing the geometric network capabilities. If the geometric network inputs would not merge correctly, the ability to do upstream or downstream migration tracing would not be possible. Therefore, the better option was to resample the four-foot grid dataset with a larger cell size to obtain a grid below the threshold, instead of breaking the grids into two separate areas.

These model runs were very slow running on the server through the network. An alternative that was explored was to run the analysis on a stand-alone workstation. A Dell Precision Workstation 340 was selected to run the analysis. This computer has a 36 gigabyte SCSI hard drive with a 2.4 GHz processor and 1gigabyte of RAM. All subsequent jobs with Arc Hydro functions were run from the hard drive of this machine.

6.2.2 12-foot cell size large scale model

The study was reevaluated and the limitations of Arc Hydro were taken into account. It was determined that a large contiguous area was preferred to create one unbroken geodatabase. To accomplish this, a mosaic was created from 53 four-foot LIDAR tiles to produce a seamless grid that was over 2GB in size. This data set was then resampled using the nearest neighbor method to produce a new dataset that could be utilized by Arc Hydro. This twelve-foot cell size data set was 7334 by 8000 cells and 235MB in size.

A quick cursory analysis found that the stream network created with the 12-foot grid and 500-cell stream resolution was moved in relation to a stream network created with the original four-foot DEM of the same area and same stream cell resolution. The stream network was only slightly offset in comparison to the four-foot stream network. This offset is an adverse but expected result when the grid is resampled.

6.2.2.1 10000-cell stream definition

A coarse 10000-cell stream definition was chosen to limit the number of catchments and stream segments. The other model runs had not been able to complete the conversion from the raster grid model to the geodatabase polygon model. The limitation of the model was centered on population of the HydroIDs in the geodatabase. With too many catchments the HydroIDs would not populate correctly. The HydroID is the primary key that the Arc Hydro data model uses to promote relationships to other layers. With the cell count being below the limit of 10000 X 10000 and a coarse stream definition the model ran to completion.

Using a 10000-cell stream definition corresponds to a stream being generated from a 33-acre drainage area. This led to 1384 catchments, hydrojunctions, drainagepoints, and drainageline objects being generated for each layer. All geodatabase layers were populated quickly and the geometric network was created successfully. This model run was successful, but the large area of the delineated catchments that were created does not allow for pollution sources to be tracked at a detailed level.

6.2.2.2 3025-cell stream definition

Creating the stream layer using 10000 cells generated a coarse stream layer and catchments. With the success of a 10000-cell stream definition model run a stream network of 3025 cells was chosen to create the stream network. This means a stream network is created from a drainage area of 10 acres. Using this stream definition there were 4870 objects created for the drainageline and catchment layers for the study area.

This model run was successful until the geometric network was created. An error was generated stating that the “File sharing lock count was exceeded. Increase

MaxLocksPerFile registry entry." This error was researched on the ESRI website and an article on how to correct the error was found (ESRI Support Center 2004). The file lock area size was increased from 9500 records to 20000.

The geometric network could not be created from the existing geodatabase files. When trying to recreate the geometric network after changing the file lock size, an error was generated stating that the DrainID for the geometric network layer did not match the already created layers. When running the "Hydro Network Generation" function in Network Tools to create the geometric network, extra fields are generated and populated in Catchments, AdjointCatchment, and DrainagePoint. The generation of these new fields could have been the cause of the error generated. These new fields created might not correlate with the already created fields. To fix this error, the Arc Hydro geodatabase was deleted. A new Arc Hydro geodatabase was created starting with the "catchment polygon processing" function in the terrain processing menu. This function transfers the created grid catchments to a geodatabase polygon class. With the use of the new geodatabase and the increase in the file lock area size, the model ran to successful completion. All geodatabase feature classes were successfully generated including the geometric network.

With all the limitations that were found when running the model from a base DEM utilizing Arc Hydro, this model run was the most useful. Although the stream network was offset from the original four-foot DEM, no other way was found to model an area this large using the Arc Hydro functions. The stream network and catchments based on 10 acres is a relatively fine drainage area model as illustrated by Figure 1.

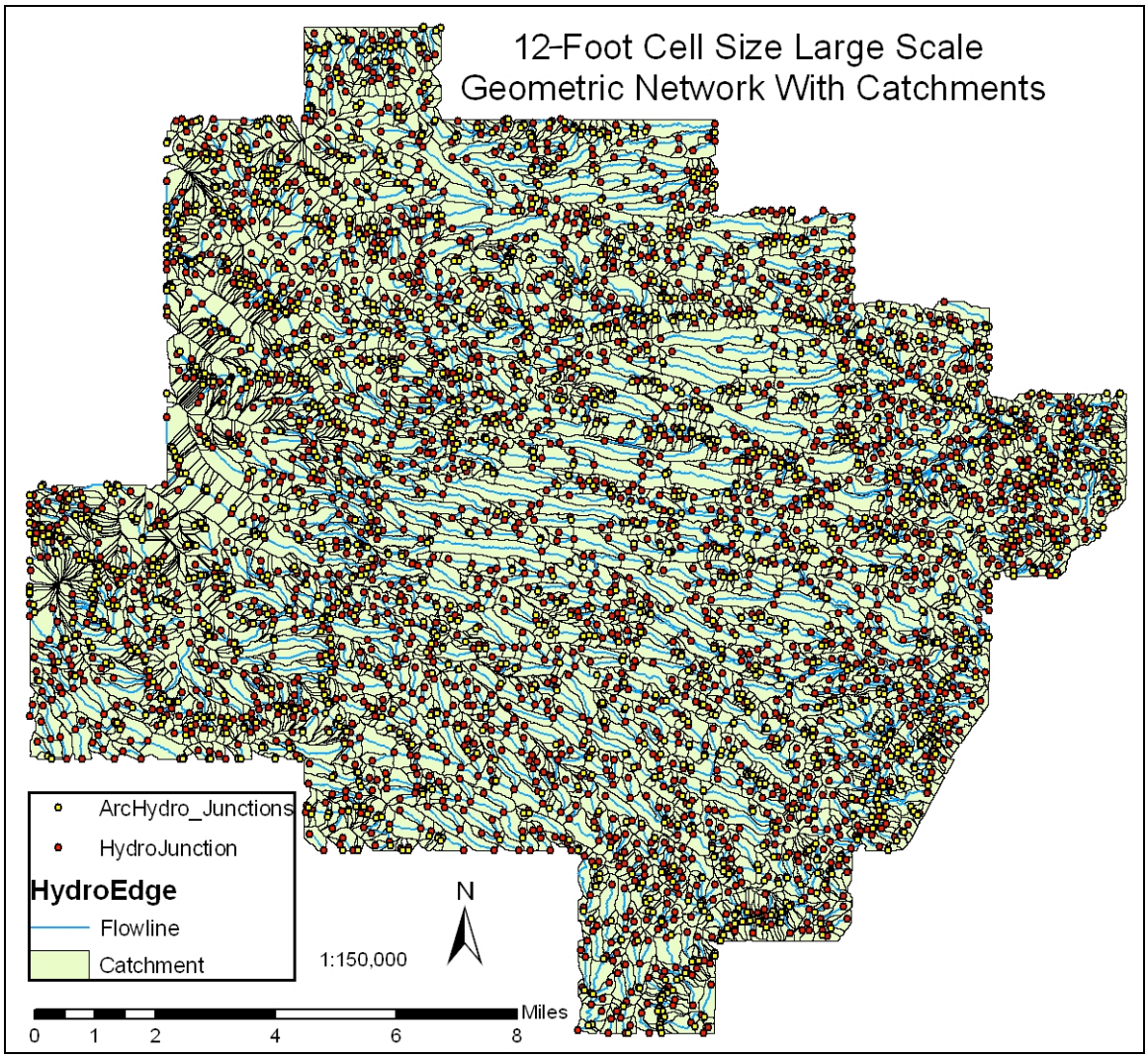


Figure 2 Arc Hydro 12-foot cell size model

6.2.3 Four-foot cell size clipped LANL boundary large scale model

The 53-tile four-foot mosaic was clipped to the LANL boundary. This grid at 11759 X 12256 cells was over the threshold limit for a successful model run. In addition, upon examination of the PRSs that were outside the boundary, it was determined that too many of the PRSs were outside the LANL boundary. Listed below are the PRSs that are outside the main LANL boundary, or straddle the LANL boundary and are both inside and outside the boundary.

PRSs outside LANL boundary

- 216 PRSs are outside the LANL boundary
- 19 PRSs with high erosion are outside the LANL boundary

PRSs straddling the LANL boundary

- 35 PRSs straddle the LANL boundary and are both inside and outside
- 9 PRSs with high erosion straddle the LANL boundary and are both inside and outside

6.2.4 8-foot cell size large scale model

The grid size for this model exceeded the threshold that Arc Hydro support stated could be used to generate all layers in the Arc Hydro data model. The grid is 11001 by 12001, which is just slightly larger than the 10000 by 10000 limit, and is 518 megabytes. Varying the size of the stream definition is one way to test the limits of the model. As the stream definition is increased the number of stream segments, junctions, and catchments also increase. The model limitation was tested by starting with a stream being defined by an area of one acre. When this did not allow the geodatabase to be populated, the stream definition area was increased, first to two acres and then to five acres.

The model was run with the stream definition at 680 cells or one acre defining a stream. With the stream definition this fine, there was a "runtime C++ error" when defining the catchments. Catchments are the first layer populated when converting from a raster grid to a geodatabase vector model. The geodatabase polygon catchments were built but the HydroID field did not populate correctly. The HydroID serves as the primary key to allow relations to be built between the tables. Without the HydroID field being populated, the relationships between the layers cannot be built.

The model was run again with 1360 cells or two acres defining the streams. This had the same results that were obtained with the one-acre stream definitions. The catchment geodatabase polygon layer did not have the HydroID field populated.

The model was then run with 5440 cells or eight acres defining the stream network. With this model run the catchments were delineated correctly with the HydroID field being correctly populated; however, the model did not correctly create the hydro network. The geometric network datasets were created but the GridID, HydroID, and DrainID fields were not populated.

A solution that allows the model to run correctly to completion was investigated. A new version of Arc Hydro was found on the Arc Hydro website (University of Texas at Austin Center for Research in Water Resources, 2004). The model that was being used was Arc Hydro Tools v1.1 beta 2, which was delivered with the Arc Hydro book. The newer version found on the website was Arc Hydro Tools v1.1 beta 8. The newer model had an optional requirement to download an install **msxml** parser 4.0 to replace **msxml** parser 3.0 used for the beta 2 version. Both of these software upgrades were accomplished and the program seemed more stable. Screens would not white out while running processes and extra functionality was evident, such as cleaning streams when building the DrainageLine layer. The layer that was not populating correctly with previous model runs was the Arc Hydro geometric network layer. The Arc Hydro program to this point had only been loading the grids into RAM and had not been utilizing the paging file. Using the new beta 8 version and running the catchment grid to polygon conversion function caused the computer to slow considerably and load the paging file with up to 600 Megabytes of data. The Arc Hydro Tools v1.1 beta 8 version

started building this layer without the screen going blank and proceeded all the way until the layer was 96% finished. At this point a "Microsoft Visual C++ Library Runtime Error" abnormal program termination occurred, and ArcGIS was closed without the layer finishing being populated. At this point the model run using the eight-foot grid cell size was abandoned.

6.2.5 Large scale geometric network model conclusions

The four-foot and eight-foot cell size models were over 10000 by 10000 cells and Arc Hydro would not create the geometric networks for these large grid sizes. Many different scenarios, including an updated Arc Hydro program was utilized to complete the modeling. The 12-foot grid size was under the cell threshold and the geometric network was created successfully. Therefore the large-scale modeling using Arc Hydro for all functions was only able to be completed using the 12-foot cell model.

The eight-foot cell size was close to the maximum number of cells but the geodatabase polygon would not populate correctly. With the success of the 10000-cell 12-foot cell size model run, the model parameters were tested for the eight-foot cell size model. The initial catchments that were created from the 10000-cell 12-foot model run were not detailed enough for a useful fine scale analysis. The 3025-cell 12-foot model run was successful after changes to the file sharing lock account size for the geodatabase functions. This 12-foot cell size model using 3025-cells for stream definition ran to successful completion and has the most utility of the two successful model runs.

6.3 Monitoring Station Watershed Geometric Network Modeling

The previous model created small catchments for each stream junction. The Arc Hydro data model completed during this stage of modeling used sub-watersheds created

from the storm water station monitoring points snapped to the drainage line instead of catchments. A relationship was then defined between the storm water monitoring stations and the stream junctions according to the Arc Hydro data model requirements. The sub-watersheds generally have a much larger drainage area than the catchments.

Originally the 53 tile four-foot mosaic based on LIDAR data used in the large-scale Arc Hydro modeling was going to be utilized. However, errors were found in the four-foot LIDAR mosaic with respect to elevation. The resampled 12-foot LIDAR-based mosaic did not contain these elevation errors. Two different variations were run in order to correct the grid errors. Arc Hydro and ArcInfo workstation were both used for error corrections of the 53 four-foot LIDAR tile mosaic.

These errors were not fully corrected using the different variations. In addition it was found that a storm water station was added to the project that was outside of the original 53 LIDAR tile four-foot mosaic. It was expected that recreating the mosaic would remove the errors found in the grid. There were six more grids added to the mosaic for a total of 59 four-foot LIDAR tiles being combined. This 59 four-foot LIDAR tile mosaic was used to complete the watershed modeling using ArcInfo Workstation, Arc Hydro, and ArcCatalog.

Steps in watershed modeling in ArcInfo Workstation

1. Fill mosaic LIDAR grid
2. Create flow direction grid
3. Create flow accumulation grid
4. Create stream network
5. Export stream network to geodatabase feature class

Steps in watershed modeling in Arc Hydro

1. Fill sinks in conditioned DEM
2. Create flow direction grid
3. Create flow accumulation grid
4. Create stream network

5. Export stream network to feature class
6. Snap storm water station monitoring points to stream feature class
7. Create storm water stations sub-watersheds using a snapped feature class

The stream network, sub-watersheds, monitoring points and snapped monitoring points were loaded into an Arc Hydro geodatabase shell. The names of the layers were changed to correspond to the names required in the Arc Hydro geodatabase model. With the limitations of the terrain processing tools and the stream network creation issues in Arc Hydro, the final geometric network was created using ArcCatalog. Once all the layers were created and named according to the Arc Hydro geodatabase model the Arc Hydro UML schema was applied to the geodatabase. This created the relationships between the layers and ensured the network conformed to the Arc Hydro data model. All unused layers were deleted from the Arc Hydro database after the schema was applied. Obenour (2003) outlined the procedures used in this study to create an Arc Hydro dataset.

There are 86 storm water-monitoring stations at LANL. A subset of the storm water stations were used for modeling purposes. Stations not included were:

1. Stations above the LANL boundary that do not have PRS sites above them.
2. Storm water stations termed conventional stations that monitor other industrial activities such as Primary Metal Facilities regulated under the NPDES MSGP. (These stations monitor very small areas and the watershed delineation should be conducted on a smaller scale using the 1-foot LIDAR.)
3. Stations used in a pinon-juniper tree thinning study related to the Cerro Grande tree thinning project.

4. Stations at the TA-54 low-level radioactive waste storage area (This should be studied at a smaller scale with the one-foot LIDAR.)

The limitations found in Arc Hydro were the result of the conversion from raster grid modeling to a geodatabase polygon format and creating the geometric network. This part of the study bypassed the geometric network limitations by using ArcCatalog geometric network functions instead of the Arc Hydro geometric network functions. The geodatabase structure in Microsoft Access was utilized with a limited Arc Hydro data structure. The stream network was kept fairly coarse to keep the number of stream links to a minimum. This ensured the geometric network in the Microsoft Access geodatabase had a fairly small number of elements. One of the limitations found was the population of the fields associated with the geometric network. Also the overhead with a very large detailed stream network might slow the network tracing to a point it would not be useful.

The storm water stations eliminated from the network would have needed a very detailed stream network for the stations to be represented on the network. Figure 3 illustrates the difference in the stream networks created from two acres and 100 acres. The storm water stations that were eliminated would generally need the detail represented by the two-acre stream network. The 100-acre stream network has 1629 stream segments, while the two-acre stream network contains 90335 stream segments.

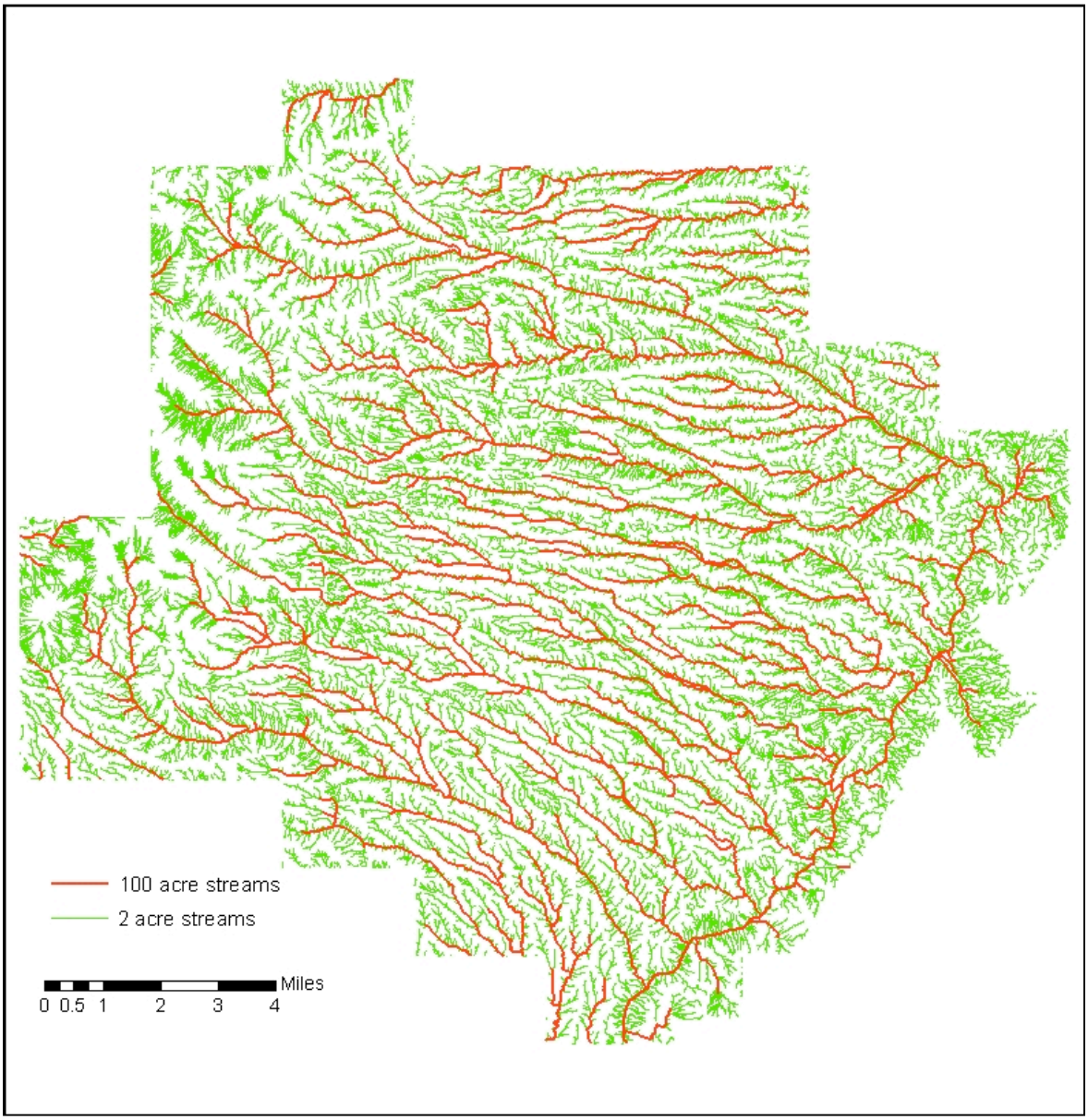


Figure 3 Stream network comparison

6.3.1 ArcInfo Workstation 53 four-foot mosaic

With the large grids used in this study it was found that ArcInfo workstation would run the raster grid functions faster than Arc Hydro for ArcGIS. Therefore ArcInfo workstation was used for many of the raster grid modeling functions during the next phase of the modeling. This phase of modeling started with the 53 tile four-foot mosaic until it was discovered that additional area was required to include all of the storm water

stations. As mentioned earlier, an error was found when reviewing the grid for minimum and maximum elevation values. The grid error was not found until this section of the modeling, but was elaborated on earlier. During this section, ArcInfo workstation was used to fill the grids before the grid error was found. When running FILL it was assumed that the cells with the incorrect elevation values would be filled to the correct elevation so no sinks would exist in the grid. However, the output of the FILL function still contained cells that were less than 2000 feet. The minimum elevation for the grids should be over 5000 feet. The eight-foot and 12-foot grids that were resampled for the earlier model runs from this four-foot grid had the correct elevations. In an effort to correct the elevation values a CON function was used that replaced all cells below 2000 feet with a 5000-foot cell value. This CON function appeared to be an acceptable way to fix the elevation error in this grid.

The FILL function was run in ArcInfo before the CON function was applied to determine if the elevation errors would be corrected. FILL in ArcInfo workstation took six passes to complete for the 54-tile mosaic. The numbers of sinks filled in each pass are listed below.

1. 275182 # of sinks
2. 19973 # of sinks
3. 1269 # of sinks
4. 90 # of sinks
5. 7# of sinks
6. –1 # of sinks

The cells that were below 2000 feet were filled to a small extent but still did not extend over 2000 feet. It was found that two of the 59 grids had elevation values below 5000 feet. Since these elevations were not filled, these errors should not affect the model.

Running another CON function, all cells below 5000 were denoted with a one, and all other cells labeled as a zero or no data. This showed that 968 cells were below the 5000-foot mark. The results of the CON function are shown below.

CON function of 53 tile four-foot mosaic

- 313,650,610 cells over 5000
- 968 cells under 5000

This model run was abandoned after it was found that the 53-tile four-foot grid mosaic needed to be larger to include all of the storm water stations. This part of the modeling did return some good information about the grid errors that were introduced into the 53 tile four-foot LIDAR mosaic. It illuminated that the grid was acceptable for use in watershed modeling, that the grid errors were not sinks, and that the grid errors should not have an effect on the model.

6.3.2 Arc Hydro 53 four-foot mosaic

The FILL function in ArcInfo workstation did not correct the grid elevation errors. The FILL function in Arc Hydro was used after the CON function had been applied to determine if it would correct the grid elevation errors. The same steps were followed that were applied to the Arc Info workstation model run; only Arc Hydro was utilized. With the CON function applied to bring the cells up from below 2000 feet to 5000 feet the FILL function did not fill the cells any higher. All cells remained at 5000 feet after FILL was run.

It was assumed that Arc Hydro might correctly fill the elevation grid errors. The FILL function in Arc Hydro did not fill the grid to the correct elevation. With this failure of Arc Hydro to fill the 53-tile four-foot grid mosaic, it was determined that extra tiles would be added for a total of 59 four-foot grid tiles. The area of this mosaic would cover

all the storm water stations. The grid errors could have been introduced during creation of the mosaic. Adding the extra tiles and recreating the mosaic might correct these errors.

6.3.3 Arc Hydro and ArcInfo Workstation 59 four-foot mosaic

The 53 four-foot tile mosaic contained grid errors. A new mosaic was created using 59 four-foot tiles. This 59-tile mosaic covered all the storm water stations used in the study. The issues that arose while creating this new 59 four-foot tile mosaic and the differences from the 53 four-foot tile mosaic are explored in detail below.

ArcInfo workstation limits the number of tiles it will mosaic at one time to 50 tiles. For the first error free run, 37 tiles were used to create the mosaic. However, when the additional 16 tiles were added to the 37 tiles mosaic to yield the 53-grid mosaic, errors were generated. The original 37 four-foot tile mosaic was error free. The error free 37-tile mosaic had 22 grids added to create the 59 four-foot tile mosaic. This yielded a grid size of 2069 megabytes. This 59 four-foot tile mosaic was listed as having 24001 X 22001 cells.

The 59-mosaic grid listed the same physical size as the 53-mosaic grid, 2069 megabytes. When the grid was described in ArcInfo Workstation or the properties were checked in ArcCatalog, the 53-mosaic and 59-mosaic contained the same number of grid cells, 24001 X 22001. Upon visual examination of the two mosaics, the 59-tile mosaic appears to contain the extra tiles, when compared to the 53-tile mosaic.

A CON function was run to determine the number of cells in the grid and the number of cells above and below 2000 feet. The number of cells over 2000 is also greater than the 53 four-foot tile mosaic. 313651578 (53 mosaic grid count) –

333267904(59 mosaic grid count) = 19616326 (amount of cells greater for the 59 mosaic grid count). ESRI (2004) states the hard-coded 2 gigabyte file size limit for the ESRI GRID format has been removed in ArcGIS 9. This study was completed using ArcGIS 8. The 59 four-foot tile mosaic used for the study must have been on the fringe of the size limit. The cells don't list as being counted but the function still works on the entire grid.

CON Function of 59 four-foot tile mosaic

- 333266936 cells over 2000
- 968 cells under 2000

The number of cells under 2000, 968, is the same for the 53 and 59 tile mosaics.

FILL in ArcInfo workstation ran in six passes for the 59-tile mosaic. The numbers of sinks filled in each pass are listed below. The number of sinks filled was much greater for the 59-mosaic than the 53-mosaic.

1. 328987 # of sinks
2. 24308 # of sinks
3. 1508 # of sinks
4. 104 # of sinks
5. 8# of sinks
6. –1 # of sinks

The stream network used for this model run was based on 50 acres for stream definition. This allowed all the stations that had watersheds delineated to be placed on the stream network. Table 2 lists all the storm water stations used for the model. With a stream network that is finer in detail, such as 10 acres, it is probable that the geometric network would not be created.

Table 2 Storm water stations evaluated

# Stations	NAME	SYNONYM	LATITUDE	LONGITUDE
1	Los Alamos below Ice Rink	E026	35.880156431	-106.325073136
2	Los Alamos above DP Canyon	E030	35.872591708	-106.260048578
3	DP above TA-21	E038	35.880191617	-106.282815694
4	DP below Meadow at TA-21	E039	35.878046081	-106.274351747
5	DP above Los Alamos Canyon	E040	35.873320053	-106.259633825
6	Los Alamos above SR-4	E042	35.867077108	-106.223885564
7	Los Alamos Canyon Weir above SR-4	E049	35.867158772	-106.218449758
8	Los Alamos below LA Weir	E050	35.867158500	-106.217430444
9	Pueblo above Acid	E055	35.889027753	-106.304044789
10	Acid above Pueblo	E056	35.888832736	-106.303952489
11	Pueblo above SR-502	E060	35.870872697	-106.216870303
12	Bayo below TA-10	E070	35.886928019	-106.242821883
13	Guaje above Rendija	E089	35.915120114	-106.229766794
14	Rendija above Guaje	E090	35.911303597	-106.226763511
15	Guaje at SR-502	E099	35.884924756	-106.163660258
16	Los Alamos Canyon near Otowi Bridge	E110	35.883048358	-106.150180058
17	Sandia below Wetlands	E123	35.873060186	-106.309869442
18	Sandia above Firing Range	E124	35.864468125	-106.261070544
19	Sandia above SR-4	E125	35.859072494	-106.226194239
20	Mortandad below Effluent Canyon	E200	35.865395781	-106.296138008
21	Mortandad above Ten Site	E201	35.862972094	-106.274787489
22	Ten Site above Mortandad	E201.5	35.860463775	-106.274931156
23	Mortandad above Sediment Traps	E202	35.860864292	-106.270813847
24	Mortandad below Sediment Traps	E203	35.860886667	-106.268383217
25	Mortandad at LANL Boundary	E204	35.855838983	-106.245285725
26	Canada del Buey near TA-46	E218	35.855686758	-106.278634094
27	Canada del Buey near MDA G	E225	35.833670550	-106.239426419
28	Canada del Buey above SR-4	E230	35.827329697	-106.212014003
29	Pajarito below SR-501	E240	35.867955144	-106.352557042
30	Pajarito above Starmers	E241	35.859342375	-106.336844661
31	Starmers above Pajarito	E242	35.859103306	-106.336919322
32	La Delfe above Pajarito	E242.5	35.856892833	-106.332220233
33	Pajarito above Twomile	E243	35.853856922	-106.296600397
34	Twomile above Pajarito	E244	35.854193069	-106.296208122
35	Pajarito above TA-18	E245	35.851178492	-106.286504250
36	Pajarito above Threemile	E245.5	35.845929183	-106.274730219
37	Threemile above Pajarito	E246	35.839138467	-106.271399300
38	Pajarito above SR-4	E250	35.824083044	-106.227944683
39	Water above SR-501	E252	35.838351475	-106.361869936
40	Canon de Valle above SR-501	E253	35.851776417	-106.354621342
41	Canon de Valle below MDA P	E256	35.850244506	-106.332393567
42	Water above S Site Canyon	E260	35.830795417	-106.307423817
43	S Site Canyon above Water	E261	35.830961536	-106.307618597
44	Water below MDA AB	E262.5	35.825137094	-106.284211544
45	Water at SR-4	E263	35.805556258	-106.247735858
46	Indio at SR-4	E264	35.805037833	-106.247563872
47	Water below SR-4	E265	35.804900783	-106.242106375
48	Potrillo at Lower Slobbovia	E266	35.829714792	-106.259304683
49	Potrillo above SR-4	E267	35.813350125	-106.233384483
50	Fence below Meenie	E267.5	35.820095256	-106. 256048069
51	Ancho above north fork Ancho	E273	35.786182889	-106.251698256
52	Ancho below SR-4	E275	35.781748864	-106.244938783
53	Ancho Canyon spring tributary below SR-4	E300	35.796075883	-106.248174853
54	Chaquehui at TA-33	E338	35.769738939	-106.252101425
55	Chaquehui tributary at TA-33	E340	35.779613186	-106.250366369
56	Rio de los Frijoles at Bandelier	E350	35.776961819	-106.269345292

When using the geodatabase stream layer created from the ArcInfo workstation stream grid, the geometric network did not build correctly. The geometric network when built contained loops that did not allow the flow to be routed downstream. To rectify this loop issue, an Arc Hydro generated stream link grid and the flow direction grid were used to create the geodatabase stream layer. This allowed the geometric network to be built correctly. ArcInfo does contain a stream link grid process. If ArcInfo is used to build the stream network, the stream link function should be used to allow network connectivity in the final geometric network.

To allow upstream and downstream tracing, the final nodes on the stream network must be labeled as sinks. The geometric network is built from the HydroEdge and HydroJunction feature classes. During the geometric network build process, a HydroNetwork Junctions feature class was created. The HydroNetwork Junctions feature class stores point features for all stream junctions.

Before creating the geometric network, the HydroEdge feature class was clipped to the watershed layer. The last stream point feature on the network should be the HydroJunction that corresponds to the watershed outlet. Most of the HydroJunction point features were within a few feet of the HydroEdge feature class end. When the geometric network was created without the HydroJunctions at the end of each line, a HydroNetwork Junctions point feature was placed there. The HydroNetwork Junctions feature class does not have the functionality of sinks; therefore the network would not allow upstream tracing from the end of the geometric network. Once the HydroJunction feature class points were moved to the end of the HydroEdge feature class, upstream tracing was enabled.

Once the Arc Hydro geodatabase model was complete with flow direction initialized, the ArcHydro UML schema was applied. The schema was applied through ArcCatalog using the schema wizard. Using the Arc Hydro framework schema, the relationships, domains, and extra feature classes were configured to comply with the Arc Hydro data model geodatabase structure. The extra fields added through application of the Arc Hydro UML schema were either populated, such as length downstream for junctions, or deleted, such as DrainID. This application of the Arc Hydro framework schema made the geodatabase fully compliant with the Arc Hydro data model. The results of the model can be seen in Figure 4.

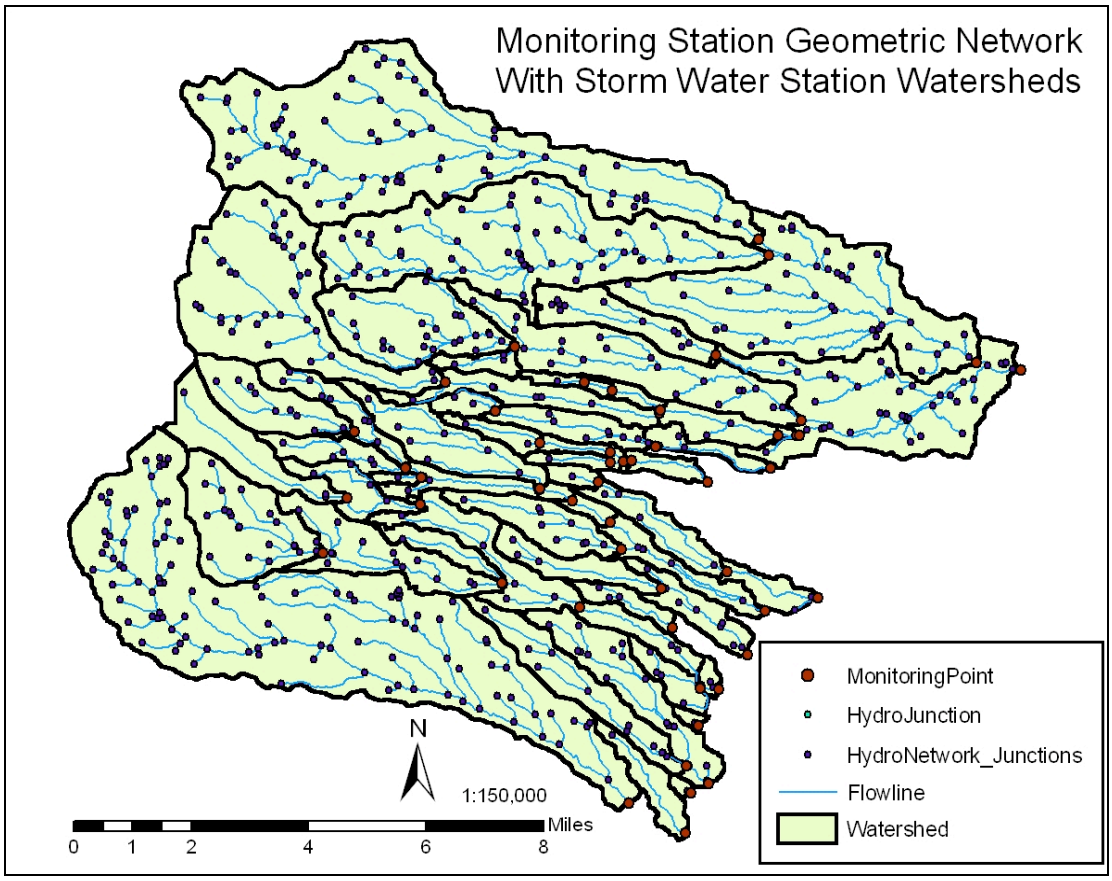


Figure 4 Monitoring station geometric network model

6.3.4 Monitoring station geometric model conclusions

The grid elevation errors were problematic throughout the study. ArcInfo workstation filled the grids and allowed a check on the number of sinks filled. When using the Arc Hydro FILL function after a CON function was applied, the cells were not filled past the CON function elevation. The cells for which the CON function changed the elevations were not considered sinks that would affect the hydrologic processes of the model. Arc Hydro took much longer to fill the grids than ArcInfo Workstation but the maximum height for each model run was the same as the original grid. Generally the functionality in Arc Hydro and ArcInfo workstation was similar when working with raster files. The difference in functionality occurs when moving into the geodatabase environment. ArcInfo workstation does not support the extra geodatabase functionality. The stream layer creation is one area that must be considered during raster modeling. Creating the stream raster as a stream link instead of using a CON statement for stream creation in ArcInfo workstation should allow the geometric network to be created successfully without loops. Arc Hydro uses the stream link functionality to create the geodatabase layer file, which can be mimicked using the streamlink ArcInfo Workstation function.

When creating the geometric network from a point and line file, a detailed check needs to be completed before their creation. To allow for flow direction to be stored without loops, the last point on the line must belong to the HydroJunction layer. If the point is not at the end of the line, a Junction class point will be placed there, causing a loop in the flow direction. This results in an uphill flow pattern.

6.4 Hydrologic Model Conclusions

Completing the hydrologic data modeling from a base raster utilizing Arc Hydro functions from start to finish allows a very robust finished product. This product can be built if the limitations of the Arc Hydro terrain processing tools are heeded. The model is limited to a grid of 10000 by 10000 cells. One variation that must be considered is the area used to create the stream layer. If too small an area is used, the limitations of the models will be exceeded. Overall the sequence of functions used to create the Arc Hydro data model is very simple and works seamlessly.

If a model is built without using the systematic Arc Hydro functions, the tutorial by Obenour (2003) is a required reference. Other issues must be taken into account when creating this network. These include creating the stream network using the stream link function, and making sure the last point on the stream layer used to create the geometric network belongs to the HydroJunction point file. Make sure that the stream layer used does not contain loops that will interfere with the upstream or downstream tracing.

When comparing Figure 3 to Figure 4, it is easy to discern the finer detail of the catchments areas in comparison to the watershed drainage areas. The storm water station watershed model shown in Figure 4 can be used to determine possible PRSs impacts to storm water stations. The catchments area can then be overlain to determine an area to place a monitoring site closer to the source; therefore the storm water station model can be used as an initial screening tool with the catchments model allowing a finer monitoring grid to be utilized for placement of storm water stations closer to a possible source.

7 Data Analysis

7.1 Methods

All layers and analytical data tables used for the maps were loaded into the watershed geometric network geodatabase, with the exception of the hillshade, as a personal geodatabase will not accept raster files. This created a self-contained geodatabase with all layers and tables consolidated in one database. The analyte tables were also added to this geodatabase as table features. Building a geodatabase relationship between the analyte table and the PRS layer was considered. Instead a join function in ArcMap between the analytical tables and the storm water station layer allowed the relationship to be built.

The advanced feature in the join function allowed only the matching records to be retained. The retained records represent the PRS and storm water stations that have values greater than their respective screen levels. This allows a relationship to be determined between the analytical data greater than the screening level for the PRSs and the storm water stations by watershed.

7.2 Mapping

A map was prepared for each analyte to illustrate the PRSs in relation to the storm monitoring station sites by watershed. There were 14 maps generated representing all analytes studied. Included on the maps are the major roads for map orientation, and watercourses. Storm water stations and their corresponding watersheds created in the geometric network process are shown on the maps. Only the PRSs that have a value higher than background are shown on the maps. Storm water monitoring stations are

only shown if they have a value greater than the DWDCG or NPDES benchmark value. The maps allow a distance from the storm water station to a PRS to be determined.

A hillshade was built from the 59 four-foot LIDAR tile mosaic. The hillshade was used to allow better topographic feature representation. The hillshade was then clipped to the watersheds to allow layer matching. When the clip to shape function under data frame in ArcMap was used, the draw time was increased close to ten fold. This did not make it feasible to use this option; so all layers were clipped to the watersheds.

7.2.1 Map symbolization

The PRSs with high erosion were symbolized using orange graduated colors according to analyte value. The regular PRSs were symbolized using purple graduated colors. The PRSs were broken into five classes using the natural breaks (Jenks) method. The storm water stations were symbolized using graduated colors ranging from yellow to blue according to analyte values and were broken into five classes using the natural breaks (Jenks) method.

7.2.2 Labeling

The labeling of the PRS sites was an area that was problematic. Label density required that a large-scale map would have to be utilized. An E size (34 X 44) map was used for areas that had a large number of PRSs with analyte values greater than background. For sites with a smaller number of PRSs exceeding the background value for a given analyte, a D size (24 X 34 inches) map was generated. Table 3 lists the map size used for each analyte. If the map is an E size map, it can be inferred that there were a large number of PRS sediment values that exceeded the background value.

Table 3 Map sizes

Analyte	Map Size
Aluminum (Al)	D
Americium 241 (AM-241)	E
Cadmium (Cd)	E
Copper (Cu)	E
Iron (Fe)	D
Magnesium (Mg)	D
Lead (Pb)	E
Plutonium 238 (Pu-238)	E
Plutonium 239 (Pu-239)	E
Strontium 90 (Sr-90)	D
Uranium 234 (U-234)	D
Uranium 235 (U-235)	D
Uranium 238 (U-238)	D
Zinc (Zn)	E

The labels for each storm water station site are shown in green to easily correlate the label to a storm water station. Labels have a leader associated with the tag. This allows the label to be placed away from the site so the label does not cover the site. Not covering the site is beneficial and allows the reader to identify the analyte level by site color. It was found that once the storm water stations were joined to the analytical data, multiple labels would be created for a site if the site had more than one analyte value over the screening level. This was due to the storm water stations being a point layer with limited labeling options; therefore, all storm water stations for each map were labeled individually by using the label tool and clicking each point individually.

High erosion PRS sites were labeled with an orange tag and a leader. The orange corresponds to the orange graduated color theme used for the PRS layer. This allows an easy correlation between the orange symbology of the PRS and the label. A purple label was used for regular PRSs that do not have high erosion. This label color corresponds to

the purple graduated color scheme used for the regular PRSs. This is best illustrated by reviewing the map example shown in Figure 5.

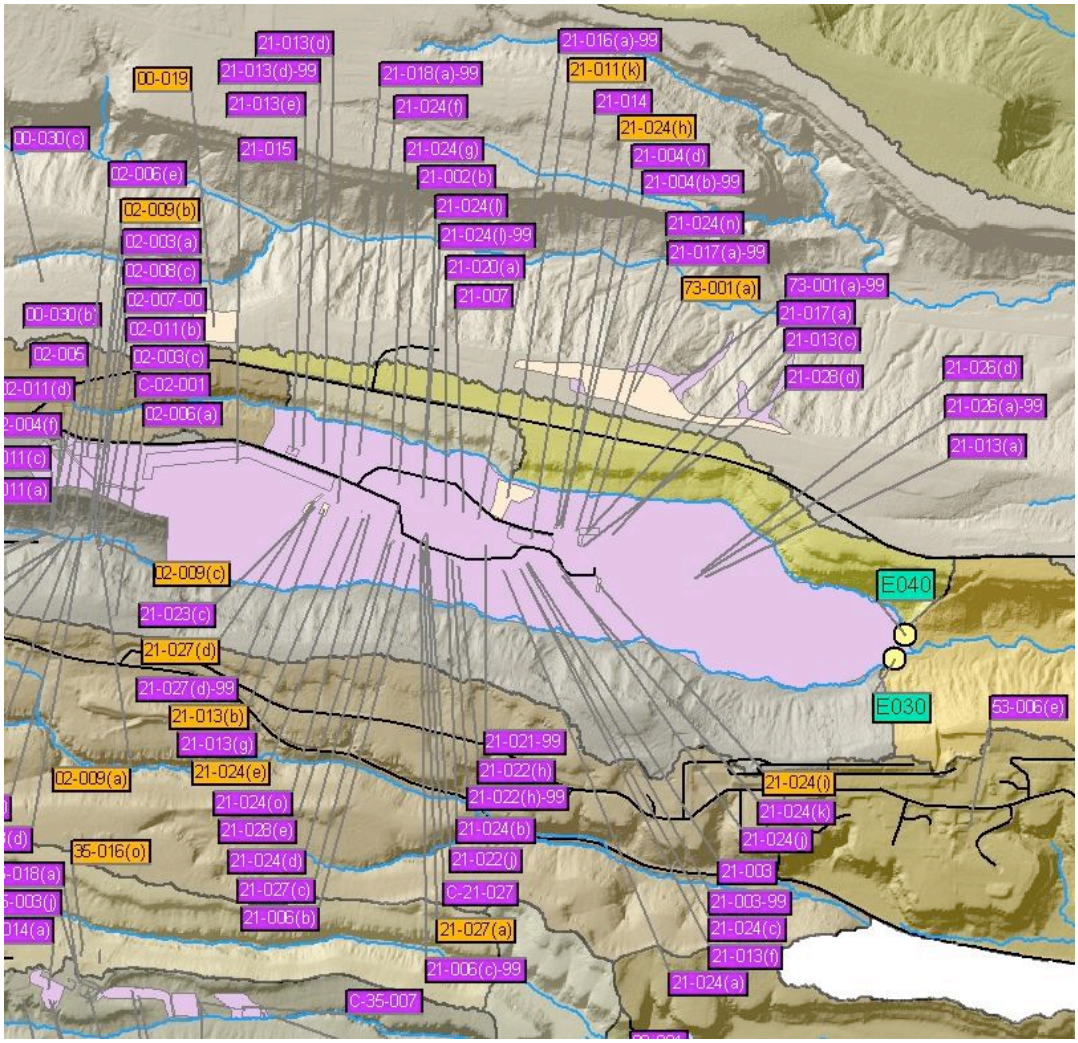


Figure 5 Map example

After completing a number of the maps, and moving all annotation labels for the PRSs, it was noticed that the black lettering did not show up well with the purple labels. The lettering for the purple labels was changed to white to help readability. The black lettering was not redone for all the maps already created due to the large amount of work involved. Thus some of the maps contain purple labels with black lettering and some have white lettering.

All labels for PRS sites were converted to annotation. An annotation geodatabase was created to house all annotation layers. The labels for the high erosion PRSs were duplicated by the regular PRSs during the annotation creation process. All labels were moved individually due to the number of sites and corresponding labels that were created. The duplicate regular PRSs that correspond to the high erosion PRSs were deleted during the move process. This eliminated any duplicate labels. It was noted on the maps that all high erosion PRSs are also a regular PRS, so if a label is shown for a high PRS that this site is also a regular PRS.

7.2.3 Geometric Network Tracing

Geometric networks can be used to trace downstream from a PRS, or upstream from a storm water station. Tracing downstream allows impacts to be determined for all downstream entities located in or near the stream channel. Tracing upstream allows possible contaminant sources to be determined. After these impacts are determined, controls such as check dams to control sediment transport can be placed in the stream channel. Another option would be to do remediation and removal of the contaminant. Using the geometric network trace functions can aid in formulating a plan for pollution control and tracking.

If a PRS was found to have high erosion and an elevated analyte value, the impacts of this PRS can be tracked using a downstream geometric network trace. All network traces in this section use Pu-239 for demonstration purposes. This is done by placing a flag, shown as a green square, on the stream network edge or junction. Examining Figure 6 it can be seen that a flag has been placed on the stream edge nearest to the largest PRS in the watershed. The downstream geometric trace is then initiated

using the utility network analyst toolbar in ArcGIS. If the flag is placed on the stream edge as in figure 6, and a downstream trace is initiated, the segment length to the nearest upstream junction will also be highlighted. Figure 6 illustrates this tracing technique using the E200 storm water station and watershed. The stream area highlighted in red corresponds to the stream area affected. Placement of the PRSs in the E200 storm water station watershed allows a determination of the PRSs that could impact the E200 storm water station. This storm water station also has elevated values that would suggest a relationship between the PRSs and the storm water station E200. With both entities having elevated values the relationship between them is implied.

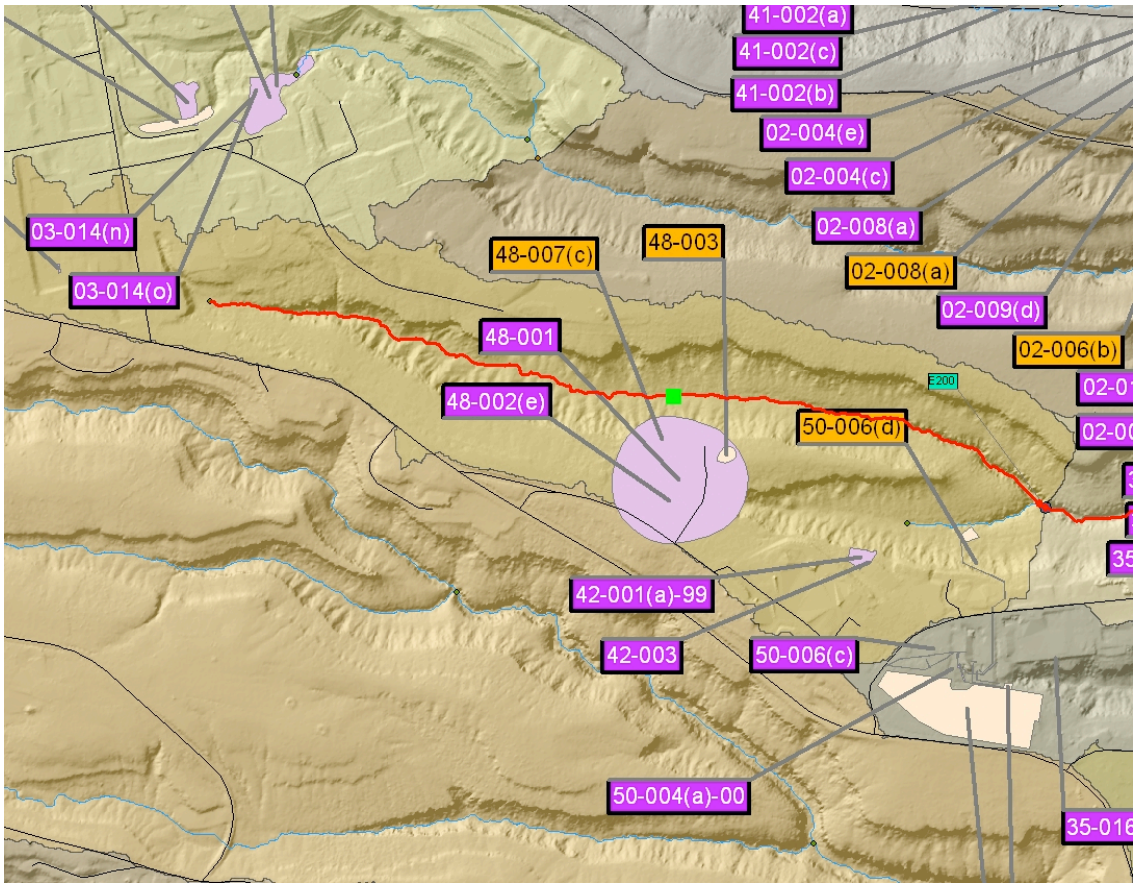


Figure 6 Pu-239 downstream geometric network trace close-up

Figure 7 shows the full extent of the PRS impact from the geometric network trace initiated in figure 6. This illustrates the full length of stream channel that would be affected. Other spatial themes could be brought into the project to determine if these entities might be impacted. With the large area affected shown by this trace, there is a greater possibility that entities would be found that could be affected. However, the storm water stations for the three watersheds below the affected E200 storm water station are not listed on figure 7. Just as in the maps if the storm water stations are not present, there were no values greater than the DWDCG for Pu-239 for that site. Therefore these storm water stations have not been impacted by the PRSs that are contained in the E200 watershed. The Pu-239 that has been transported and measured in samples at E200 can be assumed to be deposited in the channel, banks, or floodplains. This sediment has not migrated to the stations below E200 as determined through utilization of the trace function.

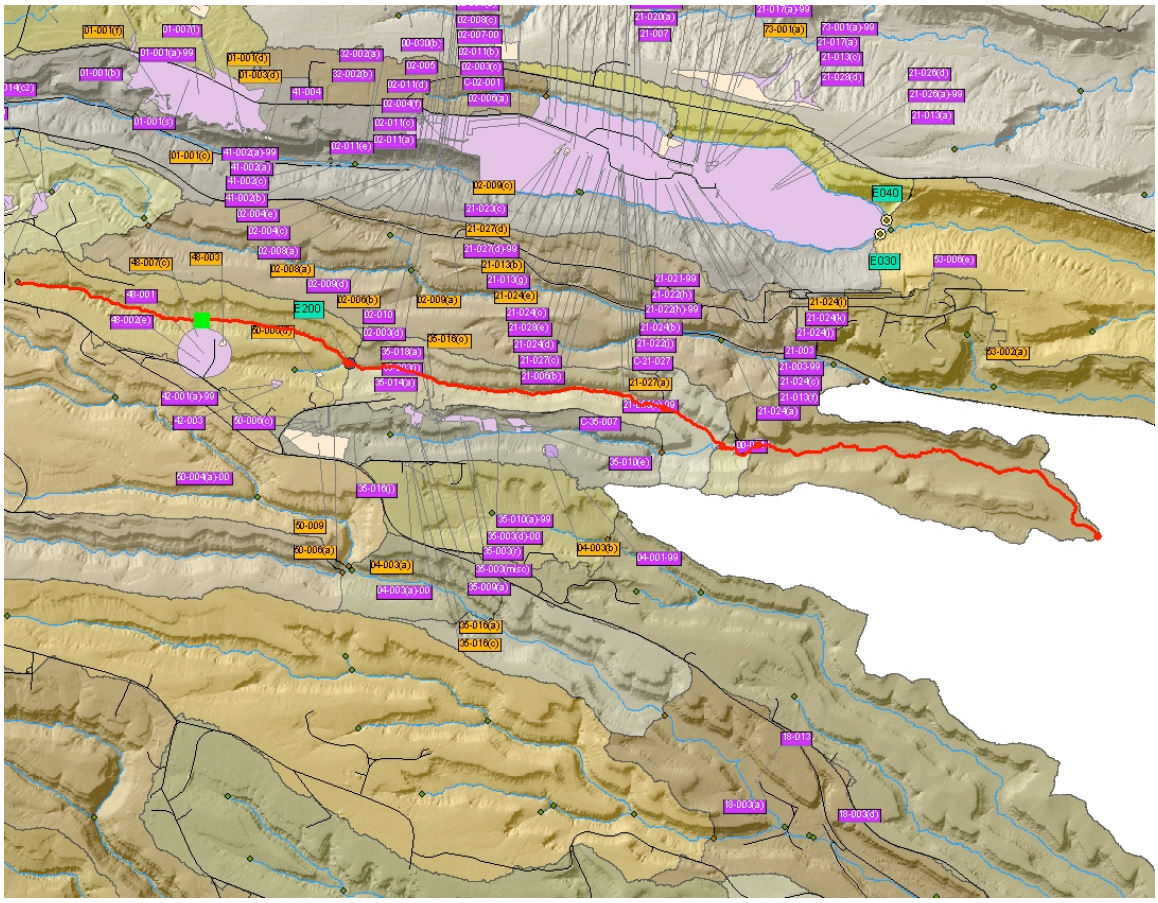


Figure 7 Pu-239 downstream geometric network trace overview

Alternatively an upstream trace can be initiated by placing a flag at a storm water station that has high analyte values. Figure 8 shows an upstream trace initiated from station E200. This trace has been returned as selection as illustrated by the blue line. The red line shown in Figure 6 and 7 was returned as a graphic. The return of the trace function may be as a graphic or a selection.

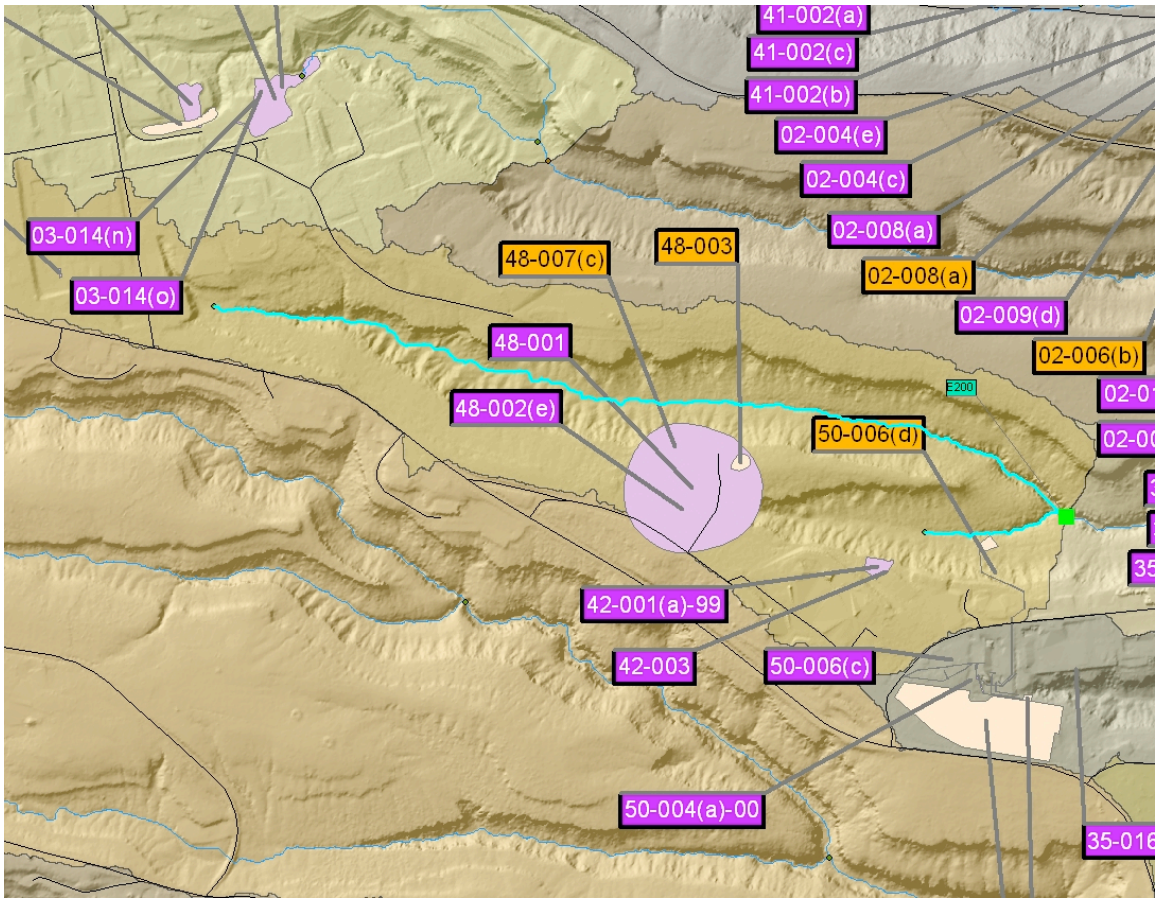


Figure 8 Pu-239 upstream geometric network trace

A select by location query can be run on the returned selection in Figure 8. Buffering the trace function selected stream layer and then selecting PRSs that are within 1500 feet is illustrated in Figure 9. This select query using a stream buffer will return PRSs that are nearest to the stream channel and would have the most probability of impacting the storm water station. The selected PRSs, 03-014(n) and 03-014(o), shown in the upper left corner of figure 9 are not in the E200 watershed. These PRSs were selected as being close to the selected stream course. They can be ruled out of relationship as they are contained in a separate watershed. These PRS could not impact storm water station E200.

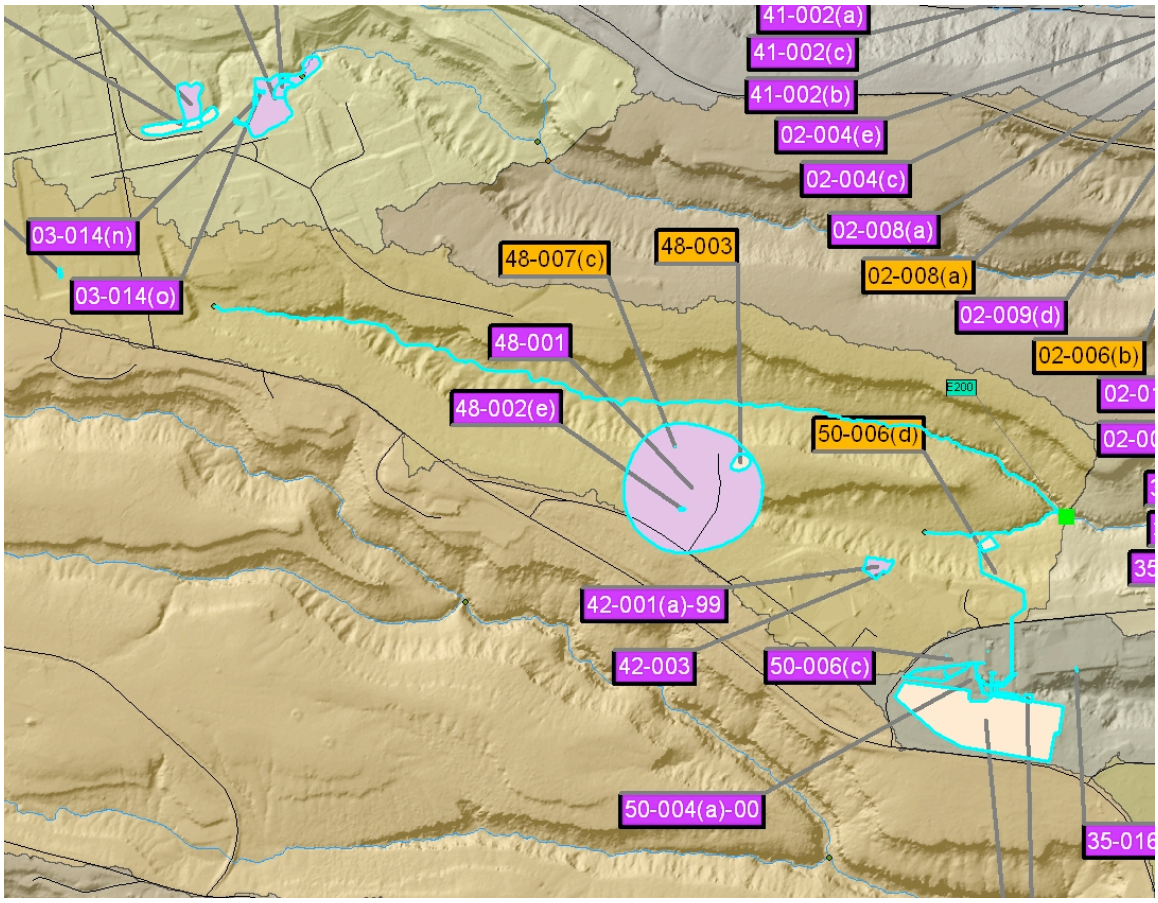


Figure 9 Pu-239 upstream geometric trace with select by location query

The network tracing was done using the watershed geometric network geodatabase. The catchments layer generated during the large scale modeling can be added to the network trace and selections generated in Figure 9. The catchment layer is shown as red outlines in Figure 10, with red points representing the drainage points for each catchment. A storm water station can be placed closer to the PRS that have been selected in the query process using the catchment layer. This proposed storm water monitoring station is shown in Figure 10. This storm water monitoring site would monitor PRSs 48-001, 48-002(e), 42-001(a)-99, and 42-003. The area monitored for this proposed storm water station is 51.6 acres, while the drainage area for E200 is 331 acres. This station placed at

the catchment outlet would help to narrow down the possible sources by determining if the smaller number of monitored PRS sites are having Pu-239 transported off-site. If the proposed storm water monitoring station samples show high Pu-239 values, it can be inferred that there is Pu-239 being transported off site. These PRSs can then be assumed to be the contributing contamination sources to storm water station E200.

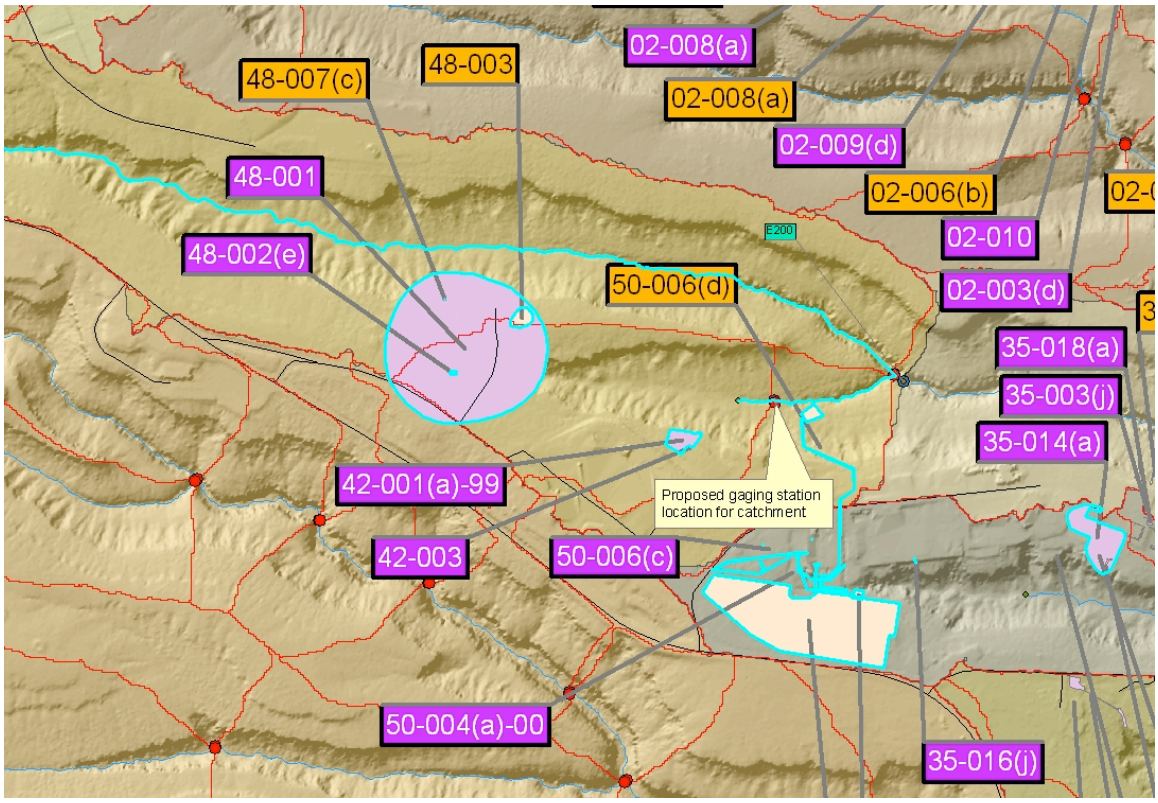


Figure 10 Pu-239 upstream geometric trace with catchments

7.2.4 Map conclusions

Creating the maps allows only the analytes with values higher than a screening level to be retained on the map during the join process. Tables were built that list the PRSs in relation to the storm water station watershed they are contained by. The maps list a value range in which a PRS falls. Specific mean values for the PRSs are found on the CD accompanying this document.

The maps allow determination of analyte clustering in a specific area. Due to the large size of LANL, clustering of contaminants in different areas is expected. Many different types of activities are pursued at LANL, each located in a different area. Each of these activities has a contaminant type that is associated with the activity. The amount of output from this activity cannot be determined without using mapping techniques to allow this clustering to become evident. These maps allow the spatial distribution of the contaminant types throughout LANL to be quickly determined.

The maps also illustrate the regular and potential release sites that have an impact on the storm water stations by watershed. By symbolizing the PRSs and storm water stations by their analyte values, PRSs sites with high erosion and high analyte values can be easily related to the storm water station by noting which watershed the PRS belongs to. Thus a relationship between the PRSs, high erosion PRSs, and the storm water stations can be easily visualized be reviewing each map.

The geometric trace is a powerful tool and allows many different types of analysis to be utilized. Only a few of the techniques that are possible have been illustrated here. This is a new type of data structure for GIS and many more uses will be developed in the future. The different types of analysis, from trace functions to the use of catchments to refine source contribution tracking, can be very useful for further study and determination of relationships between the PRSs and storm water stations.

7.3 Tables

Tables were created to illustrate the PRS average analyte values for each analyte that was present in a watershed. The tables illustrate which storm water stations had analyte values higher than a benchmark or DWDCG, and the PRSs with high erosion potential.

A summary table was created that lists the number of analytes by PRS that were greater than background by watershed. ArcMap, Microsoft Access, and Microsoft Excel were used to create the final tables. These tables can be viewed on the accompanying CD.

7.3.1 Average PRS value by storm water station watershed tables

ArcMap was used to intersect the regular PRS layer with the storm water station watershed layer. This process developed a table that includes the PRSs that are resident inside each watershed. The new intersect layer was stored in geodatabase format. When the layer is created, a location table and an attribute table are built. The selected records from each joined storm water table were than exported to the geodatabase to capture the join information.

Using the geodatabase format allowed direct access to the layers in Microsoft Access. CROSSTAB queries were run for each analyte using the regular PRS intersect layers that showed the PRSs as rows with the average analyte value over background and the storm water stations as columns. The average analyte value is calculated using all values over background for a specific site. SELECT DISTINCT queries were run for both the erosion PRS intersect and the storm water station layer. When using the join function, if there was more than one sample for a PRS or storm water station, then a row existed for each value. This means that a station could be shown multiple times, which was a problem for labeling discussed earlier. Using the SELECT DISTINCT query allowed the stations to be listed only one time.

All CROSSTAB and SELECT DISTINCT query results were transferred to Microsoft Excel for final formatting. The CROSSTAB query was the file that contained the required information, except it did not show which storm water stations had analyte

values over the benchmark or DWDCG. There was also no representation of the PRSs with high erosion potential. The SELECT DISTINCT query for storm water was used to color-code the storm water stations in the CROSSTAB query. If the storm water station was not represented in the CROSSTAB query, there were no PRS sites over background in the watershed for that storm water station. This storm water station was added to the storm water station column list and colored yellow. The other stations that were in the select distinct list were also colored yellow as they represented storm water stations that had analyte values over the benchmark or DWDCG. The SELECT DISTINCT query was used to color the PRSs in the CROSSTAB query red to correspond to PRSs having high erosion potential. PRSs with high erosion were already present in the regular PRS list in the CROSSTAB query, so no sites had to be entered into the list.

The tables on the CD for each of the 14 analytes show the storm water stations that have an analyte level higher than a benchmark value or DWDCG in yellow. If a storm water station is listed but not in yellow there were sediment values over background but no elevated storm analyte values. The storm water stations are shown as columns as they have fewer values than the PRSs. The average values shown in the table are associated with the analyte values over background for the PRSs. This allows the PRSs that are contained by each watershed and their average sediment analyte concentrations to be easily determined.

7.3.2 Number of analytes over background table

Another table on the CD was summarized from the tables outlined in section 7.3.1. This table was built in Microsoft Access with all storm water stations listed as columns. The data for each of the 14 analytes was written to this table using an append query.

Another query was written that counted the number of times an analyte appeared for each PRS by storm water station watershed. This allowed an easy check to see the number of analytes from 0 – 14 that were greater than background for each PRS. If a five is cross referenced for a PRS and storm water station, then that PRS had five analytes that were higher than background for that specific storm water station. Just as in the other tables, if the storm water station column is yellow, this station exceeded a benchmark value or a DWDCG. If the PRS row is red, that site has high erosion potential.

7.3.3 Results

Table 4 summarized the table that was outlined in section 7.3.2 above. This table was built by counting the number of sites in each watershed that had a value of one or greater. This table shows the number of PRSs that are above a background value by watershed. Table 4 also lists the percentages of high erosion PRSs to regular PRSs. This table quantifies the number of regular and high erosion PRS sites for each storm water station by watershed.

These references apply to all tables (see CD for other tables).

- Value for tables for specific analytes is the average PRS value for all samples above background (See CD)
- Number shown from 0 to 14 (see CD) is the number of analytes that had a value over background for a specific PRS
- Red highlight of PRS-ID means that the site has high erosion potential (see CD)
- Yellow highlight of storm water station means that the analyte value for the station was over the benchmark

Table 4 Number of PRSs over background by watershed

	Storm Water Stations																			
PRS Type	E026	E030	E038	E039	E040	E042	E049	E050	E055	E056	E060	E070	E089	E090	E099	E110	E123	E124	E125	E200
Erosion	0	17	1	1	2	1	0	0	1	4	3	1	0	1	0	0	2	1	3	6
Regular	0	85	3	21	19	3	0	0	1	9	20	5	0	4	0	0	24	5	8	20
Percent erosion to regular	0	20	33	5	11	33	0	0	100	44	15	20	0	25	0	0	8	20	38	30

	Storm Water Stations																		
PRS Type	E201	E201.5	E202	E203	E204	E218	E225	E230	E240	E241	E242	E242.5	E243	E244	E245	E245.5	E246	E250	E252
Erosion	4	13	0	4	2	12	4	0	0	1	4	1	4	3	0	0	3	3	0
Regular	12	34	0	8	5	18	22	1	0	1	5	2	8	27	0	1	19	20	0
Percent erosion to regular	33	38	0	50	40	67	18	0	0	100	80	50	50	11	0	0	16	15	0

	Storm Water Stations																
PRS Type	E253	E256	E260	E261	E262.5	E263	E264	E265	E266	E267	E267.5	E273	E275	E300	E338	E340	E350
Erosion	0	5	6	0	12	0	0	0	4	1	1	0	5	0	4	2	0
Regular	0	24	39	15	64	0	0	0	13	2	3	5	24	0	10	13	0
Percent erosion to regular	0	21	15	0	19	0	0	0	31	50	33	0	21	0	40	15	0

The bullets below summarize information from Table 4.

- Number of PRS sites with high erosion and values greater than background = 136
- Number of PRS sites with values greater than background = 626
- Percentage of high erosion and values greater than background PRSs to values greater than background PRSs = 136/626 = 22 percent
    - 22 Percent of the PRSs with high background values also have high erosion potential.

- 16 of 56 storm water sites do not have values greater than a benchmark value or DWDCG
    - 16/56 = 29 percent of stations do not have values greater than a benchmark value or DWDCG

- Total Area of high erosion PRSs greater than background = 99 acres
- Total Area of regular PRSs greater than background = 1168 acres
- Percent of erosion PRS area to regular = 99/1168 = 8.5 percent
    - The area of erosion PRSs is only 8.5 percent of the regular PRSs area.

- Four storm water stations have no PRSs with values over background and no storm water values over a benchmark or DWDCG.
- Four storm water stations have over 10 high erosion sites with values over the background in their watershed.
- There are 13 storm water stations that have 20 or more regular erosion sites with values over background in their watershed.
- The E030 watershed has the highest number of regular and erosion PRSs in its watershed.

- Twelve of the storm water stations have values greater than a benchmark or DWCDG and do not have any PRSs that are greater than background.

The research identified storm water station watersheds that could be highly impacted by the large number of PRSs and high erosion PRSs with analyte values over background. This is evident by reviewing Table 4; however, when reviewing Table 4 there is no discernable relationship. One thing must be remarked upon again. Since the high erosion PRSs are also counted as regular PRSs, the number of regular PRSs would be less if the high erosion PRSs were subtracted from the regular PRS sites before comparison. Table 4 lists E218 with 12 erosion and 18 regular PRSs. If the high erosion PRSs were subtracted, with no double counting, from the regular PRSs E218 would have 12 high erosion PRSs and only 6 regular PRSs.

7.4 Statistical Analysis

This study utilized the GIS modeling and analyses functions in the Arc Hydro tools and data model to determine if there is a relationship between the PRSs and storm water stations. A purely statistical analysis could help in determining if a relationship exists between the PRSs and the storm water stations that could not be found using GIS analysis alone. A full statistical analysis would need to be very rigorous and is outside the scope of this GIS-based thesis research. However, a cursory attempt at a statistical analysis was done using Pu-239 as the test analyte.

The data was organized into two separate areas so a t-Test could be run on the data. The first uses all values for PRSs in a watershed for both the regular and high erosion PRSs to compare against the storm water station value for that watershed. The mean value for all PRSs inside the watershed was calculated, for both regular and high erosion PRSs. The mean value for the storm water station was then calculated. The test

set was compared, and only watersheds that had values for both PRSs and storm water stations were retained. The regular PRS data set has 9 matches and the high erosion dataset had 7 matches. If only a PRS or storm water station mean value was found this data point was not included in the t-Test. The second statistical analysis looked at one storm water station in comparison to all of the regular and high erosion PRSs contained in the watershed. All values for both regular and high erosion PRSs were used to compare against all values for the storm water station. For the regular PRSs there were over 70 data points compared against 12 for the storm water station. The high erosion PRSs had only 15 data points to compare against the 12 for the storm water station.

Statistical t-Tests were run to determine if the PRS sediment values and the storm water runoff values could be considered to come from the same population. The t-Test results were very inconclusive and erratic and were not conclusive in determining if the two sample sets could be considered to come from the same population. Therefore the results of these initial attempts at a statistical analysis will not be included in this research. Further research where a rigorous statistical methodology could be applied to the results gained through this GIS analysis could help to improve on the determination of a relationship between the PRSs and the storm water stations by watershed.

One of the things that could have biased the results of the initial t-Tests is that the units were different. The PRS values for Pu-239 are in pCi/g and the storm water values are in pCi/L. The storm water values could be converted to pCi/g by using a known value of total suspended solids (TSS) in mg/L for the same storm event. The total suspended solids vary from around 5000 to 100000 mg/L for the storm water stations. This variability would have a large impact on the known activity of Pu-239 at a storm

water site. Depending on the TSS concentration the Pu-239 value could go up or down in relation to the PRS sediment value.

Correlation looks at the change in one variable based on another. This requires that the data have a one to one relationship. A correlation was run on the data set created for the first type of t-Test that was based on the mean values for all storm water stations and PRSs with matching data points. The data set contained 9 matching mean values for PRSs and watersheds. A scatter plot was developed and a trend line plotted including an R2 value. The R2 value for the correlation was below .1, which reveals almost no correlation between the PRS sediment values and the storm water runoff values.

The highly complex system in regards to the sediment transport, deposition and re-deposition of the sediments in the stream channel does not allow a simple statistical analysis, for correlation or t-Tests, to link these two variables. When looking at the stream channel dynamics over the history of the PRS, many contaminates that used to be resident at the PRSs have migrated into the main channel and been deposited and concentrated on the channel, banks, or floodplains in pockets. The varying nature of the runoff may pick these contaminates up and transport them as suspended sediment depending on the size of the runoff event. This variation between runoff events that erratically transport the sediment, which may be sampled at the storm water station, adds complexity to the system. This complexity in the system needs to be reduced in order to run a complementary statistical test. The storm water stations are located in stream channels and are distant from the source PRSs, which makes a direct correlation of these analytes problematic. Using a distance decay function might help to alleviate some of the impact but the varying deposition and re-suspension of the analytes in the stream system

and the probability of sampling this sediment packet is still problematic for a statistical analysis.

8 Conclusions

8.1 Summary

This research was conducted to determine if a relationship could be established between the two types of PRSs, regular and high erosion, and the storm water stations in and around Los Alamos National Laboratory. The first part of this research focused on the creation of two Arc Hydro data model compliant geodatabases. These geodatabases were built using two completely different processes. The catchments geodatabase was evaluated using five different scenarios. The final catchment geodatabase was created using a grid resampled to a 12-foot cell size. Arc Hydro functions were applied to this 12-foot cell size grid for completion of the Arc Hydro data model compliant geodatabase. The watershed geodatabase was created by applying the Arc Hydro UML schema to a geodatabase populated with the required spatial layers using the ArcCatalog schema wizard, which created a fully compliant Arc Hydro data model geodatabase. Grid errors were found and explored during the watershed modeling processes. It was determined that these errors would not affect the modeling processes. The results from these geodatabases were used for analysis and comparison of the PRS sediment concentrations to the storm water station analyte values.

Analytical tables for each of the 14 analytes were added to the watershed Arc Hydro data model geodatabase. Spatial and database queries were implemented that led to the development of three separate table types. Tables for each analyte showing the average value for PRSs by watershed, and a table with the number of analytes greater than background for each PRS by watershed are included on the CD with this document.

A table with the number of regular and high erosion PRSs greater than background by watershed is shown as table 4.

Fourteen maps were created illustrating the PRSs that have values greater than background in relation to the storm water stations by watershed. The maps show a watershed for each storm water station making it easy to identify the storm water station that each PRS drains into. Clustering of PRSs can also be easily determined. This clustering shows the location of areas that should have the greatest impact to storm water stations. High analyte values can also be easily determined on the maps due to the use of the graduated color function for the PRSs and storm water stations. Utilizing the Pu-239, map a geometric trace was demonstrated that showed the processes that can be used to track contaminants upstream or downstream from the PRSs or storm water stations.

A statistical analysis was initiated on the data from the spatial and database query results. This statistical analysis did not definitively show a relationship between the PRSs and the storm water stations. Numerous issues are involved that did not allow the statistical evaluation to successfully correlate these two data sets.

This primary research objective of establishing a relationship between PRSs and storm water stations could not be answered definitively. However there were many useful conclusions drawn during the analysis that can help to obtain a solution to the primary research objective. With further study utilizing the methods outlined, more progress could be made in determining if high erosion PRSs have a greater impact on storm water runoff than the regular PRSs. The research did result in successfully meeting the secondary objectives of this research. These objectives included creating a GIS modeling procedure for contaminant analysis, large scale raster modeling leading to the

creation of Arc Hydro data model compliant geodatabases, creation of geometric networks for hydrologic analysis, and analysis of the relationships between the PRSs and storm water stations by watershed.

8.2 Discussion of Results

The raster based modeling section of the research was successful in creating two Arc Hydro data model compliant geodatabases. The limitation of the Arc Hydro data model with regard to grid size was tested during creation of the catchment-based geodatabase. Issues with loops were explored during the watershed-based geodatabase creation. These geodatabases can be successfully used for their intended purpose of contaminant source tracing and storm water station placement.

The development of a large-scale and small-scale geometric model has made it possible to use both to track possible sources. When an analyte value over a standard is detected at a storm water station, a flag can be placed at this location and the upstream and downstream impacts noted. The upstream area can be returned as a selection. This selection can be buffered and the nearest PRSs can be determined, as these sites would generally have the highest impact.

Creation of the geodatabases using Arc Hydro functions, or the UML schema, shows the versatility that can be used to build an Arc Hydro data model compliant geodatabase. Once created, both geodatabases have the same appearance and functions but the path to creation differs greatly. The ability to create an Arc Hydro compliant geodatabase from existing spatial layers or from a base DEM, as was done for this research, allows great flexibility in building of the final product. One of the benefits is that this product, no matter how it was created, will have the same functionality once finished.

The size difference between the regular and high erosion PRSs is an issue in determination of a relationship between the PRSs and the storm water stations. The high erosion PRSs are only 8.5% of the area of the regular PRSs with analyte values greater than background. This large difference in area could offset the higher erosion potential PRS impact on the storm water stations. The high erosion PRSs might still have a greater impact if area is not taken into account. If the larger area of the regular PRSs is taken into account, the impact of higher erosion could be compensated for. Other analysis could be conducted to review this effect, such as distance weighting of PRSs from the storm water station by analyte while taking into account the analyte value. A mass balance approach could also be used where the total area of the PRSs along with the analyte value are used to calculate a mass balance. This would return a value of total area of PRS affected along with a numerical value that could be compared against a mass balance of the same analyte in the storm water, using the volume of runoff and analyte value.

There is no evident relationship between the storm water stations and the high erosion and regular PRS from this analysis. Due to deposition of the sediments in floodplains leading to heterogeneous packets being developed, which could be picked up and transported during a storm event, the measurement of the analytes bound to the sediments at a storm water station is difficult. Due to the complexity of the stream system, a relationship between the sediment and storm water is very hard to quantify. A relationship may be determined by conducting an analysis at a smaller scale. Each analyte would need to be examined individually to determine if a relationship exists between the two types of PRSs and the storm water stations. It cannot be determined if

the high erosion PRSs have a greater impact on the storm water stations than the regular PRSs without a very rigorous statistical evaluation that is beyond the scope of this GIS-based analysis.

8.3 Limitations of Study

During the Arc Hydro raster based modeling it was found the largest grid that could be used was 10000 by 10000 grid cells. The four-foot LIDAR mosaic that was used for the study had more grid cells than the Arc Hydro limit. Numerous ways were explored to test the grid cell limits imposed when using the Arc Hydro program functions. The final solution required resampling the grid to a twelve foot cell size to bring the number of cells below the limit.

Resampling of the LIDAR DEM from four-foot to 12-foot caused a shift in the stream course for the catchment Arc Hydro data model. This was noted when the streams for the catchment and watershed Arc Hydro data models were overlaid. Error due to resampling was also propagated to the catchment and junctions layers. An accuracy assessment to determine the amount of error due to resampling could be applied. This would allow a quantification of the error for the resampled 12-foot LIDAR DEM in relation to the four-foot LIDAR DEM.

The complexity of the stream system that was identified during statistical analysis was the principal limitation to proving the question posed by this research. Reducing the dimensionality that is evident in the impacts to storm water would allow a better representation statistically. The number of PRSs inside a storm water station watershed and the channel dynamics lead to numerous dimensions that could be modeled in the statistical analysis.

8.4 Direction of Future Research

The geometric network created for this research can be used to track impacts to the storm water stations. Upstream traces could be initiated from a storm water station that had analyte values over the screening level. Select by location queries could be written to pick out the PRS sites that nearest to the selected stream reach. New data sets could be created with these selected sites. The new data sets could be displayed using the map layout created for this study. Further refining the PRSs using this methodology would allow better representation of PRSs that would be more likely to have an impact on the storm water stations.

There were storm water stations that were not included in the watershed Arc Hydro data model. Very small drainage areas are associated with these storm water stations. A higher resolution model would be required for these storm water stations. These storm water stations would benefit from the use of the one-foot LIDAR DEM data to create a compliant Arc Hydro data model. This higher resolution one-foot LIDAR Arc Hydro data model could be used as a check against the four-foot LIDAR watershed Arc Hydro data model.

The Arc Hydro data model has a time series module that was not implemented with this research. Flow data exists for the storm water stations that could be used to implement this time series module. This would allow mass transport of the analytes to be calculated. The geometric network could be assigned weights based on transport times to give a better estimation of the transport volume. A groundwater Arc Hydro data model is being developed. With the flow data added to the Arc Hydro data model created for this

research, and a link established to a groundwater Arc Hydro data model, the groundwater surface water interactions could be explored.

This research was completed using data extracted from the PRS analyte database and storm water analyte database. A more useful approach would be to set up the geometric networks in the SDE SQL server instance and link this directly to the SQL server PRS database and the storm water Oracle database. The source tracking could be refined and rerun when new analytical data is added to the database. Thus, as more of the PRSs are sampled and added to the database, these data would automatically be shown as a possible source contributor to the storm water stations. Also as the storm water stations are sampled, with the possibility of new contaminates being discovered, the possible sources would be current, leading to real time geometric network source tracking.

9 References

Carey, J.W.; Cole, G.L. 2002. Description of the Cerro Grande fire laser-altimetry (LIDAR) data set. Los Alamos National Laboratory Report LA-13892-MS.

ESRI, 2004. ArcGIS Spatial Analyst for ArcGIS 9. http://www.esri.com/software/arcgis/extensions/spatialanalyst/about/whats-new4.html

ESRI Canada. 2004. ArcMap 8.1 (ArcInfo) - How to Perform a Network Trace over a Geometric Network in a Geodatabase http://www.esricanada.com/english/support/get_tech/arcgis/Gdb_network_trace.asp

ESRI Forums. 2003. Adjoint catchment processing. Water Resources/Arc Hydro Discussion Forums. http://forums.esri.com/Thread.asp?c=121&f=1271&t=79236&mc=3.

ESRI Support Center. 2004. File sharing lock count exceeded. Increase MaxLocksPerFile registry entry. http://support.esri.com/index.cfm?fa=knowledgebase.techarticles.articleShow&d=23423

Gallaher B., Koch R., Mullen K. 2002. Quality of Storm Water Runoff at Los Alamos National Laboratory in 2000 with Emphasis on the Impacts of the Cerro Grande Fire Los Alamos National Laboratory Report LA-13926.

Katzman, D., Ryti, R., Tardiff, M., Hardesty, B. 1999. Evaluation of Sediment and Alluvial Groundwater in DP Canyon Reaches DP-1, DP-2, DP-3 and DP-4. Los Alamos National Laboratory Report LA-UR 4238.

Longmire, P.A., Reneau, S.L., Watt, P.M., McFadden, L.D., Gardner, J.N., Duffy, C.J., Ryti, R.T. 1995. Natural Background Geochemistry, Geomorphology, and Pedigenesis of Selected Soil Profiles and Bandelier Tuff Los Alamos, New Mexico. Los Alamos National Laboratory Report LA-12913-MS.

Maidment, D.R. 2002. Arc Hydro GIS for Water Resources. ESRI Press.

Mason, D, Maidment, D.R., 2000. An Analysis of a Methodology for Generating Watershed Parameters using GIS. Center For Research in Water Resources. http://www.crwr.utexas.edu/online.html.

Mullen K. 2000. Watershed Management Plan. Los Alamos National Laboratory Report LA-UR 03-3788.

Obenour, D. 2003. Developing an Arc Hydro Dataset. http://civilu.ce.utexas.edu/stu/obenoudr/gisreport_files/AH_data_inst_pic.doc.

Osborne, K.G. 2000. Water Quality Tool Incorporating Non Point Sources. University of Texas at Austin Thesis Paper.

Reneau, S., Ryti, R., Tardiff, M., Linn, J. 1998. Evaluation of Sediment Contamination in Lower Los Alamos Canyon Reaches LA-4 and LA-5. Los Alamos National Laboratory Report LA-UR-98-3975.

Ryti R.T., Longmire P.A., Broxton D.E., Reneau S.L. Mcdonald E.V. 1998. Inorganic and Radionuclide Background Data for Soils, Canyon Sediments, and Bandelier Tuff at Los Alamos National Laboratory. Los Alamos National Laboratory Report LA-UR 98-4847.

University of Texas at Austin Center for Research in Water Resources, 2004. Arc Hydro Tools and Documentation. http://www.crwr.utexas.edu/gis/gishydro04/index.htm.

U.S. Department of Energy. 1993. Order 5400.5 Radiation protection of the public and the environment.

U.S. Environmental Protection Agency. 2000. Final Reissuance of National Pollutant Discharge Elimination System (NPDES) Storm Water Multi-Sector General Permit for Industrial Activities; Notice. Federal Register Vol. 65, No. 210.

Veenis, S. 2004. Surface Water Site Assessments. Risk Reduction and Remediation Services Standard Operating Procedure. SOP-2.01 ER 2004-0084.

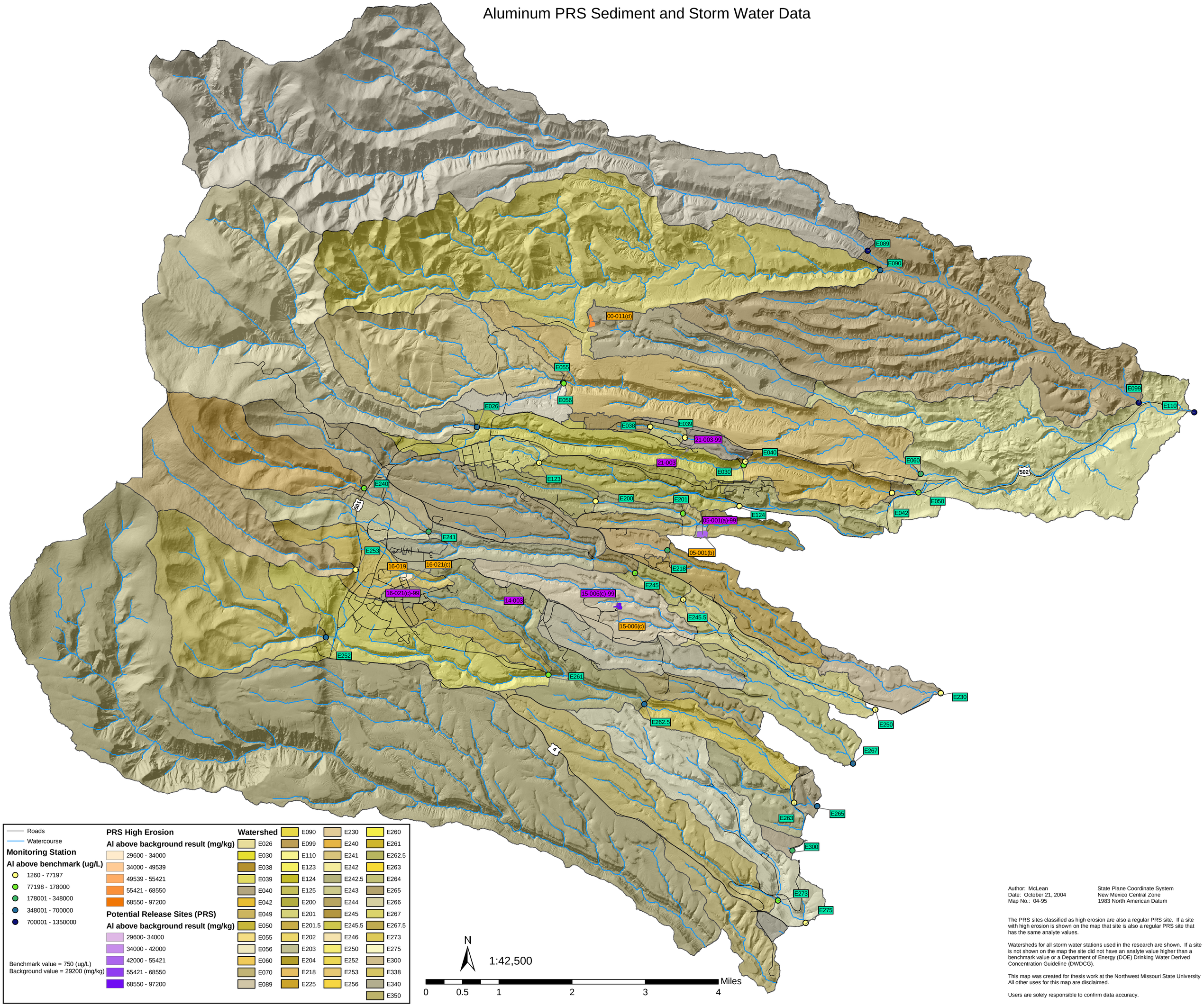
10 Appendix

10.1 Maps

Maps are shown for all 14 analytes. The maps were created as D or E size maps as specified in Table 3 (see CD for electronic format).

10.1.1 Figure A1 Aluminum PRS Sediment and Storm Water Data

Aluminum PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum

The PRS sites classified as high erosion are also a regular PRS site. If a site with high erosion is shown on the map that site is also a regular PRS site that has the same analyte values.

Watersheds for all storm water stations used in the research are shown. If a site is not shown on the map the site did not have an analyte value higher than a benchmark value or a Department of Energy (DOE) Drinking Water Derived Concentration Guideline (DWDCG).

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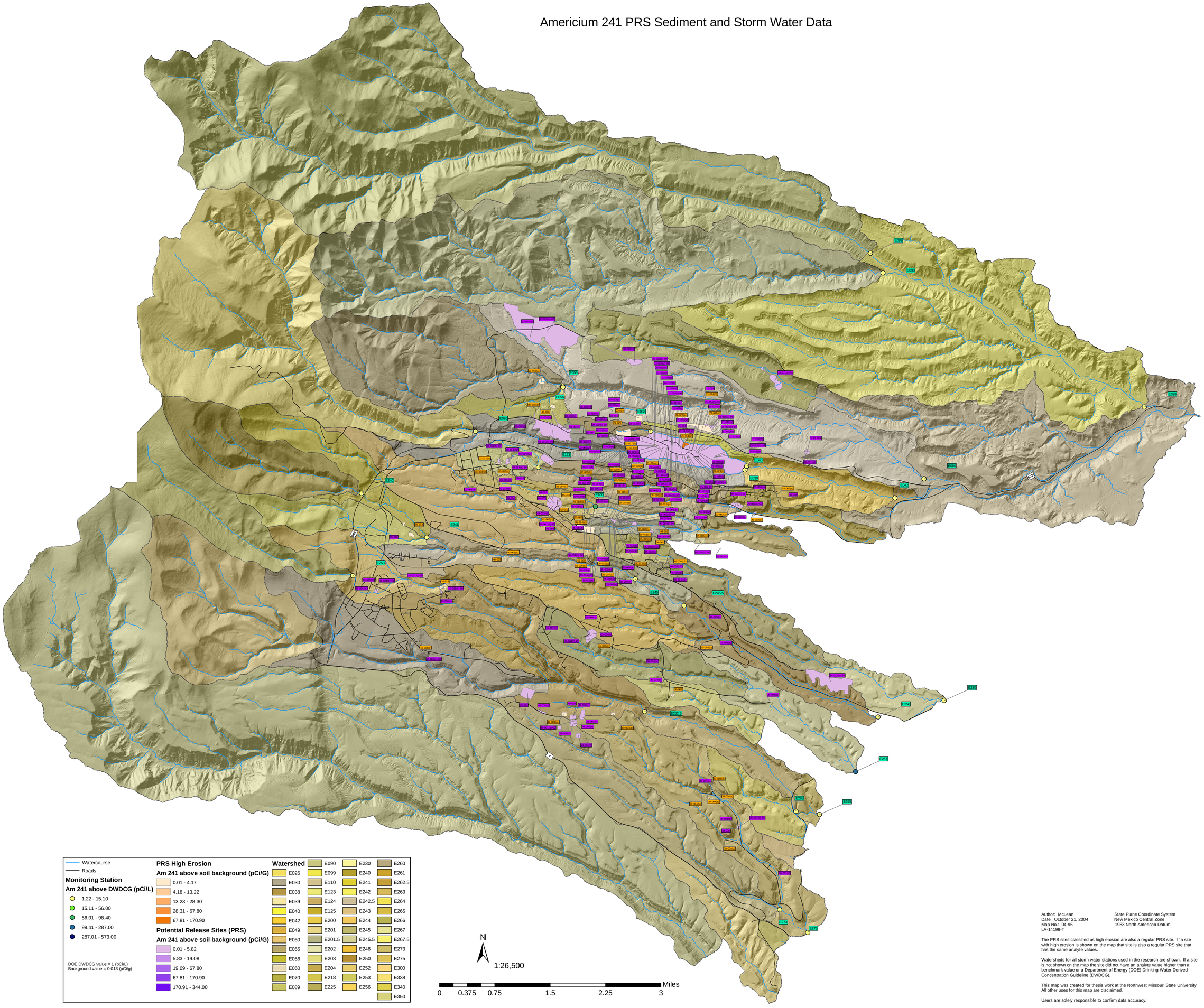
Users are solely responsible to confirm data accuracy.

10.1.2 Figure A2 Americium 241 PRS Sediment and Storm Water Data

Americium 241 PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
LA-14199-T

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum

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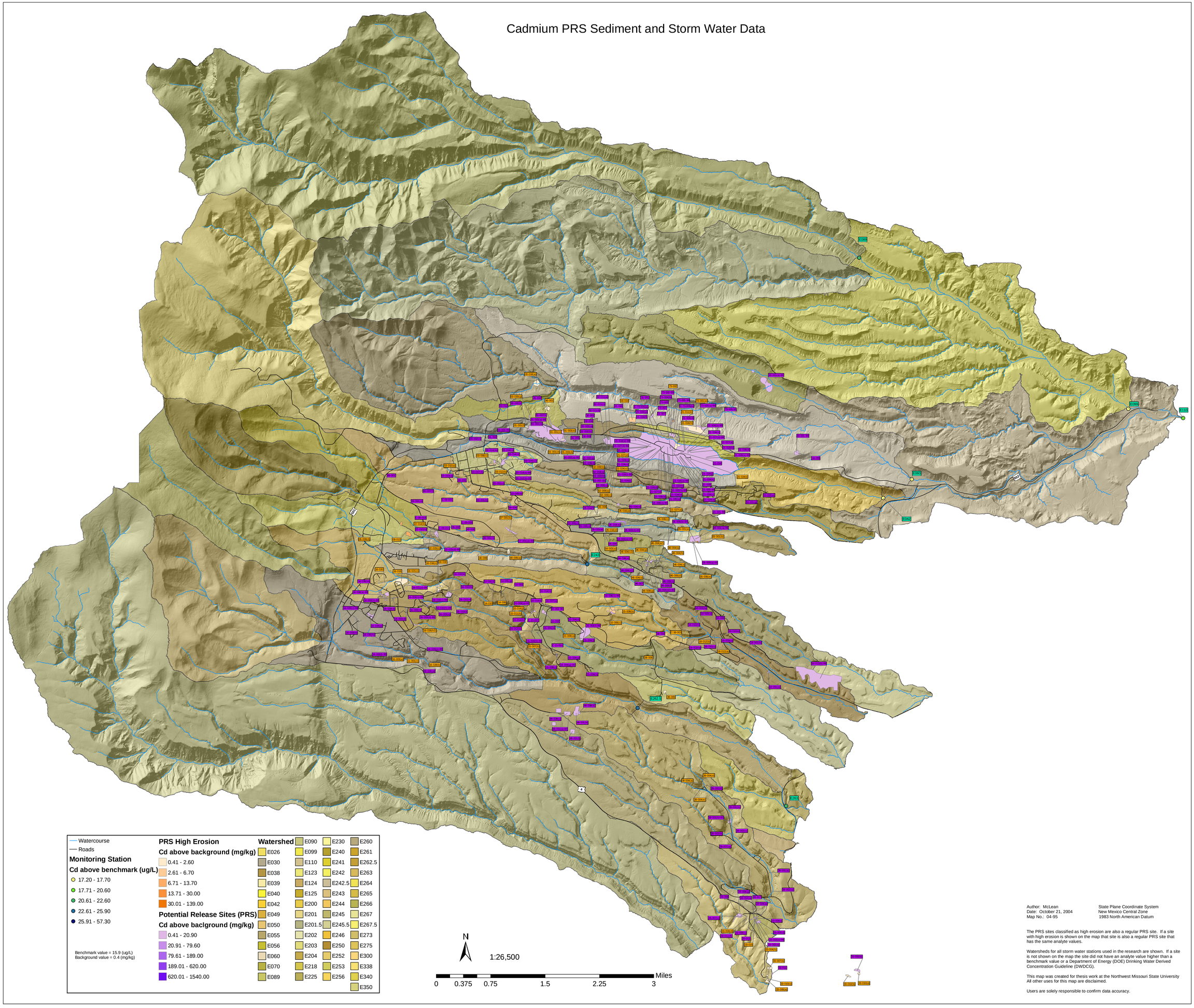
10.1.3 Figure A3 Cadmium PRS Sediment and Storm Water Data

Cadmium PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum

The PRS sites classified as high erosion are also a regular PRS site. If a site with high erosion is shown on the map that site is also a regular PRS site that has the same analyte values.

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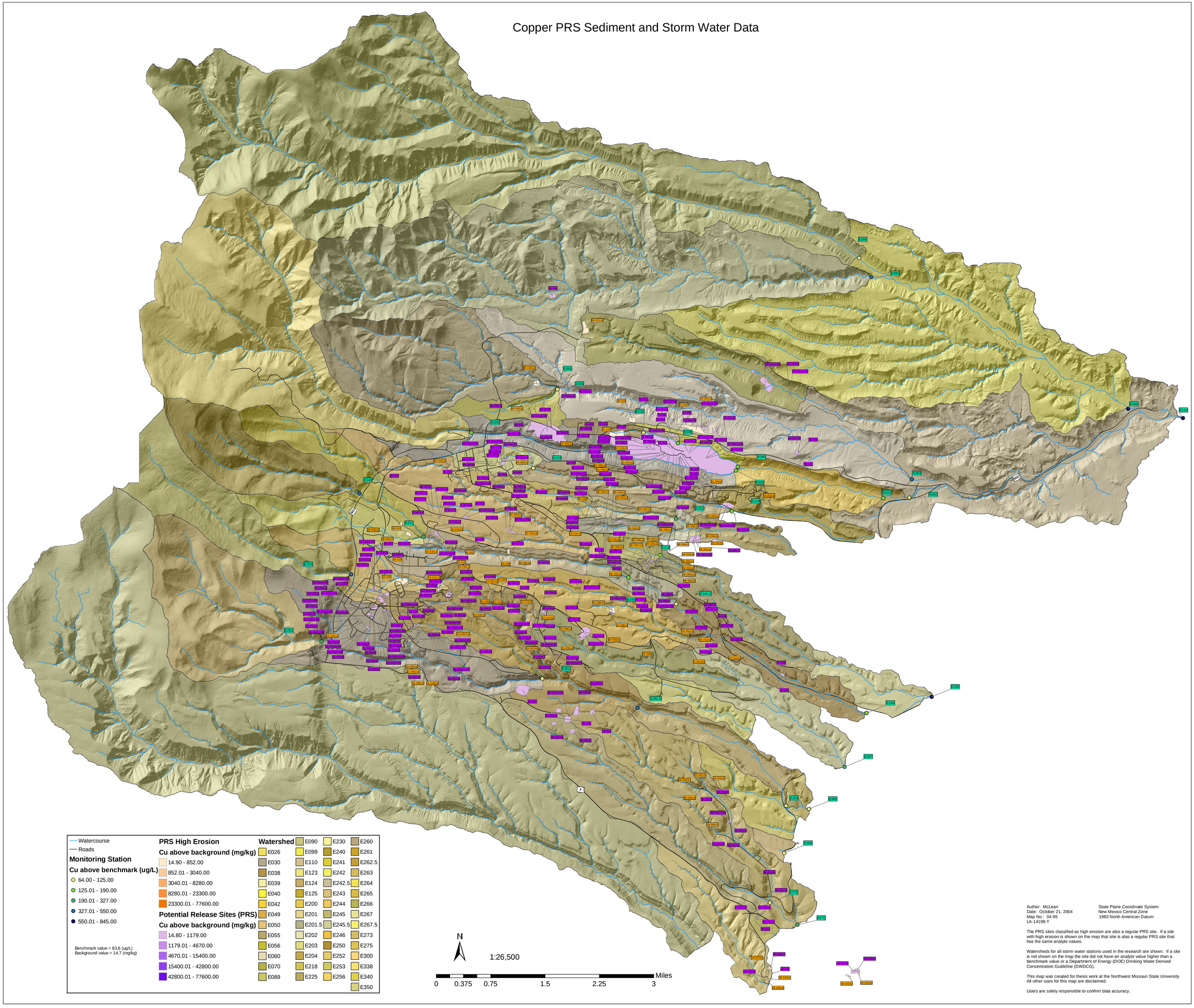
10.1.4 Figure A4 Copper PRS Sediment and Storm Water Data

Copper PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
LA-14199-T

State Plane Coordinate System
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1983 North American Datum

The PRS sites classified as high erosion are also a regular PRS site. If a site with high erosion is shown on the map that site is also a regular PRS site that has the same analyte values.

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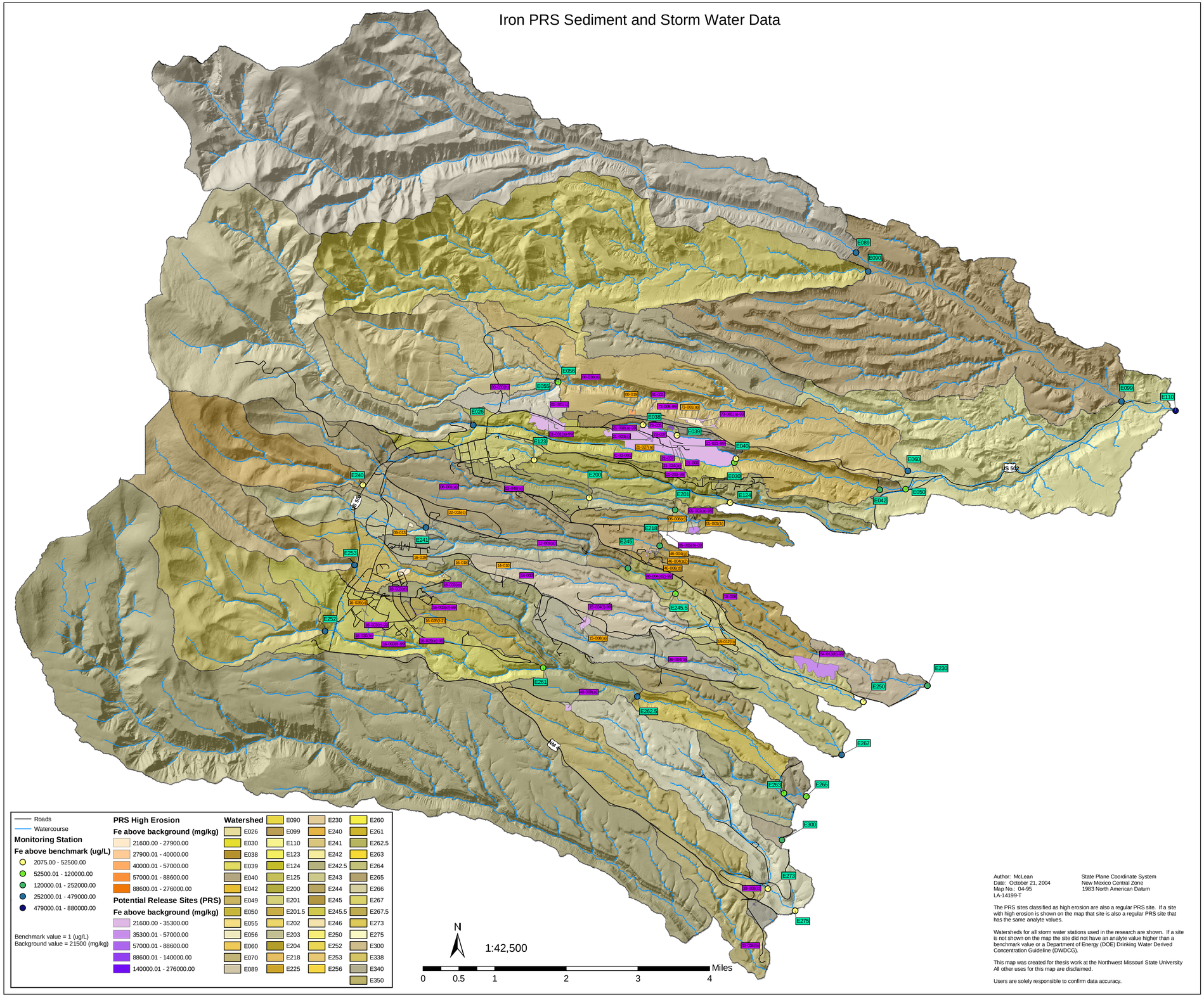
10.1.5 Figure A5 Iron PRS Sediment and Storm Water Data

Iron PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
LA-14199-T

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum

The PRS sites classified as high erosion are also a regular PRS site. If a site with high erosion is shown on the map that site is also a regular PRS site that has the same analyte values.

Watersheds for all storm water stations used in the research are shown. If a site is not shown on the map the site did not have an analyte value higher than a benchmark value or a Department of Energy (DOE) Drinking Water Derived Concentration Guideline (DWDCG).

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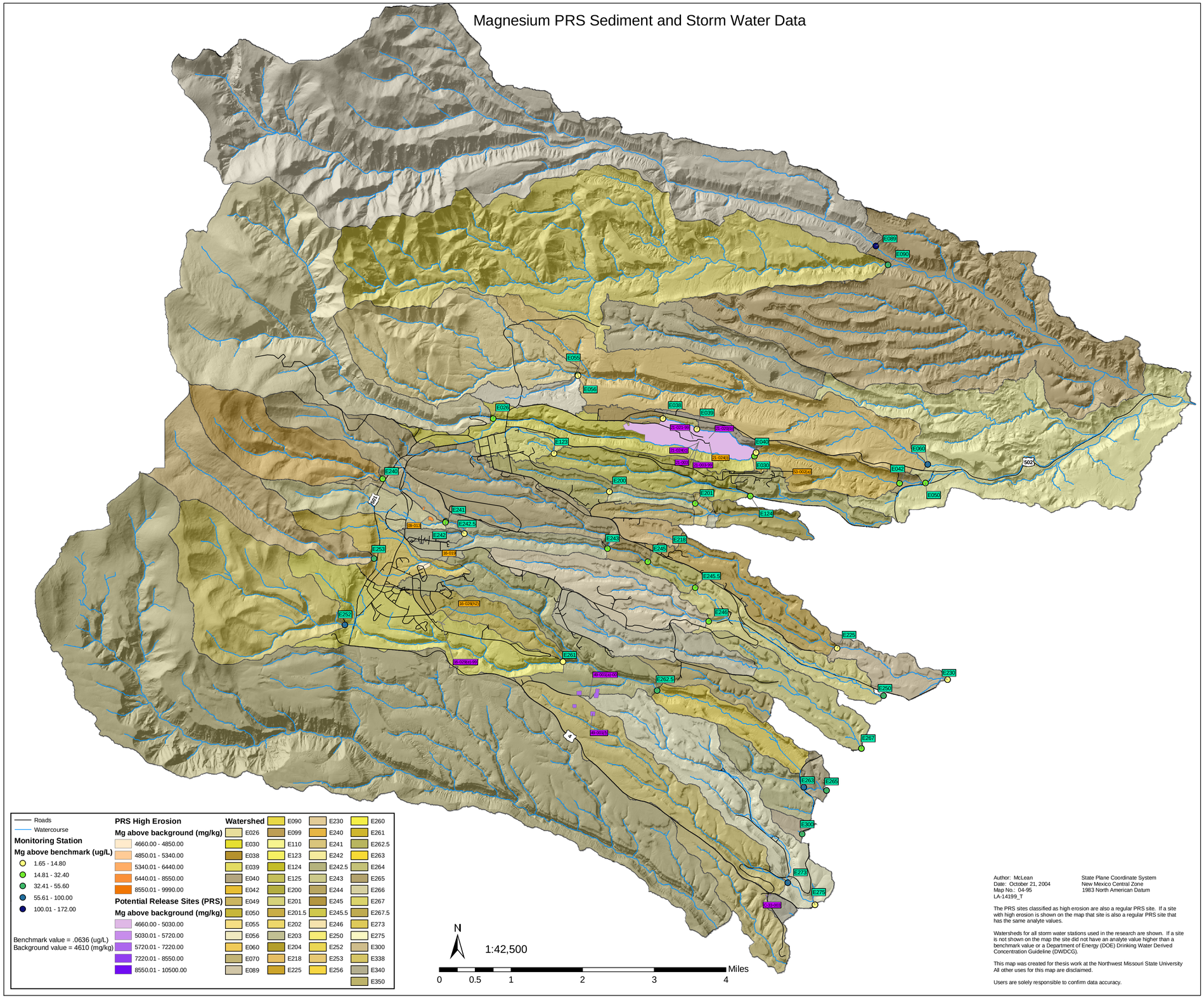
10.1.6 Figure A6Magnesium PRS Sediment and Storm Water Data

Magnesium PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
LA-14199_T

State Plane Coordinate System
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1983 North American Datum

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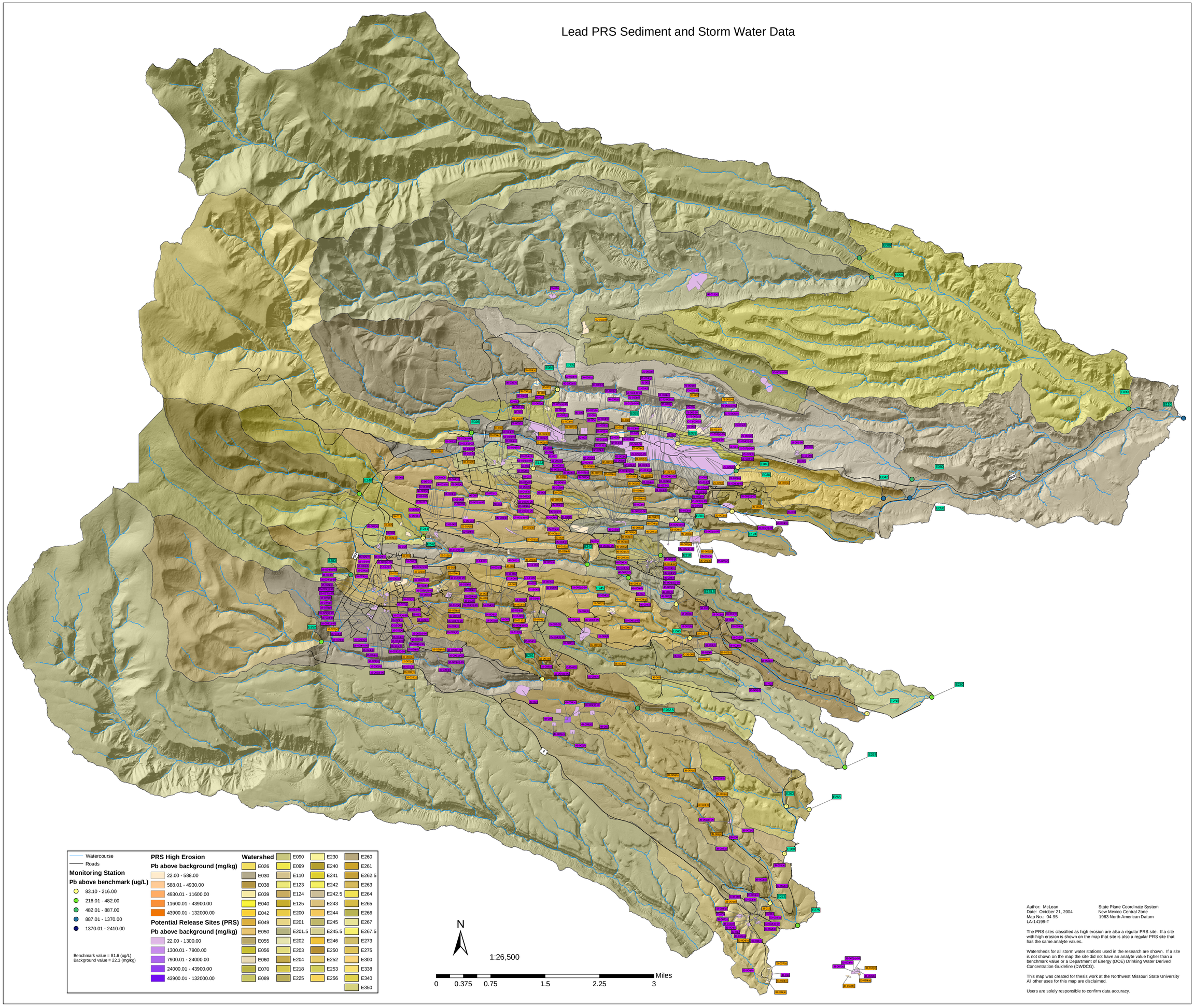
10.1.7 Figure A7Lead PRS Sediment and Storm Water Data

Lead PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
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State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum

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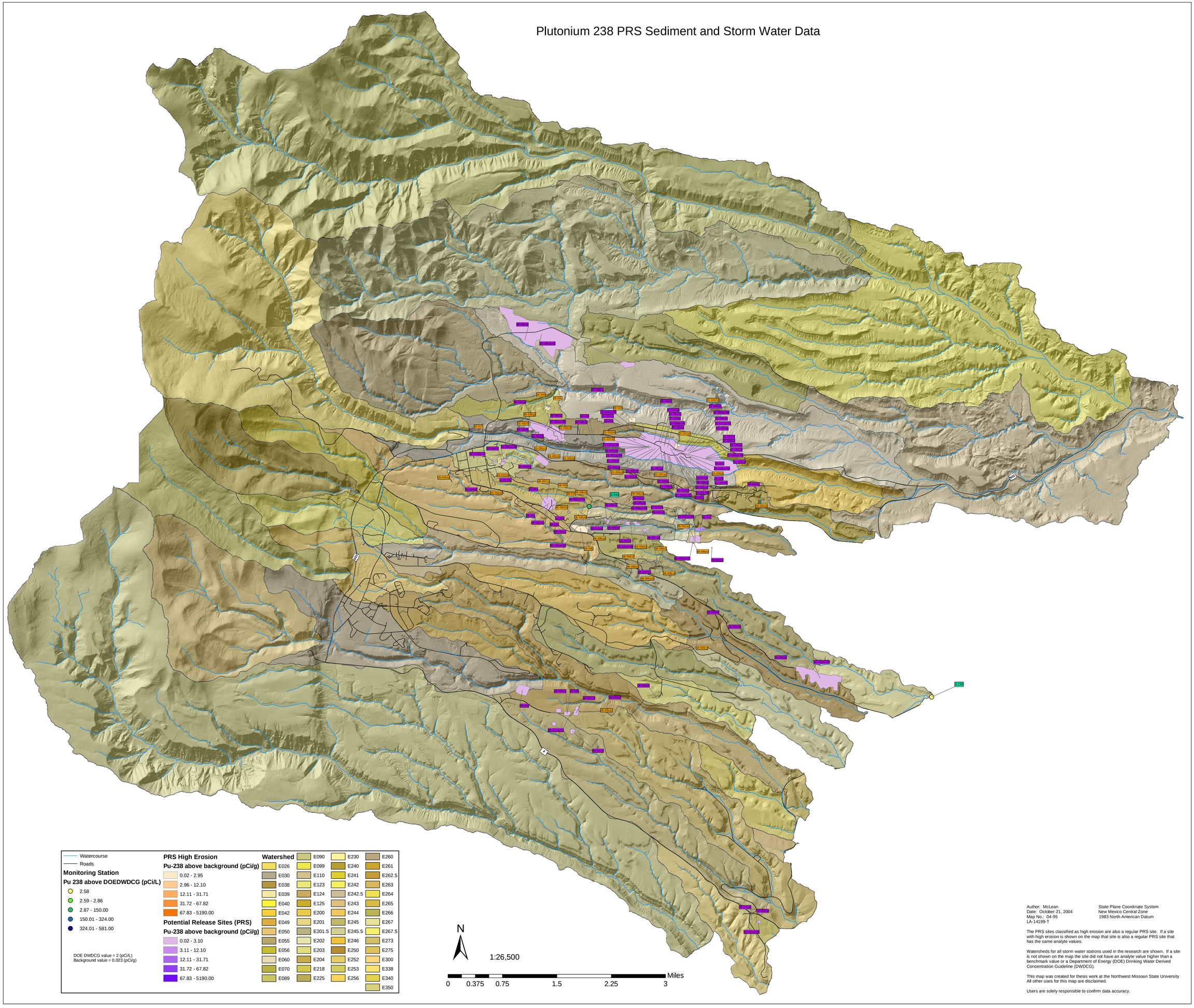
10.1.8 Figure A8 Plutonium 238 PRS Sediment and Storm Water Data

Plutonium 238 PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
LA-14199-T

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum

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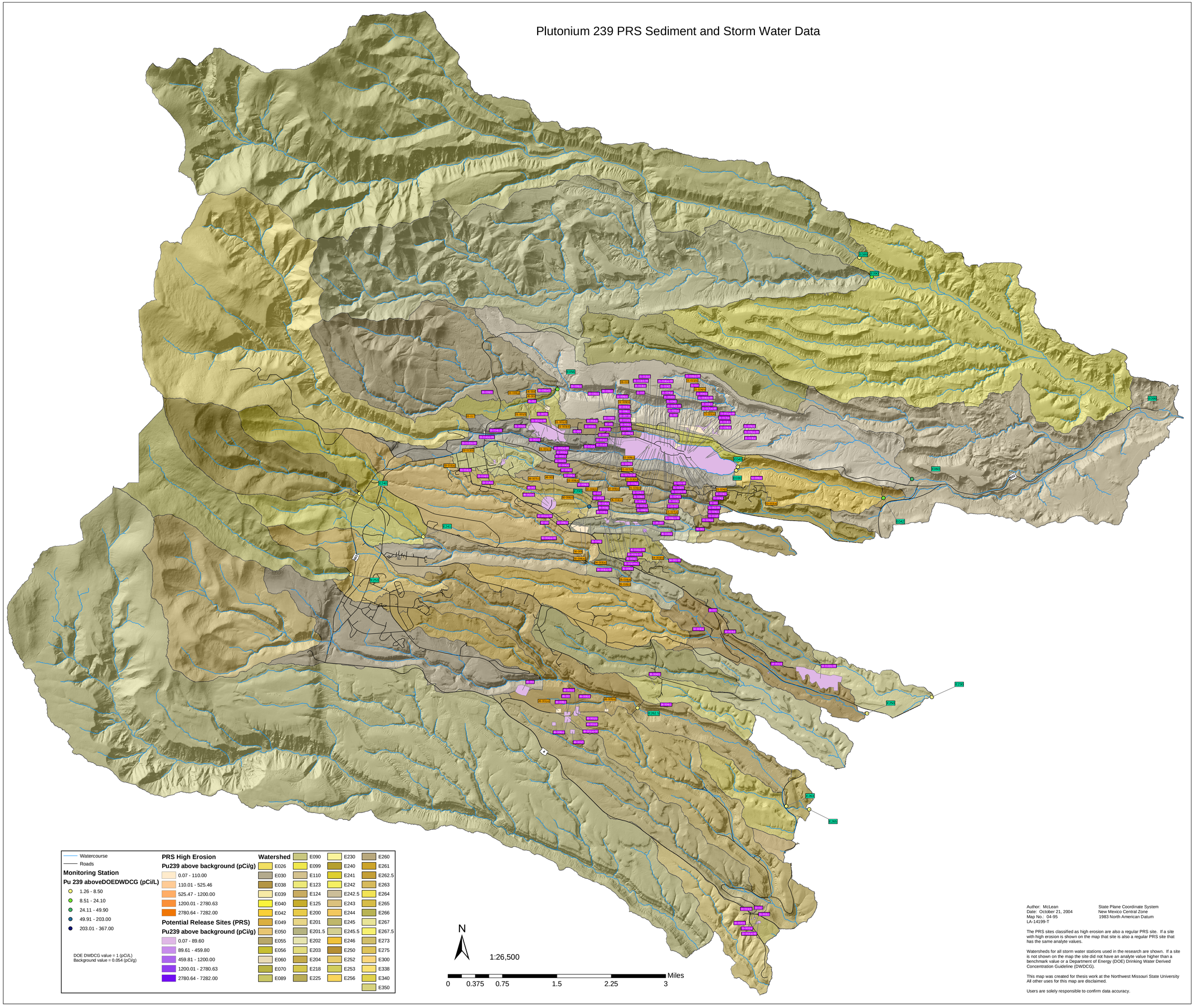
10.1.9 Figure A9 Plutonium 239 PRS Sediment and Storm Water Data

Plutonium 239 PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
LA-14199-T

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum

The PRS sites classified as high erosion are also a regular PRS site. If a site with high erosion is shown on the map that site is also a regular PRS site that has the same analyte values.

Watersheds for all storm water stations used in the research are shown. If a site is not shown on the map the site did not have an analyte value higher than a benchmark value or a Department of Energy (DOE) Drinking Water Derived Concentration Guideline (DWDCG).

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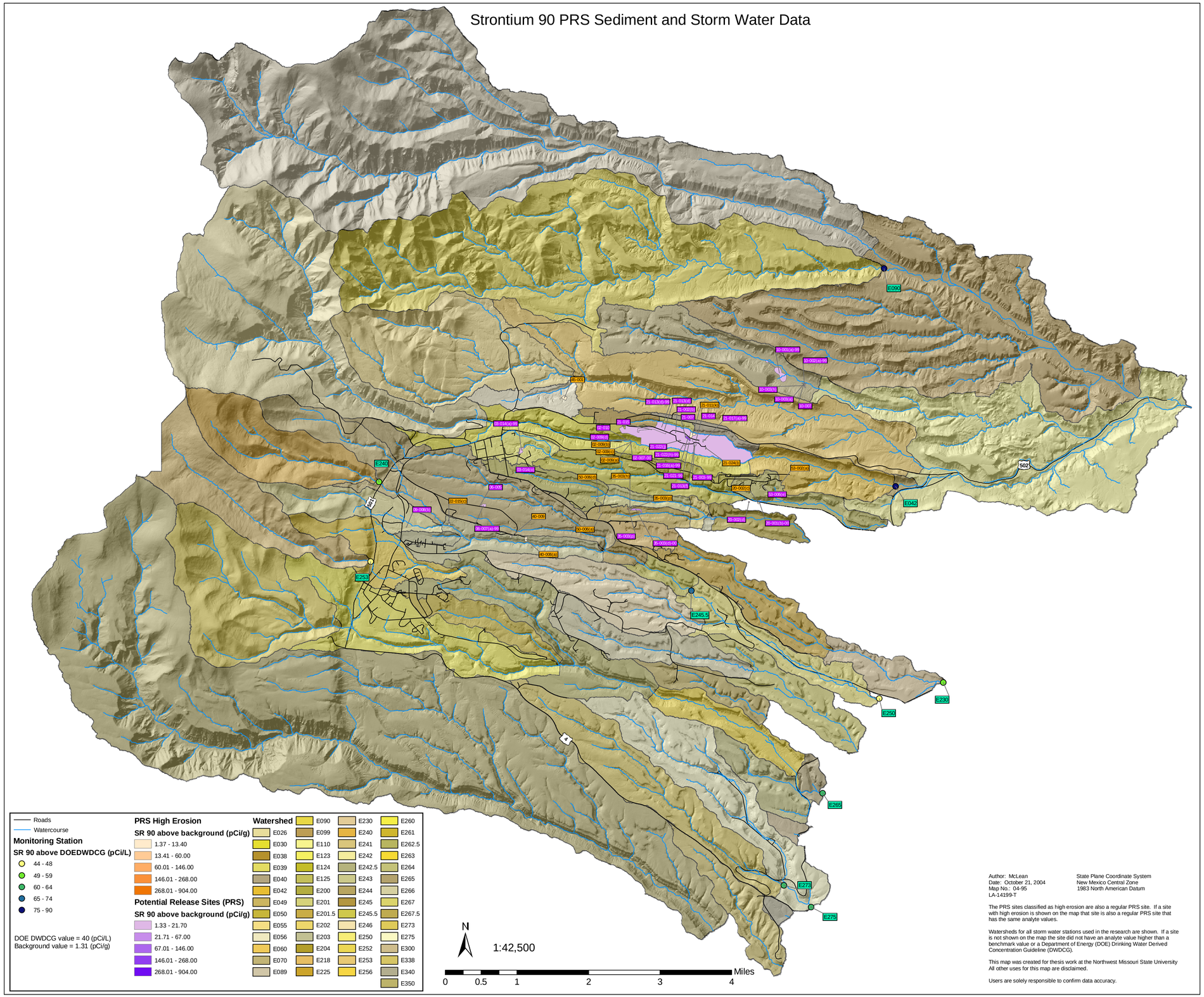
10.1.10 Figure A10 Strontium 90 PRS Sediment and Storm Water Data

Strontium 90 PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
LA-14199-T

State Plane Coordinate System
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1983 North American Datum

The PRS sites classified as high erosion are also a regular PRS site. If a site with high erosion is shown on the map that site is also a regular PRS site that has the same analyte values.

Watersheds for all storm water stations used in the research are shown. If a site is not shown on the map the site did not have an analyte value higher than a benchmark value or a Department of Energy (DOE) Drinking Water Derived Concentration Guideline (DWDCG).

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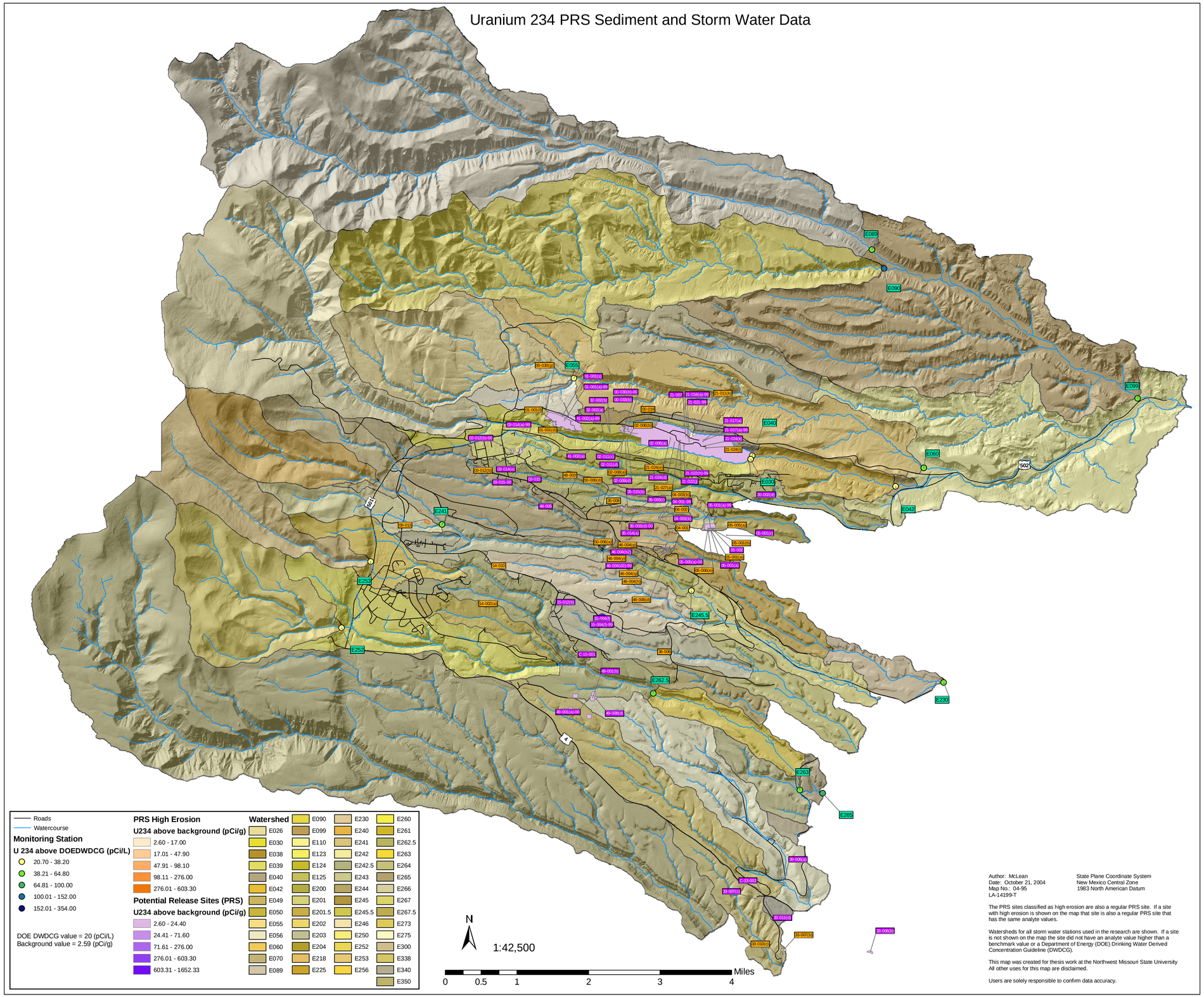
10.1.11 Figure A11 Uranium 234 PRS Sediment and Storm Water Data

Uranium 234 PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
LA-14199-T

State Plane Coordinate System
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Watersheds for all storm water stations used in the research are shown. If a site is not shown on the map the site did not have an analyte value higher than a benchmark value or a Department of Energy (DOE) Drinking Water Derived Concentration Guideline (DWDCG).

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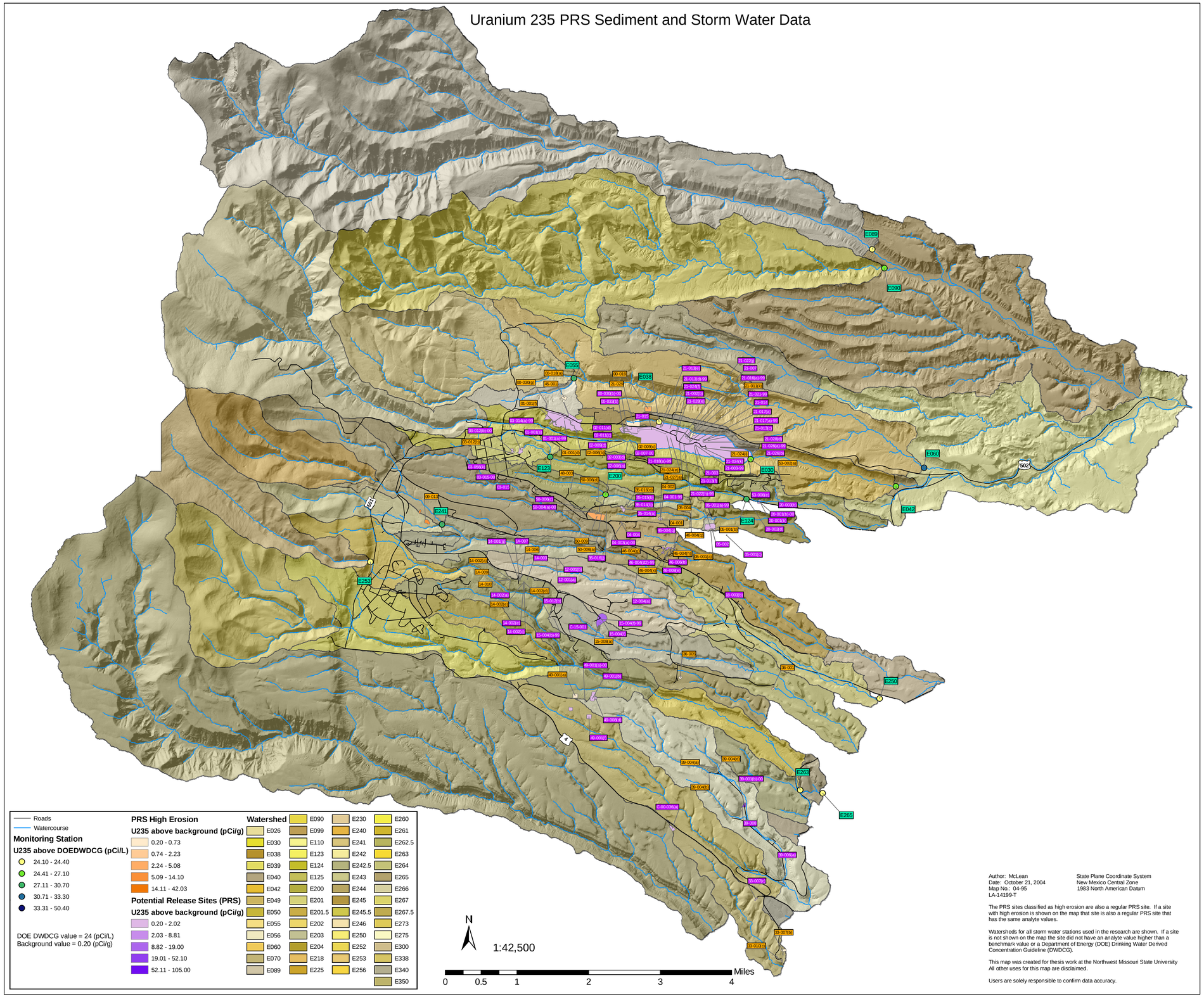
10.1.12 Figure A12 Uranium 235 PRS Sediment and Storm Water Data

Uranium 235 PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
LA-14199-T

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum

The PRS sites classified as high erosion are also a regular PRS site. If a site with high erosion is shown on the map that site is also a regular PRS site that has the same analyte values.

Watersheds for all storm water stations used in the research are shown. If a site is not shown on the map the site did not have an analyte value higher than a benchmark value or a Department of Energy (DOE) Drinking Water Derived Concentration Guideline (DWDCG).

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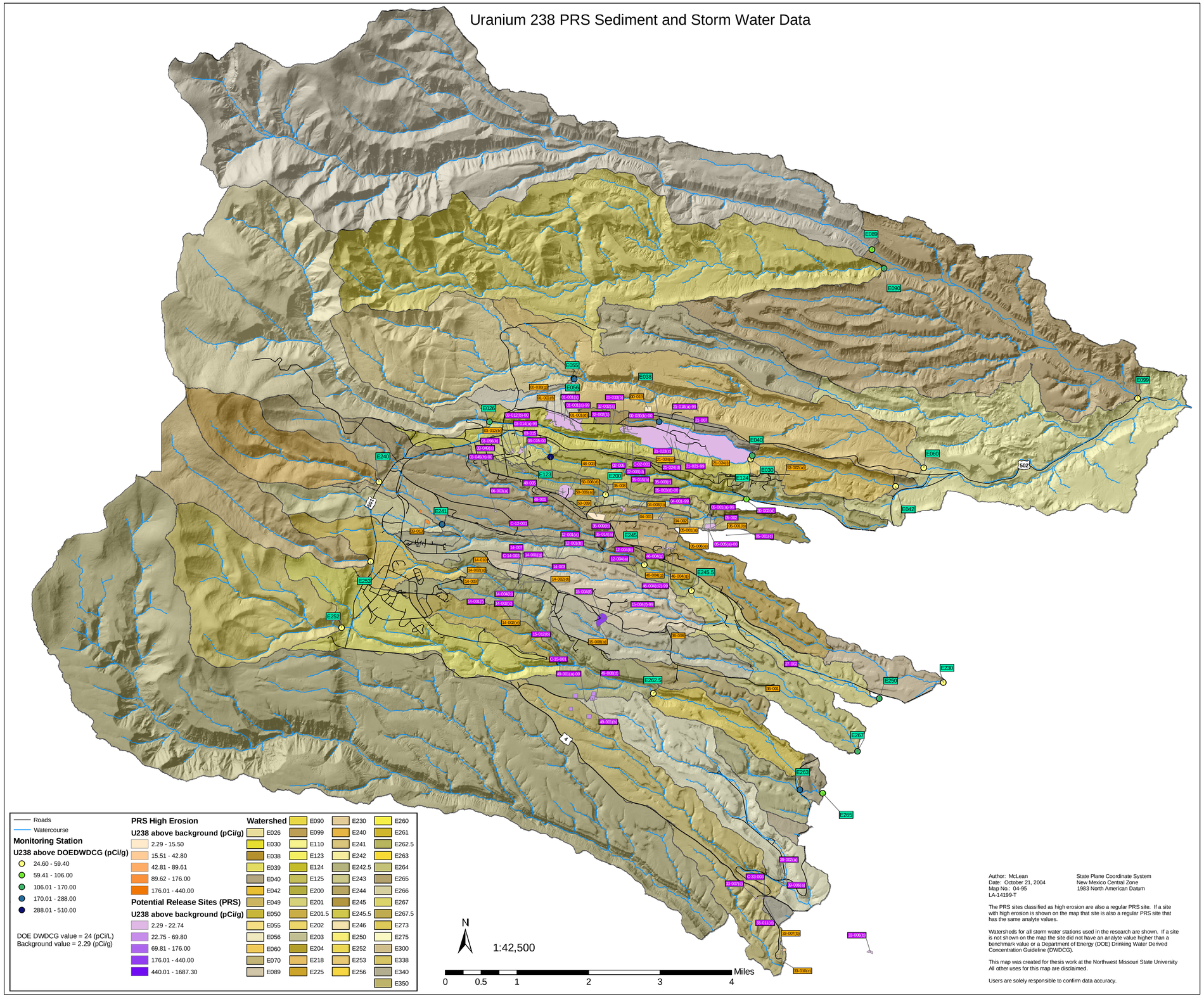
10.1.13 Figure A13 Uranium 238 PRS Sediment and Storm Water Data

Uranium 238 PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
LA-14199-T

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum

The PRS sites classified as high erosion are also a regular PRS site. If a site with high erosion is shown on the map that site is also a regular PRS site that has the same analyte values.

Watersheds for all storm water stations used in the research are shown. If a site is not shown on the map the site did not have an analyte value higher than a benchmark value or a Department of Energy (DOE) Drinking Water Derived Concentration Guideline (DWDCG).

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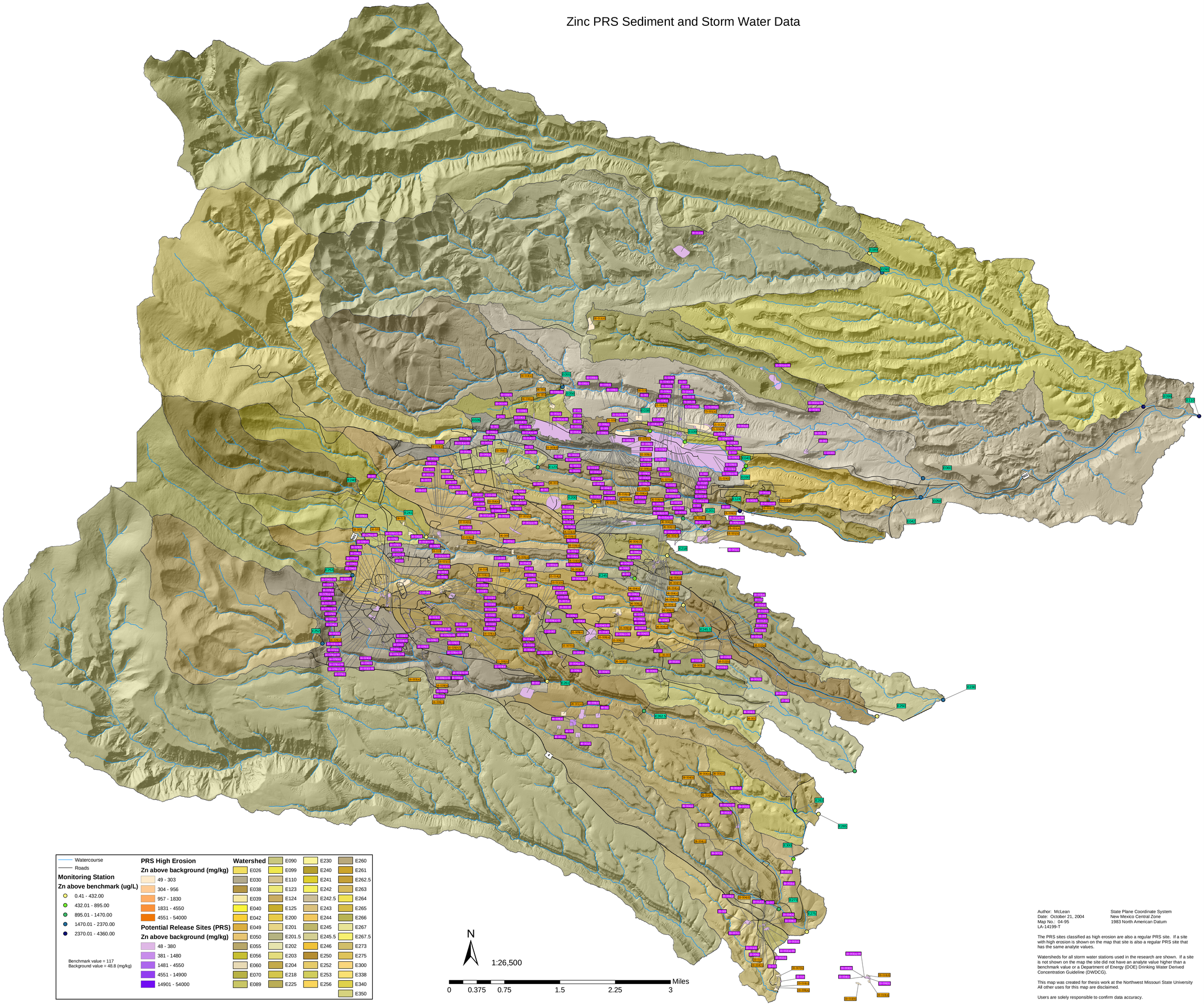
10.1.14 Figure A14 Zinc PRS Sediment and Storm Water Data

Zinc PRS Sediment and Storm Water Data



Author: McLean
Date: October 21, 2004
Map No.: 04-95
LA-14199-T

State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum

The PRS sites classified as high erosion are also a regular PRS site. If a site with high erosion is shown on the map that site is also a regular PRS site that has the same analyte values.

Watersheds for all storm water stations used in the research are shown. If a site is not shown on the map the site did not have an analyte value higher than a benchmark value or a Department of Energy (DOE) Drinking Water Derived Concentration Gudeline (DWDCG).

This map was created for thesis work at the Northwest Missouri State University All other uses for this map are disclaimed.

Users are solely responsible to confirm data accuracy.

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