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Baseline Mapping Study of the Steed Pond Aquifer and Crouch Branch Confining Unit Beneath A/M Area, Savannah River Site, Aiken, South Carolina (U)

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EXECUTIVE SUMMARY

This report presents the results of a baseline mapping project conducted for the Environmental Restoration Department (ERD) at Savannah River Site. The purpose of this report is to map the distribution of mud (clay and silt-sized material) within each hydrogeologic unit from the surface down to the top of the Crouch Branch aquifer beneath the A/M Area. The distribution of mud layers and variations in the percentage of clay and silt within the strata is extremely important in order to fully characterize the extent of DNAPL beneath the A/M Area and determine the geometry of the contaminant plumes emanating from them. Precision mapping of these layers can aid in locating areas where contamination is most likely to have migrated into the saturated zone. In addition, this information can be used to refine the current remediation systems or assist in designing new remedial systems.

This report models, in ascending order, the Crouch Branch confining unit, the "Lost Lake" aquifer zone, the "green clay" confining zone, and the "M Area" aquifer zone of the Steed Pond aquifer, and the vadose zone. The model is based on sedimentological and geophysical data from 42 selected cores in the study area. The report presents altitude-contour, isopach and lithofacies mud distribution maps of each unit.

The mud distribution for the "lower", "middle", and "upper" intervals of the Crouch Branch confining unit indicates a series of abrupt facies changes beneath the study area. The distribution of mud in the northern sector of the study area indicates all three intervals consist primarily of sand. In the remainder of the study area, the "middle" and "upper" intervals both consist primarily of sand, with a relatively sporadic distribution of mud in comparison to the "lower" interval. The "lower interval" consists primarily of thick clay layers with high mud percentages in the central and southern sectors of the study area and represents the most competent and extensive portion of the Crouch Branch confining unit. The absence of significant quantities of mud from all three intervals in the northern sector of the A/M Area indicates that the overlying Steed Pond aquifer is in hydraulic communication with the Crouch Branch aquifer in this region. This facies change is probably a significant contributor to the migration of dissolved contamination from the Steed Pond aquifer into the Crouch Branch aquifer.

The mud distribution is sporadic for zones within the Steed Pond aquifer. The "Lost Lake" aquifer zone has a low mud distribution with the exception of the southwest corner of the study area. The most prominent feature recognized in the "Lost Lake" aquifer zone is a

sandy region extending north-south through the central portion of the study area. This interval contains less than 10% mud and exceeds 50 feet in thickness, representing a significant permeable sand body that may serve as a preferential contaminant pathway. The "green clay" confining zone consists primarily of sand with moderate amounts of interbedded clay present in the southeastern part of the study area where the unit is relatively thin. The "green clay" is probably a competent confining zone southeast of the M Area Basin. The interval which comprises the "M Area" aquifer zone and vadose zone is characterized by relatively clean sand interbedded with thin and discontinuous silty sand and clay. These layers constitute a small fraction of the total thickness and are not apparent when averaged over the entire interval, indicating that the "M Area" aquifer zone and vadose zone require further differentiation to be modeled effectively using the techniques described in the report.

Enhancement of the baseline mapping study would benefit from: 1) coupling the facies analysis with observed groundwater contamination data to refine plume geometry, 2) addition of shallower cores to the data set that meet the same quality assurance requirements to enhance model resolution, 3) delineation of depositional intervals within the "M Area" aquifer zone and vadose zone to increase the vertical resolution of the hydrogeologic model and identify areas of possible DNAPL contamination riding on the fine-grained sediment layers within the vadose zone.

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ACRONYMS

bgl	below ground level
CBA	Crouch Branch aquifer
CBCU	Crouch Branch confining unit
DEM	digital elevation model
DOE	United States Department of Energy
DNAPL	dense, non-aqueous phase liquid
ESSOP	Environmental Sciences Section Operating Procedure
ft	foot/feet
GCCZ	"green clay" confining zone (of the Steed Pond aquifer)
GIMS	Geochemical Information Management System
ID	identification
kg	kilogram
LLAZ	"Lost Lake" aquifer zone (of the Steed Pond aquifer)
m	meter(s)
MAAZ	"M Area" aquifer zone (of the Steed Pond aquifer)
msl	mean sea level
PCE	perchloroethene (tetrachloroethylene)
ppm	part(s) per million
QA	Quality Assurance
QC	Quality Control
SPA	Steed Pond aquifer

ACRONYMS (Continued)

SRS	Savannah River Site
SRTC	Savannah River Technology Center
TCE	trichloroethylene
TDEM	time-domain electromagnetic
VOC	volatile organic compound
WSRC	Westinghouse Savannah River Company
yr	year

1.0 INTRODUCTION

1.1 Background

The Savannah River Site (SRS) is a U.S. Department of Energy (DOE) facility that was set aside in 1950 as a controlled area for production of nuclear materials for national defense. The DOE and its contractors are responsible for the operation of the SRS. Westinghouse Savannah River Company (WSRC) currently manages and operates the site.

This report focuses on the A/M Area at the north boundary of the SRS (Figure 1-1). This area includes the facilities which were used for fabrication of reactor fuel and target assemblies (M Area), laboratory facilities (SRTC), and administrative support facilities (A Area). Operations within the A/M Area resulted in the release of chlorinated solvents to the subsurface (Marine and Bledsoe, 1984). Released solvents include trichlorethylene (TCE), tetrachloroethylene (PCE) and 1,1,1-trichloroethane (TCA) which have contaminated the soil and groundwater within the area. Since the detection of these volatile organic compounds (VOCs), the SRS has aggressively pursued a rigorous program of soil and groundwater remediation. The SRS remediation program includes a series of soil-vapor extraction units for removal of contaminants in the vadose zone, and an extensive network of recovery wells for extraction and treatment of groundwater. SRS maintains an on-site research and demonstration program for developing innovative remediation techniques and maximizing the efficiency and effectiveness of the SRS remediation strategy. The SRS remediation strategy includes on-going characterization of subsurface features and conditions that may have a significant influence on groundwater flow and contaminant transport.

1.2 Objective and Approach

This report presents the results of a baseline mapping project conducted for the Environmental Restoration Department (ERD) at SRS. The purpose of this report is to map the distribution of mud (clay and silt-sized material) within each hydrogeologic unit from the surface down to the top of the Crouch Branch aquifer beneath the A/M Area. Recent characterization efforts have focused on locating VOCs in dense non-aqueous phase liquids (DNAPL) in the subsurface which serve as a long-term source for dissolved groundwater contamination within the A/M Area (Looney and others, 1992). DNAPL migrates down through the vadose zone into the saturated zone. The relatively high density of the DNAPL causes it to move in an overall vertical direction, following a "path of least resistance" through zones of highly permeable, coarse-grained sand and gravel. The DNAPLs tend to slow and spread laterally upon encountering strata composed of less-permeable silty sand and clay. Distribution of DNAPL is therefore related to the distribution of less-permeable, fine-grained sediment. Indirect assessment techniques have been applied to historical groundwater concentrations in the A/M Area and indicate that the distribution of DNAPL may be laterally extensive (Jackson et al., 1996).

Once emplaced within the saturated zone, the DNAPL serves as a source for the release of dissolved phases of VOCs to the groundwater. The dissolved VOCs are carried within the groundwater in the form of plumes, which emanate from the DNAPL and extend in a direction parallel to the local gradient. The transport and fate of dissolved VOCs depends upon the extent of the "source" DNAPL, and the distribution of coarse-grained sand and gravel within the aquifer.

The distribution of fine-grained sediment layers and variations in the percentage of clay and silt within the strata is extremely important in order to fully characterize the extent of DNAPL layers beneath the A/M Area and determine the geometry of the contaminant plumes emanating from them. Precision mapping of these geologic features can aid in locating areas where contamination is most likely to have migrated into the saturated zone. These data are valuable aids for accurate modeling of groundwater flow and contaminant transport. In addition, this information can be used to refine the current remediation systems or assist in designing new remedial systems.

1.3 Description of the Study Area

The SRS occupies approximately 300 square miles within Aiken, Barnwell, and Allendale counties in southwestern South Carolina. The site is centered 22.5 miles southeast of Augusta, Georgia, approximately 100 miles from the Atlantic Coast within the Upper Atlantic Coastal Plain Physiographic Province (Figure 1-1). The SRS is situated on the Aiken Plateau of the Atlantic Coastal Plain at an average elevation of 300 feet above mean sea level (ft msl). Overall, the plateau has a highly dissected surface characterized by broad inter-fluvial areas with narrow, steep-sided valleys. Local relief can attain 280 feet (Siple, 1967). The Aiken plateau is well drained, although many poorly drained sinks and depressions exist, especially in upland areas. The Savannah River forms the southwest boundary of the SRS (Figure 1-1). The study area comprises approximately eight square miles in the A/M Area near the northern boundary of the SRS (Figure 1-2).

1.3.1 *Lithostratigraphy*

The SRS is underlain by sediment of the Atlantic Coastal Plain. The Atlantic Coastal Plain consists of a southeast-dipping wedge of unconsolidated and semi-consolidated sediment that extends from its contact with the Piedmont Province at the Fall Line to the edge of the continental shelf. These deposits consist of sediment that is deltaic and near-shore marine in origin, with evidence of considerable fluvial influence (Fallaw and Price, 1995). The sediment consists of interbedded sand, muddy sand, and mud (clay and silt), with a subordinate amount of calcareous sediment. Strata range from Late Cretaceous to Miocene in age and rest unconformably on crystalline and sedimentary basement rock (Figure 1-3). The A/M Area lies within the up-dip area of the coastal plain deposits, approximately 20 miles from the Fall Line (Figure 1-1). Beneath the A/M Area, Cretaceous-aged strata rest on crystalline basement rock at a depth of 500 to 700 feet below the land surface (ft bls).

Detailed descriptions of the geology and lithostratigraphy of the SRS and A/M Area are presented in several recent reports (Gordon, 1982; Christensen and Gordon, 1983; Fallaw and Sargent, 1982; Colquhoun and others, 1983; Marine and Bledsoe, 1984; Logan and Euler, 1989; Fallaw and others, 1990; Aadland and others, 1991; Snipes, 1991; Fallaw and Price, 1992; Lewis and Aadland, 1992; Lewis and Aadland, 1994; Aadland and others, 1995; and Fallaw and Price, 1995). This study utilizes the lithostratigraphic nomenclature presented in Fallaw and Price (1995).

1.3.2 *Hydrostratigraphy of the Study Area*

The hydrostratigraphy of the SRS has been the subject of several different systems of hydrostratigraphic classification. This report incorporates the hydrostratigraphic nomenclature currently established for the SRS region and A/M Area by Aadland and others (1995a, 1995b). This study focuses on the up-dip part of the Floridan-Midville aquifer system as defined for A/M Area by Aadland and others (1995b). Strata within units of the Floridan-Midville aquifer system that exhibit internally consistent hydraulic characteristics and which, on a local scale, behave as distinct hydrostratigraphic units, are delineated as informal aquifer and confining zones (Aadland and others, 1995b). Figure 1-3 correlates the nomenclature of Aadland and others (1995b) with the lithostratigraphy of Fallaw and Price (1995).

The hydrostratigraphy of the A/M Area consists of three aquifers within the Floridan-Midville aquifer system divided by one confining unit and one confining system.

The hydrostratigraphy of A/M Area includes three aquifers of the Floridan-Midville aquifer system. The Floridan-Midville aquifer system includes, in descending order, the McQueen Branch aquifer, the Crouch Branch aquifer, and the Steed Pond aquifer. The Crouch Branch aquifer (CBA) is the principal water-producing aquifer at SRS and is the deepest unit that is sampled by the current monitoring well system. This study focuses on the hydrogeology of the units that overlie the CBA.

1.3.2.1 Crouch Branch Confining Unit

The Crouch Branch confining unit (CBCU) separates the Crouch Branch aquifer from the Steed Pond aquifer. The CBCU may be divided into three hydrogeologic zones beneath the A/M Area (Aadland and others, 1995b). These zones, in descending order, are the "upper clay" confining zone, the "middle sand" aquifer zone, and the "lower clay" confining zone. The "upper clay" confining zone thins and disappears toward the northern edge of A/M Area. In this region, the "middle sand" aquifer zone coalesces with the overlying "Lost Lake" aquifer zone of the Steed Pond aquifer. In the western part of the A/M Area, these zones are not delineated due to the absence of the sand beds referred to as the "middle sand" aquifer zone. In the northeastern portion of the area the clay beds of the "upper clay" and "lower clay" zone of the unit are thin or absent. It is in this region where groundwater flow occurs between the overlying Steed Pond aquifer and the underlying Crouch Branch aquifer (Aadland and others, 1995b).

1.3.2.2 Steed Pond Aquifer

The Steed Pond Aquifer (SPA) is composed primarily of sand and clayey sands interbeds (Aadland and others, 1995b). The SPA is divided into the "M Area" aquifer zone, "green clay" confining zone, and "Lost Lake" aquifer zone. In areas where the "green clay" confining zone thins and disappears the "M Area" aquifer zone coalesces with the "Lost Lake" aquifer zone and is referred to simply as the undifferentiated SPA.

"Lost Lake" aquifer zone. The "Lost Lake" aquifer zone (LLAZ) consists of yellow, tan, orange, and brown , loose to slightly indurated, fine to coarse, moderately to well-sorted, occasionally pebbly sand and minor clayey sand.

"Green Clay" confining zone. The "Green Clay" confining zone (GCCZ) overlies the LLAZ. This zone is considered correlative with the clay and silty clay beds of the Gordon confining unit of the Floridan aquifer system south of Upper Three Runs (Aadland and others, 1995b). In the A/M Area the "green clay" confining zone consists of primarily orange and yellow, fine to coarse, poorly to well-sorted, often pebbly sand and clayey sand interbedded with gray, green, and tan clay to silty clay beds (Fallaw and Price, 1992). Aadland and others (1995b) consider these clay and silty clay beds the "green clay" confining zone when they are sufficiently thick and continuous.

"M Area" aquifer zone. The "M Area" aquifer zone (MAAZ) extends from the water table to the top of the "green clay" confining zone (Aadland and others, 1995b). In A/M Area the MAAZ consists of orange to tan and yellow, fine to coarse, poorly to well-sorted sand of the Tobacco Road and Dry Branch formations (Fallaw and Price, 1992). Pebbly layers, interbedded clay laminae, and clay interbeds (up to 8 ft thick) are common.

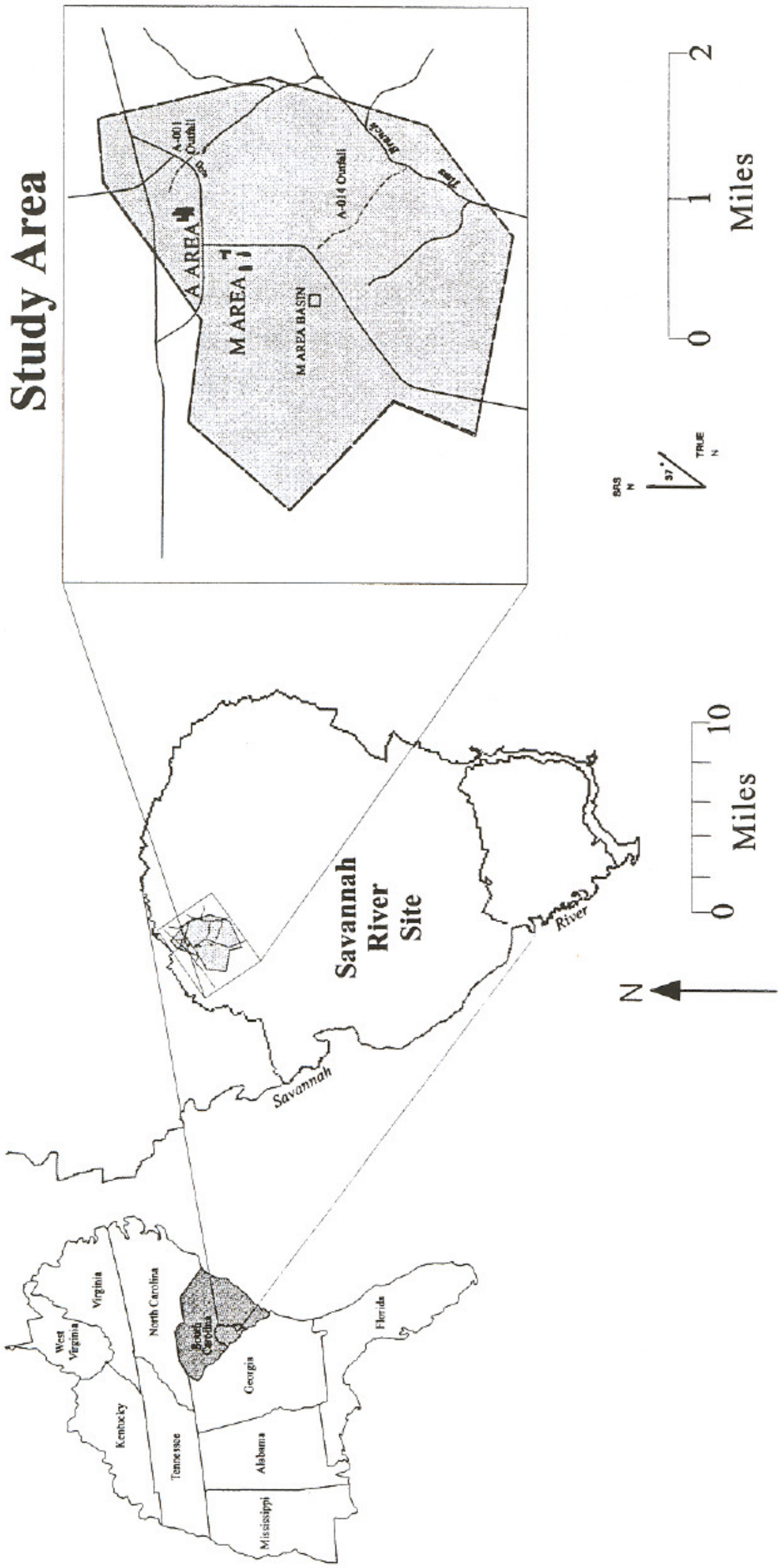


Figure 1-1. Location of the Savannah River Site and the A/M Area

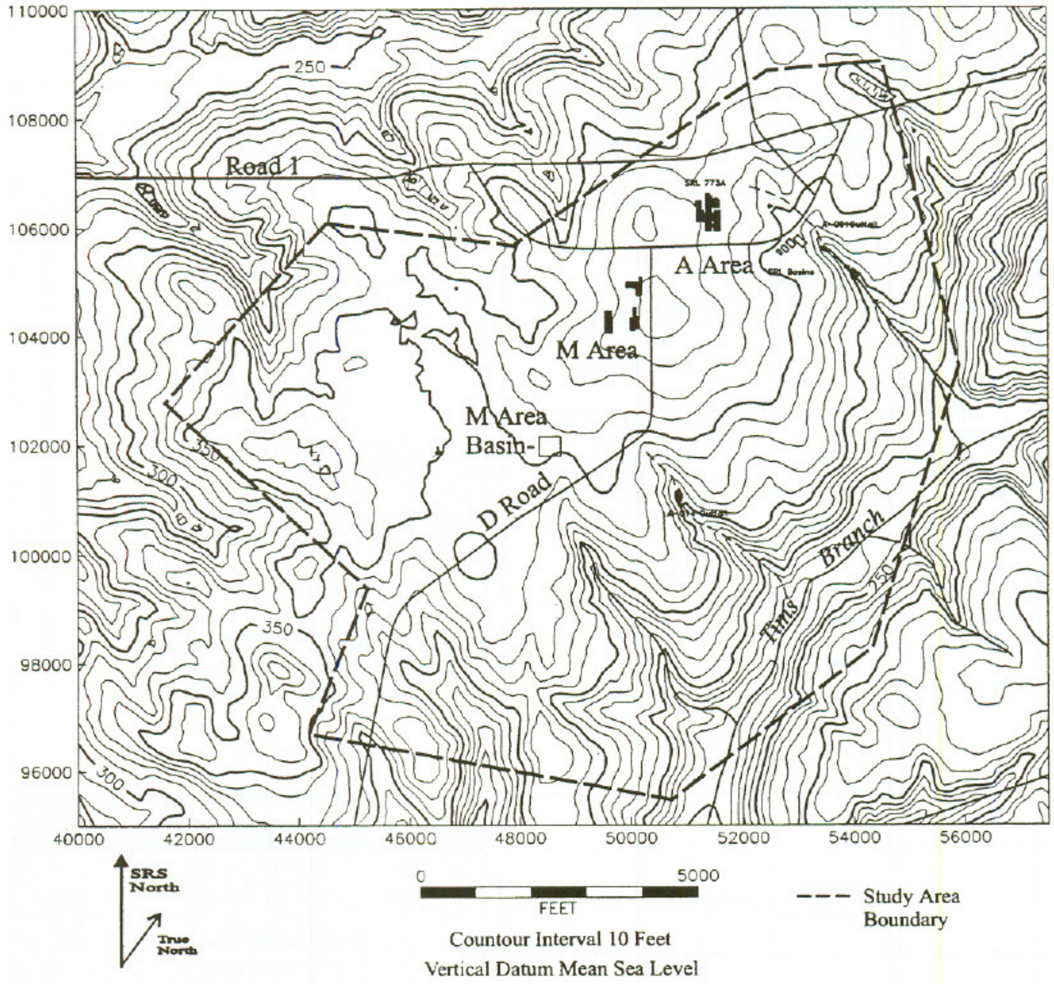


Figure 1-2. Topography of the A/M Area and Study Area Boundary

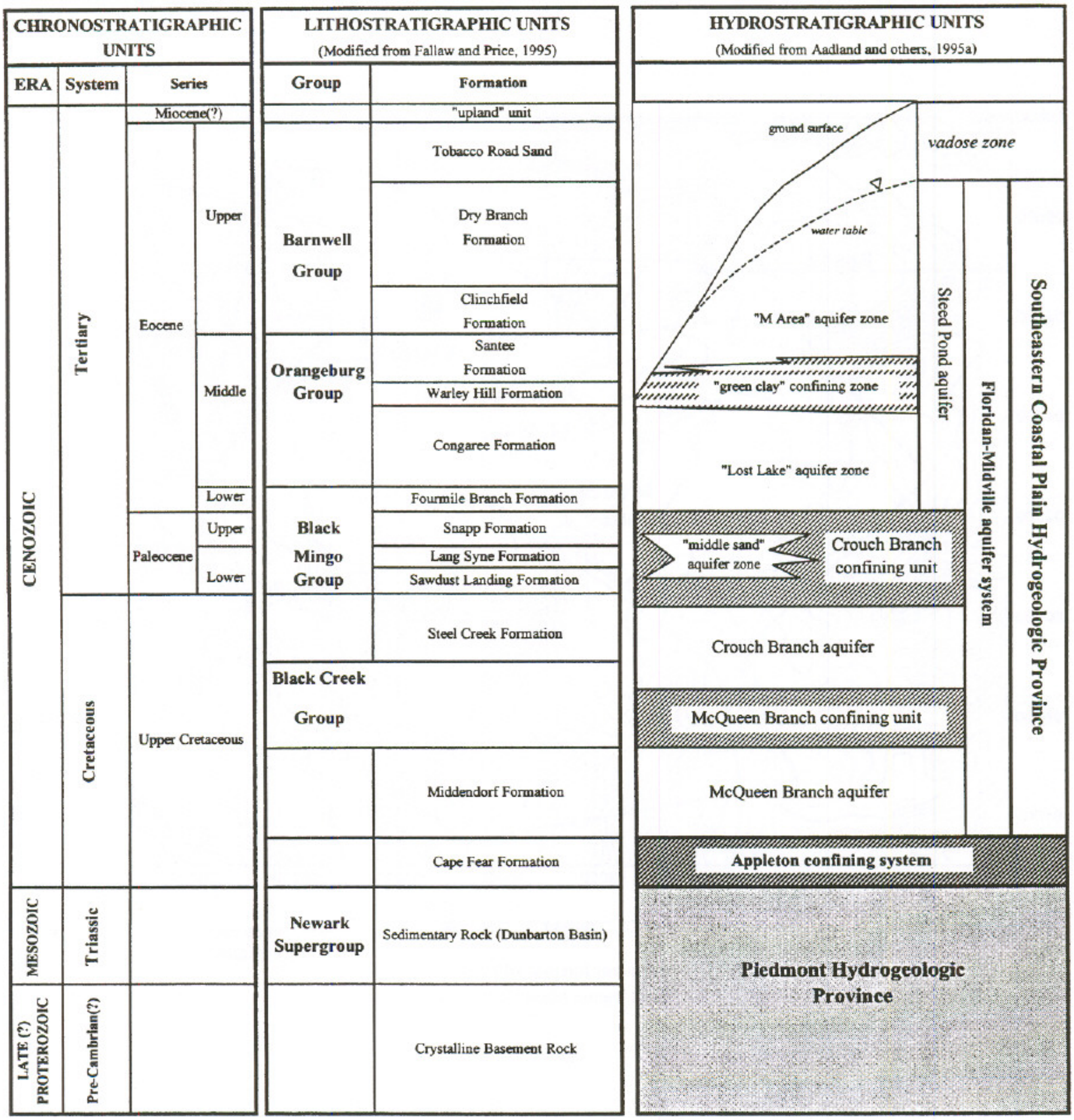


Figure 1-3. Comparison of Lithostratigraphic and Hydrostratigraphic Units beneath A/M Area at SRS

2.0 METHODS

Data utilized in this study include SRS coordinates, elevations, geophysical logs, and drill-core descriptions. The study utilized down-hole geophysical data including caliper, gamma-ray and resistivity logs for delineating aquifer and confining units and for correlating specific horizons from core to core.

2.1 Data Collection

This study utilized data from 42 continuous cores drilled in A/M Area (Figure 2-1, Table 2-1). The quality requirements of this study included an internally consistent set of data. This required that the core descriptions be consistent so that similar horizons could be readily identified and correlated. All of the cores were drilled during the past five years and were described on a foot-by-foot basis in the SRS Core Laboratory by geologists working under the same Quality Assurance and Quality Control (QA/QC) program.

The process for selection of the cores was two-fold. Initially all of the cores drilled within the A/M area were considered. However, due to the poor condition of many of the older cores, the relatively shallow depth of penetration, and poor core recovery, many of these were eliminated from consideration for use in this study. Criteria for the final core selection was based on:

total depth drilled;

overall core recovery;

consistency of core description;

geographic location;

current condition of the core;

availability of geophysical logs.

It was considered extremely important that the cores penetrate the CBCU for delineation of the vertical and lateral extent of fine-grained sediments within this unit.

The core descriptions used in this study are included as Appendix A to this report. All core samples have been described following ESSOP-2-15 (WSRC, 1990). A summary of the core description format is included as Appendix B.

Most of the cores used in this study were drilled as soil borings for exploratory purposes and were not completed as monitoring wells. Because of this, many of the core locations have only been documented in field activities reports for the soil boring installations. Some of the coordinates provided in these reports are preliminary, pre-drill locations. Based on this study the preliminary, pre-drill locations should be validated. This study deferred to the core locations provided in Appendix C of Aadland and others (1995b). The locations of cores drilled after 1995 were taken from field activities reports or sources. Table 2-2 lists the source for each core location.

2.2 Data Qualification

A rigorous Quality Review of the data was performed, comparing the core descriptions and geophysical logs with the list of unit boundaries. Geologists made refinements to these boundaries to ensure internal consistency between the unit boundaries and the lithology of the hydrostratigraphic units.

2.3 Database Structure

A relational database was constructed for this project using Paradox® (version 7.0) software. All geological and hydrological data was collected for the A/M Area and entered into the database. Measured values were integrated with the hydrostratigraphic "picks" to create data output files to meet EarthVision® format and content requirements. The database is constructed so that revisions made to the subjective data (hydrostratigraphic "picks") are documented. The database records and dates each revision to the picked boundaries, and automatically regenerates updated output files for re-loading into EarthVision®. This aspect of the database facilitates data evaluation and revision, and provides a means by which to maintain a history of the subjective data set.

2.4 Hydrogeologic Model

2.4.1 *Hydrostratigraphic Methods*

Hydrostratigraphic boundaries for cores are determined through evaluation of several factors. Gamma-ray logs are used in combination with resistivity logs to evaluate the potential confining properties of the strata. In general, low resistivity and high gamma-ray values indicate clay-rich sediment that impedes the flow of ground water. Core descriptions are used (in conjunction with the geophysical logs) to select boundaries between confining and transmissive units. Percentage of mud and estimated porosity are the primary criteria used.

If core recovery is good, the foot-by-foot description is an excellent tool for determining the vertical extent of a confining or transmissive lithology.

Because of its variable lithology and the sporadic distribution of the “upper” clay and “middle sand” zones, the Crouch Branch confining unit was not “picked” as a single layer in the model . This study utilized sedimentological concepts to model the distribution of mud-sized material within the CBCU and SPA. Depositional sequences were identified and correlated based on lithologic parameters within each interval. The Crouch Branch confining unit is comprised of layers clay and sand layers which have been assigned to several lithostratigraphic units deposited as separate sequences (Aadland and others 1995a, 1995b). The core descriptions were used to identify distinct depositional sequences within the strata between the top of the CBA and the top of the LLAZ.

Three distinct horizons that could be consistently picked and correlated from core to core across the area were identified within the CBCU. The horizons exhibit characteristics consistent with depositional surfaces, including abundant gravel and clay balls. These horizons generally correspond with a significant change in the induration of the sediment, with looser material overlying harder material. The horizons are usually characterized by an abrupt change in modal grain size, often from clay (mud-sized sediment) to coarse sand with gravel. Clay balls similar in color to underlying clay are common within the bottom five feet of the overlying interval.

Each of the three horizons (interval tops) were correlated to distinctive geophysical signatures on the down-hole gamma-ray and resistivity logs. The log patterns were used in conjunction with the geologic descriptions to correlate the horizons from core to core.

These horizons are herein referred to as the “lower”, middle, and “upper” intervals of the CBCU. It must be emphasized that the CBCU horizons used in this study are not direct correlatives with the boundaries for the hydrostratigraphic zones within the CBCU as defined by Aadland (1995b). “Picked” tops for the hydrostratigraphic units are tabulated in Table 2-3.

The database was used to prepare a hydrogeologic model of the A/M Area. The model was constructed with EarthVision® software. EarthVision® processes sets of spatial and property data by calculating minimum-tension grids to contour a “best fit” of the data. The grids can contour data in 3 dimensions (x,y,z), such as the top of a geologic unit, as two-dimensional grids, or contour data in 4-dimensions: x,y,z, and a "property." An example of a property might be the variation of the percentage of mud within a geologic unit.

2.4.2 *Two-Dimensional Grid Calculation*

Data for the tops unit and interval horizons were exported from the Paradox® database into EarthVision®. After minor format changes, the data was processed by the EarthVision minimum-tension gridding algorithm, producing a two-dimensional grid of the horizon.

The EarthVision® model utilizes digitized x,y,z data for all U.S. Geological Survey topographic coverage of the A/M Area. The data originate from USGS digital elevation model (DEM) data files. The DEM data are processed in the same manner as the data for the unit boundaries to produce a grid representing the topography of the study area. The high density of data points in this data set produced a two-dimensional grid of exceptional accuracy and detail. This grid was then used in subsequent two-dimensional and three-dimensional gridding to determine the extent of hydrostratigraphic units that crop out in the study area.

2.4.3 *Three-Dimensional Grid Calculation*

The property data processed by EarthVision® consisted of the foot-by-foot lithologic descriptions made from continuous core samples taken from the A/M Area. Lithologic data was exported from the Paradox® database and formatted for use in the EarthVision® three-dimensional Minimum-Tension Gridding module. The EarthVision® software allows a wide variety of options in how the three-dimensional grids are calculated. The lithology was first processed using the two-dimensional grids of the lithostratigraphic units as limiting surfaces. This effectively prevented the model from "seeing" any lithologic information from outside the lithostratigraphic interval during the gridding process. The gridding algorithm then calculated "best fits" for the lithologic property within each lithostratigraphic unit using only the data from within the unit as delineated by the geologist and gridded by EarthVision®. This technique produces a property model of the hydrogeology that is consistent with the unit boundaries. A model built in this manner will be more accurate for hydrogeologic analysis and groundwater modeling.

2.4.4 *Mapping*

2.4.4.1 Altitude Contour Maps

Altitude contour maps were constructed for each hydrostratigraphic unit using the two-dimensional grids that were calculated from the scattered data for the unit tops. The maps are plotted using the *Contour and Basemap* module of EarthVision®. Contour intervals are chosen by individual data set so as to convey the information clearly and concisely, but virtually any level of detail is possible. An effort was made to keep the contour interval to within one-tenth of the range of the z-values. This serves to minimize the number of contour lines, yet generally maintains a level of detail suitable for interpretation of the map.

2.4.4.2 Isopach Maps

Two-dimensional grids of unit thickness (isopach grids) were calculated by first comparing the two-dimensional grids of the unit base and unit top with the two-dimensional grid of the topography. Isopach maps of vertical unit thickness were calculated from comparison of the two-dimensional grids of the unit base and unit top. A value was then written to the corresponding nodes of the resultant grid (the isopach grid) equal to the vertical distance between the base and upper surface of the unit.

The resultant two-dimensional isopach grids were contoured using EarthVision® in the same fashion as the structure-contour maps.

2.4.4.3 Lithofacies Maps

Lithofacies maps were created to depict the lateral distribution of mud and the internal variation of the mud content within the unit. Maps of the geometric mean and standard deviation of the mud content were created from the property data in the three-dimensional grids for each of the intervals. EarthVision's Formula Processor calculated (vertically) the geometric mean and standard deviation of the mud percentages within the unit at each grid node. These calculations produced two-dimensional grids which are expressed as maps to illustrate the lateral distribution of the geometric mean, and the internal variation of the mean within the interval. The maps of the geometric mean express the overall mud content within the unit. The maps of the standard deviation give an indication of the degree of vertical lithologic variation, such as interbedding of sediment types. Both of these lithofacies parameters are functions of the thickness of the unit. Analyses made using these lithofacies maps must therefore consider the geometry depicted by the isopach maps.

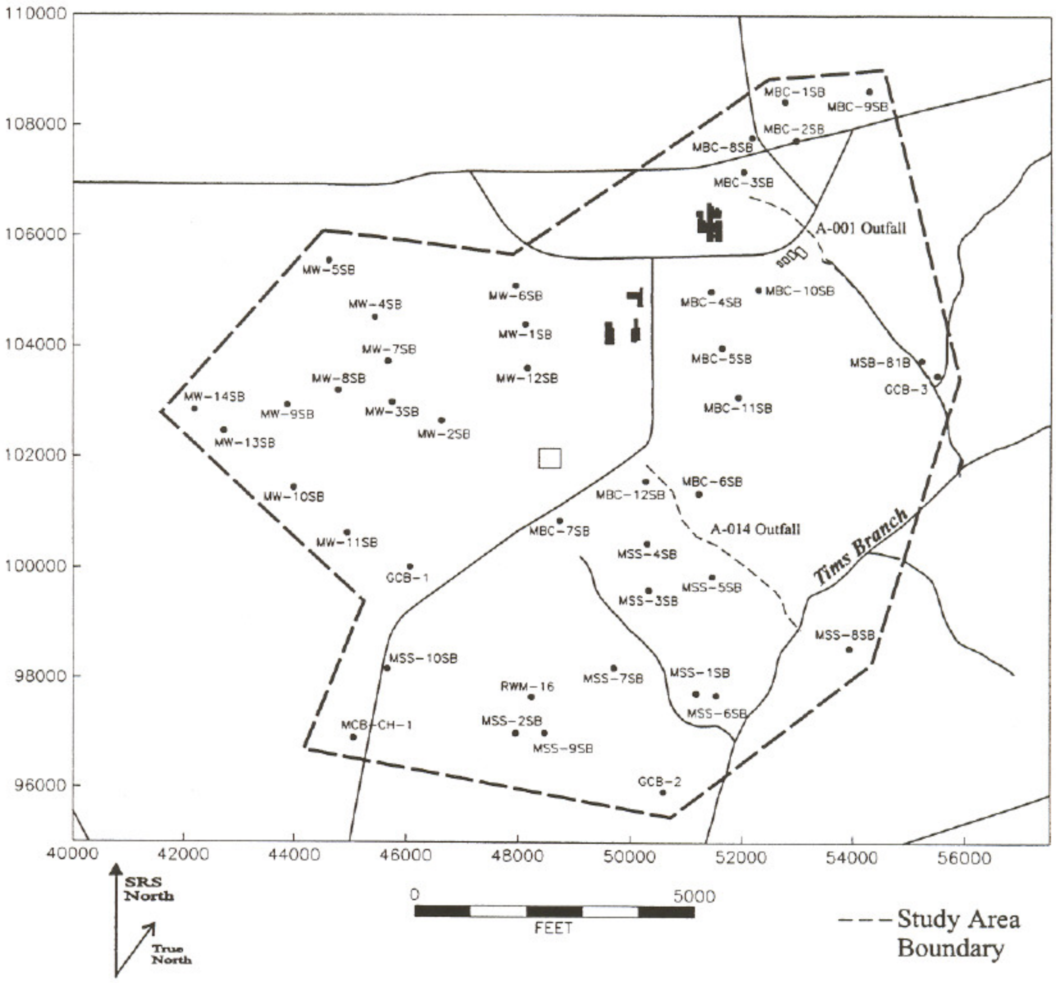


Figure 2-1. Locations of Cores Used in the Study

Table 2-1. Summary of Cored Intervals

	Cored Interval (ft bgl)		
Core ID	Top	Bottom	Recovery (%)
GCB-1	10	300	84
GCB-2	1	230	67
GCB-3	1	200	82
MBC-1SB	1	365	78
MBC-2SB	1	365	79
MBC-3SB	1	270	87
MBC-4SB	1	365	82
MBC-5SB	1	365	67
MBC-6SB	1	365	75
MBC-7SB	1	365	76
MBC-8SB	1	210	86
MBC-9SB	1	347	78
MBC-10SB	1	607	85
MBC-11SB	1	347	81
MBC-12SB	1	607	88
MCB-CH-1	1	350	81
MSB-81B	1	136	63
MSS-1SB	1	290	76
MSS-2SB	1	250	88
MSS-3SB	1	230	87
MSS-4SB	1	250	85
MSS-5SB	1	250	78
MSS-6SB	1	250	74
MSS-7SB	1	250	85
MSS-8SB	1	250	80
MSS-9SB	1	250	88
MSS-10SB	1	250	85
MW-1SB	1	260	78
MW-2SB	1	260	77
MW-3SB	1	248	87
MW-4SB	1	260	81
MW-5SB	1	255	71
MW-6SB	1	250	84
MW-7SB	121	260	44
MW-8SB	121	272	46

Table 2-1. Summary of Cored Intervals (Continued)

	Cored Interval (ft bgl)		
Core ID	Top	Bottom	**Recovery (%)**
MW-9SB	121	272	39
MW-10SB	120	269	33
MW-11SB	1	540	80
MW-12SB	121	507	60
MW-13SB	121	308	41
MW-14SB	1	515	52
RWM-16	1	224	76

Table 2-2. Coordinates of Core Locations

Core ID	SRS Easting (ft)	SRS Northing (ft)	Surface Elevation (ft msl)	Reference
GCB-1	46074.39	100006.75	335.8	Schlumberger, 1996a
GCB-2	50599.7	95924.9	221	Schlumberger, 1996b
GCB-3	55502.72	103488.45	255.7	Western-Atlas, 1996
MBC-1SB	52780	108450	371.8	Aadland and others, 1995b
MBC-2SB	52975	107750	379.8	Aadland and others, 1995b
MBC-3SB	52035	107178	366.8	Aadland and others, 1995b
MBC-4SB	51445	105008	380.8	Aadland and others, 1995b
MBC-5SB	51641	103983	370.8	Aadland and others, 1995b
MBC-6SB	51234.5	101346.4	326.8	WSRC, 1997
MBC-7SB	48750	100850	328.8	Aadland and others, 1995b
MBC-8SB	52189.41	107798.58	380	Aadland and others, 1995b
MBC-9SB	54286.4	108646.7	349.8	Aadland and others, 1995b
MBC-10SB	52302.92	105042	359.8	Aadland and others, 1995b
MBC-11SB	51837.2	103090.5	360.8	Aadland and others, 1995b
MBC-12SB	50284.19	101570.5	336.8	Aadland and others, 1995b
MCB-CH-1	45069	96903	317.8	Aadland and others, 1995b
MSB-81B	55230.4	103762.7	265.1	WSRC, 1996a
MSS-1SB	51185.9	97717.7	261.8	Aadland and others, 1995b
MSS-2SB	47936.4	96992.1	298.8	Aadland and others, 1995b
MSS-3SB	50336.5	99594.2	318.8	Aadland and others, 1995b
MSS-4SB	50308.7	100442	337.8	Aadland and others, 1995b
MSS-5SB	51469.9	99842.9	304.8	Aadland and others, 1995b
MSS-6SB	51541	97682.9	252.8	Aadland and others, 1995b
MSS-7SB	49715.6	98180.6	297.8	Aadland and others, 1995b
MSS-8SB	53943.4	98545	283.8	Aadland and others, 1995b
MSS-9SB	48477.9	96996.9	316.8	Aadland and others, 1995b
MSS-10SB	45674	98159	305.8	Aadland and others, 1995b
MW-1SB	48128	104396	345.8	Aadland and others, 1995b
MW-2SB	46659	102653	347.8	Aadland and others, 1995b
MW-3SB	45752	102982	347.8	Aadland and others, 1995b
MW-4SB	45441	104523	350.8	Aadland and others, 1995b
MW-5SB	44618	105553	334.8	Aadland and others, 1995b
MW-6SB	47954	105098	337.8	Aadland and others, 1995b
MW-7SB	45680.41	103726.41	358	WSRC, 1996b
MW-8SB	44790.4	103199.01	357.5	WSRC, 1996b
MW-9SB	43880.29	102934.67	353.8	WSRC, 1996b

Table 2-2. Coordinates of Core Locations (Continued)

Core ID	SRS Easting (ft)	SRS Northing (ft)	Surface Elevation (ft msl)	Reference
MW-10SB	43994.16	101446.29	367.9	WSRC, 1996b
MW-11SB	44951.23	100621.11	358.1	WSRC, 1996b
MW-12SB	48163.57	103608.04	348.4	WSRC, 1996b
MW-13SB	42730.26	102465.26	361.4	WSRC, 1996b
MW-14SB	42195.92	102846.99	341.5	WSRC, 1996b
RWM-16	48244.8	97647.2	318.4	WSRC, 1996a

Table 2.3. Unit Boundaries and Interval Tops

Core ID	Surface Elevation	Steed Pond Aquifer GCCZ	Steed Pond Aquifer LLAZ	Crouch Branch Confining Unit "upper" interval	Crouch Branch Confining Unit "middle" interval	Crouch Branch Confining Unit "lower" interval	Crouch Branch Aquifer
GCB-1	335.8	210.8	189.8	123.8	109.8	104.8	44.8
GCB-2	221	abs	abs	127	115	75	30
GCB-3	255.7	214.7	191.7	140.7	126.7	100.7	68.7
MBC-1SB	371.8	196.8	187.8	127.8	121.8	115.8	92.8
MBC-2SB	379.8	212.8	197.8	129.8	124.8	118.8	101.8
MBC-3SB	366.8	221.8	210.8	124.8	NP	118.8	NP
MBC-4SB	380.8	206.8	187.8	128.8	109.8	103.8	69.8
MBC-5SB	370.8	205.8	195.8	125.8	110.8	95.8	68.8
MBC-6SB	326.8	209.8	184.8	126.8	118.8	101.8	55.8
MBC-7SB	328.8	211.8	195.8	144.8	128.8	82.8	60.8
MBC-8SB	380	202	190	NP	NP	NP	NP
MBC-9SB	349.8	209.8	196.8	129.8	117.8	104.8	79.8
MBC-10SB	359.8	199.8	190.8	136.8	124.8	109.8	49.8
MBC-11SB	360.8	213.8	193.8	116.8	104.8	93.8	64.8
MBC-12SB	336.8	208.8	195.8	141.8	126.8	106.8	49.8
MCB-CH-1	317.8	200.8	182.8	117.8	110.8	80.8	53.8
MSB-81B	265.1	206.1	196.1	150.1	140.1	NP	NP
MSS-1SB	261.8	215.8	183.8	131.8	108.8	94.8	41.8
MSS-2SB	298.8	210.8	181.8	128.8	109.8	88.8	NP
MSS-3SB	318.8	208.8	193.8	138.8	128.8	100.8	NP
MSS-4SB	337.8	222.8	194.8	132.8	127.8	99.8	NP
MSS-5SB	304.8	199.8	188.8	143.8	115.8	88.8	NP
MSS-6SB	252.8	209.8	180.8	120.8	109.8	91.8	57.8
MSS-7SB	297.8	222.8	194.8	132.8	122.8	90.8	NP
MSS-8SB	283.8	208.8	184.8	126.8	115.8	83.8	55.8
MSS-9SB	316.8	214.8	190.8	136.8	126.8	92.8	NP
MSS-10SB	305.8	211.8	187.8	122.8	105.8	93.8	NP
MW-1SB	345.8	200.8	188.8	136.8	125.8	118.8	NP
MW-2SB	347.8	217.8	192.8	147.8	134.8	104.8	NP
MW-3SB	347.8	203.8	186.8	157.8	111.8	102.8	NP
MW-4SB	350.8	205.8	181.8	139.8	110.8	107.8	NP
MW-5SB	334.8	214.8	190.8	149.8	121.8	109.8	NP
MW-6SB	337.8	197.8	187.8	129.8	117.8	105.8	NP
MW-7SB	358	211	197	141	114	109	NP

Table 2.3. Unit Boundaries and Interval Tops (Continued)

Core ID	Surface Elevation	Steed Pond Aquifer GCCZ	Steed Pond Aquifer LLAZ	Crouch Branch Confining Unit "upper" interval	Crouch Branch Confining Unit "middle" interval	Crouch Branch Confining Unit "lower" interval	Crouch Branch Aquifer
MW-8SB	357.5	207.5	189.5	148.5	112.5	105.5	NP
MW-9SB	353.8	219.8	190.8	138.8	111.8	100.8	NP
MW-10SB	367.9	209.9	191.9	148.9	111.9	99.9	NP
MW-11SB	358.1	219.1	198.1	146.1	109.1	92.1	NP
MW-12SB	348.4	201.4	186.4	143.4	121.4	95.4	68.4
MW-13SB	361.4	211.4	200.4	139.4	119.4	96.4	65.4
MW-14SB	341.5	214.5	196.5	136.5	111.5	90.5	45.5
RWM-16	318.4	221.4	197.4	140.4	115.4	95.4	NP

Notes

LLAZ - "Lost Lake" aquifer zone

GCCZ - "green clay" confining zone

abs - horizon absent

NP - horizon not penetrated

3.0 RESULTS

3.1 Unit Geometry and Facies Analysis

The resultant maps are presented as Figures 3-1 through 3-24.

3.1.1 Crouch Branch Confining Unit

3.1.1.1 "Lower" Interval

The base of the "lower" interval of the CBCU is defined by the top of the CBA (Figure 3-1). The measured elevation of this surface varies from 102 to 30 ft msl. Figure 3-1 indicates this surface dips to the south-southeast. The contour pattern depicts an undulated surface, marked by pronounced ridges and troughs that are aligned along a southeast trend. There is one prominent basin centered on the axis of a trough beneath A Area.

The configuration of the top of the "lower" interval of the CBCU is depicted in Figure 3-2. This surface is defined by the base of the "middle" interval of the CBCU. Measured elevations vary from 119 to 75 ft msl. Figure 3-2 indicates that this surface dips to the south-southeast. The contour patterns indicate a series of ridges and troughs that trend south and southeast. The isopach map of the "lower" interval of the CBCU indicates a variation from 17 to 60 ft in measured thickness (Figure 3-3). The "lower" interval of the CBCU is generally thicker in areas that correspond with troughs on the top of the CBA. The isopach map indicates that an especially thick section of this interval fills the trough on the top of the CBA beneath A Area (Figure 3-1).

Figures 3-4 and 3-5 depict the variation in mud percentage within the "lower" interval of the CBCU. The geometric mean of the mud percentage is generally large in areas where this interval is relatively thick, ranging from 75% in the center of the study area to 90-95% in the southern part. This interval contains relatively small quantities of mud beneath the northeast corner of the study area, especially within the trough beneath A Area.

Areas of small standard deviation values and high mud content are related to the internal consistency of this unit. These areas likely consist of thicker clay layers which constitute the majority of lower interval. These areas represent the most competent parts of the CBCU beneath A/M Area. The area of low mud percentages and small standard deviations in the northeast corner of the study area represent areas of clean well-sorted sands. These are probably a result of sand fill in the trough on the top of the CBA. In contrast, the areas of low mud percentages with higher standard deviations probably represent interbedded sands and clays of various thicknesses.

3.1.1.2 "Middle" Interval

The base of the "middle" interval is depicted in Figure 3-2. Figure 3-6 shows the configuration of the top of the "middle" interval. The measured elevation of this surface varies from 105 to 140 ft msl. The isopach map of the "middle" interval varies from 46 ft. to 3 ft. The isopach map indicates that thick parts of this interval generally correspond with troughs on the top of the "lower" interval (Figure 3-2). The distribution of mud within the "middle" interval is depicted in Figures 3-8 and 3-9. The mean mud fraction varies from less than 5% to greater than 60%. The larger mud percentages generally correlate with the thinner parts of the interval, especially in the southern sector of the A/M Area and in the western part of the study area toward the Silverton Road Waste Site.

The standard deviation of the mud fraction within the "middle" interval varies from greater than 25 to less than 5, and is generally larger in areas where the mean mud fraction is higher (Figures 3-8 and 3-9). The larger standard deviations within the areas of high mud content probably reflect interbedded lithology on a scale that is less than the thickness of the interval. Across the study area, standard deviation values display considerable variation, indicating the mud-rich areas are discontinuous. It is therefore likely that that the mud-rich parts of the "middle" interval of the Crouch Branch confining unit are composed of interbedded layers of sand and mud that are not laterally extensive.

3.1.1.3 "Upper" Interval

The base of the "upper" interval of the CBCU defines the top of the "middle" interval (Figure 3-6). The contour pattern on this surface indicates two prominent troughs, one that trends northwest to southeast centered beneath A and M areas, the other trends north to south along the west edge of the study area. The configuration of the top of the "upper" interval is shown in Figure 3-10. The measured elevation of the top of this interval varies from 117 to 158 ft msl. The measured thickness of the "upper" interval varies from 5 to 46 ft, and is shown in Figure 3-11. The "upper" interval is generally thickest in areas where the top displays local highs, especially in the western part of the study area (Figure 3-10).

The distribution of mud within the "upper" interval is depicted in Figures 3-12 and 3-13. Mean mud content ranges from less than 5% to greater than 80%. In general, areas with high mean mud values correspond with thin parts of the interval (Figures 3-11 and 3-12). The map of the standard deviation of the mud fraction indicates high internal variability of the mud content. The areas with higher mean mud values generally correspond with larger standard deviation values. This indicates that where significant amounts of clay do exist, they are interbedded with sand.

The distribution of mud depicted in Figures 3-4, 3-8, and 3-12, indicates that in the northeast corner of the study, area all three intervals consist primarily of sand. Figure 3-4 shows the "lower" interval to consist primarily of mud except in the extreme northeast corner of Northern Sector. The "middle" and "upper" intervals both consist primarily of sand, with a relatively sporadic distribution of mud in comparison with the mud distribution in the "lower" interval. The areas of mean mud values which are greater than 50% within the "upper" interval (Figure 3-12) probably define the areal extent of the "upper clay" confining zone of the CBCU (Figure 1-3) (Aadland and others, 1995b). The absence of significant quantities of mud from all three intervals in the northern sector of the A/M Area indicates that the Steed Pond Aquifer is probably in hydraulic communication with the CBA in this part of the study area.

3.1.2 Steed Pond Aquifer

3.1.2.1 "Lost Lake" Aquifer Zone

The base of the LLAZ is defined by the top of the "upper" interval of the CBCU (Figure 3-10). The top of the LLAZ is depicted in Figure 3-14, and the thickness is illustrated in Figure 3-15. The measured elevations of the top of this interval vary from 181 to 211 ft msl and the measured thickness varies from 29 to 86 feet Thicker parts of the LLAZ generally correspond with troughs on the top of the "upper" interval of the CBCU. The LLAZ is thinnest in the western half of the study area where the top of the "upper" interval of the CBCU is high and the top of the LLAZ troughs trending northeast - southwest.

The distribution of mud within the LLAZ is depicted in Figures 3-16 and 3-17. The mud content ranges from less than 5% to greater than 25% with standard deviations ranging from less than 5 to greater than 30. Figure 3-16 indicates that relatively high mud percentages within the LLAZ are present in the southwest corner of the study area. This area trends northeast to southwest from the M Area basin to the southwest corner of the study area. The higher values generally correspond with relatively thick parts of the LLAZ that coincide with lower areas on the top of the "upper" interval of the CBCU. The areas of low mud percentages correspond with small standard deviation values, indicating that these parts of the LLAZ consist of relatively massively bedded sand, with small amounts of mud.

Contours on the top of the LLAZ indicate a ridge that rises above the 190-foot contour and trends north to south across Southern Sector (Figure 3-15). This ridge corresponds with areas where thickness exceeds 50 ft and the mean mud fraction is less than 10% with standard deviations less than 10% (Figures 3-16, 3-17, and 3-18). This area represents a significant sand body that may serve as a preferential pathway within the LLAZ.

3.1.2.2 "Green Clay" Confining Zone

The base of the GCCZ is depicted in Figure 3-14. The top of the GCCZ is defined by the base of the MAAZ and is shown in Figure 3-18. Measured elevations of this surface vary from 197 to 223 ft msl. The measured thickness varies from 9 to 32 ft and is illustrated in Figure 3-19. The GCCZ is generally thicker in the southern part of the study area and where this interval has filled troughs in the top of the LLAZ. The thickest section of this interval is present in the southeast corner of the Southern Sector. The isopach map indicates a locally thick section of this unit in the vicinity of the local high area in the northeast corner of the study area (Figure 3-19).

The distribution of mud within the GCCZ is depicted in Figures 3-20 and 3-21. Figure 3-20 indicates that the mean mud content within the GCCZ varies from less than 5% to greater than 50% and is significantly higher in the southeast corner and southern edge of the study area. The isolated thick area northeast of A Area is characterized by relatively small mud percentages. The GCCZ contains very little mud at the western end of the study area. The standard deviation of the mean mud percentages is generally greater in the areas with larger mud fractions. The parts of the GCCZ that lack mud tend to be thicker, and show smaller standard deviation values. This indicates that the GCCZ consists primarily of sand, with moderate amounts of interbedded clay present in the southeastern part of the study area where the unit is relatively thin. The maps of mud distribution indicate that the GCCZ is probably a competent confining zone southeast of the M Area Basin. The low mud percentages and low standard deviation values west of the M Area Basin suggest that the GCCZ is relatively permeable in this area.

3.1.2.3 "M-Area" Aquifer Zone and Vadose Zone

The MAAZ and the vadose zone are combine into a single interval in the current hydrogeologic model. The base of the MAAZ is defined by the top of the GCCZ (Figure 3-

18). The top of this interval is defined by the topographic surface depicted in Figure 1-2. The isopach map shown in Figure 3-22 presents the total thickness of the MAAZ and the vadose zone. The contour patterns on this map are largely influenced by the local topography. The thickness of this interval varies from 43 to 174 feet. The distribution of mud within this interval is depicted in Figures 3-23 and 3-24.

This interval is characterized by relatively clean sand interbedded with. thin and discontinuous silty sand and clay. The thin and discontinuous clay layers constitute a small fraction of the total thickness of the unit. These layers are not apparent when averaged over such a thick section of sediment as illustrated in Figure 3-23. The standard deviation does indicate that the mud distribution is laterally discontinuous in Figure 3-24.

Previous investigations have concluded that the MAAZ contains at least three semi-confining/confining zones beneath A/M Area. These zones consist of thin layers of silty sand and clay and are laterally discontinuous across the area (Eddy and others, 1991, Eddy-Dilek and others, 1993).

3.2 Comparison with Observed Extent of Groundwater Contamination

The primary component for migration of contamination in this form is advective transport mechanisms. One of the most important processes and parameters that influence this type of contaminant transport is the distribution of hydraulic conductivity. The hydraulic conductivity couples with the regional groundwater sources and discharge areas to control groundwater migration patterns. An understanding of regional groundwater flow patterns, historical source information, and distribution of hydraulic conductivity allows investigators to effectively stage and deploy remediation programs.

Effective characterization of DNAPL is often complicated by several factors. The migration of DNAPL through the subsurface is driven predominately by capillary and gravitational forces. The magnitude and direction of these forces are complex and are controlled by local variations in permeability of the soil. Current research indicates that DNAPL migration occurs at a sub-meter scale, much smaller than the resolution of conventional characterization methods.

Two forms of TCE contamination are present beneath A/M Area. Dissolved TCE in groundwater plumes is the most widespread form, and is virtually ubiquitous in the shallow aquifer beneath the area. DNAPL contamination is less widespread, but continuously contributes TCE to the plumes. An effective remediation program will not only address the dissolved phase in the plumes, but will focus on locating, characterizing, and remediating the DNAPL from which the plumes emanate.

The migration of DNAPL downward into the saturated zone and laterally along lithologic strata serves to characterize the primary type of contamination associated with the Western Sector and Central Sector (M Area Basin and A-014 Outfall). Characterization and remediation efforts in the Western Sector require identifying the location and thickness of DNAPL along these strata and the deployment of appropriate DNAPL removal/destruction technologies.

Current DNAPL characterization strategies are focusing primarily on the GCCZ and vadose zone. This strategy include the "middle" clay of the LLAZ. The GCCZ is believed to be the most significant contributor to horizontal migration of DNAPL in the A/M Area (Jackson and others, 1997). The current conceptual model describes DNAPL as migrating from the M-Area Basin in a westerly direction, toward monitoring well clusters MSB-23 and MSB-76 (Looney and others, 1992). Data from several monitoring wells and depth-discrete samples along this route indicate a probable presence of DNAPL above and below the GCCZ. These data indicate that as the DNAPL has moved west, it has also migrated vertically, down through the GCCZ and into the LLAZ. Layers of low permeability in the LLAZ appear to have inhibited further vertical migration.

The altitude contour map of the GCCZ presented in Figure 3-18 supports the concept of westward migration from the M-Area Basin. Even more dramatic is the distinct decrease in the mean mud fraction west of the M-Area Basin that is presented in Figure 3-20. The facies change associated with the decrease in mean mud percentage indicates an overall increase in permeability of the sediment. This increase in permeability will allow DNAPL to migrate through the GCCZ as it moves west from the basin. Monitoring wells west of the M-Area Basin indicate elevated contaminant concentrations in the upper part of the LLAZ.

In A/M Area, the presence of subsurface DNAPL has combined with the local groundwater flow patterns to create a large TCE plume south of the M-Area Basin and the A-014 Outfall. This plume is migrating down through the GCCZ and moving south toward Upper Three Runs Creek. Downward migration is a result of several parameters including facies changes in the GCCZ, the location of regional groundwater divides, and groundwater discharge zones. These parameters combine to create a strong downward vertical gradient across the GCCZ. Once below the GCCZ, the proximity of groundwater discharge zones and the effects of the Crouch Branch confining unit result in the southward migration of the plume. This migration pattern is the source of the relatively large plume associated with the Southern Sector.

The distribution of mean mud fraction for the LLAZ presented in Figure 3-16 presents a similar distribution as that for TCE. The low mud percentages indicate coarser-grained sediment, which in turn relates to higher hydraulic conductivity. There is a definite similarity between the distribution of elevated concentrations of TCE and low mud fraction within the LLAZ. In a completely homogeneous medium, dispersion would result in equal spreading of the contaminant along the principal flow line emanating from the source. Data from the area southwest of the M-Area Basin indicates relatively low concentrations. It is likely that the migration of the large TCE plume beneath Southern Sector is facilitated by the facies changes illustrated in Figure 3-16.

The sporadic and discontinuous geometry of confining layers in the Northern Sector has resulted in the migration of a plume of dissolved TCE down into the upper part of the CBA. The discontinuities and thinning of the CBCU have been recently characterized using surface geophysical methods. A recent study integrated surface-time domain electromagnetic (TDEM) and shear-wave reflection surveys with interpretation of geophysical well logs (Blackhawk Geometrics, 1996; Eddy-Dilek and others, 1997). The study concluded that TDEM conductance measurements provide an accurate measure of the clay content for sediment within the CBCU. The investigation identified a difference in facies within the CBCU in the vicinity of A Area when compared to those in other parts of the A/M Area. The investigation attributed these changes to changes in stratigraphy and depositional environment. The facies changes identified in the TDEM investigation agree with the thinning and absence of the "upper clay" and "lower clay" confining zones in the northeast part of the study area as reported in Aadland and others (1995b), and the absence of the "middle sand" aquifer zone in the western portion of the A/M Area.

Examination of the mean mud fraction distribution for the "lower", "middle", and "upper" intervals of the CBCU indicates a series of dramatic facies changes beneath A Area. The most dramatic change is in the sediment within the "lower" interval. This sediment constitutes the "lower clay" confining zone of the Crouch Branch confining unit, regarded by investigators as the most significant confining layer beneath the Central and Southern sectors of A/M Area. Figure 3-4 indicates the character of this unit in the northeast is dramatically different from that in other parts of the study area. The distribution of mud shows a remarkable similarity to the distribution of overall conductance shown by the TDEM survey. The facies change is believed to be a significant contributor to the migration of dissolved contamination from the Steed Pond aquifer into the Crouch Branch aquifer.

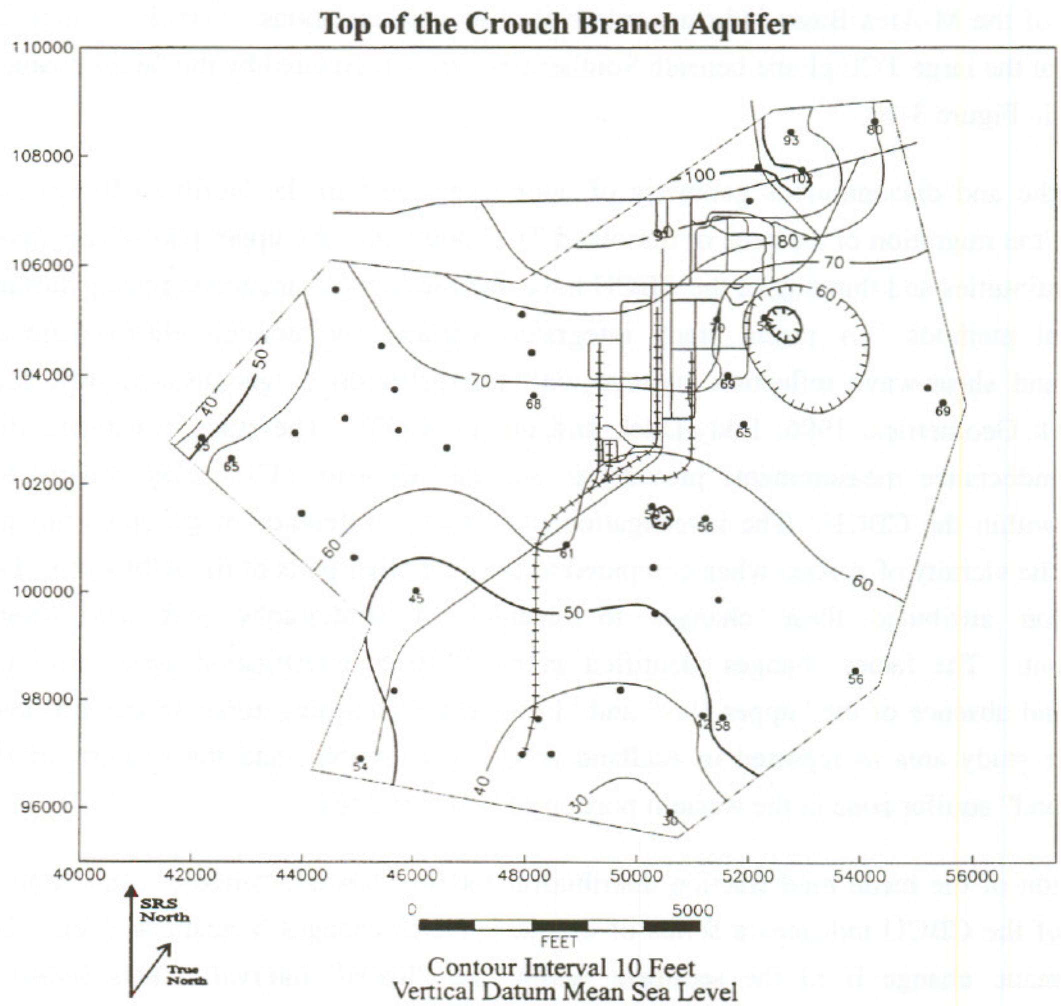


Figure 3-1. Altitude Contour Map of the Top of the Crouch Branch Aquifer/Base of the Crouch Branch Confining Unit

Top of the "Lower" Interval of the Crouch Branch Confining Unit

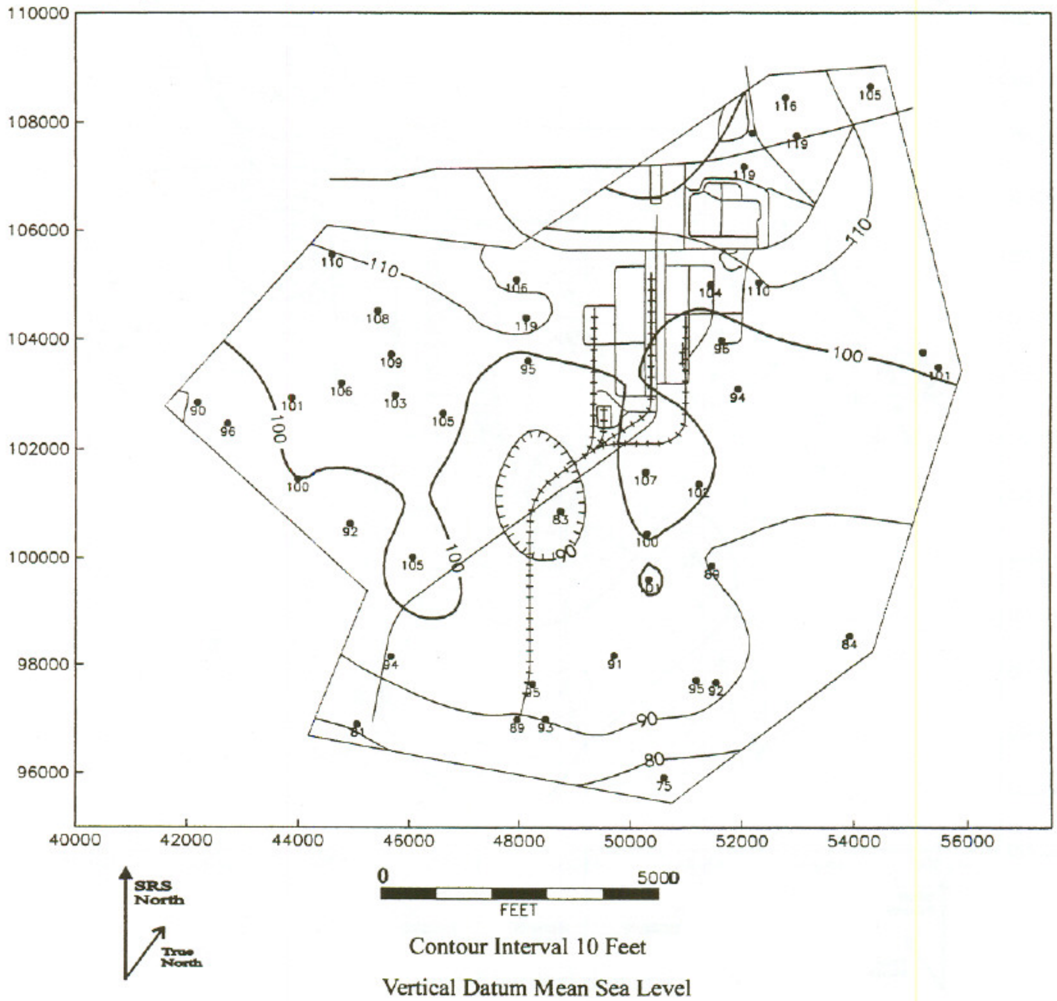


Figure 3-2. Altitude Contour Map of the Top of the "Lower" Interval/Base of the "Middle" Interval of the Crouch Branch Confining Unit

Isopach of the "Lower" Interval of the Crouch Confining Unit

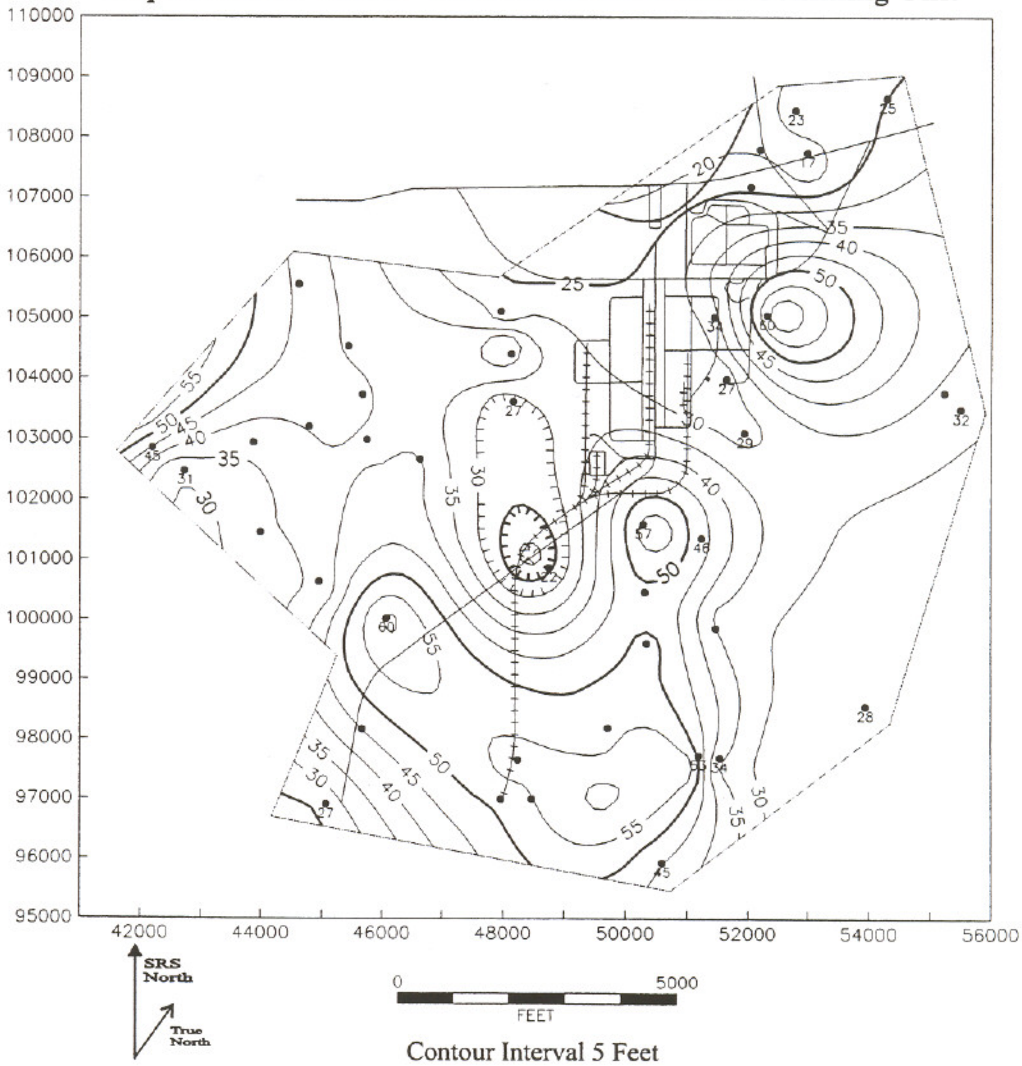


Figure 3-3. Isopach Map of the "Lower" Interval of the Crouch Branch Confining Unit

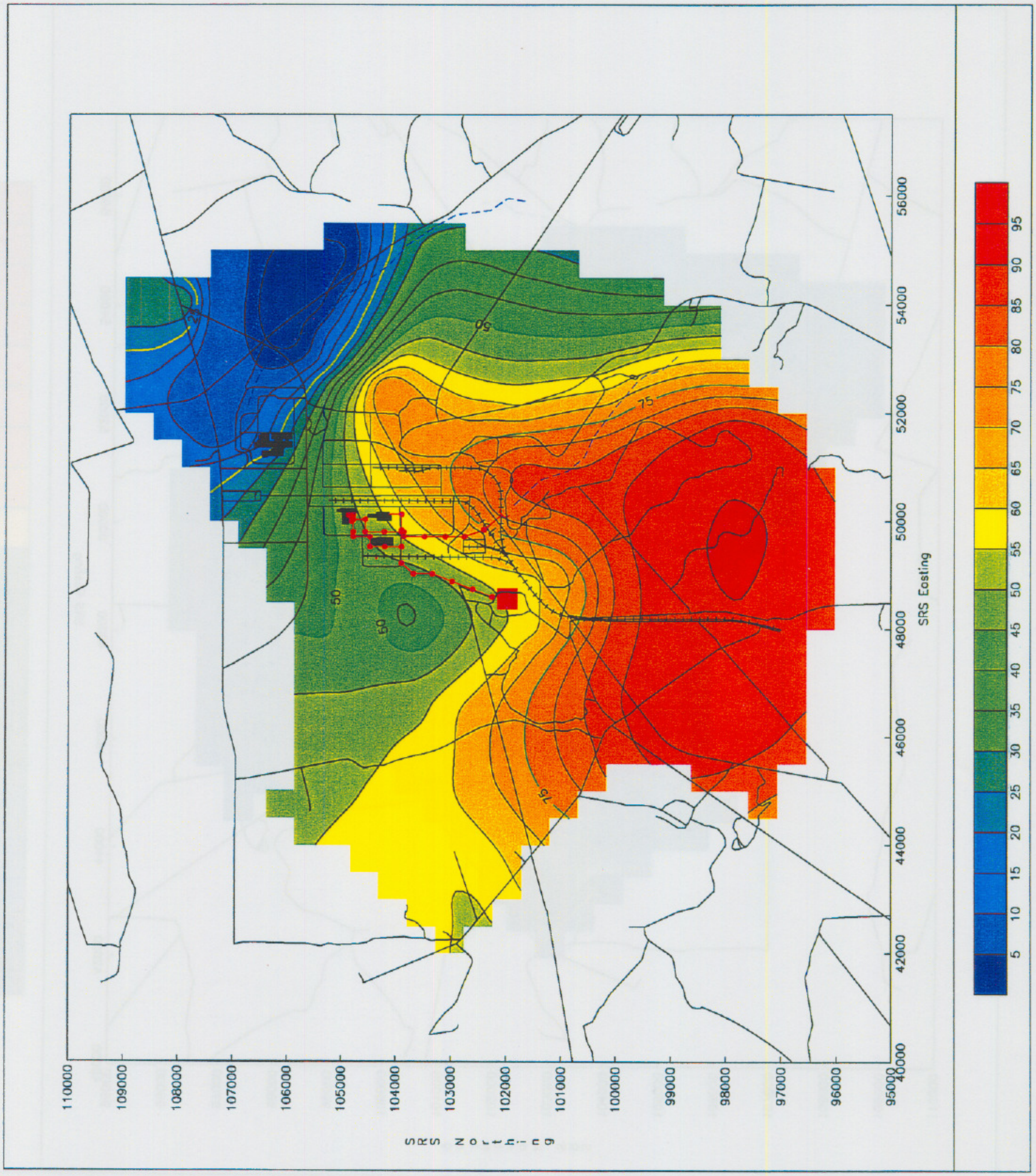


Figure 3-4. Geometric Mean of Mud Percentage within the "Lower" Interval of the Crouch Branch Confining Unit

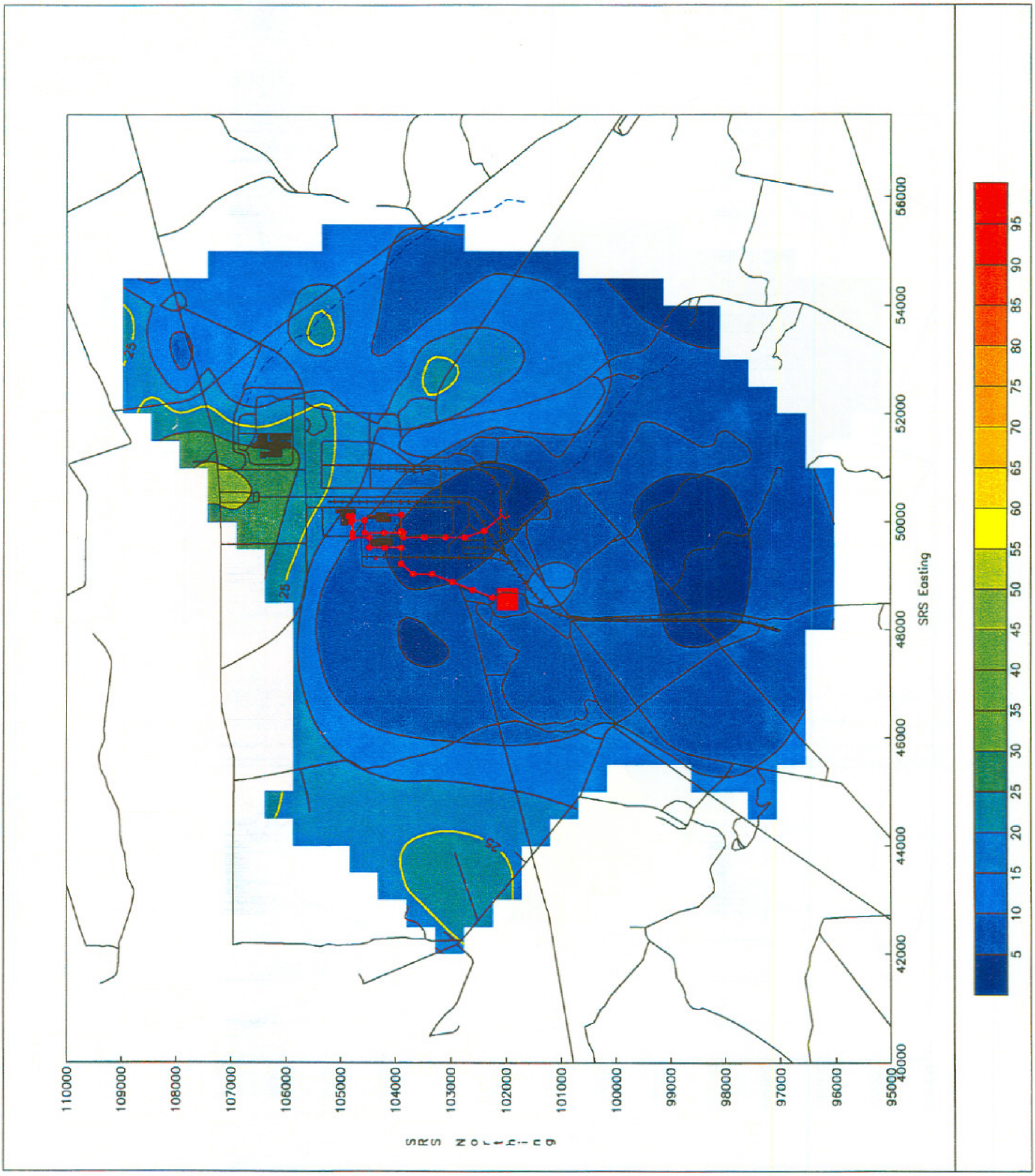


Figure 3-5. Standard Deviation of Mud Percentage within the "Lower" Interval of the Crouch Branch Confining Unit

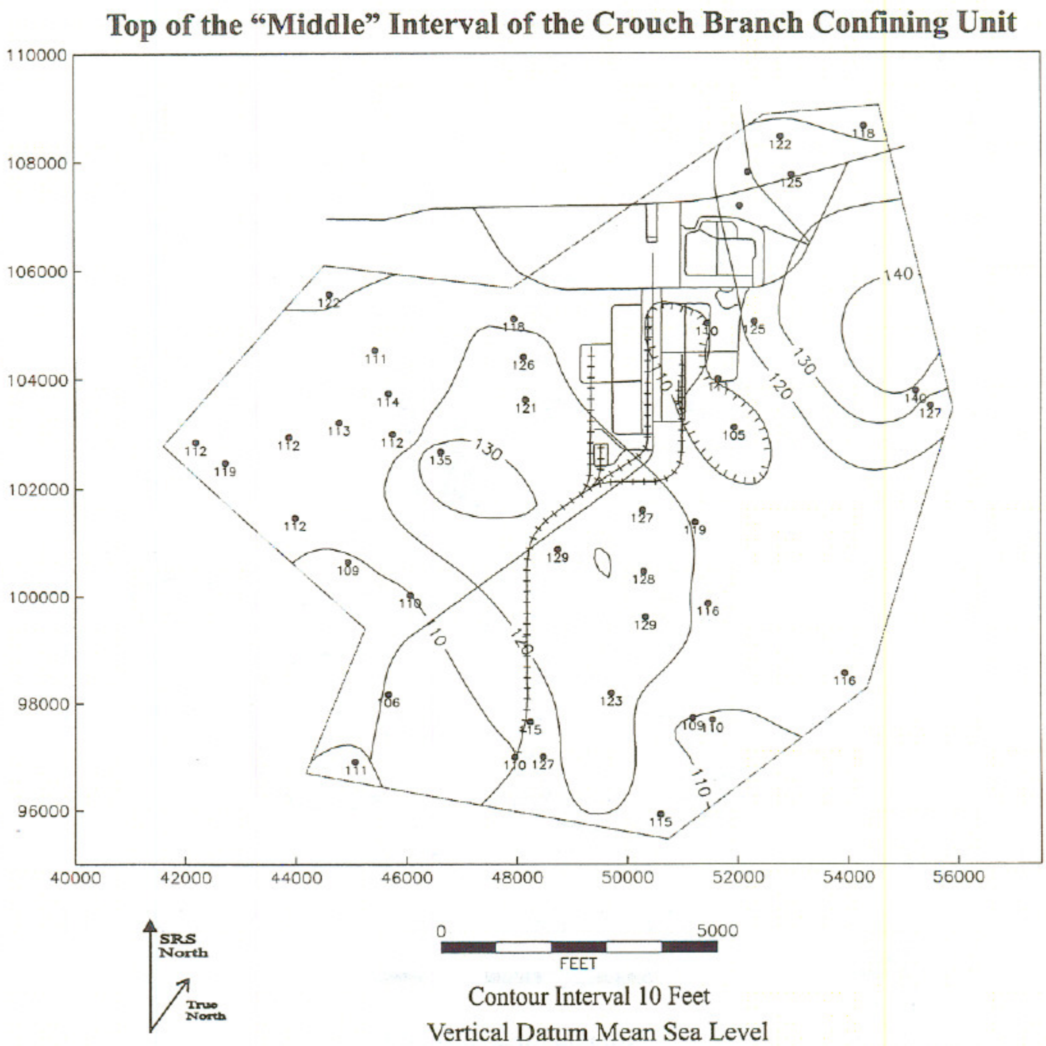
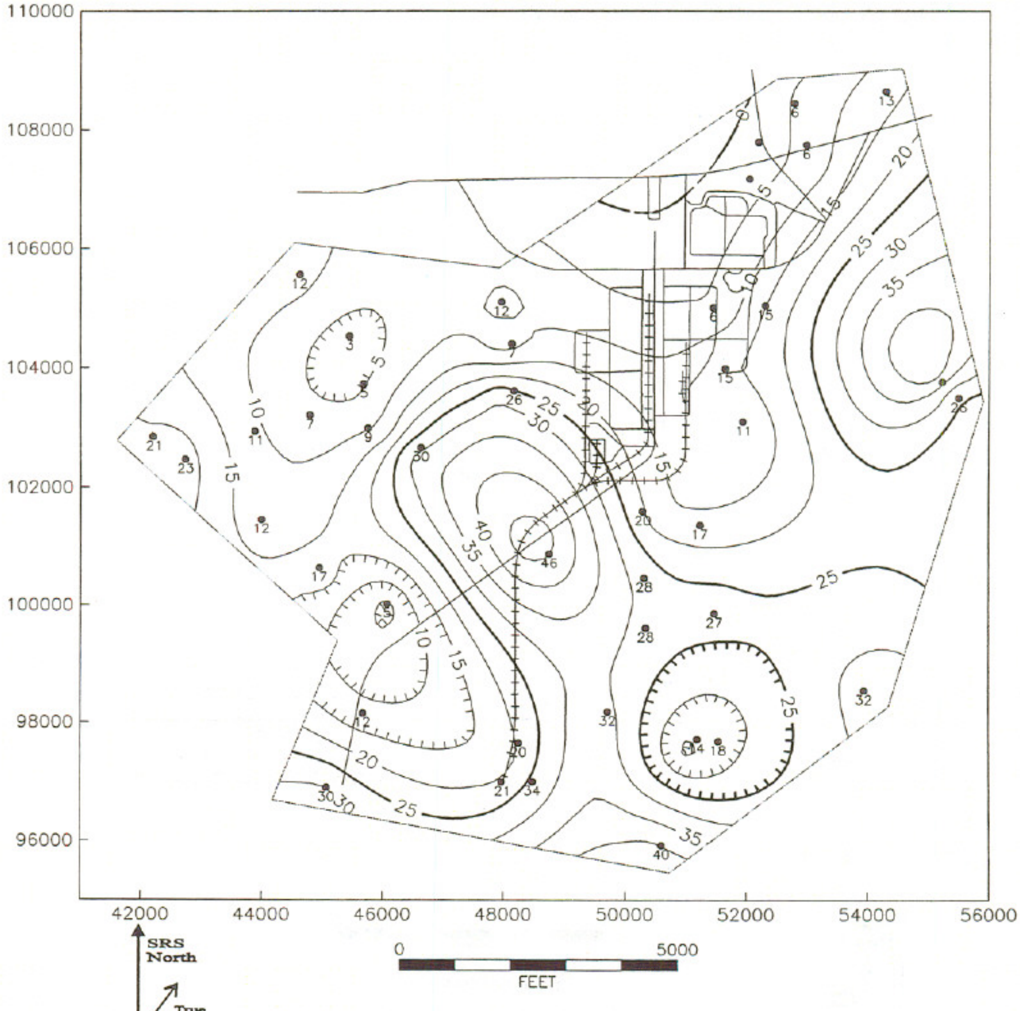


Figure 3-6. Altitude Contour Map of the Top of the "Middle" Interval/Base of the "Upper" Interval of the Crouch Branch Confining Unit

Isopach of the "Middle" Interval of the Crouch Branch Confining Unit



Contour Interval 5 Feet

Figure 3-7. Isopach Map of the "Middle" Interval of the Crouch Branch Confining Unit

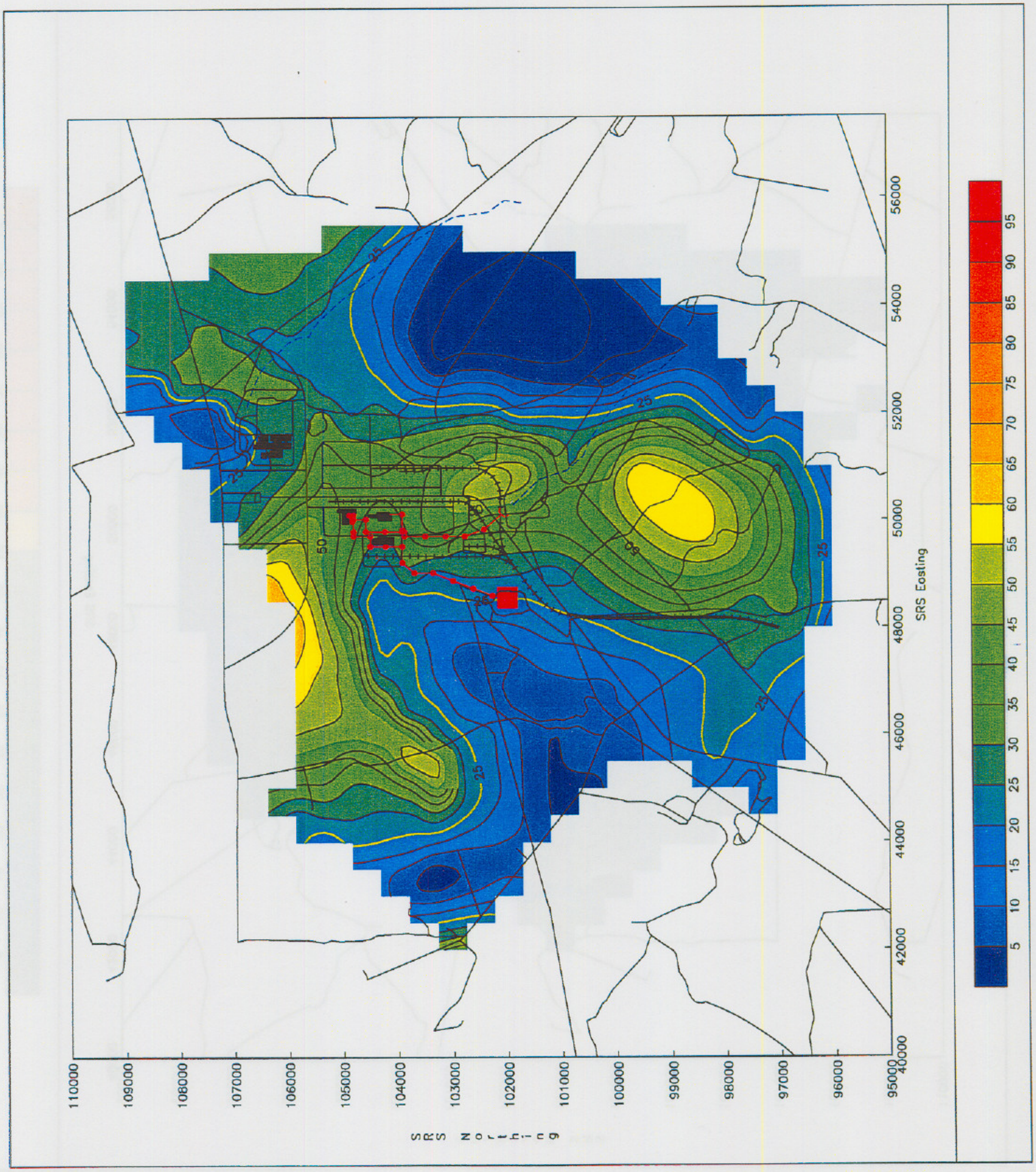


Figure 3-8. Geometric Mean of Mud Percentage within the "Middle" Interval of the Crouch Branch Confining Unit

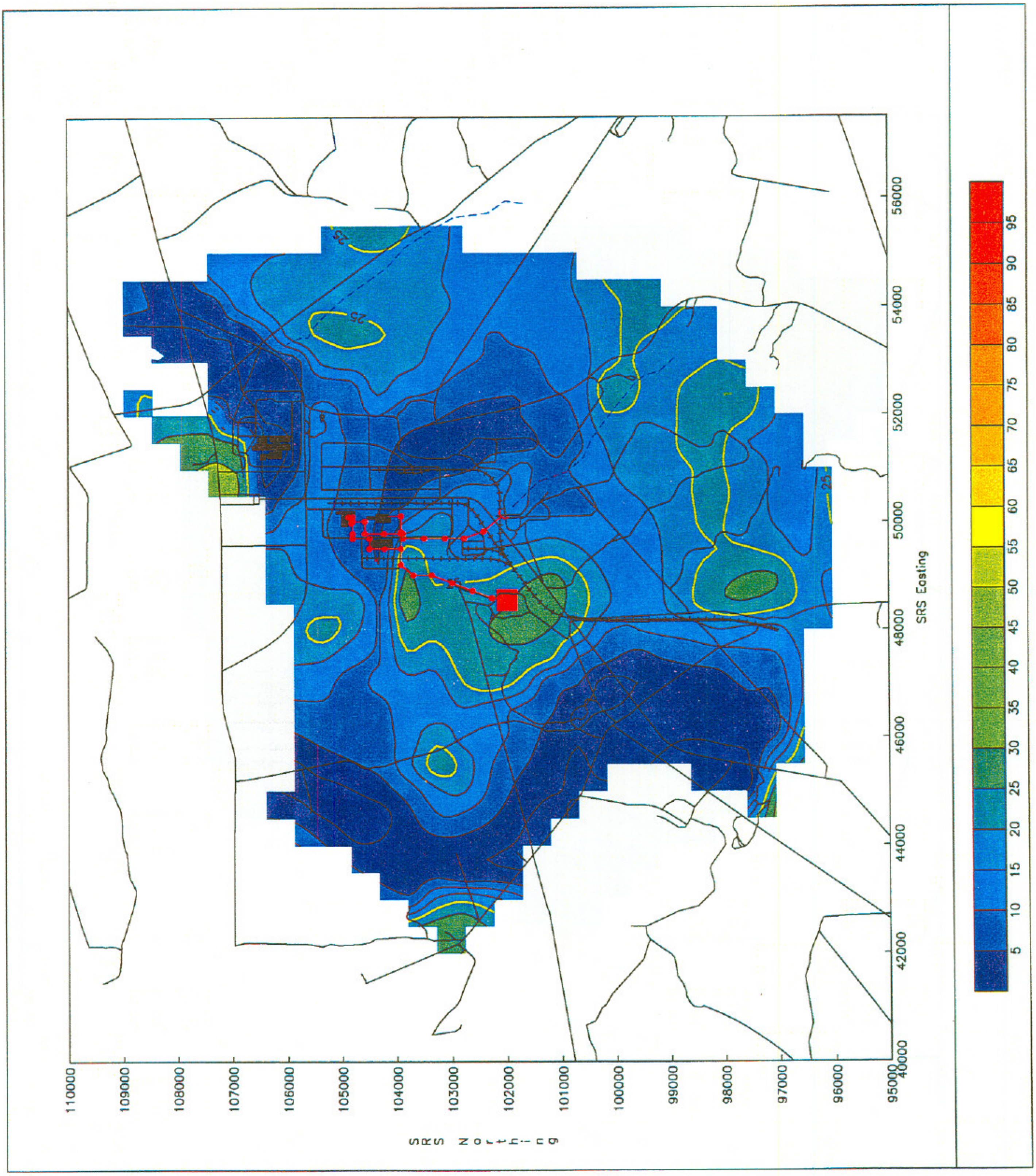


Figure 3-9. Standard Deviation of Mud Percentage within the "Middle" Interval of the Crouch Branch Confining Unit

Top of the "Upper" Interval of the Crouch Branch Confining Unit

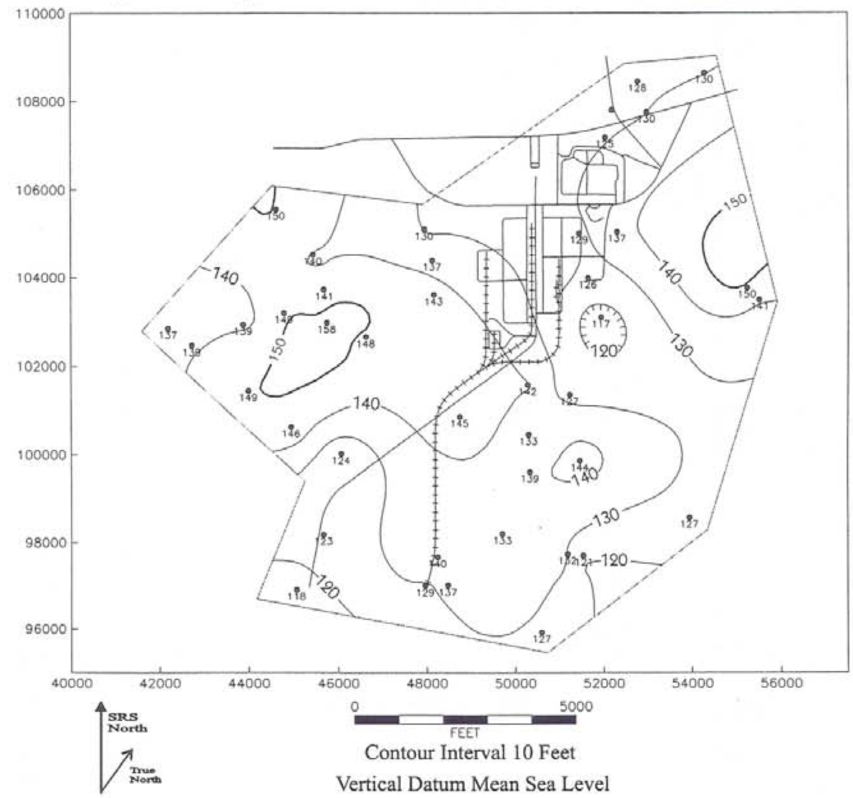


Figure 3-10. Altitude Contour Map of the Top of the "Upper" Interval of the Crouch Branch Confining Unit/Base of the "Lost Lake" Aquifer Zone

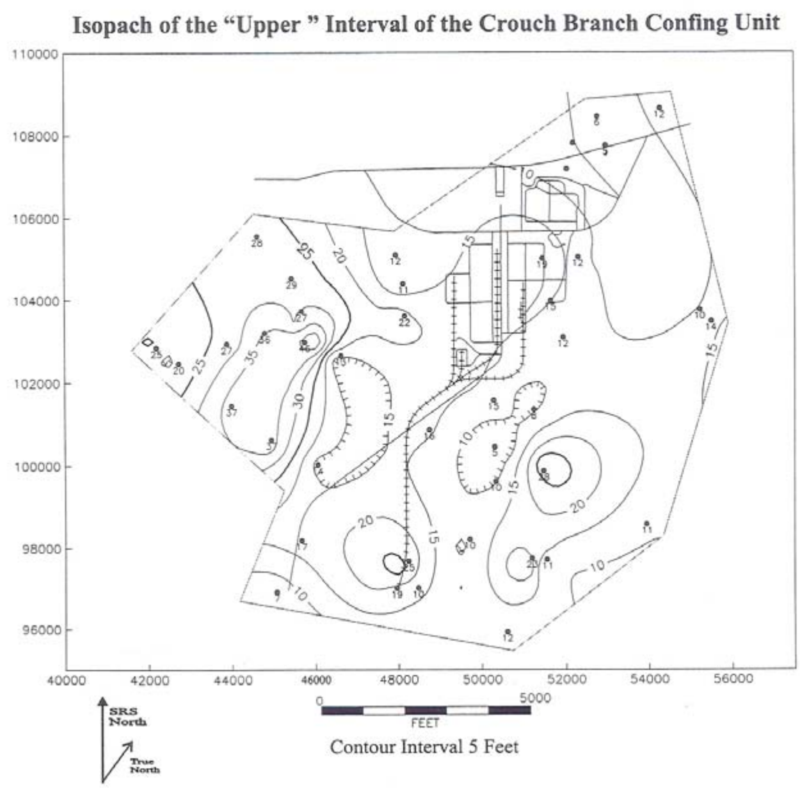


Figure 3-11. Isopach Map of the "Upper" Interval of the Crouch Branch Confining Unit

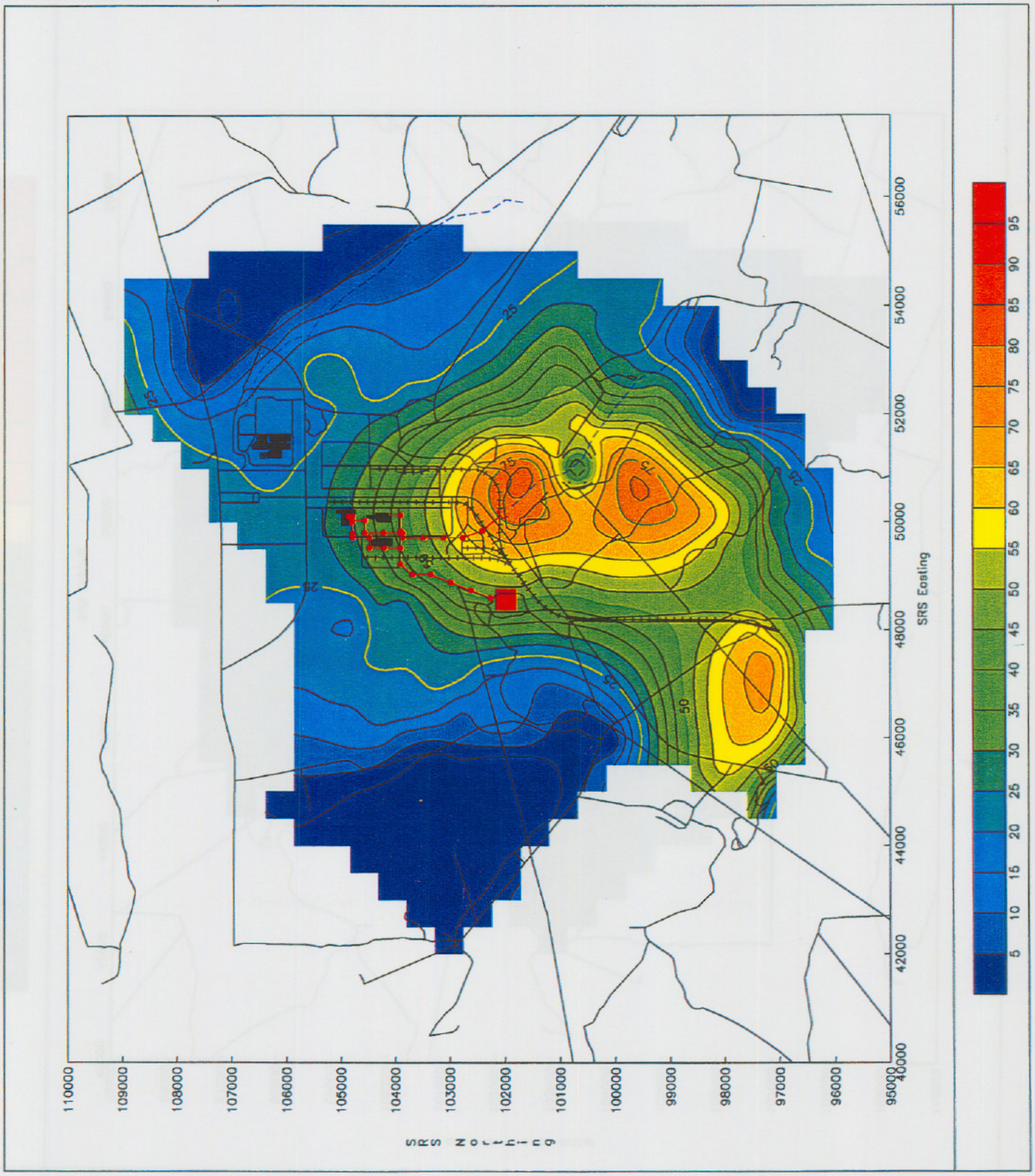


Figure 3-12. Geometric Mean of Mud Percentage within the "Upper" Interval of the Crouch Branch Confining Unit

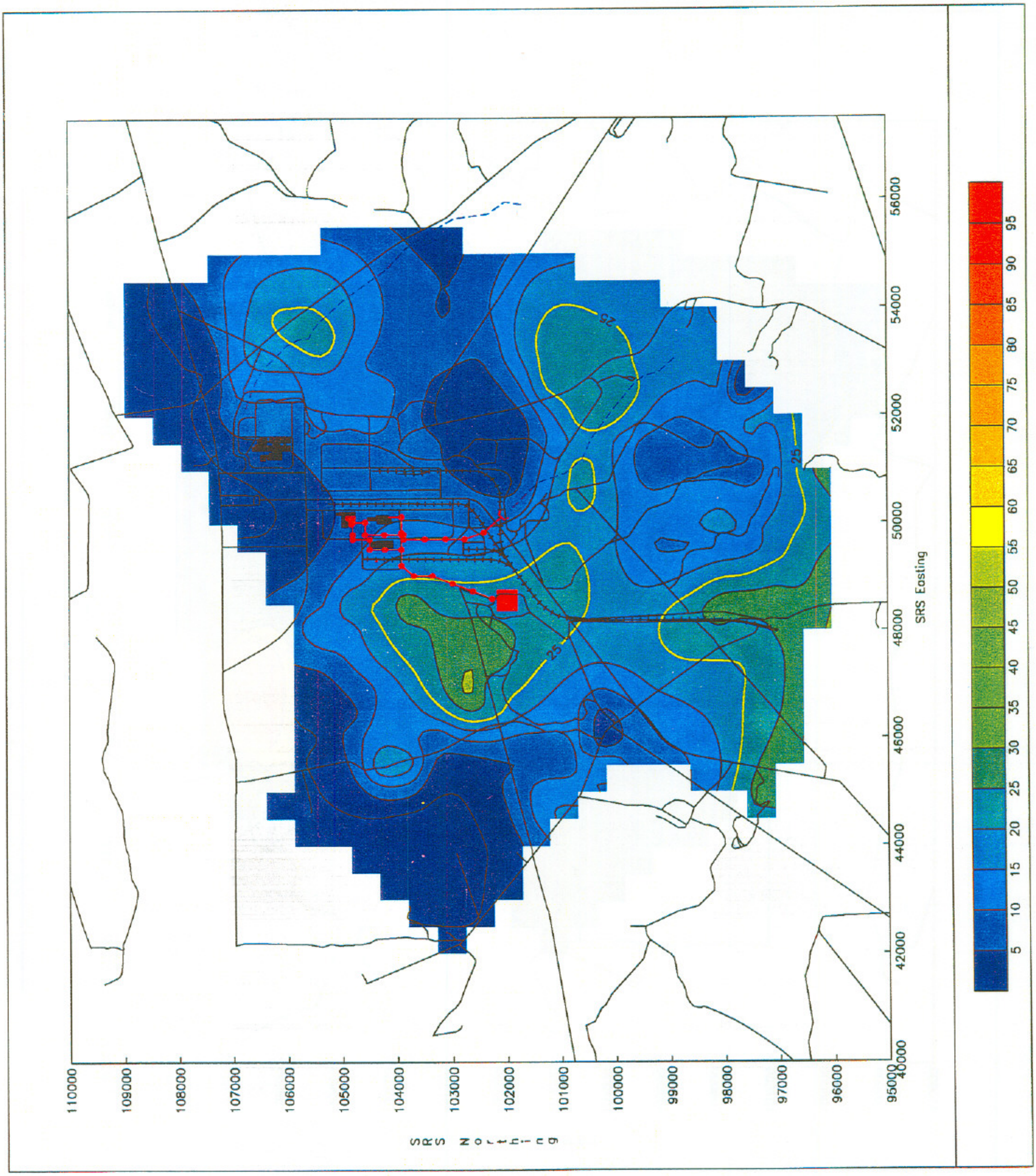


Figure 3-13. Standard Deviation of Mud Percentage within the "Upper" Interval of the Crouch Branch Confining Unit

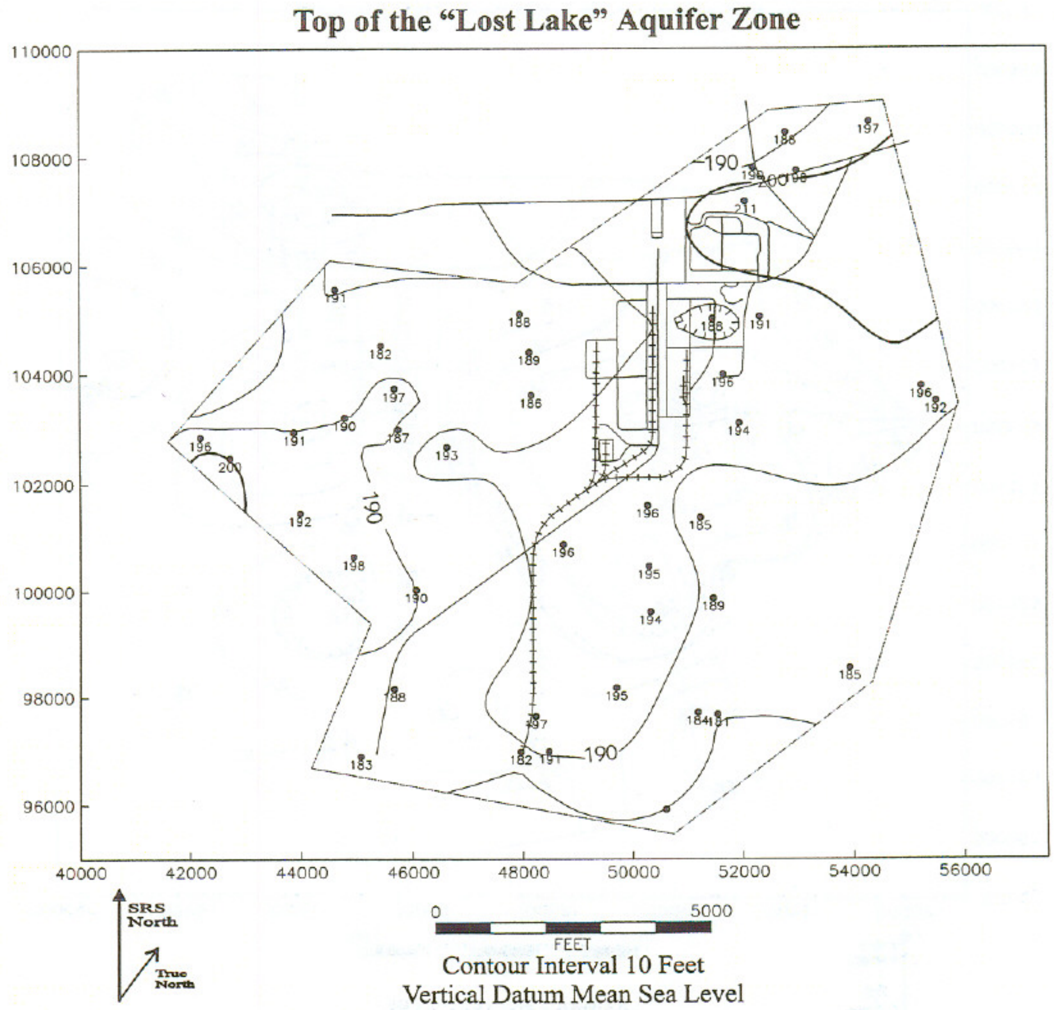


Figure 3-14. Altitude Contour Map of the Top of the "Lost Lake" Aquifer Zone/Base of the "Green Clay" Confining Zone of the Steed Pond Aquifer

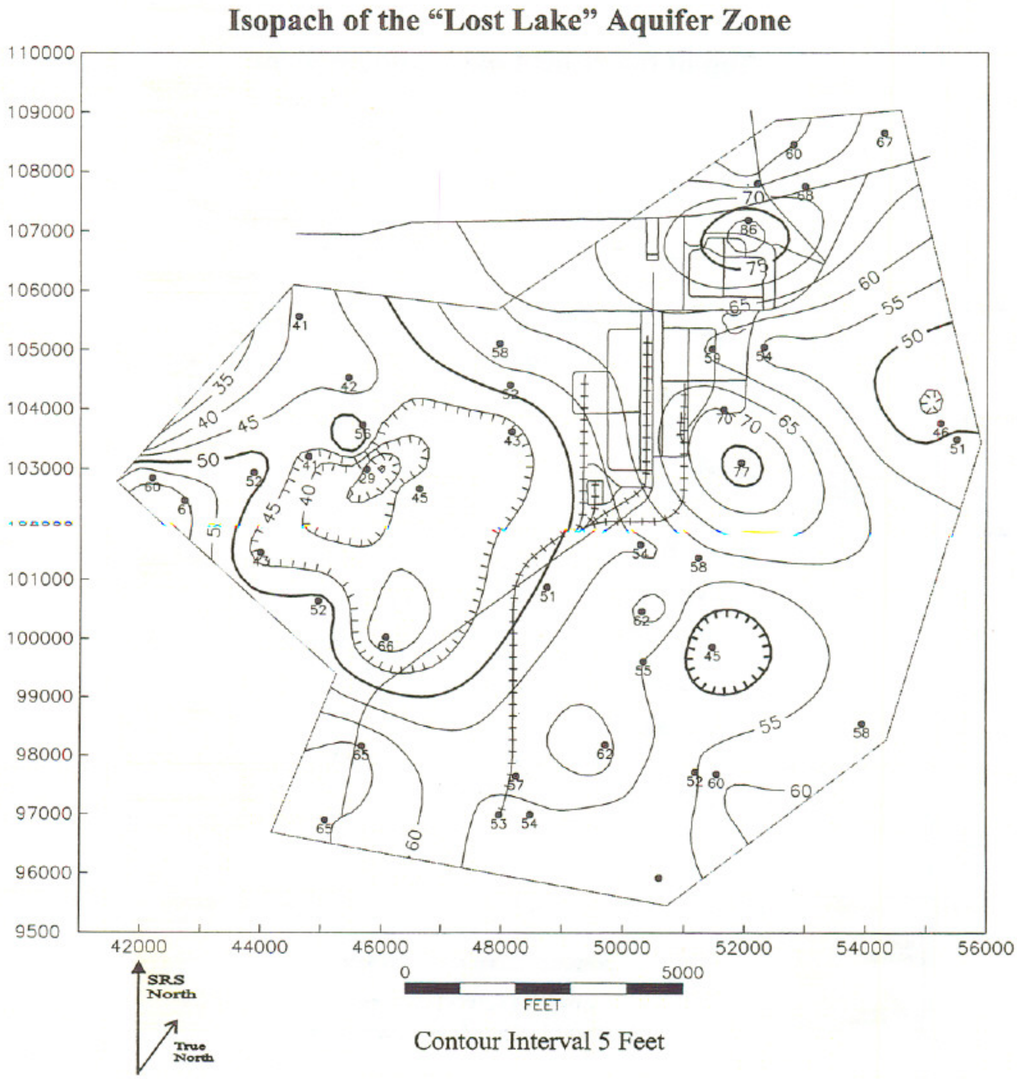


Figure 3-15. Isopach Map of the "Lost Lake" Aquifer Zone of the Steed Pond Aquifer

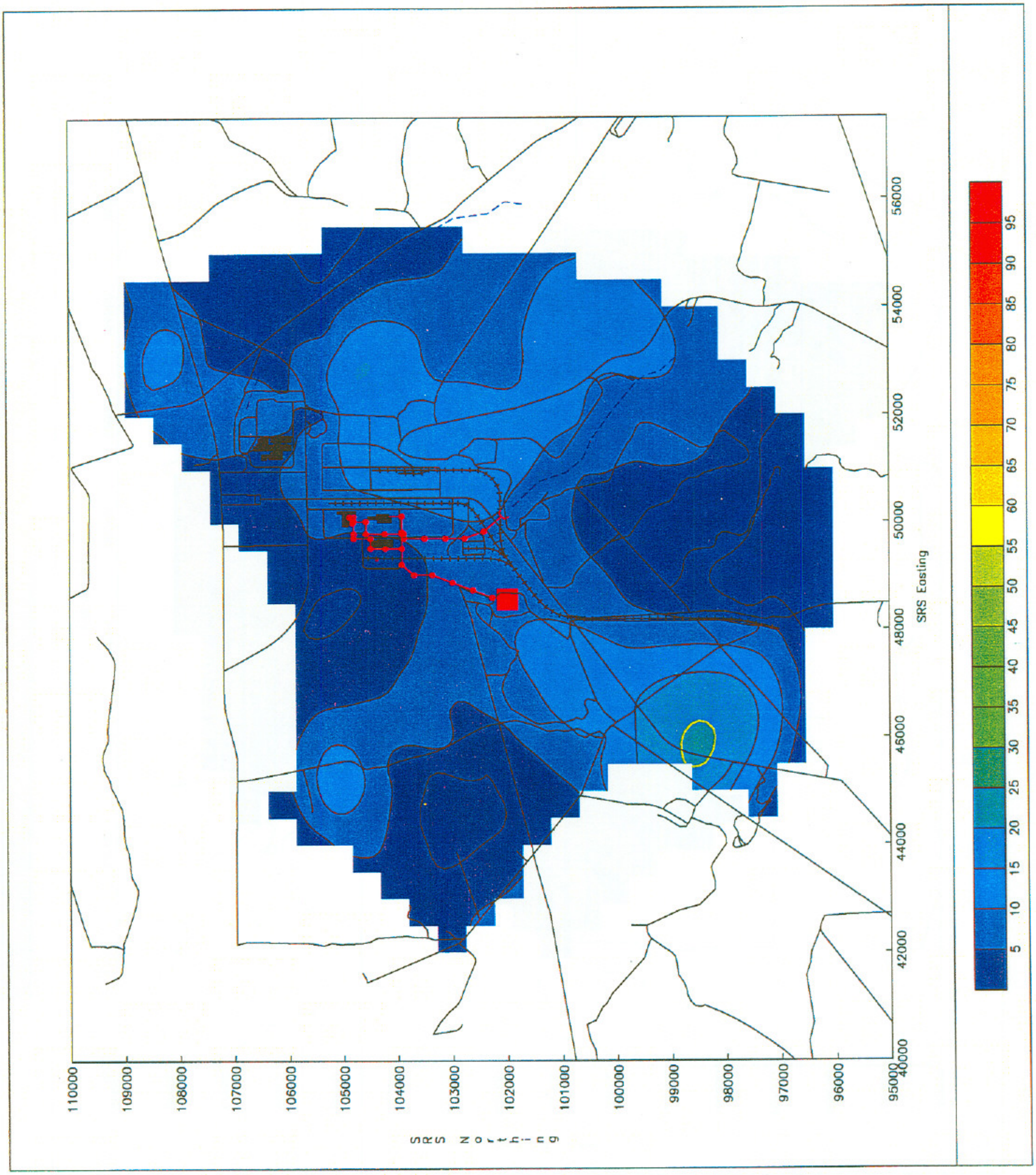


Figure 3-16. Geometric Mean of Mud Percentage within the "Lost Lake" Aquifer Zone of the Steed Pond Aquifer

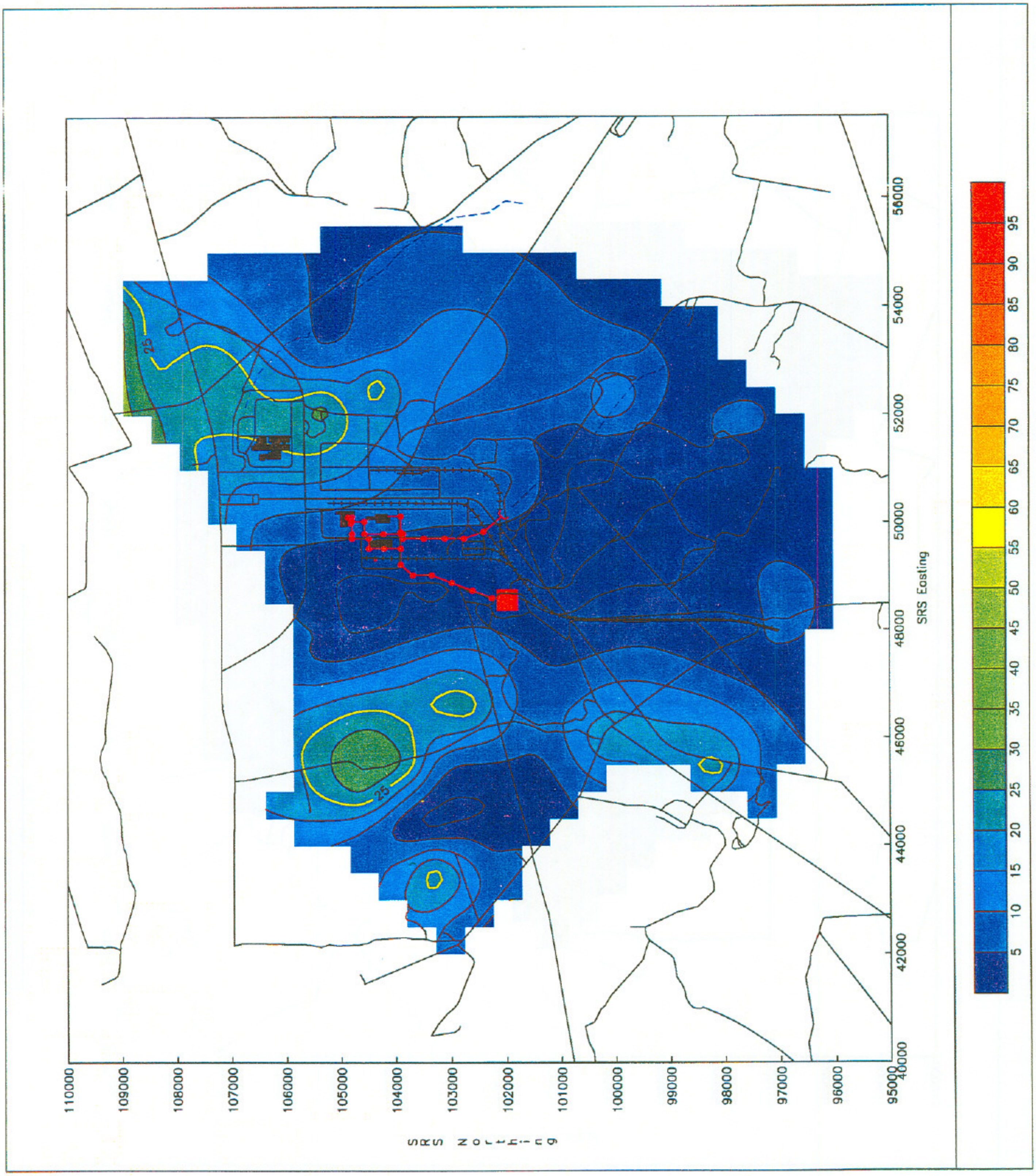


Figure 3-17. Standard Deviation of Mud Percentage within the "Lost Lake" Aquifer Zone of the Steed Pond Aquifer

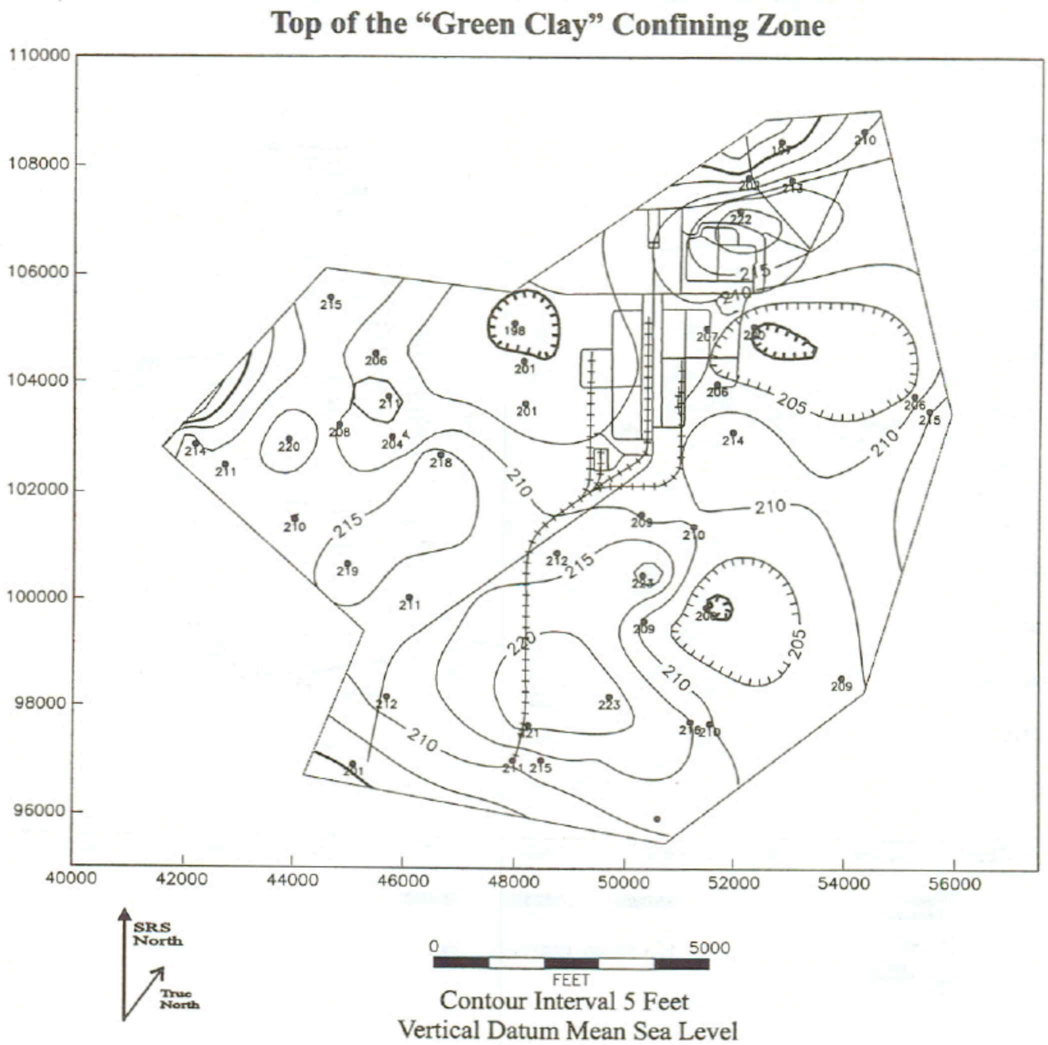


Figure 3-18. Altitude Contour Map of the Top of the "Green Clay" Confining Zone/Base of the "M Area" Aquifer Zone of the Steed Pond Aquifer

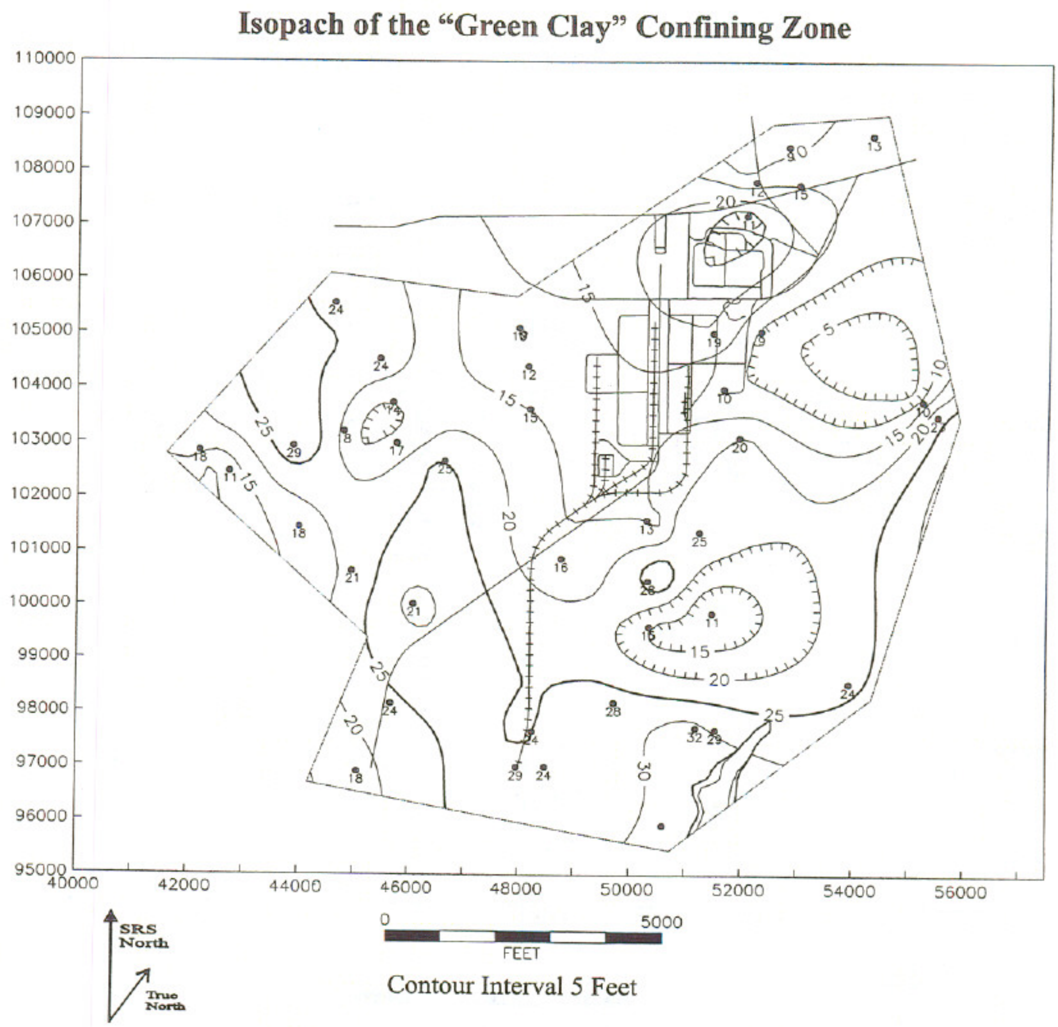


Figure 3-19. Isopach Map of the "Green Clay" Confining Zone of the Steed Pond Aquifer

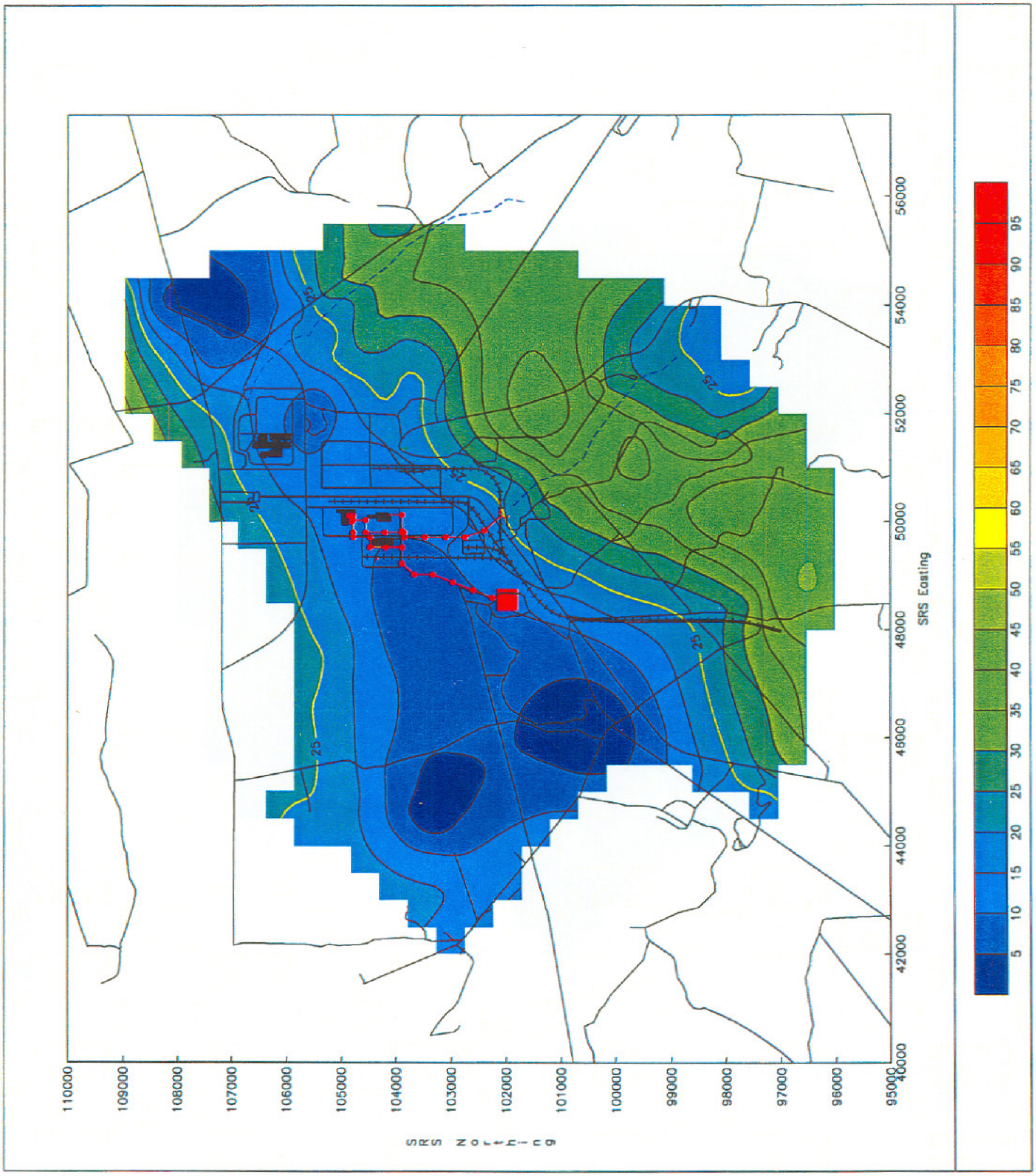


Figure 3-20. Geometric Mean of Mud Percentage within the "Green Clay" Confining Zone of the Steed Pond Aquifer

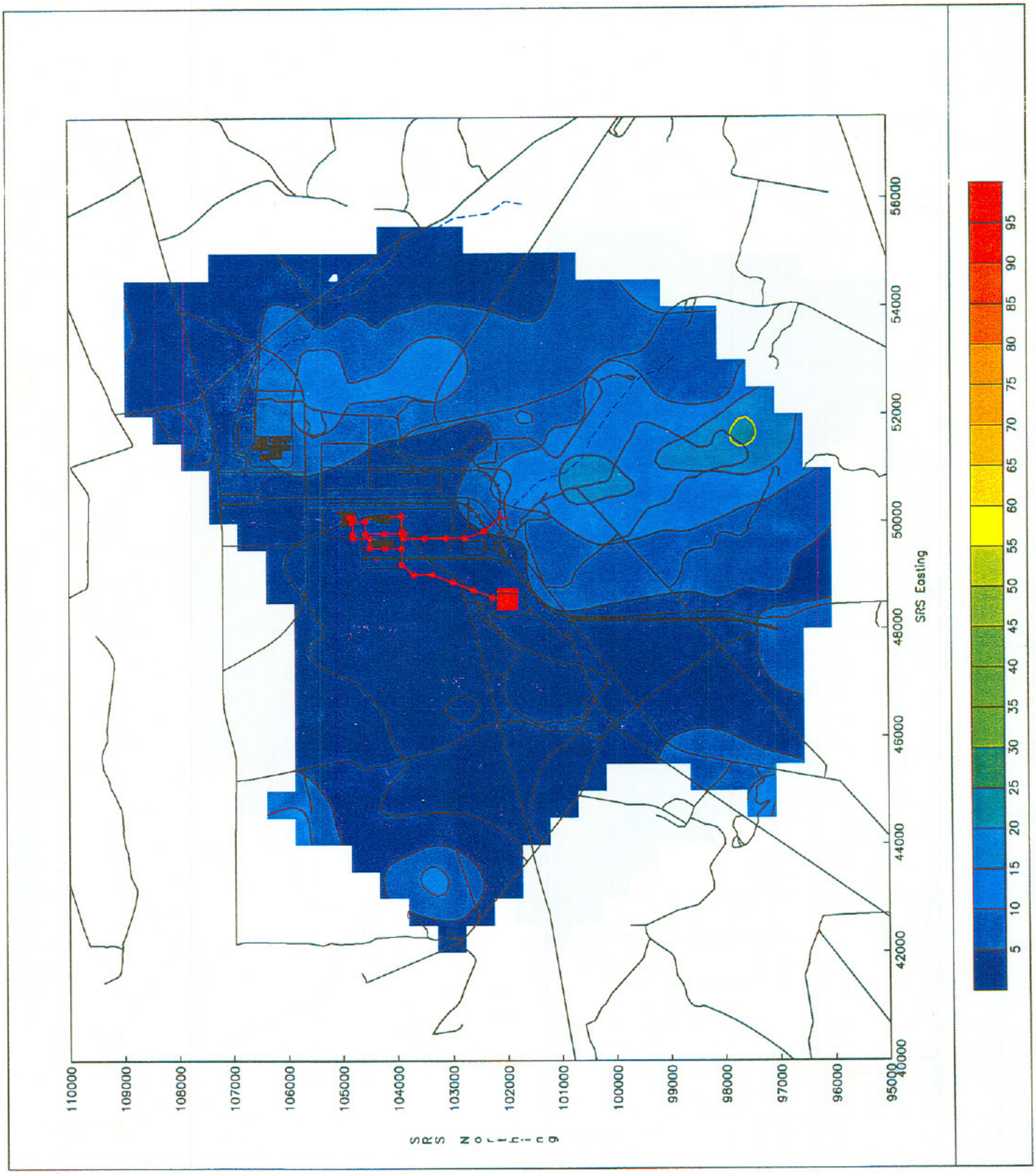


Figure 3-21. Standard Deviation of Mud Percentage within the "Green Clay" Confining Zone of the Steed Pond Aquifer

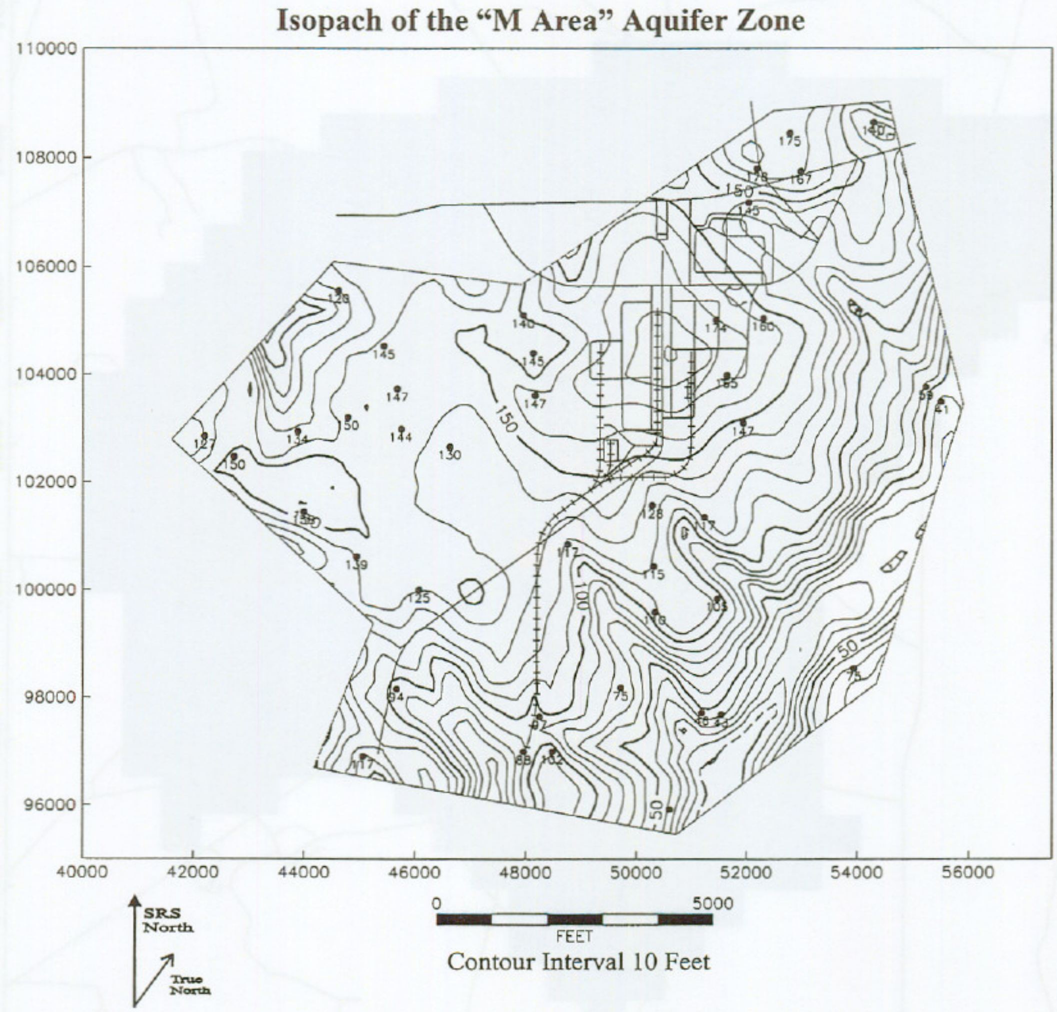


Figure 3-22. Isopach Map of the "M Area" Aquifer Zone of the Steed Pond Aquifer and the Vadose Zone

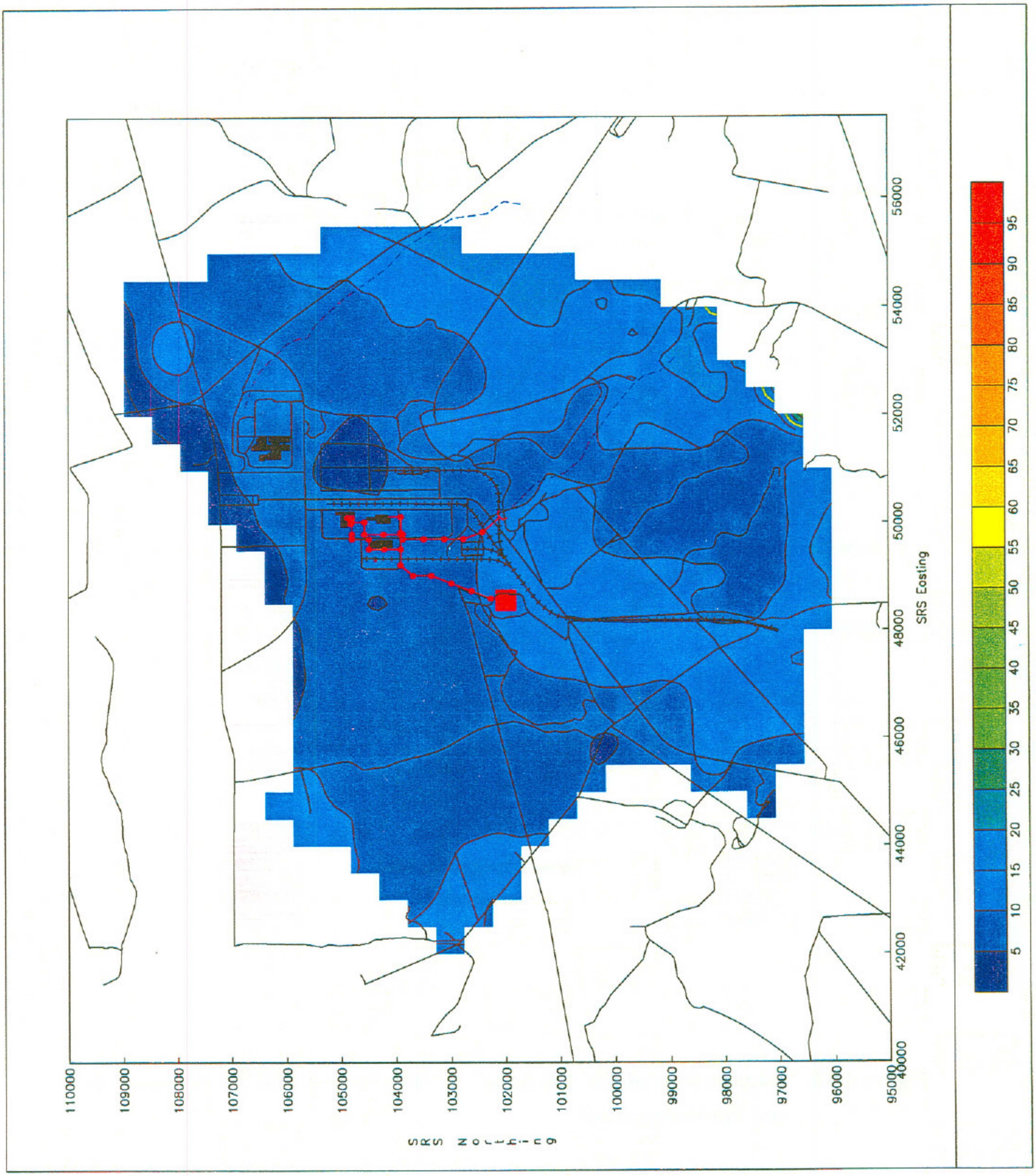


Figure 3-23. Geometric Mean of Mud Percentage within the "M Area" Aquifer Zone of the Steed Pond Aquifer and the Vadose Zone

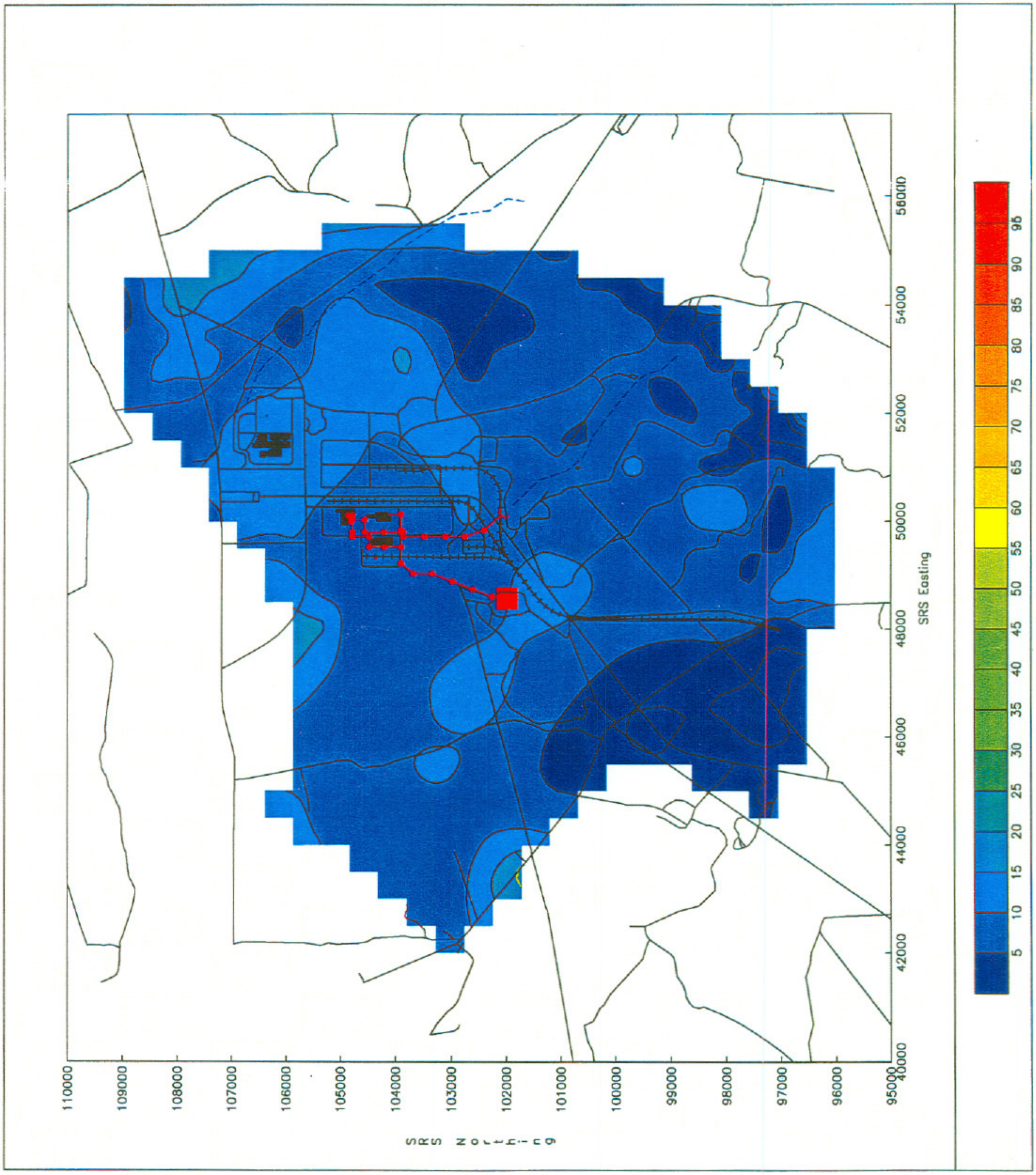


Figure 3-24. Standard Deviation of Mud Percentage within the "M Area" Aquifer Zone of the Steed Pond Aquifer and the Vadose Zone

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4.0 SUMMARY AND RECOMMENDATIONS

The extent of mud within hydrostratigraphic units can be modeled most effectively by selecting discrete depositional intervals within which to model lithologic parameters.

1. The clay layers within the CBCU are laterally continuous primarily within the "lower clay" confining zone.

2. The hydrogeologic model presented in this report suggests that the SPA and the CBA are in hydraulic communication in the western sector and in the northeast corner of the study area. Future work should incorporate recently completed cores from Western Sector and Northern sector to refine the model in these areas.

3. There are strata within the "Lost Lake" aquifer zone beneath Southern Sector that may serve as preferential pathways for groundwater flow within the vicinity of the M-Area Basin.

Recommendations for future work:

Couple the results of the facies analysis with data for observed groundwater contamination to refine the models for plume geometry beneath A/M Area.

Refine data from USGS digital elevation models (DEM) by validating the USGS data set with surveyed points within the study area. This will minimize the errors associated with poorer grid resolution in the stream valleys and the lack of finished-grade contours in the USGS data set.

Add shallower cores to the data set that meet same QA requirements to enhance the resolution of the model in the upper CBCU and SPA.

Identify horizons within the MAAZ and vadose zone that will increase the vertical resolution of the model and improve the distribution of fine-grained sediments in these units.

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5.0 REFERENCES

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APPENDIX A. Core Descriptions

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APPENDIX B. SRS Core Logging Format

NOTE:

This appendix presents an explanation of all data fields in the description code used at SRS. Database fieldnames are indicated with underlined, boldface type. Superheadings (groups of related fields) are indicated in italics with underlined, boldface type. Content is adapted from WSRC ESSOP-2-15, *Binocular Examination of Sediment Core Samples*.

GENERAL

1). Make letters and numbers clear and unambiguous. Use standard, block and uppercase letters. Use letters and numbers only; no symbols.

2). Left justify letters; Right Justify numbers.

3). Estimating percentages

-If constituent <10% or 90%, use increments of 1%

-If constituent between 10% and 90%, use increments of 5%

-Highest value is 99%

-Use .1 for trace quantities (<1%)

4). Core Description

Log core from bottom up. Slice core to observe sedimentary structures. Thin layers or laminae, less than a few inches, should be noted under **STRUCTURE**.

Certain properties are best determined in hand specimen: color, structure, maximum size, roundness, sorting, etc., are best determined with a binocular microscope.

5). If there is sediment, especially pebbles and sand, in the top few inches of a core that is obviously different from the underlying material, it probably fell down ("caved") from up the hole and should not be described.

APPENDIX B. SRS Core Logging Format (Continued)

6). Put your initials (e.g., LOGGED BY: PAT) and date (DD-MM-YY format) in upper left corner of the log sheet. Fill in the page numbers in upper right corner (e.g., 1 of 8). Check in lower right corner of log sheet whether core is WET or DRY. Log core in sequence and record all page numbers in sequence.

WELL (Cols. 1-8)

Record only on top line of sheet.

Cols 1-3 [**Well Series**] Letter or letters. Left justify (LJ).

Cols. 4-6 [**Well Number**] Number. Right justify (RJ).

Cols. 7-8 [**Screen Zone**] Letter. Left Justify (LJ).

Examples: P_18TA

CMP_09_

DEPTH (Cols. 9-12)

Starting at bottom of core, describe in one-foot increments. Assume that missing core results from failure to sample bottom of interval. Record on computer load sheets from the bottom of the sheet upward.

(Right Justify) (RJ).

Examples: 115

89

7

127

APPENDIX B. SRS Core Logging Format (Continued)

RECOVERY [INDUR] (Col. 14) = Degree of lithification

1 = Loose	Core unlithified.
2 = Friable	Core coherent, but easily disaggregated.
3 = Hard	Core firm, but grains can be dislodged.
4 = Very Hard	Hard rock (some carbonates, silicified rock, or iron oxides).

COLOR (Cols. 15-19)

Left Justify (LJ).

Use most common or overall color. Prefix main rock color with shade. (i.e., light, medium, or dark).

Colors: Use first two letters of color:

BR = Brown

OR = Orange

PI = Pink

PU = Purple

RE = Red

TA = Tan

WH = White

YE = Yellow

Exceptions:

BE = Blue

APPENDIX B. SRS Core Logging Format (Continued)

BK = Black

GN = Green

GY = Gray

MT = Mottled

VAR = Variegated

<u>**STRUCTURE**</u> (Cols. 20-27) = Sedimentary Structures

Left Justify.

Leave <u>BLANK</u> for massive, structureless beds.

B = Color banded (B + color; e.g., BGY = banded gray)

BR = Brecciated

BU = Burrow

CLB = Clay Balls (Any gravel sized clay)

CTN = Chert Nodule

FE = Iron oxide nodule

FR = Fracture

FS = Fissile

ICA = Interbedded or interlaminated Calcarenite

ICL = Interbedded or interlaminated Clay (silt + clay)

IMC = Interbedded or interlaminated Micrite

IPB = Interbedded or interlaminated Pebbles

APPENDIX B. SRS Core Logging Format (Continued)

ISD = Interbedded or interlaminated Sand

MCB= Micrite Balls or fragments (gravel sized)

MT = Mottled

PE = Pelleted

PY = Pyrite

RT = Root structure (cast or mold)

VN = Mineral vein

WSP = Wispy laminations or bedding

XB = Cross-bedded

Examples: IPBCLB = Interbedded pebbles and clay balls

PYVN = Pyrite Vein

SILICATE **[Use only for siliciclastic fraction]** (Cols. 28-38)

PERCENT GRAVEL, SAND, MUD [%GR % SD % MD] (Cols. 28-38)

Normalize estimated percent siliciclastic gravel, sand and mud (silt + clay) to 100% and record in appropriate column.

Right Justify.

%GR (Cols. 28-29) **= % GRAVEL (>2mm)**

%SD (Cols. 30-31) **= % SAND (2mm - 0.0625mm)**

%MD (Cols. 32-33) **= % MUD (<0.0625mm)**

SIZE (Cols. 34-37)

APPENDIX B. SRS Core Logging Format (Continued)

<u>**MX**</u> (Cols. 34-35 = **MAXIMUM SIZE**

Left Justify.

Record maximum size of siliciclastic fraction using following abbreviations:

BO = Boulder (> 256mm)

UC = Upper Cobble (128-256mm)

LC = Lower Cobble (64-128mm)

UP = Upper Cobble (16-64mm)

LP = Lower Pebble (4-16mm)

GR = Granule (2-4mm)

VC = Very Coarse sand (1-2mm)

C = Coarse sand (0.5-1mm)

M = Medium sand (0.25-0.5mm)

F = Fine sand (0.125-0.25)

VF = Very Fine sand (0.0625-0.125mm)

CL = Silt and Clay (<0.0625mm)

<u>**MD**</u> (Cols. 36-37) = **MODAL SIZE**

Modal Size = Most Abundant Size Fraction

Left Justify.

May not be applicable to some carbonates (i.e., those that contain little or no siliciclastic material).

APPENDIX B. SRS Core Logging Format (Continued)

Record modal size using following abbreviations:

BO = Boulder (> 256mm)

UC = Upper Cobble (128-256mm)

LC = Lower Cobble (64-128mm)

UP = Upper Cobble (16-64mm)

LP = Lower Pebble (4-16mm)

GR = Granule (2-4mm)

VC = Very Coarse sand (1-2mm)

C = Coarse sand (0.5-1mm)

M = Medium sand (0.25-0.5mm)

F = Fine sand (0.125-0.25)

VF = Very Fine sand (0.0625-0.125mm)

CL = Silt and Clay (<0.0625mm)

<u>ROUNDNESS</u> [RND] (Col. 38)

Record <u>Average</u> <u>Roundness</u> of <u>Quartz</u> grains only, using following scale:

1 = Very angular

2 = Angular

3 = Subangular

4 = Subrounded

6 = Rounded

APPENDIX B. SRS Core Logging Format (Continued)

9 = Well-rounded

CARBONATE LITHOLOGY **[Use only for carbonate fraction]** (Cols. 39-48)

PERCENT (CARBONATE) **GRAVEL, SAND, MUD [%GR, %SD, %MD]** (Cols. 39-44)

Normalize estimated percent carbonate gravel, sand, and mud to 100%, and record in appropriate column.

Right Justify.

%GR (Cols. 39-40) **= % CARBONATE GRAVEL (>2mm)**

%SD (Cols. 41-42) **= % CARBONATE SAND (>2mm-0.0625mm)**

%MD (Cols. 43-44) **= % CARBONATE MUD (>0.0625mm)**

PERCENT CEMENT [%CMT] (Cols. 45-46)

Record total percent carbonate plus other cement (silica, iron sulfides, iron oxides, phosphate, glauconite, etc.).

Right Justify.

PERCENT CARBONATE [%CAR] (Cols. 47-48)

Check any suspicious sample with 10% hydrochloric acid, and estimate total percent carbonate.

Record total percent carbonate (Sum of matrix, cement, fossils, and other carbonate grains), without normalizing to 100%.

Right Justify.

APPENDIX B. SRS Core Logging Format (Continued)

ROCK NAME [%NAME] (Cols. 49-56)

Left Justify.

I. No Carbonate Present (<1% Carbonate)

A. If one size fraction 75% or greater, use following:

PB = Pebbles

SD = Sand

ST = Silt

CL = Clay

B. If another fraction is 25% or greater, use as a modifier with most abundant fraction last.

Example: SDCL = Sandy Clay

C. If **two or more** components are 25% or greater, list the **most abundant fraction last.**

Example: PBSDCL =Pebbly, Sandy Clay

Note: In most clastic sediments, it is difficult to distinguish silt from clay. Generally, use CL (clay) for mixtures of clay and silt. Use ST (silt) only for silt or siltstone that is highly porous.

APPENDIX B. SRS Core Logging Format (Continued)

II. Carbonate Present (<1% Carbonate)

A. If Carbonate 75% or greater:

BL = Biomoldic Limestone (numerous megafossil molds)

CA= Calcarenite (granular, sand-sized carbonate)

GM= Green Micrite (looks like green clay)

MC= Micrite (lime mud; chalk)

SL = Shell Limestone (shells &/or shell fragments)

VL = Vuggy Limestone (numerous vugs)

XL = Crystalline Limestone (hard, massive)

B. If Carbonate 50-75%:

Prefix carbonate rock name with other constituent(s), least abundant first.

Examples: SDSL = Sandy Shell Limestone

GLSDMC = Glauconitic Sandy Micrite

C. If Carbonate 1-50%:

Prefix main rock name with carbonate modifier.

Examples: CM = Carbonated-cemented

CMSD = Carbonate-cemented siliciclastic Sand

MCCL = Micritic Clay (clay is silicate)

SLSD = Shelly siliciclastic Sand

APPENDIX B. SRS Core Logging Format (Continued)

III. Other Lithologic Types

Must be 25% or greater in siliciclastic to be used as a modifier.

Use the following abbreviations:

AR = Arkosic (feldspathic)

CT = Chert cement or replacement (use for any silica)

FE = Iron oxides (cement or replacement)

GL = Glauconite (green grains or cement)

LG = Lignite (soft, brown to black, woody fragments)

MU = Muscovite

PH = Phosphate (brown to black shell, bone, or tooth)

PY = Iron sulfides (pyrite or marcasite)

Examples:

PHMC = Phosphatic Micrite

CTSLMC = Shelly Micrite with Chert

SORTING [SORT] (Col. 57)

Record overall sorting of rock using following scale:

W (Well sorted)	If 90% within 2 size classes
M (Moderately sorted)	If 90% within 4 size classes
P (Poorly sorted)	If 90% > 4 size classes
V (Very poorly sorted)	If 90% > 6 size classes

APPENDIX B. SRS Core Logging Format (Continued)

If a sand contains >25% CL (silt + clay) or MC, use P or V.

PERCENT POROSITY [%POR] (COL. 58-59)

Use for all lithologies. Left Justify (LJ).

Estimate percent of large pores by looking at whole core; estimate percent of small pores (2mm) using binocular microscope. Total porosity is sum of large and small pores.

Use following scale:

P (Poor) = <5% porosity

M (Moderate) = 5-15% porosity

G (Good) = 15-30% porosity

E (Excellent) = >30% porosity

PORE TYPE [PORE TYPE] (Cols. 60-61)

Use for all lithologies.

Record most abundant pore type in Cols. 60-61 using the following abbreviations:

BP = Between Particle (interparticle) pore

CH= Channel pore

MI = Micropore

MO= Moldic pore

VU= Vug pore

WP= Within Particle (intraparticle) pore

APPENDIX B. SRS Core Logging Format (Continued)

PERCENT MUSCOVITE [%MUSC] (Cols. 62-63)

Record estimated volume percent muscovite.

Right Justify.

PERCENT GLAUCONITE [%GLAU] (Cols. 64-65)

Record estimated volume percent glauconite (As grains, matrix, or cement).

Right Justify.

PERCENT LIGNITE [%LIGN] (Cols. 66-67)

Record estimated volume percent lignite (As dark, soft, woody, peaty or coaly material).

Right Justify.

PERCENT SULPHIDES [%SULP] (Cols. 68-69)

Record estimated volume percent marcasite or pyrite.

Right Justify.

HEAVY MINERALS [HEAV] (Col. 70)

Record estimated volume percent heavy minerals (opaque and non-opaque) using the following scale:

R (Rare) = Very few heavy mineral grains

C (Common) = Heavy mineral grains easy to find

APPENDIX B. SRS Core Logging Format (Continued)

A (Abundant) = "Loaded" with heavy mineral grains

FOSSILS (Cols. 71-80)

List most abundant first. Do not skip spaces between abbreviations.

If fossils are present, but you can't identify, note YE for YES.

If silicified, note CT first, then type(s).

Left justify.

Use the following abbreviations (for FOSSILS):

BA = Barnacle

BR = Bryozoan

ES = Echinoid Spine

FO = Foraminifer

GA = Gastropod

GI = *Crassostrea gigantissima*

OS = Ostracode

PL = Pelecypod

SA = Echinoderm (sand dollar)

SP = Sponge spicule

Examples: CTPLGA = Silicified Pelecypods and Gastropods

BRFO = Bryozoans and Foraminifers