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Analysis Report
Task 1B of AP-110
Identify Plugged and Abandoned Oil or Gas Wells Not Sealed Through the Culebra with Cement, and Units to Which the Culebra Might Be Connected

(AP-110: Analysis Plan for Evaluation of Culebra Water-Level-Rise Scenarios)

Task Number 1.4.1.1

Report Date: September 13, 2004

Author: _____ 12/15/04
Dennis W. Powers
Consulting Geologist
Date

Technical Review: _____ 12/15/04
Richard L. Beauheim, 6822
Repository Performance Department
Date

QA Review: _____ 12/13/04
Steve Davis, 6820
Carlsbad Programs Group
Date

Management Review: _____ 12/15/04
M.J. Rigali, 6822
Repository Performance Department
Date

WIPP:1.4.1.1:TD:QA-L:AP-110 Analysis Reports

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Analysis Report for Task 1B, AP-110
Identify Plugged and Abandoned Oil or Gas Wells Not Sealed Through the Culebra with Cement, and Units to Which the Culebra Might Be Connected

Introduction

This analysis report has been prepared and submitted to meet the requirements of Task 1B of Analysis Plan AP-110, Evaluation of Culebra Water-Level-Rise Scenarios (Beauheim, 2003). Task 1B is listed in AP-110, page 19, as the second bullet item. The analyst is Dennis W. Powers, Ph.D., Consulting Geologist, Anthony, TX 79821.

The general area for this study comprises most of 12 townships, located in townships T21S to T24S, ranges R30-32E. Most of the data considered fall within the boundaries of the hydrological modeling domain (Fig. 1) (see Beauheim, 2003). No unusual geological methods were used in this program; Culebra depth at drillholes was acquired from an existing database or by interpreting geophysical logs from a particular drillhole or from a nearby drillhole. Records from the Oil Conservation Division (OCD) of the New Mexico Energy, Minerals and Natural Resources Department were accessed (http://www.emnrd.state.nm.us/ocd/, "OCD Online," "Imaging") to confirm or develop information about cementing the Culebra in plugged and abandoned (P&A) oil or gas wells. This task does not evaluate whether P&A wells meet OCD regulations; a well with an open interval across the Culebra may be plugged according to requirements.

Task 1B Elements

Five general steps are used to identify a) oil or gas drillholes, reported as P&A, that might not be sealed through the Culebra with cement and b) units to which the Culebra might be connected:

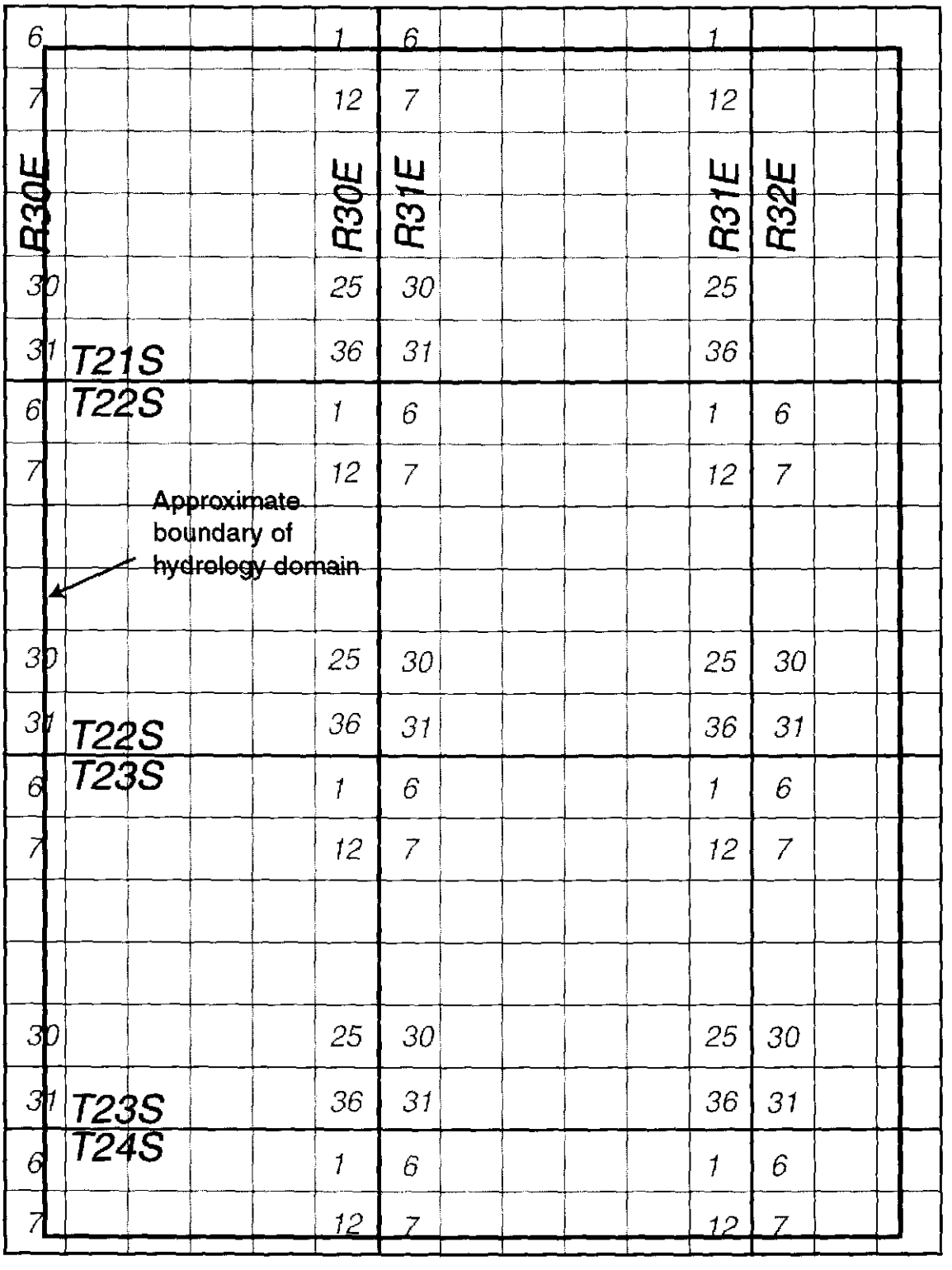
1) identify the set of P&A drillholes within the area,
2) establish the cementing and casing records relevant to the Culebra,
3) establish or estimate the depth of the Culebra encountered in the drillhole,
4) evaluate sealing of the Culebra by cement, and
5) estimate the stratigraphic interval open to the Culebra where the Culebra is not sealed.

The initial source of data for steps 1) and 2) is the Delaware Basin drillhole database maintained by David Hughes, Washington Regulatory and Environmental Services (WRES). The sources of data for 3) include previous work in support of Analysis Plan 088 (Powers, 2002, 2003) and some additional data collected from on-line geophysical log files at the OCD website ("Log Files"). For step 4, the information on casing cement intervals and plugging intervals was compared to Culebra depths developed during step 3.

Task 1B, Step 1. The analysis plan calls for identifying P&A oil or gas drillholes for which the Culebra may not be isolated by cement. The domain of interest lies within the Delaware Basin, in the vicinity of the Waste Isolation Pilot Plant (WIPP). The drillhole database maintained by David Hughes is accepted as a record of reported drillholes within this area.

A Microsoft Access table, titled "New Mexico Hydrocarbon-2004," obtained from David Hughes in June 2004, includes drillholes from oil or gas exploration and development within the Delaware Basin. A usable subset of this table was developed by selecting P&A drillholes within the hydrology domain (red rectangles on Figs. 1 and 2).

Figure 1 Task 1B AP-110
Initial Area of Selected P&A Oil or Gas Drillholes
From "New Mexico Hydrocarbon-2004"



Task 1B, Step 2. The analysis plan calls for establishing the cementing and casing records for drillholes as a part of understanding the possible role of unplugged Culebra intervals. The database from Dave Hughes includes information about dates of drilling and P&A, surface casing depths and cementing, and P&A intervals and volumes that are useful for evaluating the isolation of the Culebra from other intervals. This information was extracted from the database, along with other items such as location data, to help in the evaluation. An initial review of P&A records showed that oil or gas wells are commonly plugged with cement through intervals that are not specific to the Culebra and can be widely spaced. In addition, surface casing strings in the drillholes commonly exceed the depth of the Culebra. *Based on this initial review, the analysis focused on establishing the intervals cemented behind surface casing(s). If the Culebra was not cemented behind casing, the plugs were then evaluated to determine what intervals were isolated.*

The quality of the information in the database about surface casing cements and plugging is considered good where available, but the information was not available for all drillholes evaluated. Spot checks of plugging information in the database showed good correspondence to file data at the OCD. Where casing cement data or plugging information were not included in the Hughes database, on-line files of the OCD were consulted to try to obtain the relevant information. For a few drillholes, the information about casing cement or plugs was limited or could not be assessed.

Task 1B, Step 3. To meet the objectives of the Analysis Plan, the depth of the Culebra in the drillholes in the data set must be established or estimated. Culebra depth was available from previous work (Powers, 2002, 2003) for some oil or gas wells, and these data were matched to the drillholes in the data set. Where Culebra depth was not available for a particular drillhole, it was estimated based on information from surrounding drillholes (see methods). Estimated depths and new data from geophysical logs in *AP-110 Task1B.xls* have been differentiated by red numbers from depths obtained from previous work (black font).

Task 1B, Step 4. The Analysis Plan requires evaluating the isolation of the Culebra in the P&A oil or gas drillholes in the data set. As noted in Step 2, a review of existing data indicated that it was much more likely that cemented surface casing(s) would isolate the Culebra than would cement plugs placed as part of P&A. The first step of evaluating was to compare the record of cemented intervals behind surface casing(s) to Culebra depth (see methods). The first or second surface casing string commonly exceeded the depth of the Culebra. Where it could be established that cement was circulated behind the casing until cement reached the surface, the Culebra was assessed as being cemented and isolated from saturated zones above or below the Culebra. Where such direct statements were not available, the volume of cement circulated behind the casing was compared to volume of the annulus to assess the status of cementing the Culebra (see methods). Where the Culebra was determined to be open behind the annulus, or the status of casing cements could not be established, the plugs were examined to determine if the Culebra was directly cemented (with no casing or tubing across the Culebra) or what interval including the Culebra might be bounded by cement plugs.

Three basic categories were assigned based on this evaluation:

- Surface casing cemented across the Culebra or Culebra plugged (O in Fig. 2)
- Surface casing not cemented across Culebra and cement plugs from P&A not across Culebra (X in Fig. 2)
- Undetermined if Culebra is cemented behind surface casing or by plugs (+ in Fig. 2).

The drillhole locations and cement/plug categories are plotted (Fig. 2) to show distribution within and adjacent to the hydrologic domain (red rectangle). H-9 is also shown as a reference point for later discussion.

Task 1B, Step 5. To meet the last objective of Task 1B, the stratigraphic intervals open to the Culebra were estimated using background knowledge of the units. The Culebra was assumed to be up to 30 ft thick. The interval from Culebra to Salado was assumed to be about 100 ft although this becomes thicker to the east where halite is more commonly present in the lower Rustler. The interval above the Culebra to the overlying redbeds (Dewey Lake Formation) was assumed to be 200+ ft, as this interval also thickens eastward because of halite in various Rustler Members. More precise determinations of the stratigraphic intervals potentially open to the Culebra are possible, although more detailed stratigraphic data would be needed for each drillhole. Given the limits on cementing and other data, this step was not expected to change the general conclusions and was not pursued.

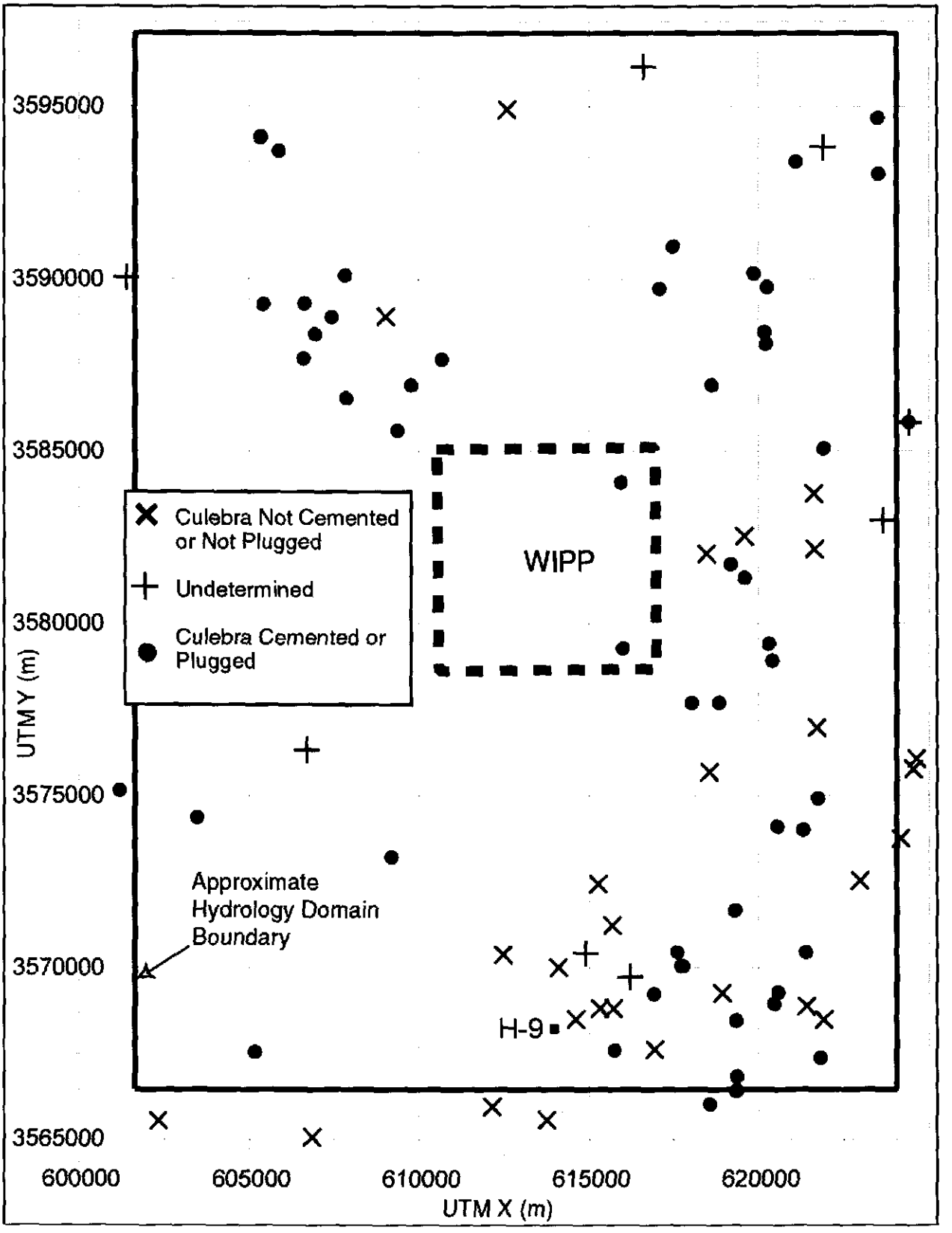
Methods

Several areas in developing the casing cement or plug evaluation required that methods be applied to equivalent information among drillholes. Developing location coordinates is vital for data checking and later modeling exercises. It was necessary to estimate Culebra depth at a few drillholes where data were not available. Where cementing or plugging information provided cement amounts but not all depth information, it was appropriate to estimate the cemented interval. A method was used to develop necessary information for each of these areas.

The desired location information for each drillhole included UTM (Universal Transverse Mercator) coordinates (North American Datum 1927 - NAD27). For the drillholes included in the final subset, the Hughes database included New Mexico State Plane coordinates, and these were accepted as valid. UTM (NAD27) coordinates were computed from the State Plane coordinates using the software Corpscon for Windows Version 5.11.08 (see Powers, 2002, for a discussion of techniques and software background).

Depth to top of Culebra for many drillholes was obtained from previous work (Powers, 2002, 2003). The data in the previous work were converted from metric units (m) to English units (ft) by dividing the metric units by 0.3048 in MS Excel 2002. The depths were matched to each individual well in the P&A list by location and name. These data are shown in black font in *AP-110 Task1B.xls* in column "Top of Culebra Depth (ft)." For the remaining wells, the depth to Culebra was obtained from a geophysical log accessed through the OCD on-line site or was estimated from a nearby well in the Powers (2002, 2003) work, and the information was entered directly into the table. These values are shown in red fonts. The analysis is generally not very sensitive to slight differences based on estimates from nearby locations.

Figure 2 Task 1B AP-110
Map of P&A Oil or Gas Wells In or Near the Hydrology Domain



For the P&A drillholes selected from Hughes's database, information in the table for a few of the drillholes indicates top of cement behind the casing or for P&A intervals, allowing direct comparison with the Culebra depth. Most required a check of on-line records at OCD to provide appropriate information. Records that include specific wording, such as "circ 110 sx to pit," that indicated complete cementing behind the casing across the Culebra were taken at face value. Statements only indicating cement was "circulated" were not by themselves taken to indicate complete cementing, although that is the likely meaning. Where ambiguity existed, the volume in the annulus between the bottom of the cemented interval and top of Culebra was estimated (see below). If the number of sacks of cement used exceeds the estimated volume (in cu ft), the Culebra was assessed as cemented behind the casing. This estimation does not take into account any drillhole enlargements during drilling, but cement volume is typically 1.3 cu ft/sack or more (Halliburton, undated), providing a margin for the comparison.

The volume estimated for the annulus follows the bottom formula indicated in Figure 3, modified for the Excel spreadsheet as follows:

$$V = \pi \text{ (casing depth-top Culebra)}((\text{drillhole diameter}/2)^2 - (\text{casing diameter}/2)^2)/144$$

where V is in cubic ft, depths are in units of ft and the diameters are in units of inches. Dividing by 144 (sq inches/sq ft) converts the area of the annulus to dimensions of square feet. The electronic version of the spreadsheet shows the entries for the formula if the cell in the column "Estimated Cement Volume" is selected. Data for the formula is entered based on values in other columns showing cement volume, depths, bit, and casing diameters. Because the relevant data are not located in the same cells for different wells, these were not referred to by using a cell address within the table. The formula values can be observed by accessing the cell with the calculation.

Data Sources and Quality Assurance

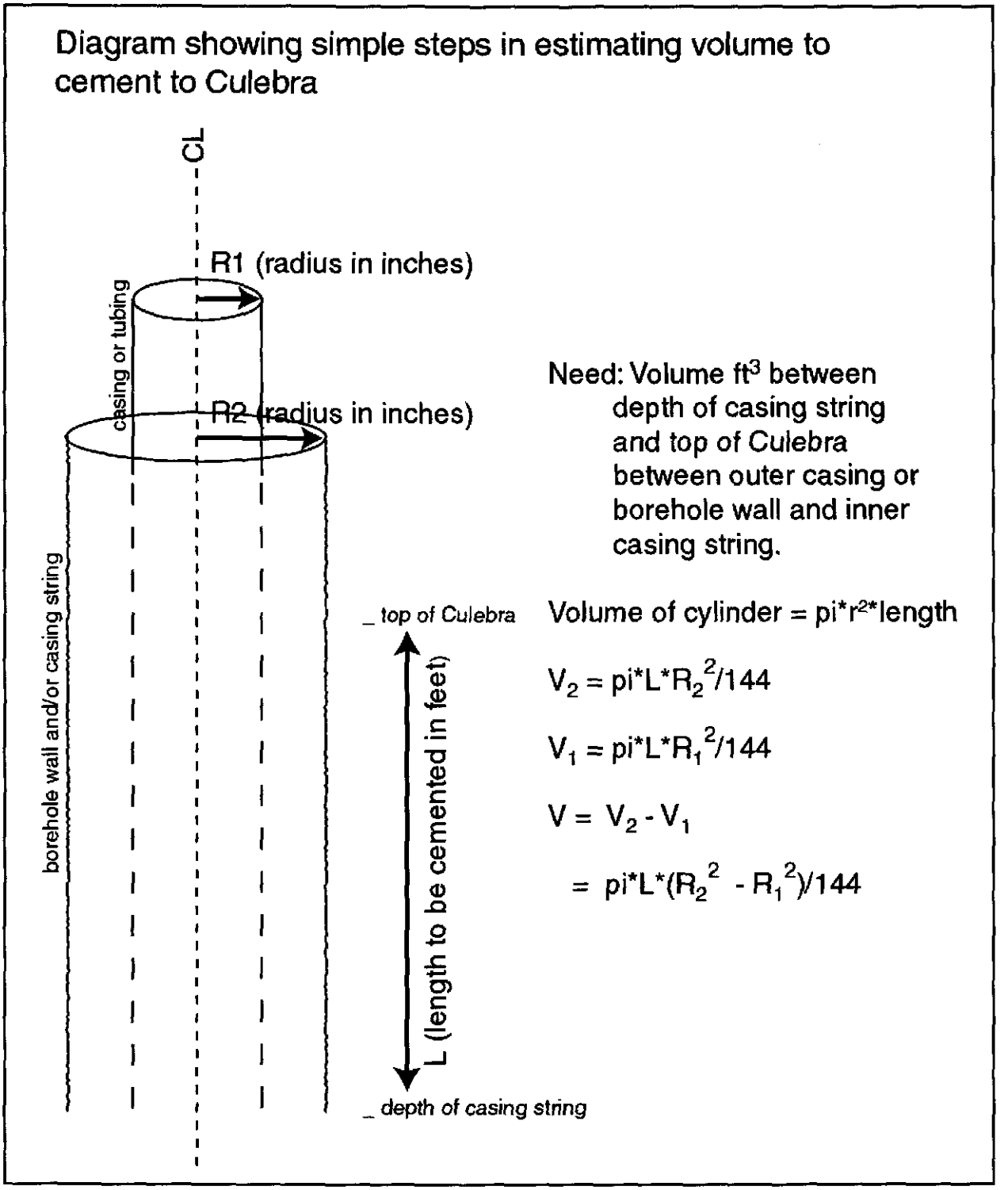
For the main records, a Microsoft Access Table titled "New Mexico Hydrocarbon-2004" was obtained from David Hughes (WRES), and this table was accepted as a record of oil or gas drillholes for the study area. A subset of plugged and abandoned wells was exported from Access as a Microsoft Excel table for paring down to the wells within or near the hydrology modeling domain and for entering and manipulating additional data.

Location data in New Mexico State Plane Coordinates from "New Mexico Hydrocarbon-2004" were accepted as given, and UTM (m) coordinates were generated using *Corpscon for Windows 5.11.08*, which was checked as indicated below in the section on Routine Calculations.

Data about the drillhole located at the OCD site were accepted as given, although details were often checked through different files to obtain the most consistent information. The specific files are not provided here, as they are available on-line to the public.

Estimated Culebra depth, at locations where hole-specific data are not available, and new data entered by examining geophysical logs on file with OCD are distinguished in the data table by a red font.

Figure 3 Task 1B AP-110
Illustration of Calculation for Estimating Cement Volume
Required to Cement Annulus Through the Top of Culebra



Microsoft Excel 2002 table *AP-110 Task 1B.xls* attached to this report as an electronic file shows the final assessment of Culebra plugging and supporting data.

Discussion

The records from various sources are considered representative and reasonably complete as a listing of plugged and abandoned oil or gas wells for the study area. Nevertheless, the cementing or plugging records from the OCD for a few drillholes are incomplete, are unreadable, or the well file shows no records. No companies have been contacted for records to try to reduce the uncertainties for these wells. It is more important to examine the impact, if any, of known uncemented or unplugged wells on Culebra water levels than it is to reduce the number of wells with undetermined cementing and plugging through the Culebra.

Several columns added to *AP-110 Task 1B.xls* provide keys to the evaluation. The column "Casing 1 or Casing 2 Cemented Through Culebra" indicates the preliminary assessment of casing cements only. The initial assessment is summarized as yes, no, or some less certain outcome indicated by "?" or text. The adjacent column "Notes re Casing 1 or Casing 2 Cemented Through Culebra" provides relevant summary notes derived from inspection of data included in the Hughes source database (black font) or data derived from inspection of well files on-line at OCD (red font). If casing cement is not reported as circulated back to the surface or pit, the next column "Drillholes Evaluated with Volume" is reported as "yes," and the next column ("Estimated Cement Volume") shows a computed volume based on the formula presented in the section on Routine Calculations. The "Estimated Cement Volume" is commonly much smaller than the number of sacks of cement used, providing reasonable assurance that the casing has been cemented. Many of the drillholes are reported to have "circulated" cement, which likely indicates an excess of cement was placed in the annulus to cement to the surface. Nevertheless, a notation in the records on-line at OCD indicating cement was "circulated" is not assumed as direct evidence that excess cement in the annulus was circulated to the surface.

Plugging information was evaluated if the casing cement did not isolate the Culebra or the information was uncertain in some respect. The results of the plug evaluation are summarized with a value from 0 to 7 in the column "Cement Plug Evaluation." The key to column values is included at the bottom of the Excel file for reference. To evaluate the isolation of Culebra by a cement plug, the plugging depths (columns "Plug1D," "Plug2D," etc.) were first checked. If cement plug intervals existed in Hughes' database, or the information was developed by inspection of OCD records (red fonts), they were compared to the depth of the top of the Culebra. The Culebra was assumed to be 25–30 ft thick. If the cement interval was not provided, the volume of cement required to fill the drillhole through the Culebra above the first plug below the Culebra was estimated, as shown in "Estimated Cement Volume." As in the casing cementing calculations, the volume required in cubic feet was compared directly to the number of sacks used in the plug. As the volume of a sack of cement is generally about 1.3 cu ft/sack, or more with certain additives, this comparison provided some margin. For three of the six wells in which the Culebra was isolated by a cement plug ("yes – plug" in "Culebra cemented or plugged or hole didn't reach"), tubing or casing through the Culebra was present and was checked to determine if it was removed before P&A. The background evidence is summarized in column "Casing removed before P&A."

Of the 92 P&A oil or gas wells evaluated, 57 are evaluated as having clear evidence of being cemented through the Culebra. Forty-nine of these showed cement behind a casing (yes in "Culebra cemented or plugged or hole didn't reach"), 2 didn't reach the Culebra (as noted in "Interval open to Culebra"), and 6 (yes – plug) were plugged across the Culebra, as indicated by clear records.

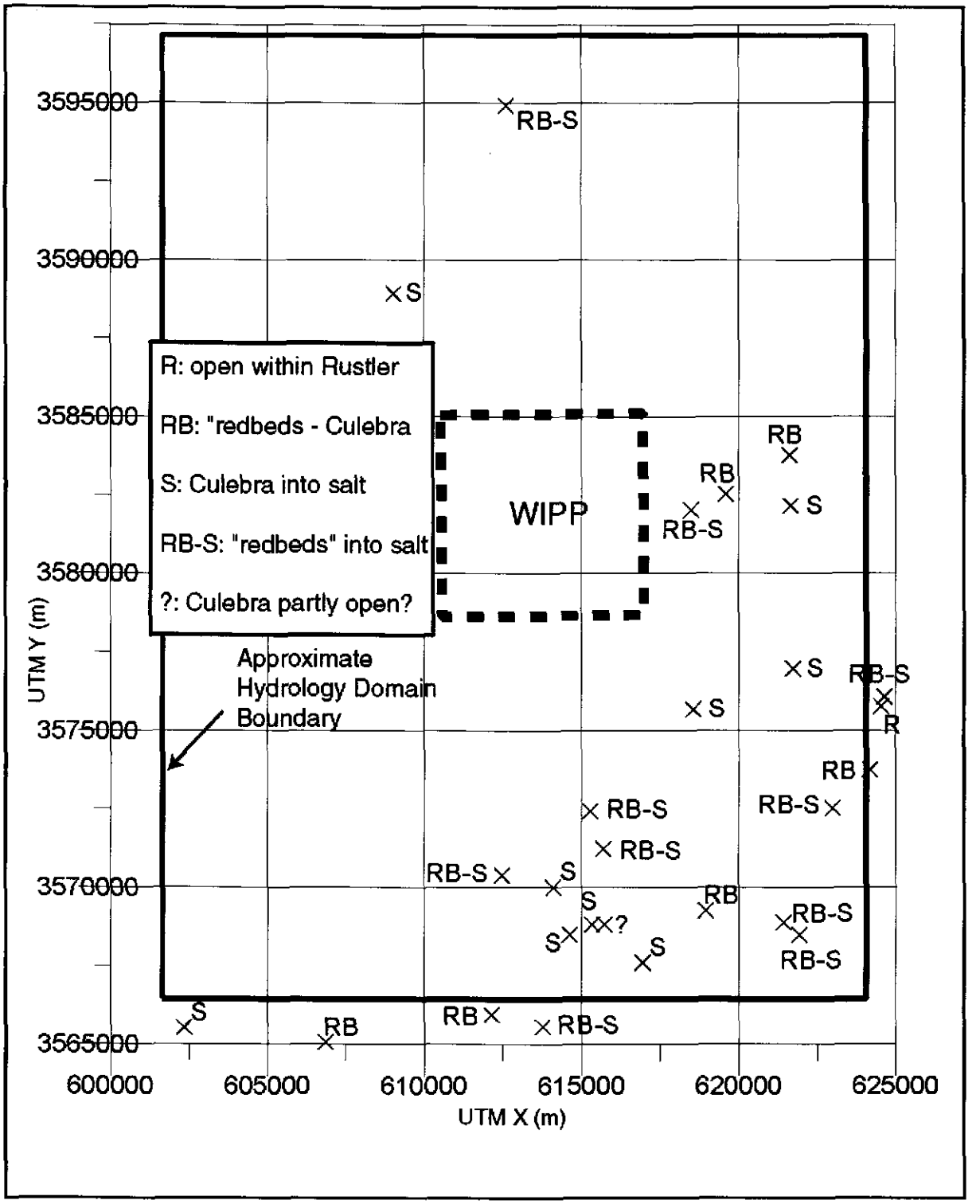
Twenty-four of the drillholes were evaluated as having no cement behind a casing or as a plug across the Culebra. For each of these drillholes, an estimate was made ("interval open to Culebra") of the stratigraphic intervals open to the Culebra. The euphemism "redbed" was used to indicate stratigraphic units above the Rustler regardless of the formation, as the units were not at this point subdivided. These units will include at least part of the Dewey Lake in all cases, and it may include the overlying Dockum Group (Santa Rosa Formation and Chinle Formation) in wells generally in the eastern part of the hydrology domain. These units can be better differentiated if necessary based on geophysical logs.

One of the 24 wells has a somewhat different history. Leonard Continental State 1 (T23S, R31E, sec 32; API 3001505844) was drilled early in 1961 and is reported as P&A on 2/23/61. Nevertheless, the OCD files indicate that responsibility for the well was officially turned over to the AEC for later plugging after use as a monitoring well for Project Gnome, a test of a nuclear device with a limited yield in salt of the Salado Formation in 1961. A search of records by David Hughes (email to Powers, September 2004) does not show this well as part of the plugging and abandoning programs of AEC or successor organizations. The location, covered by a drillpad for a more recent well, was physically searched on 9/13/04 without finding a casing for this well.

Eight drillholes are designated "undet" in the column titled "Culebra cemented or plugged or hole didn't reach" because the information to evaluate cementing was not available from the Hughes database and was not found during a review of the on-line records of the OCD. The records for three other drillholes were not adequate to establish clearly that the Culebra was completely cemented or plugged. For these three, the stratigraphic interval possibly open to the Culebra was estimated ("Interval open to Culebra"). These three drillholes are included in the category "Culebra Not Cemented or Not Plugged" on Figure 2; "undetermined" is reserved for categories where little or no information was available.

For the 27 wells where the Culebra is not cemented or plugged, the potential open intervals can be further summarized (Fig. 4). Six of the wells are assessed as open from Culebra up into the redbeds above the Rustler Formation. The redbeds have varying potential for saturated zones; south of the WIPP site, the Dewey Lake Formation may constitute an Underground Source of Drinking Water (USDW) (US DOE, 2004). Ten of the wells are assessed as being open from the Culebra into Salado or Castile, units with halite. There are 10 wells in which the open interval ranges from the redbeds through the Culebra and into the halite-bearing formations. One well has an open interval restricted to the Rustler Formation. An inspection of Figure 4 does not indicate any obvious spatial pattern to the different intervals open to the Culebra, other than that imposed by restricting drilling across WIPP and in potash areas.

Figure 4 Task 1B AP-110
Estimated Intervals Open to Culebra in Uncemented or Unplugged
P&A Oil or Gas Wells In or Near the Hydrology Domain



There is some support for the notion that drillholes neither cemented nor plugged through the Culebra are older wells. Of these 24 wells, 21 were drilled before July 1, 1979. (This is an arbitrary date, selected as a date around the time of drilling of H-9, a well monitored for WIPP where Culebra water level rises remain unexplained. See Fig. 2 for the H-9 location.) All 11 wells labeled "undet" or having some uncertainty were drilled before July 1, 1979. Of the 57 wells considered to be cemented or plugged across the Culebra, only 20 were drilled prior to July 1, 1979. If the date of January 1, 1970, is used as a comparison, the differences are more striking. Only two of the 57 wells plugged or cemented across the Culebra were drilled before that date. Of the remaining 35 wells (uncemented, unplugged, or with uncertainty), 29 were drilled before January 1, 1970. No regulatory reason or change in standard practice has been identified for this time frame, although they likely exist.

One extension of the information related to age of well and lack of cement or plugging across the Culebra is to estimate how many wells still in production within the hydrology domain might have similar casing and tubing and therefore might have an open Culebra if it is not specifically plugged later. A query of the Hughes database listed 785 oil or gas wells, including those temporarily abandoned, within or very near the boundary of the hydrology domain. Of these wells, only four were drilled before January 1, 1970. Those four were drilled in 1956, 1962, 1966, and 1969. Two are located relatively near WIPP, in T22S, R30E, sec 02 (API 3001510806), and in T22S, R30E, sec 36 (API 3001504735). Although the basis is not clear for later wells being better cemented or plugged, this comparison suggests that wells still in production or temporarily abandoned are not likely to produce a large number of wells that are not cemented or plugged across the Culebra.

There are some final points. Only drillholes that have been P&A have been evaluated here, but there has not been an assessment for each well of whether the P&A was done according to requirements of the OCD. It is clear that P&A is done on targeted intervals, such across the ends of casing strings, and is not commonly directed at the Culebra. Open intervals here for the Culebra are generally behind casings, usually in older wells; P&A efforts have only affected a few wells, as noted in the table *AP-110 Task 1B.xls.*

The table *AP-110 Task 1B.xls* includes a number of columns derived from Hughes database that are preserved for general information. A few have been modified by information found in the OCD files, and this information is in red fonts. They are not further qualified for this project and have not been further checked.

Computers and Software

The following is a summary of the various personal computer technologies (software and hardware) used in the process of compiling source data for Task 1B of Analysis Plan AP-110. Two software applications were utilized in the creation, identification, and organization of drillhole data records: *Microsoft Access 2002* and *Microsoft Excel 2002.* A conversion program developed by the U.S. Army Corps of Engineers, *Corpscon for Windows 5.11.08,* was used to convert State-Plane coordinates (NAD 27) into UTM (NAD 27) coordinates. Plots and graphs were generated using *Grapher 3.03,* a two-dimensional graphing system developed by Golden Software, Inc. The graphic files were then imported into *Adobe Illustrator 8.0* for formatting, and

finally exported in jpg formats for inclusion into the report. Word processing needs were accomplished using *Microsoft Word 2002.* All software was run on a *Dell Inspiron 8200* with an operating system of *Microsoft Windows XP.*

Electronic files attached to this report are in Excel 2002, Acrobat 5.0, or Word 2002 formats.

Routine Calculations

Two routine calculations were made to support this work and the data columns are in Table *AP-110 Task 1B.xls.* The first is simple conversion of metric depths of Culebra from Powers (2003) to English units ("Top of Culebra (ft)"). All conversions from meters to feet were done by dividing by the factor 0.3048. Several of these calculations were checked with the standard electronic calculator included as part of the Microsoft Windows XP operating system. Formula references have been removed from table *AP-110 Task 1B.xls* to avoid inadvertent changes. The second routine calculation was to estimate the volume of cement to fill the annulus between casing and formation or to plug the existing drillhole across the Culebra. Formulas can still be accessed in Table *AP-110 Task 1B.xls* under column "Estimated Cement Volume." This calculation has previously been described in Methods.

For location data, it was desired to use UTM coordinates for drillholes and other features. NM State Plane (NAD27) coordinates were available for each well in the database provided by Hughes. These were accepted as given. All State Plane coordinates were converted to UTM (NAD27) coordinates using *Corpscon for Windows 5.11.08.* As for Powers (2002), to verify the conversion of State Plane to UTM coordinates, four locations in State Plane (NAD27) coordinates (left hand column below) were converted to UTM (NAD27) coordinates (right hand column below). Within the limits of reading a topographic map using an engineer's scale, these coordinates match, and they are identical to the results obtain previously (Powers, 2002). The coordinates checked were

Horizontal Datum: State Plane, NAD 27				Horizontal Datum: UTM, NAD27		
				Horizontal Zone: 13		
				Horizontal Units: Meters		
State Plane	X	Y		UTM	X	Y
CHECK1	650000	510000	→	CHECK1	608404.72683	3585298.74965
CHECK2	650000	490000		CHECK2	608442.70416	3579204.01345
CHECK3	670000	540000		CHECK3	614442.41641	3594478.94431
CHECK4	630000	510000		CHECK4	602310.01957	3585260.74438

Corpscon is a standard tool for converting between these coordinate systems. Further testing was conducted by Powers (2002), and these tests were not repeated here; the software is the same as was used earlier.

Personnel

Dennis W. Powers did the geological interpretation and map construction. A resume is attached for information.

References Cited

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Powers, D.W., 2002, Analysis report Task 1 of AP-088, Construction of geologic contour maps: report to Sandia National Laboratories, April 17, 2002 (ERMS# 522086)

Powers, D.W., 2003, Addendum 2 to Analysis report Task 1 of AP-088, Construction of geologic contour maps: report to Sandia National Laboratories, January 13, 2003 (ERMS# 525199)

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List of Electronic Files Submitted

The following electronic files have been submitted for Task 1B:

Main report file:	Task 1B Analysis Report for AP-110 8013-04.doc (Word 2002)
Figures:	Task 1B for AP-110 Figure 1.pdf (Acrobat 5.0 file) Task 1B for AP-110 Figure 2.pdf (Acrobat 5.0 file) Task 1B for AP-110 Figure 3.pdf (Acrobat 5.0 file) Task 1B for AP-110 Figure 4.pdf (Acrobat 5.0 file)
Data source table:	*AP-110 Task 1B.xls* (Excel 2002)

Resumé for Dennis W. Powers (Word 2002)