Analysis Report
Task 1B of AP-114
Identify Possible Area of Recharge to the Culebra West and South of WIPP

(AP-114: Analysis Plan for Evaluation and Recalibration of Culebra Transmissivity Fields)

Task Number 1.4.1.1

Report Date: April 1, 2006

Author: _____   _____

                                   Dennis W. Powers   Date
                                   Consulting Geologist

Technical Review: _____   _____

                                     Joseph F. Kanney, 6821   Date
                                     Performance Assessment Department

QA Review: _____   _____

                                     Douglas R. Edmiston, 6820   Date
                                     Carlsbad Programs Group

Management Review: _____   _____

                                     M.J. Rigali, 6822   Date
                                     Repository Performance Department

WIPP:1.4.1.1:TD:QA-L:AP-114 Analysis Reports

Table of Contents
Task 1B of AP-114

Analysis Report for Task 1B, AP-114
Identify Possible Area of Recharge to the Culebra West and South of WIPP

1.0 Introduction

This analysis report has been prepared and submitted to meet the requirements of Task 1B of Analysis Plan AP-114 (Beauheim, 2004; effective 10/11/04) for evaluation and recalibration of Culebra transmissivity fields. Task 1B requires identifying possible areas of recharge to the Culebra south and west of the Waste Isolation Pilot Plant (WIPP) site. The data developed in this task will be used in Task 3 (of AP-114) to evaluate alternative boundary conditions for hydrologic modeling.

The general area for this study south and west of the WIPP site is centered on the southeastern arm of Nash Draw (Figure 1). The boundaries to the west and south correspond to the limits used for earlier modeling (see figure 2, Beauheim, 2004); the northern and eastern boundaries included the southeastern arm of Nash Draw and an area beyond the apparent eastern extent of the draw. The Universal Transverse Mercator (UTM) (North American Datum 1927 - NAD27) western and eastern boundaries are at 601700 m Easting and 615000 m Easting, respectively. The UTM (NAD27) southern and northern boundaries are at 3566500 m Northing and 3582000 m Northing, respectively.

Five "elements" were identified that contribute to understanding recharge and that can be useful for modeling the possible effects of recharge to the Culebra in the study area. These elements are surface drainage basins, an estimate of areas with differing confinement of the Culebra, the location and character of drainage channels within drainage basins, the location of specific points of recharge (e.g., sinkholes), and estimating a curve number that relates soil characteristics to how well rainfall infiltrates across the study area. Of these elements, the estimate of Culebra confinement is the most interpretive. Surface topography; features identifiable from maps, aerial photos, or field reconnaissance result in identifying drainage basins, channels, and specific points of recharge. Existing maps of soils, combined with surface reconnaissance and aerial photographs, permit relatively direct assignment of curve numbers. The degree of confinement of the Culebra in the study area, however, is not directly determinable from the surface data. As a result, a variety of surface features and well data are combined for an estimate of the areas where the Culebra is relatively less confined than it is at the WIPP site, where well test and drillhole data are more readily available. This provides a preview of the five elements identified here; each is described and discussed in more detail later.

Areas of possible recharge are identified in this Task 1B report, and task elements or types of data to use in modeling recharge are estimated with various combinations of field and existing data. No unusual geological methods were applied in this program. Topographic maps, aerial photographs, field investigations, and previous literature were used as a basis for the elements (see below) differentiated in Task 1B. The analyst is Dennis W. Powers, Ph.D., Consulting Geologist, Anthony, TX 79821.

2.0 Methods

2.1 Geological and Field Methods. Modeling (Task 3) is expected to apply parameters or factors to grid cells that are 100 m x 100 m in dimensions. To facilitate the transfer of geological data developed during Task 1B, electronic images of aerial photographs of the study area were formatted by David Hughes (WRES – Washington Regulatory and Environmental Services) with grid lines on the 100 m UTM (NAD27) values (Figure 2), and a set was printed for my use. Because of the size of the study area, Hughes divided the aerial photo coverage into 16 images (4 x 4), each with grid lines at 100 m and printed values at 500 m intervals.

The geological and field geology methods applied to this work are standard for interpreting topographic maps and aerial photographs. Some features were mapped onto the printed aerial photographs with grid lines to make it easier to use the software (below) to assign values for each task element identified. Aerial photographs and topographic maps were used in the field to identify features and a hand-held Global Positioning System (GPS) unit was used for confirmation. Field inspection in local areas helped determine the limits of various basin boundaries to supplement topographic data.

2.2 Software and Methods. To enable me to assign values for task elements to the center point of each grid cell in the study area, Glen Garrett created a macro with *Microsoft® Visual FoxPro® 8.0* (VFP). The macro shows an array of dots, each representing a specific grid cell center point. The macro enabled me to choose a particular element to map and to designate characteristics with numeric values (from 0 and having a brief description and unique color). The macro enabled me to set or change the characteristic (e.g., #3 was green and represented karst areas for Element 5 Recharge Points and Areas) for individual dots or blocks of dots. When the choices were saved, the values were transmitted to a column in a VFP database table for that element, in rows with the cell center UTM X and UTM Y coordinates. (All database element values were initially set to NULL; a value of zero differs from NULL.) The dot overlay was transparent, allowing it to be placed over a jpeg image of the aerial photo with gridlines so that dots representing grid cell centers could be placed over the appropriate cell. Figure 3 is similar to the overlay map that was displayed on screen, but this figure was produced by graphing output data separately and overlaying the graphed output on the gridded aerial photograph. Garrett developed a unique overlay (i.e., dots represented different cell center coordinates) for each image so the transmittal of data to the VFP table went smoothly.

If the specific application was reopened for any of these unique overlays and any of the elements were selected, the dot pattern would display colors corresponding to the values in the VFP table. This allowed both checking and interruption of work without losing place. Comparing the on-screen display of dot color patterns to the corresponding jpeg aerial photo or to any source of the data was a simple and effective means of checking the data.
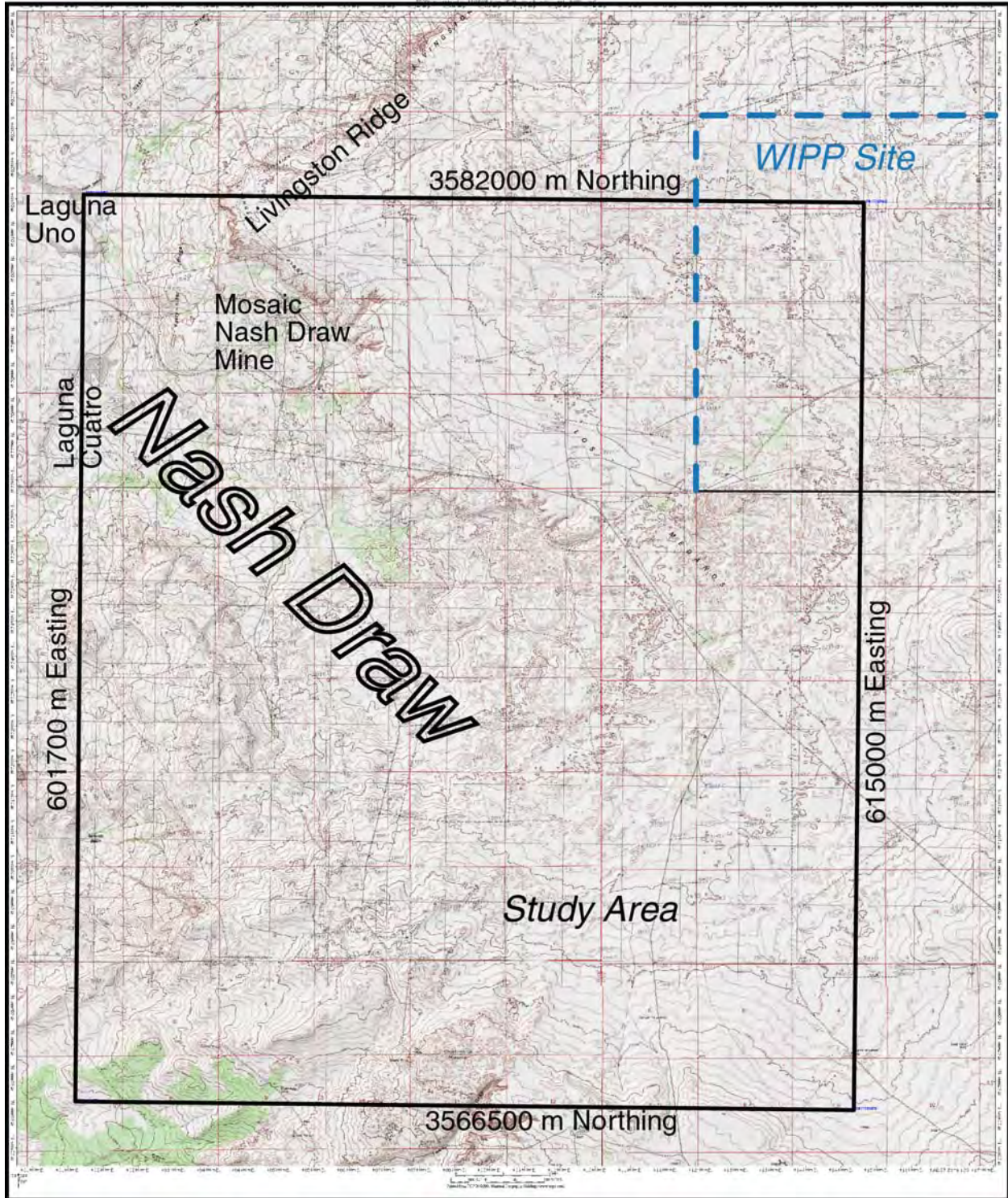
Figure 1 – Study Area. The study area shown in the black rectangle overlaps the southwestern part of the WIPP site (blue dashed outline) and is centered mainly on the southeastern arm of Nash Draw. Boundary limits are UTM (NAD27) coordinates in meters.

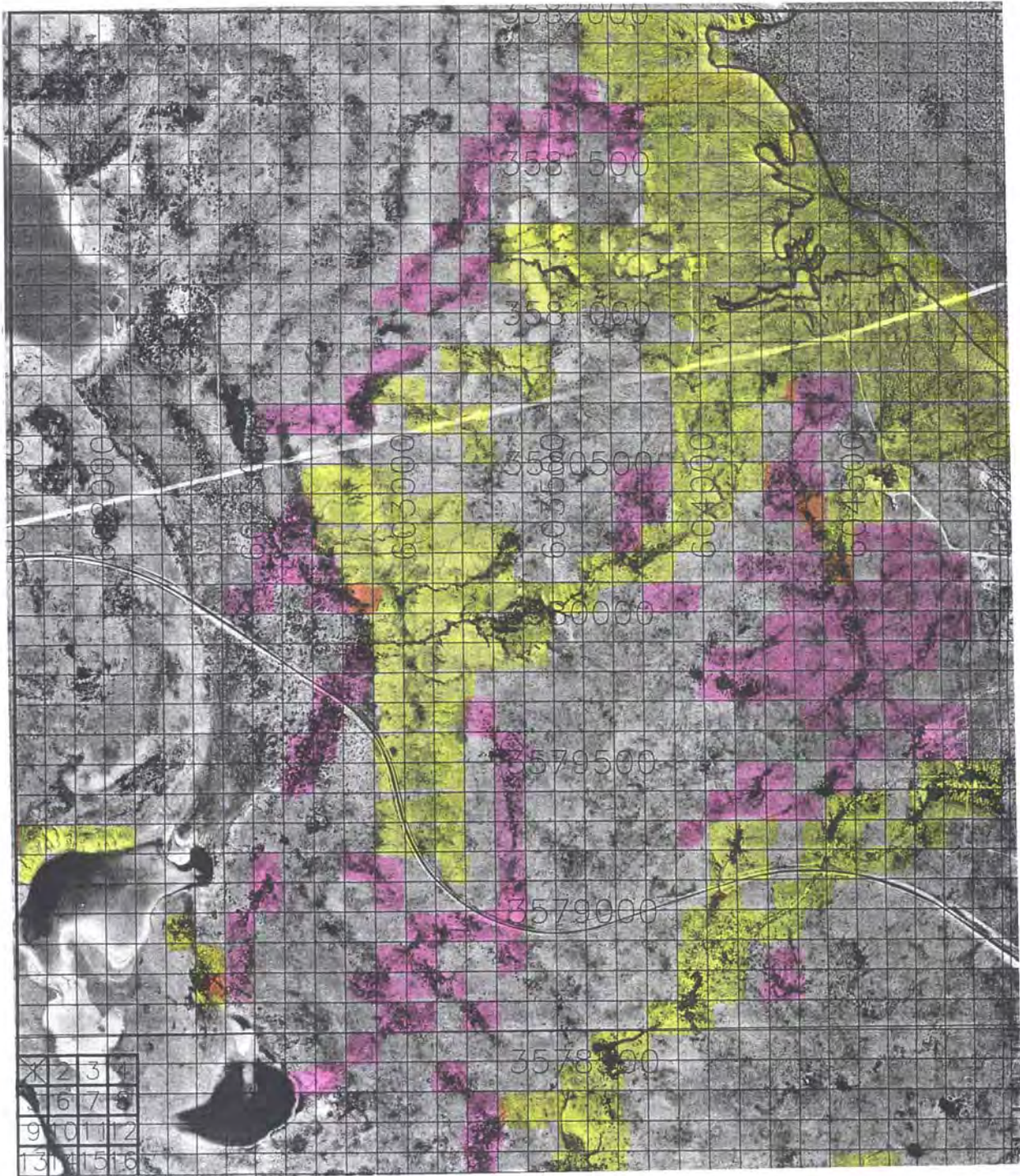Figure 2 - Example of aerial photography with 100 m gridlines. David Hughes (WRES) provided paper printouts of aerial photography from 1996 with UTM coordinate gridlines at 100 m intervals to assist in defining elements on this grid pattern. Highlight colors on the photograph represent channel types, Element 3, distinguished in this study and were used as a guide in coding the overlay (see *2.0 Methods*).

3.0 Data Sources and Quality Assurance

3.1 Data Sources and Resources. Topographic maps and aerial photographs were essential tools for Task 1B. Printed maps as well as electronic files (TOPO! version 2.7.0, a product of National Geographic) were used. Contact prints (9 inch; 1:40,000) of 1996 aerial photos from the National Aerial Photography Program (NAPP) program were used for location and feature identification. The study area is covered by overlapping images 9611-51 through 9611-55, 9610-242 through 9610-246, and 9610-231 through 9610-235. (The NAPP photos are available from the Earth Resources Observation and Science [EROS] Data Center and can be ordered by accessing http://edc.usgs.gov/products/aerial/napp.html.) After I defined the study area boundaries with UTM (NAD27) coordinates, David Hughes (WRES) used AutoCAD Map 5, combined with digital images of the NAPP photography, to print paper copies of portions of the aerial photographs with grid lines on 100 m centers. These paper copies were used as a basis for mapping various features as described in *2.0 Methods*. A basic check indicates UTM coordinates correspond closely to features known on topographic maps and located in the field with GPS units. These printed aerial photographs are accepted here as sufficiently accurate for assigning values to grid cells.

Eddy County soils have been mapped (Chugg and others, 1971) on aerial photographs at scales similar, but not identical, to those used in this study. They are much earlier, and must predate about 1960 because the roads and construction for Project Gnome are not recorded. Drainage and other natural surface features are largely unchanged, however, and the correspondence between the photographs is clear. The soil mapping is accepted as it is presented in Chugg and others (1971) with the exception that some areas of rocky outcrop were reassigned from a general dune sand (Kermit-Berino) soil association. These are in the southwestern part of the study area and are not in the main area of Nash Draw.

Some features (e.g., caves) were located on the ground using hand-held GPS units. Locations with hand-held GPS units are commonly ±4-5 m at the best. There are no important data requirements for this as GPS locations confirm other means of locating points.

For Element 5 (Curve Number), hydrologic soil groups have been assigned (Table 1) mainly as given in TR-55 (US Department of Agriculture, 1986; appendix A updated 1999). For soils with mixed or split designations (e.g., C & D), I selected a group based on the local setting. Areas mapped as gypsum soils are rocky or gypsite, with little soil profile or infiltration. I assigned them to "D", which increases estimated runoff to potential recharge points. For soils not named in Appendix A of TR-55, I assigned (red font) a hydrologic soil group based on similar soil or soil association in the study area. More details are provided with the discussion of Element 5 below.

Ground cover (also used for Element 5) for much of the study area falls within the "fair" category. Stony outcrops and active dunes are much less vegetated, and a few low-lying areas are heavily vegetated. To confirm assigning large tracts to the "fair" category based on direct observation, I asked Steve Daly (Bureau of Land Management, Carlsbad) for confirmation. He checked data from a number of small plots, especially within the Kermit-Berino soil association,
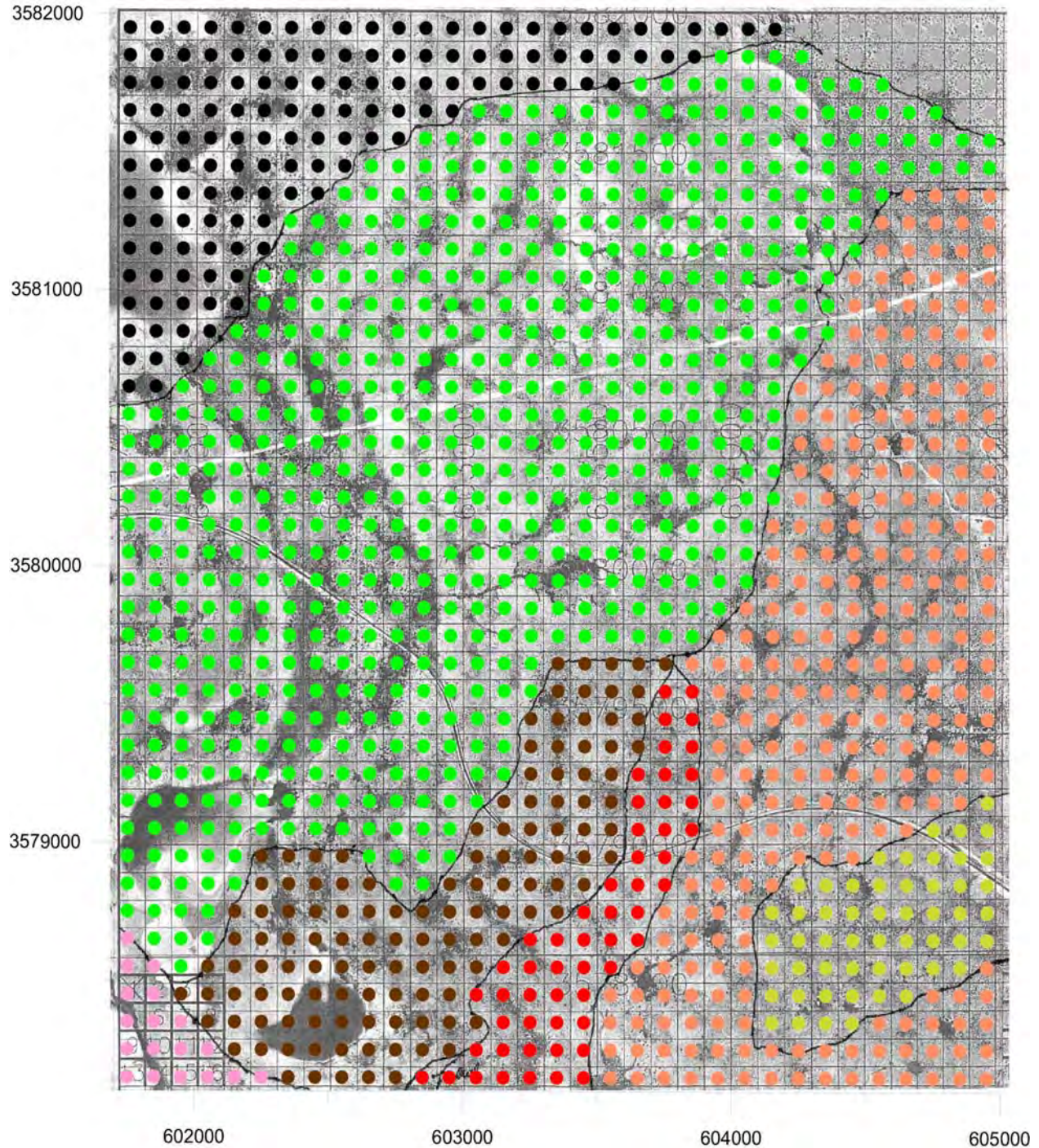
Figure 3 – Example of data values overlain on aerial photograph (same as Figure 2, but reduced in size and with Element 1- drainage basins outlined). The aerial photo underlay and dot overlay appear similar to the screen display after the dots representing grid cell centers have been keyed to the appropriate characteristic for any element (parameter). The visual display permits relatively easy checking of the proper coding, and, in this case, graphing the output data separately and overlaying the graph on the aerial photograph allows further checking that the cell coding is correct. The dots are not perfectly centered on cells due to slight distortions and slant during scanning of the aerial photo.

and he reported the average value of ground cover, including litter, was about 50%. This is the mid-point of the "fair" range, and this broad assignment of this ground cover is adequate.

Ground cover (also used for Element 5) for much of the study area falls within the "fair" category. Stony outcrops and active dunes are much less vegetated, and a few low-lying areas are heavily vegetated. To confirm assigning large tracts to the "fair" category based on direct observation, I asked Steve Daly (Bureau of Land Management, Carlsbad) for confirmation. He checked data from a number of small plots, especially within the Kermit-Berino soil association, and he reported the average value of ground cover, including litter, was about 50%. This is the mid-point of the "fair" range, and this broad assignment of this ground cover is adequate.

<u>3.2 Quality Assurance</u>. The principal quality question is the accurate transfer of data from one format (e.g., printed copies of aerial photographs) to an electronic file with a value for the center point of a grid cell. This process is essentially a transcription, as data are transferred from one "medium" to another. No calculations are made. The methods for doing this are addressed in *2.0 Methods*. Here I focus on the process by which I verified that the transcription was accurate.

The principal step is to verify that the macro transcribes a value to the proper location in a database table. The overlay template created for each of the 16 paper copies of portions of aerial photographs was assigned unique UTM X and UTM Y coordinates for each "dot" representing a cell center. Several dots on each template were checked to see that the coordinates were assigned appropriately. To test the transcription, however, the most effective means is to compare output to the source. The simplest source information to use in checking transcription comes from the assignment of drainage basins (Element 1; see Figure 3 and *Task 1B Elements* below).

An Excel table was exported from the VFP database for plotting drainage basin values separately using Grapher®. The results of plotting the output from VFP and overlaying the plot on aerial photos for a visual check are shown in *Appendix A*. The correspondence between values and underlying drainage basin definition verifies the accuracy of the data transcription.

The second step of importance to determine is that the element characteristics assigned are "correct." The figures in *Appendix A* also show that the drainage basins (Element 1) are differentiated from each other, which is the necessary verification. The colors are arbitrary, representing also the arbitrary basin number assigned to each basin. The other elements have been checked by re-examining the overlay "dot" assignments relative to the underlying information of the aerial photos with grids. Each of the elements differs, however, in the information available and the state of knowledge of the element. Element 2 Culebra Confinement is assigned broadly; at this point, there is no particular means of determining if these boundaries are "correct." Element 3 Drainage Channels is based on the visible characteristics at the scale of the aerial photographs, and these characteristics would be assigned differently at a different scale. Element 4 Recharge Areas and Points are assigned on the basis of both field examination and aerial photo characteristics. The entire area has not been searched on foot, but the designated cells likely identify the main areas and points. Element 5 Curve Number is based on the general information available from soils mapping of Eddy County evaluated in terms of approximations in TR-55. Some areas are modified from the soil map based on ground information to supplement the soil maps. Curve number assignments are compared visually to

the general areas in which soil types have been mapped, and this is adequate verification of "correct" assignments given the general nature of the data.

To assist the reader in evaluating each of the elements described in *5.0 Task 1B Elements*, the output values have been plotted separately for each element and are presented in *Appendix B* for simplicity. A "key" to values in the database that are represented by color is included for each.

4.0 Computers and Software

The main software used to create a database is *Microsoft® Visual FoxPro® 8.0* upgraded before completing the project to *Visual FoxPro® 9.0* SP1, version 09.00.0000.3307. *Windows® Picture and Fax Viewer* was used to open jpeg images of aerial photos with grid lines; these images provided a background to a macro created in VFP by Glen Garrett that enabled me to assign values to grid cell centerpoints. *Microsoft® Excel® 2002* (10.6501.6626) SP3 was used to receive and further format files exported in the *Excel* format from VFP. Plots and graphs were generated using *Grapher® 5* version 5.03, a two-dimensional graphing system developed by Golden Software, Inc. Some graphic files were then imported into *Adobe® Illustrator® 8.0* for formatting, and finally exported as *Adobe® Acrobat®* files and jpeg formats for report preparation. Word processing needs were accomplished using *Microsoft® Word 2002* (10.6612.6626)SP3. *Adobe® Acrobat® 6.0* version 6.0.3 was used to prepare a pdf file of the final report. Background topographic maps for illustrations were prepared using *TOPO!* version 2.7.0, a product purchased from National Geographic. All software has been registered to Dennis W. Powers.

All software was used on a *Dell® Inspiron® 8200* containing an Intel® Pentium® 4 2.00GHz Mobile CPU. The operating system is *Microsoft® Windows® XP* version 2002 with Service Pack 2 installed and registered to Dennis W. Powers.

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

5.0 Task 1B Elements

Five general elements or data needs were separated that are evaluated throughout the study area. In addition, some other data are provided in a separate section (*6.0 Evidence for a Recent Runoff/Recharge Event).* These elements or data needs are (briefly):
    1) surface drainage basin,
    2) Culebra confinement,
    3) drainage channels,
    4) points and areas of potential recharge, and
    5) curve number (parameter for estimating runoff).
Each of these will be described more fully to explain the values assigned for characteristics identified for each of the elements.

The depth of Culebra may be needed to model recharge. Because previous modeling of Culebra transmissivity fields has used this parameter and the geological basis (elevation maps of the

Culebra; Powers, 2003) for computing depth to Culebra has not changed, it is expected that previous estimates of Culebra depth will be used.

5.1 Task 1B, Element 1 Surface Drainage Basins. Drainage basin size and characteristics are important elements in determining how rainfall, infiltration, and runoff may contribute to recharge of the Culebra and other near-surface hydrologic units. For this task element, topographic maps, aerial photographs, and some field checking were used to define separate surface drainage basins. The characteristics of parts of the drainage basin (e.g., drainages, recharge points, curve number) are recorded as distinct task elements.

The drainage basins are mainly separated by topographic divides and local lows or concentration points that can be distinguished on the standard 7.5' quadrangle maps supplemented by study of aerial photographs. Because this is an area of evaporite karst (e.g., Powers and Owsley, 2003), collapse features, caves, or sinkholes may capture local drainage in smaller basins or subbasins (wholly enclosed by another basin). An example is that drainage basin #7 (light green dots; Page 1 Check in *Appendix A*) is wholly enclosed in drainage basin #6 (light orange dots; Page 1 Check in *Appendix A*). Drainage basin #7 is controlled by a more localized lowpoint developed by solution and collapse. From a practical point of view, very localized features (e.g., an individual alluvial doline) that may technically form subbasins (or even "subsubbasins") have not been separated because that detail is neither needed nor easily supported with topographic detail.

Large portions of the study area are covered by sand dune fields with no defined drainage and gentle slopes. They could be included within drainage basins defined over much larger areas on the basis of topography, but there seemed to be little utility in including these areas in drainage basins otherwise better defined by surface drainage. There is an exception in the data base; drainage basin #9 is the easternmost defined basin, and it exhibits dune-covered topography of Nash Draw but with little defined surface drainage. The characteristics of these areas outside defined drainage basins are included in other parameters to be used as necessary for modeling.

The values reported for this field in the electronic file range from 0 to 15. The default value was 0, and this represents areas indicated above that are dominated by sand dune topography, gentle slopes, and no developed surface drainage channels. Number values otherwise reported indicate cell centers belonging to a particular drainage basin (e.g., Figure 3).

Various features of some basins will be discussed later (*7.0 Discussion*).

5.2 Task 1B, Element 2 Culebra Confinement. For the relatively short time period considered in modeling recharge in southeastern Nash Draw, the Culebra at the WIPP site can be considered confined, with little potential for direct vertical recharge. Within portions of Nash Draw, it is clear that the Culebra is not significantly confined and water levels respond to surface events in a very short time. It is unlikely that a well-defined boundary exists between these two conditions. Here, the degree of confinement is not estimated. Instead, three zones have been identified, corresponding to the notion that there are areas where the Culebra is confined, areas where it is unconfined, and areas that represent a transition zone. The "confined" area has a relatively unambiguous definition, whereas the boundary between "transition" and "unconfined" is much

more subjective. To some degree, it should be possible to estimate the sensitivity of modeling to assumptions about confinement (and the ability to recharge the Culebra vertically) in these areas.

The area of the Culebra considered "confined" (default value 0) is defined approximately by the interpreted margin of upper Salado halite dissolution (Powers, 2003; Powers and others, 2003). There is a significant increase in Culebra transmissivity (T) values west and south of this margin, and this change is attributed to changes in fracture aperture associated with strain induced by dissolution. I infer that along this margin and to the west and south, the overlying units are also somewhat strained, changing the vertical hydraulic properties. East of the margin, they are similar to those at the WIPP site proper.

The "transition" zone (value 1) includes areas where there are some data from wells that indicate there is some vertical isolation of the Culebra, but the time constant is not known. Data from monitoring well WIPP-25 indicates that the Magenta and Culebra are not connected vertically on a short time frame. A water well (C-2111) located within the boundaries of the Mosaic Nash Draw property was drilled to a depth near the Culebra. Mini-troll data collected from this well for about 1 year indicate that it does not show pressure (water level) responses matching those in WIPP-26, the nearest monitoring well. It is reasonably isolated hydraulically from the Culebra. In addition, well records from several potash exploration holes (section 33, T23S, R30E) south of the Mosaic Nash Draw property also encountered water at a depth approximately that of the Culebra. In these drillholes, water levels rose well above the horizon where they were first observed indicating some degree of confinement. Alluvium deposited on slopes west of Livingston Ridge also appears to indicate limited vertical infiltration in this zone, and the margin of the alluvium-covered slope was taken as a general indication of the margin between the transition zone and unconfined zone. Surface drainage channels may end or change character at this margin. The transition zone includes areas similar to these in depth, general structure, and slope/drainage configuration.

The "unconfined" zone (value 2) is limited in the study area, as most indications of the Culebra being unconfined are within the more central portions of Nash Draw and out of the study area. The strategy was to select areas where the Culebra is known or believed to be very shallow (~ 30 m or less) and where observed recharge points (caves, sinkholes, alluvial dolines) are believed to access units below the Magenta. Some large caves and sinkholes are developed in the Tamarisk gypsum beds and have a greater likelihood of reaching the Culebra. Many potash exploration holes within Nash Draw encountered lost circulation zones, but the stratigraphic relationships of these zones to Culebra are not well constrained. Thus there is a general sense of factors away from Livingston Ridge and the upper Salado dissolution margin that contribute to greater vertical permeability, but these factors are generally qualitative.

One other factor that may have to be considered is that a particular location within Nash Draw may show stratigraphic relationships and rock quality signifying considerable vertical isolation for the Culebra, but it may be unimportant in a small area surrounded by unconfined units. The existence of the brine lakes in Nash Draw, including parts of the study area, present a special case regarding the concept of unconfined Culebra and near-surface rocks or sediments. The degree of infiltration through the base of these lakes is undetermined. Field observations over the years suggest that the halite at the base of the lake is not highly permeable. There are

10

unconfirmed reports that, from time to time, the brine lake (Laguna Uno; see Figure 1) at the toe of the Mosaic tailings pile will develop swallow holes in the basal halite and lose considerable volumes of brine. This seems more likely with fresh water runoff and infiltration after storms. I have directly observed brine springs from Laguna Uno feeding the Lindsay Lake area to the southwest. In addition, Tamarisk Flat (west of Laguna Cuatro) is likely recharged laterally by Laguna Uno and/or Laguna Cuatro, given the potassium sulfate mineral formation I have observed at the south end of Tamarisk Flat. These areas may also recharge the Culebra, although they are mostly outside the study area.

5.3 Task 1B, Element 3 Drainage Channels. Surface drainage channels of sufficient size to be visible on aerial photographs (1:40,000) are present in some areas of the study area. Much of the study area displays no distinguishable channels. I have also excluded areas where dune sands have partially filled arroyos or valleys but where there is no evidence of post-dune channels and runoff. Grid cells with channels have been identified here, although it has not been determined how useful these data may be for modeling recharge.

The default value (0) indicates areas without developed channels.

The areas with developed channels and little vegetation have been coded with the value 1. These are particularly best developed along Livingston Ridge, and there are also some on lesser slopes in areas of minor vegetation.

Areas with channels or arroyos that are heavily vegetated have been coded with the value 2. There are several of these on the gentle slopes on the eastern side of Livingston Ridge. The channels are eroded into or through the Mescalero caliche, are heavily vegetated, and do not have long stretches of open channel. Some of the open channel reaches (coded 1) are intermittently interrupted by vegetated stretches with little indication of a clear channel. These are also coded with the value 2. Some low areas with vegetation do not appear to be integrated into a drainage system and are left unassigned (default value 0).

5.4 Task 1B, Element 4 Points and Areas of Potential Recharge. The Analysis Plan Task 1B is directed at identifying possible areas of recharge to the Culebra. This element shows the location of, and differentiates between, several kinds of possible recharge points and areas. In general, all of the kinds of recharge points and areas are topographic lows or low slope areas where runoff can be concentrated or where specific features, such as swallowholes or caves, permit more direct recharge to the underlying units. Nevertheless, in no part of the study area have I identified a location where the Culebra crops out or where it is clear that cave, swallowholes, dolines, or other karst features lead directly to the Culebra. Within the lower areas designated "unconfined" (Element 2, above), however, it is more likely that the Culebra is near the surface and could be more directly recharged.

There are five values assigned to this element. The default value (0), assigned to the bulk of the study area, indicates that no particular recharge point or area has been defined. It includes most of the area assigned (Element 5 Curve Number) to soil types and vegetation with curve numbers indicating no runoff. One might argue that the small areas between each dune could be recharge points, but they are so numerous and distributed as to be meaningless to try to identify each one.

11

Vegetated low areas and collection points are potential recharge areas. They have been designated with the value 1 for this element. These areas will correspond closely to some of the curve number assignments based on certain soil associations and vegetative cover. This potential recharge area is mainly assigned here on the basis of topography, and they are mainly at the end of drainages, as would be expected.

Brine lake areas and adjacent marshy areas are assigned value 2 for this element. As previously discussed, it is not clear how much recharge occurs from the lakes. The brine lakes and vegetated low areas are generally the lowest topographic points relative to a drainage basin (Element 1).

Broader karst features such as karst valleys, coalesced areas of alluvial dolines, and alluvial dolines have been assigned a value of 3 for this element. These collection points or areas are generally smaller size than either lakes or vegetated low areas, and they have a more distinctive origin. [The lows for the lakes and vegetated lowlands most likely developed from dissolution subsidence, but sedimentary fill is generally greater and there is less direct association with open karst features such as caves or sinkholes.] There is sedimentary fill and vegetation indicating a level of stability for the surficial sediments in these karst valleys and other features assigned value 3. I hypothesize that they are important to the hydraulic economy of the system here by providing a reservoir for infiltration/recharge for a period after the immediate effects of a storm and runoff.

Specific features that are open conduits (swallowholes, sinkholes, caves) from the surface are mapped and given a value of 4 for this element. They are most common in and around areas assigned a value of 3. These features are expected to provide the most direct and quickest recharge of underlying layers by individual storms and associated runoff. In the study area, these features are developed in the Forty-niner Member, the Magenta Dolomite Member, the Tamarisk Member, and in gypsite deposits of Pleistocene to (?)Holocene age. In no case have I been able to establish that these conduits directly feed the Culebra, but in areas designated "unconfined" in Element 2, it seems much more likely that the Culebra is being recharged more quickly and directly than in other settings in the study area.

5.5 Task 1B, Element 5 Curve Number. In order to estimate runoff in the area, hydrologic soil types and vegetative cover were assigned and used to estimate curve number (CN) as used in Technical Release 55 (TR-55) (US Department of Agriculture, 1986). TR-55 is developed mainly for estimating runoff in urban areas, but it includes soils and vegetation that are present at and around the WIPP site. Runoff estimates are not made here; only the CN assignments and their bases are described. All grid cells within the study area were assigned a value for CN.

TR-55 distinguishes four hydrologic soil groups (A–D) based on their infiltration rates. "A" soils (very sandy in the study area) have high infiltration rates. "D" soils, represented here mainly by gypsum or gypsite at the surface, have low infiltration rates. Appendices in TR-55 assign numerous soils and soil associations to one of these soil groups. Eddy County soils have been mapped (Chugg and others, 1971) at scales that are comparable to the work done here, and those soil maps are the bases for assigned hydrologic soil groups. Not every soil mapped by Chugg and others (1971) is assigned to a hydrologic soil group in TR-55, but I assigned a group (red font,

Table 1) based on similar characters. Soil names or associations, some of their characteristics, and the hydrologic soil group assigned for the study area are indicated in Table 1. All hydrologic soil groups are represented in the study area, but it is dominated by A and D types.

The other essential characteristic for assigning CN is vegetative cover. TR-55 differentiates three vegetative cover ranges (Table 2-2d and footnotes in US Department of Agriculture, 1986). "Poor" designates < 30% ground cover, including litter, grass and brush overstory. "Fair" indicates 30–70% ground cover, and "good" designates >70% ground cover. Except for the active dune area at Los Medaños (poor), all areas assigned hydrologic soil groups A–C are also designated as "fair" ground cover (Table 1). The area assigned "D" hydrologic soil group has mainly "poor" vegetative cover where gypsite and gypsum prevail. A thin Simona soil on an "upland" area along Livingston Ridge has "fair" vegetative cover. Simona soils are a thin veneer over much less permeable Mescalero caliche, and they are assigned to hydrologic soil group D.

There are seven values assigned for CN (Table 1). Based on TR-55, A soils with fair vegetation have a curve number 55, while A soils with poor vegetation are assigned 63. B soils with fair ground cover are assigned 72, while C soils with fair ground cover are assigned 81. D soils with fair ground cover are given a CN of 86, and D soils with poor ground cover are given a CN of 88.

Because of the software methods used (see *2.0 Methods*), initial values of 0–5 were assigned for this parameter to represent values of CN of 55, 63, 72, 81, 86, and 88, respectively. Brine lake areas were assigned an initial coding value of 6. These initial coding values have been preserved, but Visual FoxPro commands were used to fill a separate database column with the corresponding CN for each coding value. At this step, brine lake areas, originally coded 6, were assigned a CN of 0.

6.0 Evidence for a Recent Runoff/Recharge Event

While conducting field work late in 2004 to support this study, I found evidence of a recent major recharge event. That evidence is described here because it provides a possible explanation of water level increases beginning in late 2004 in Nash Draw wells. It also may provide some bounds for recharge volumes and times in a particular location as further input to modeling.

The evidence is relatively straightforward, though circumstantial as to its timing. Some of the drainage channels within drainage basin #6 showed evidence of significant water flow, given the downslope flattening of grasses and debris in brush and trees. As I mapped specific features, such as caves or sinkholes, in the karst valley (Figure 4) that forms the low point in drainage basin #6, I became aware of a debris ring around the edges of the karst valley that indicates a high water mark. Within the valley, mesquite bushes were stained with reddish-brown silt/clay to a fairly uniform level above the valley floor, and floating debris such as dried cow patties were left in mesquite branches at about the same level as the top of the staining (Figure 5).

From the field evidence, the lower limits of the water volume in this event are estimated as follows:
    Area covered is estimated to be approximately 10^5 m^2.

The depth is estimated to be approximately 0.5 m, on average.

From this, the volume is estimated to be at least 5×10^4 m^3 (40.5 Acre-ft or 13.2×10^6 gal.) Because I limited the estimate of the area covered and because the flooding must have occurred over a period of time with significant volume recharging even as the high-water mark was being attained, this volume estimate may be low by factors of 2 or 3 or more.

Meteorological data from WIPP records and informal records by United Salt Corporation at Laguna Grande de la Sal and at their main plant show two major rainfall events during 2004 where 24-48 hour rainfall totaled 2.5 inches or more. One event was early in April, and this storm also caused significant flooding in Carlsbad. The other event was late in September 2004.

I assume the later (September 2004) event is registered in the debris ring, staining, and flattened grass in the watershed. The September rain event, as well as other summer rain, would likely destroy or disrupt the debris ring and staining from an earlier event. Nevertheless, the April event was similar in size and should have resulted in similar runoff, all other factors about the same. There is evidence of a rise of water levels in the fall after the late September rainfall. There is, however, no evidence of a similar rise in water levels following April storms. There are various possible explanations, but I assume for the purpose of this investigation that there is a relationship between the fall 2004 water level rise and relatively rapid recharge from a specific event. I associate the water level rise with the September event because much of the recharge should occur rather rapidly in a karst area. It seems much less likely that a response would be seen 6 months after an event if karst is significant. Either karst is much less developed in these areas (possible), leading to a lengthy delay in response, or some other factor leads to the difference between responses to the April event and the September event. There is, for example, no guarantee that the southeastern arm of Nash Draw experienced the same amount of precipitation in these two events or that antecedent conditions (e.g., soil saturation) were similar. It is not apparent that a water level rise occurred early in 2005, similar to the fall 2004 water level rise. Nevertheless, the information about a runoff event and high water can be used in part for calibration of specific recharge events, even if the timing is not pinned down.

For more than a year, I have conducted informal surveys for runoff in these areas after small rainfall events. I have found no runoff and no standing water in these areas after these rainfalls. Most rainfall events have been below an estimated 0.5 inch. It is my opinion that there is likely a threshold that may exceed 1 inch before significant runoff occurs under most conditions. This is not established by direct observation of a threshold, and the observations are not quantitative. My observations do indicate that there is not likely to be a linear relationship between rainfall, runoff, and accumulation in such areas for direct recharge through karst features.

		Characteristic	Slope (%)	Dryland Capability	Range Capability	Hydrology Class	Veg Class	Curve Number	Notes re Hydrology Class where not assigned in TR-55
Symbol	Name								
BB	Berino complex	eroded	0-3	VIIe-1	Deep Sand	A	Fair	55	Assigned "A" as similar to Kermit
BD	Berino Dune		0-3	VIIe-1	Deep Sand	A	Fair	55	Assigned "A" as similar to Kermit
BA	Berino	loamy fine sand	0-3	VIIe-2	Sandy	A	Fair	55	Assigned "A" as similar to Kermit
KM	Kermit-Berino	fine sand	0-3	VIIe-3	Hills to deep sand	A	Fair	55	
WK	Wink	loamy fine sand	0-3	VIIe-1	Deep Sand	A	Fair	55	
AD	Active Dune			VIIe-1		A	Poor	63	Assigned "A" as similar to Kermit; little vegetation
PA	Pajarito	loamy fine sand	0-3	VIIe-1	Deep Sand	B	Fair	72	Assigned "B" as similar to Largo
LA	Largo	loam	1-5	VIe-1	Loamy	B	Fair	72	Assigned "B" as sandy, alluvial soil in lows; similar to Mobeetie
MO	Mobeetie	fine sandy loam	1-5	VIIe-2	Sandy	B	Fair	72	
PD	Pajarito	duneland	0-3	VIIe-1	Deep Sand	C	Fair	81	Assigned "C" - it is more gypsite than sand - poor soil mapping
PS	Potter-Simona complex		5-25	VIIs-1 VIIe-2		C D	Fair	81	Used "C" class because of slopes generally present
TF	Tonuca	loamy fine sand	0-3	VIIe-2	Sandy	D	Fair	86	
CA	Cacique	loamy sand	0-3	VIIe-2	Sandy	D	Fair	86	
SG	Simona	gravelly fine sandy loam	0-3	VIIe-3	Sandy	D	Fair	86	
SM	Simona-Bippus complex	S: gravelly fine sandy loam 0-3% B: silty clay loam		VIIe-2 VIe-1	Sandy Bottom-land	D B	Fair	86	Used "D" class because of the pedogenic calcrete just below surface gravelly loam
RG	Reeves-Gypsum land	Reeves:0-1%	0-3	VIs-3 VIIs-3	Loamy Gyp flats	C D	Poor	88	Used "D" class because of dominance of gypsum land
GA	Gypsum land			VIIs-2	Gyp hills	D	Poor	88	Used "D" class because of dominance of gypsum land
GR	Gypsum land-Reeves		0-3	VIIs-3 VIIe-2	Gyp flats Sandy	D	Poor	88	Used "D" class because of dominance of gypsum land

Table 1
Southeastern Nash Draw Soil Groups and Characteristics
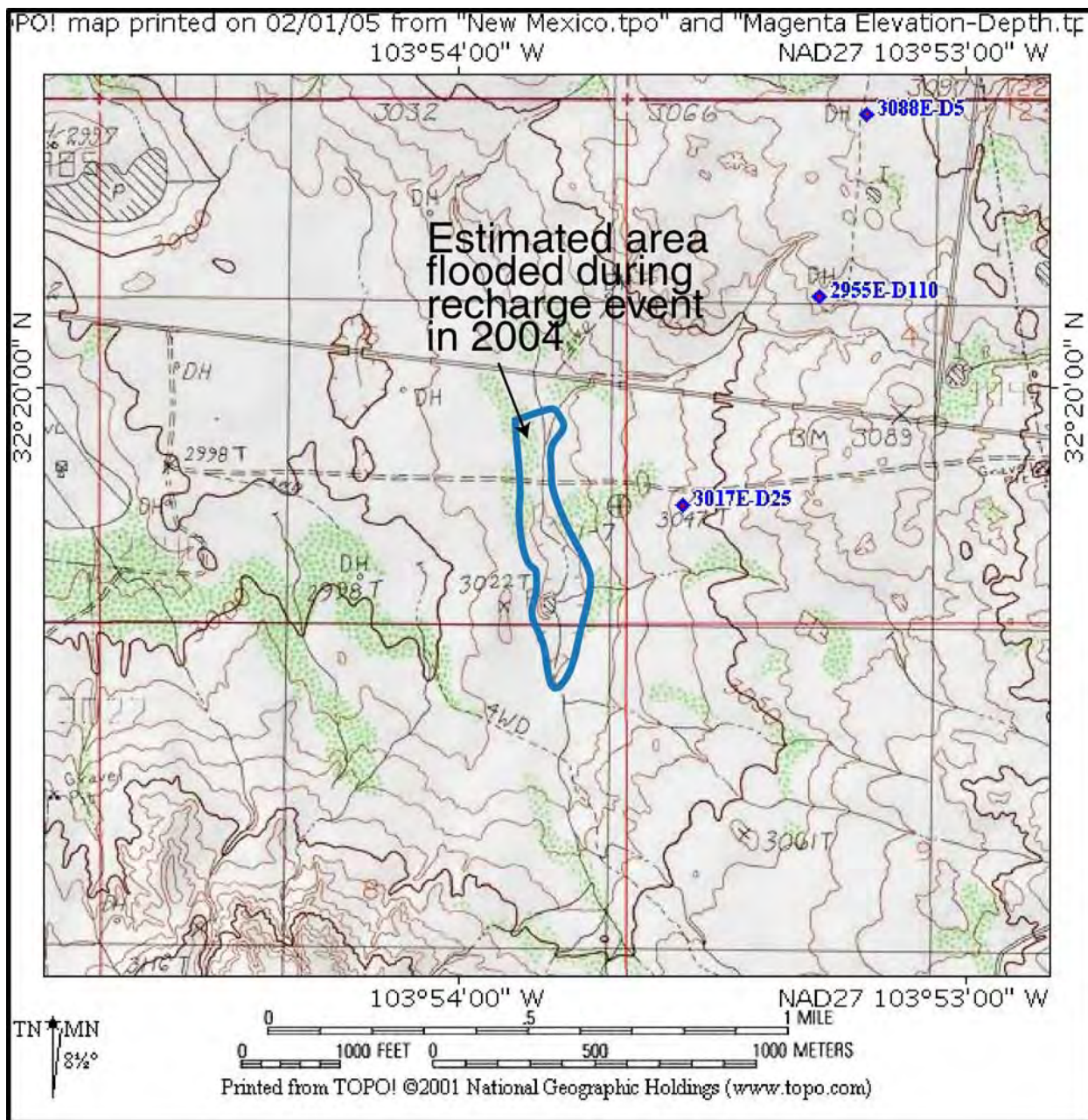
Figure 4 – Topographic map of karst valley in drainage basin #6. The blue outline is approximately the area that appears to have been covered during a flooding event sometime in 2004. The area, estimated from aerial photographs, is about 10,000 square meters at a minimum.
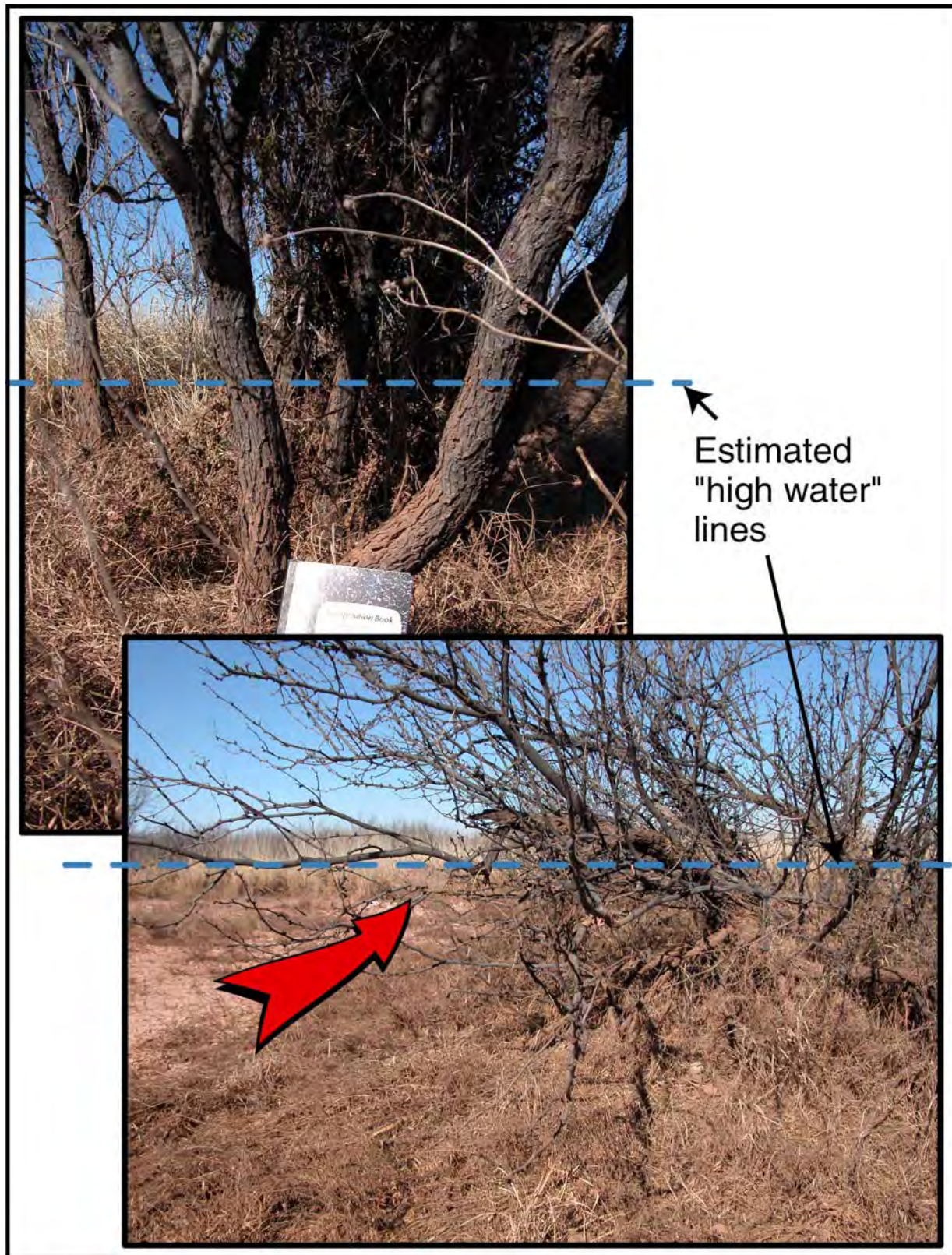
Figure 5 – "High-water" indicators in karst valley in drainage basin #6. Red arrow indicates dried cow patty resting in mesquite branch. Dashed lines show height of staining from flood water.

7.0 Discussion

7.1 Element 1 Surface Drainage Basins. Drainage basin #6 (partially displayed in Figure 3 with orange dots) is unusual among the drainage basins defined because: 1) it has the largest area of any basin with significant developed drainage channels, 2) it encompasses entirely a smaller basin defined by a major sinkhole, 3) it is likely continuous, hydraulically, in the shallow subsurface with at least one other basin of significant size, and 4) it accumulates runoff in a karst valley that is pockmarked with caves and swallowholes. This karst valley shows evidence of a significant runoff event detailed in the previous section. Drainage basin #6 is also surprising because it was not obvious how large it is until considerable work was done on topographic maps, aerial photos, and some field work.

7.2 Element 4 Points and Areas of Potential Recharge. There are some well-developed open recharge points in several drainage basins. The largest concentration is in the karst valley in drainage basin #6. Several tens of features have been located, many with conduits that are 0.5–1 m in diameter (although their cross-section at greater depth may be different). It is not possible now to determine whether these conduits are open because of the large drainage and runoff, or whether the conduits have enabled drainage capture and increase.

Important parts of the hydrologic economy, as previously mentioned, are alluvial dolines and alluvial fill in coalesced karst features. There are brackish springs in and around some of the lake areas that flow year-round. Given the uneven distribution of rainfall, there has to be some significant storage. The alluvium is one potential storage location, as normal karst conduits tend to conduct recharge rapidly and be depleted.

8.0 Personnel

Dennis W. Powers did the geological interpretation and data development for each element. A resume is attached for information. Glen Garrett (B.A.) developed the macros using *Visual FoxPro®* that enabled Powers to compile each element in a database for export. Garrett is employed as Technical Associate to Powers.

9.0 References Cited

Beauheim, R.L., 2004, Analysis Plan for Evaluation and Recalibration of Culebra Transmissivity Fields AP-114: Sandia National Laboratories, 19 p.

Chugg, J.C., Anderson, G.W., King, D.L., Jones, L.H, 1971, Soil Survey, Eddy County, New Mexico: US Department of Agriculture Soil Conservation Service, in cooperation with New Mexico Agricultural Experiment Station.

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 # 522085)

Powers, D.W., and Owsley, D., 2003, A field survey of evaporite karst along NM 128 realignment routes, *in* Johnson, K.S., and Neal, J.T., eds., Evaporite karst and engineering/

environmental problems in the United States: Oklahoma Geological Survey Circular 109, p. 233-240.

Powers, D.W., Holt, R.M., Beauheim, R.L., and McKenna, S.A., 2003, Geological factors related to the transmissivity of the Culebra Dolomite Member, Permian Rustler Formation, Delaware Basin, Southeastern New Mexico, *in* Johnson, K.S., and Neal, J.T., eds., Evaporite karst and engineering/environmental problems in the United States: Oklahoma Geological Survey Circular 109, p. 211-218.

US Department of Agriculture, 1986, Urban hydrology for small watersheds: Technical Release 55, US Department of Agriculture Natural Resources Conservation Service, Conservation Engineering Division (Appendix A updated January 1999).

10.0 List of Electronic Files Submitted

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

Main report file: Task 1B Analysis Report for AP-114 4-1-06.doc (Word 2002)
Task 1B Analysis Report for AP-114 4-1-06.pdf (Acrobat® 5.0)

Figures as separate files: Task 1B for AP-114 Figure 1.pdf (Acrobat® 5.0)
Task 1B for AP-114 Figure 2.pdf (Acrobat® 5.0)
Task 1B for AP-114 Figure 3.pdf (Acrobat® 5.0)
Task 1B for AP-114 Figure 4.pdf (Acrobat® 5.0)
Task 1B for AP-114 Figure 5.pdf (Acrobat® 5.0)

Data source table: AP-114 Task 1B.xls (Excel® 2002)

Resumé for Dennis W. Powers (Word 2002)

Appendix A

For

Analysis Report
Task 1B of AP-114
Identify Possible Area of Recharge to the Culebra West and South of WIPP

(AP-114: Analysis Plan for Evaluation and Recalibration of Culebra Transmissivity Fields)

Task Number 1.4.1.1

Report Date: April 1, 2006

Verifying Transcription of Values to Visual FoxPro Database

Software tools developed by Glen Garrett, using *Visual FoxPro 8 (VFP)*, are a form of data transcription from an onscreen display to a database table. This tool, or macro, provides a unique set of "dots" representing the center of each 100 m x 100 m cell covering the study area. Each dot is assigned a unique combination of UTM X and UTM Y (NAD 27) coordinates representing the cell center coordinates. The transparent overlay of these dots is fitted over a jpeg image of the equivalent area with dots corresponding to the cell with the same center coordinates.

The study area is divided into sixteen jpeg images ("pages") sized for convenience, each with grid lines and reference UTM coordinates. A unique transparent overlay was developed by Garrett for each jpeg image to provide control over the transcription of data for each cell in the study area. The VFP macro allowed selection of a particular element as defined in the report body. The macro also allowed selection of a particular characteristic from the list for each element.

In the operation of the macro, only one element could be selected at a time and only one characteristic could be selected for that element at any one time. It was then possible to set the selected characteristic for an individual "dot" or rectangular block or dots. The characteristic for any dot or selected block of dots could also be reset or overwritten, but the macro required selecting the "overwrite" option for this to occur.

Some individual dot (cell center) coordinates were checked each time an overlay and underlying jpeg image were changed to make sure the overlay was correctly positioned. This provided considerable confidence that the dot coordinates were correct and unique. The simplest method of verifying transcription of values, however, is to compare the database values for an element to the underlying jpeg image used as a guide to assigning the characteristic value for each cell. The distinct drainage basin assignments provided a good example for verifying transcription.

From the VFP database, I exported three columns of data (UTM X, UTM Y, and the drainage basin number) in an Excel format. I accessed the exported data with Excel and sorted the data according to basin number for plotting the data. I used Grapher to plot the data with dot symbols colored to represent differing basin numbers. After plotting the data corresponding to each of the sixteen jpeg images ("pages"), I copied the data plot and laid it over (electronically) the corresponding jpeg in an Adobe Illustrator file. The plot was sized and placed to make sure the graph grid lines corresponded to the same UTM grid lines on the jpeg image. Each "page" of the sixteen has been incorporated below to illustrate that the transcription was successful. Success is measured here by noting that each basin, as outlined on the underlying jpeg, shows a corresponding block of dots of the same color. There are no single dots or blocks of dots of a differing color within the drainage basin. The margins are reasonably represented by assigning a value (represented as a color) based on the larger part of the cell. The actual basin number (represented by a unique color) is not a significant item.

The dot overlays show the correspondence to drainage basins in the following sixteen images where data were plotted independently of the program (VFP) used to transcribe the data. I consider this a suitable verification of data transcription.
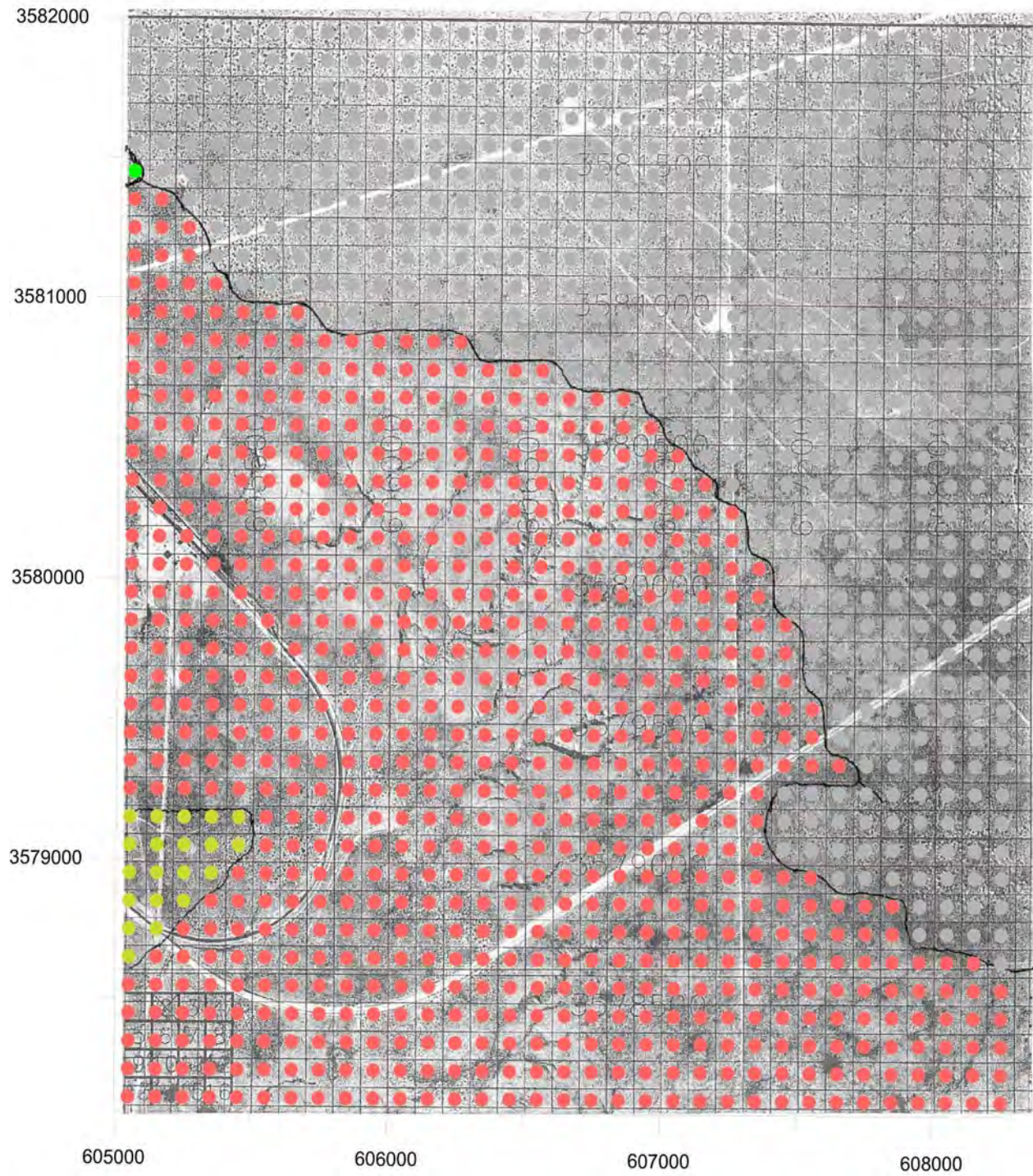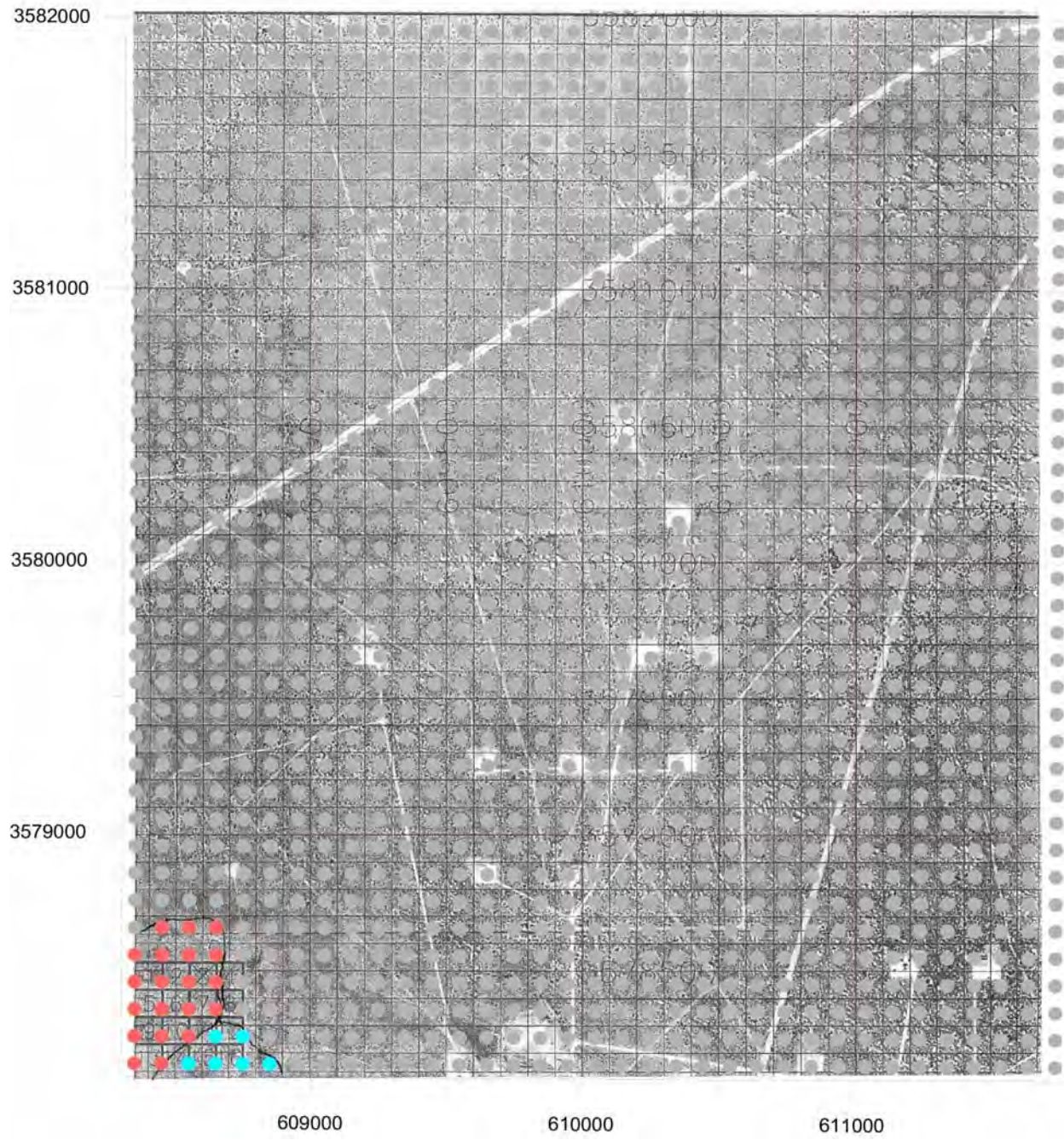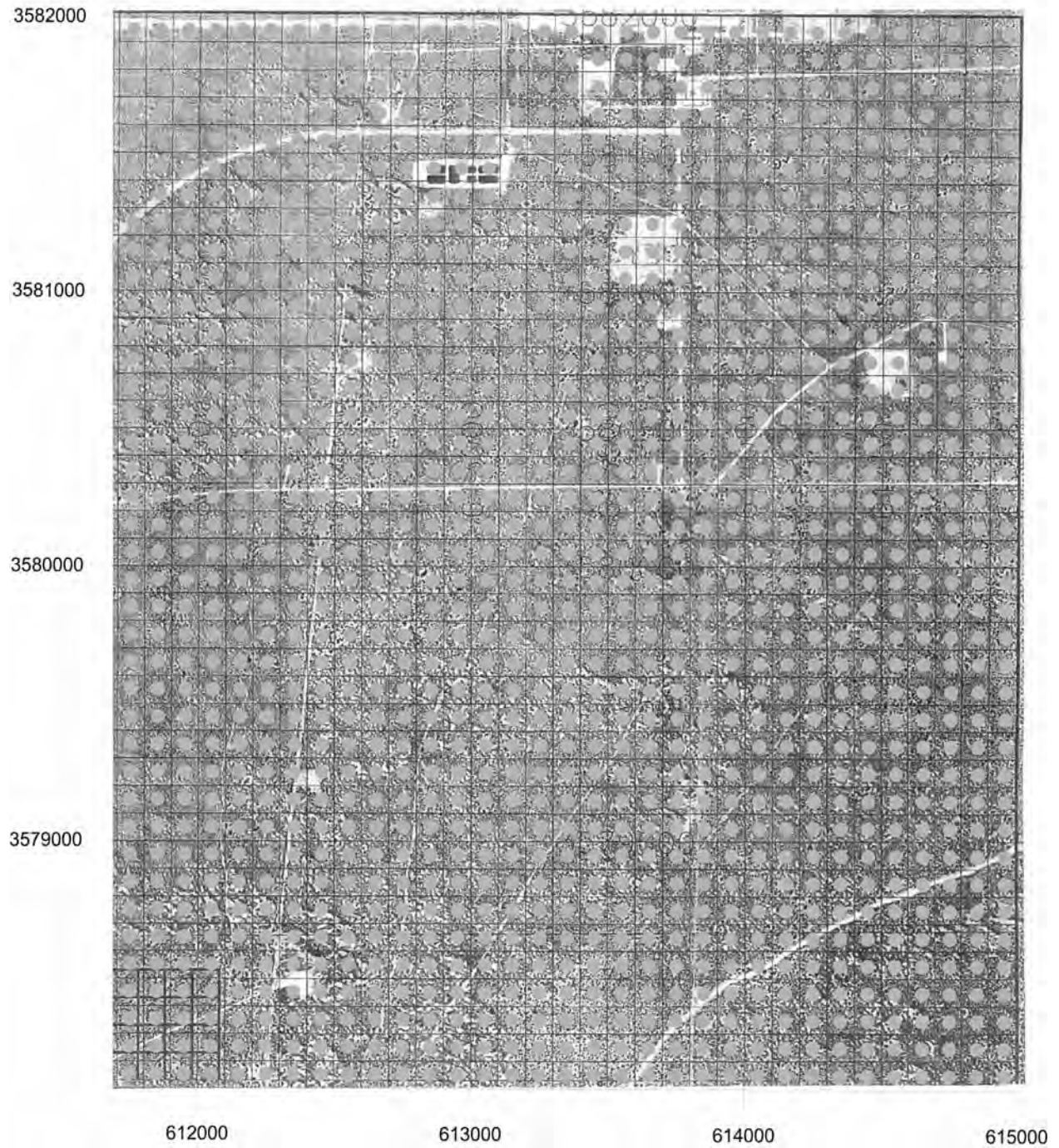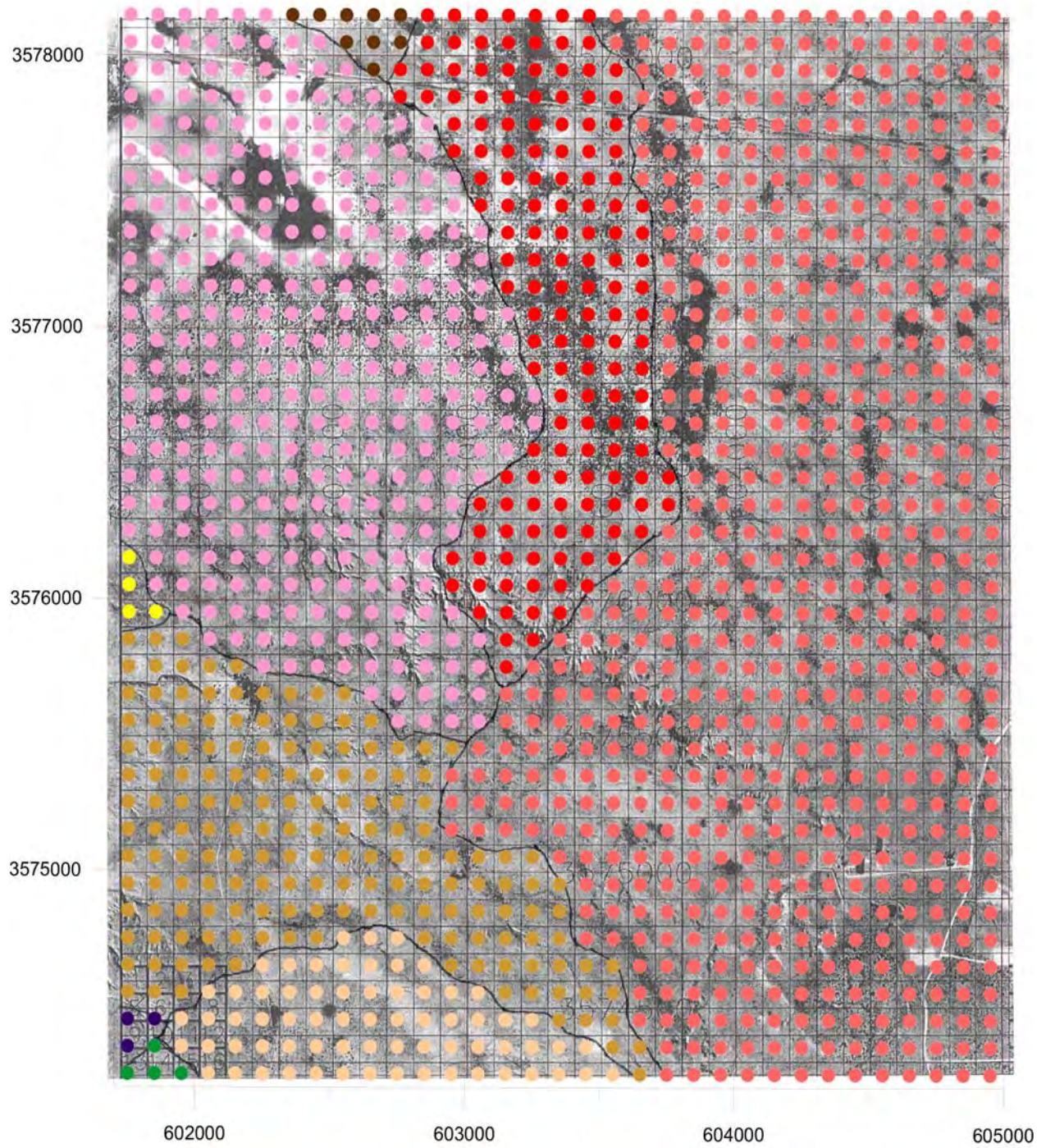
AP-114 Task 1B
Page 1 Check
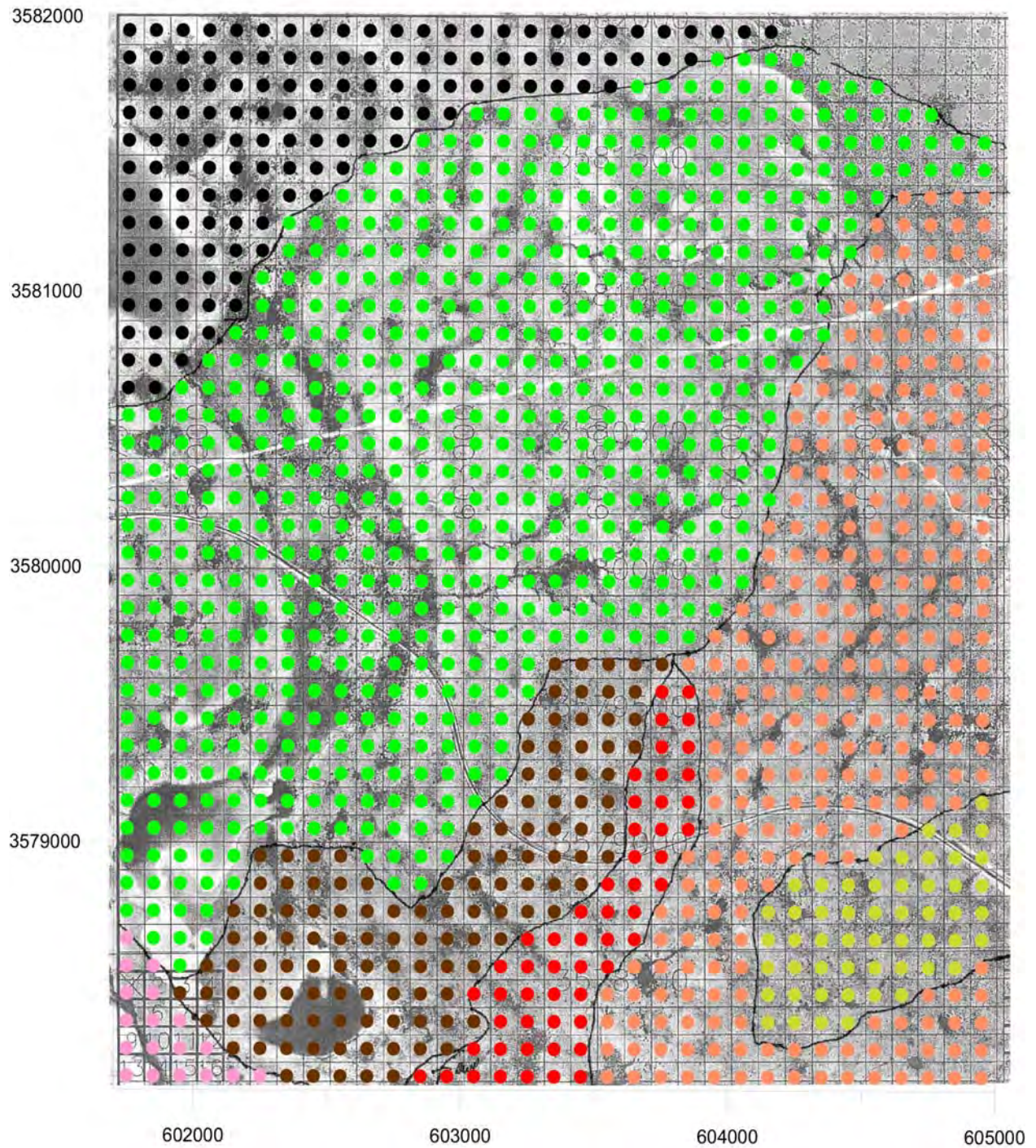
AP-114 Task 1B
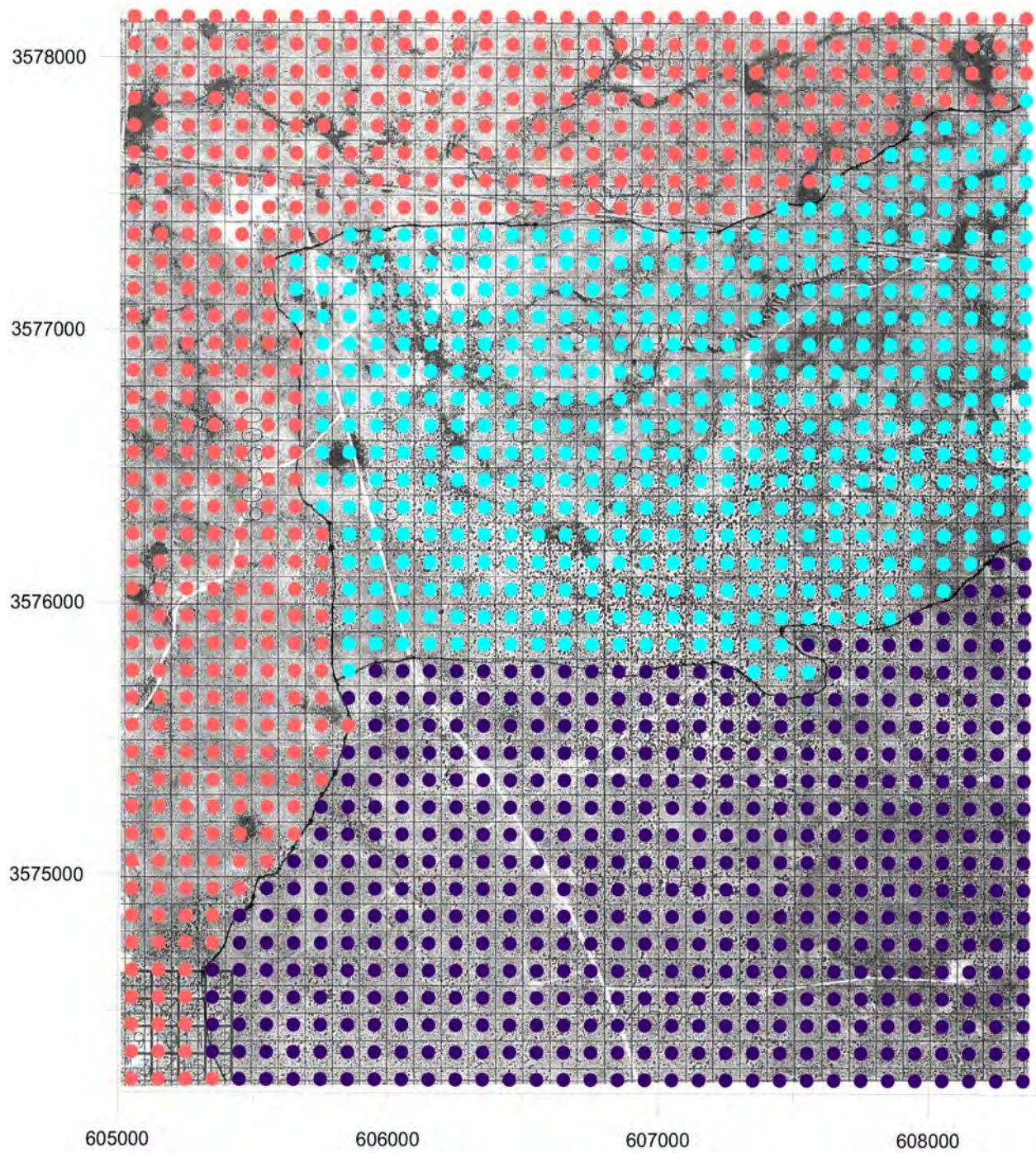## Page 2 Check

AP-114 Task 1B
Page 3 Check

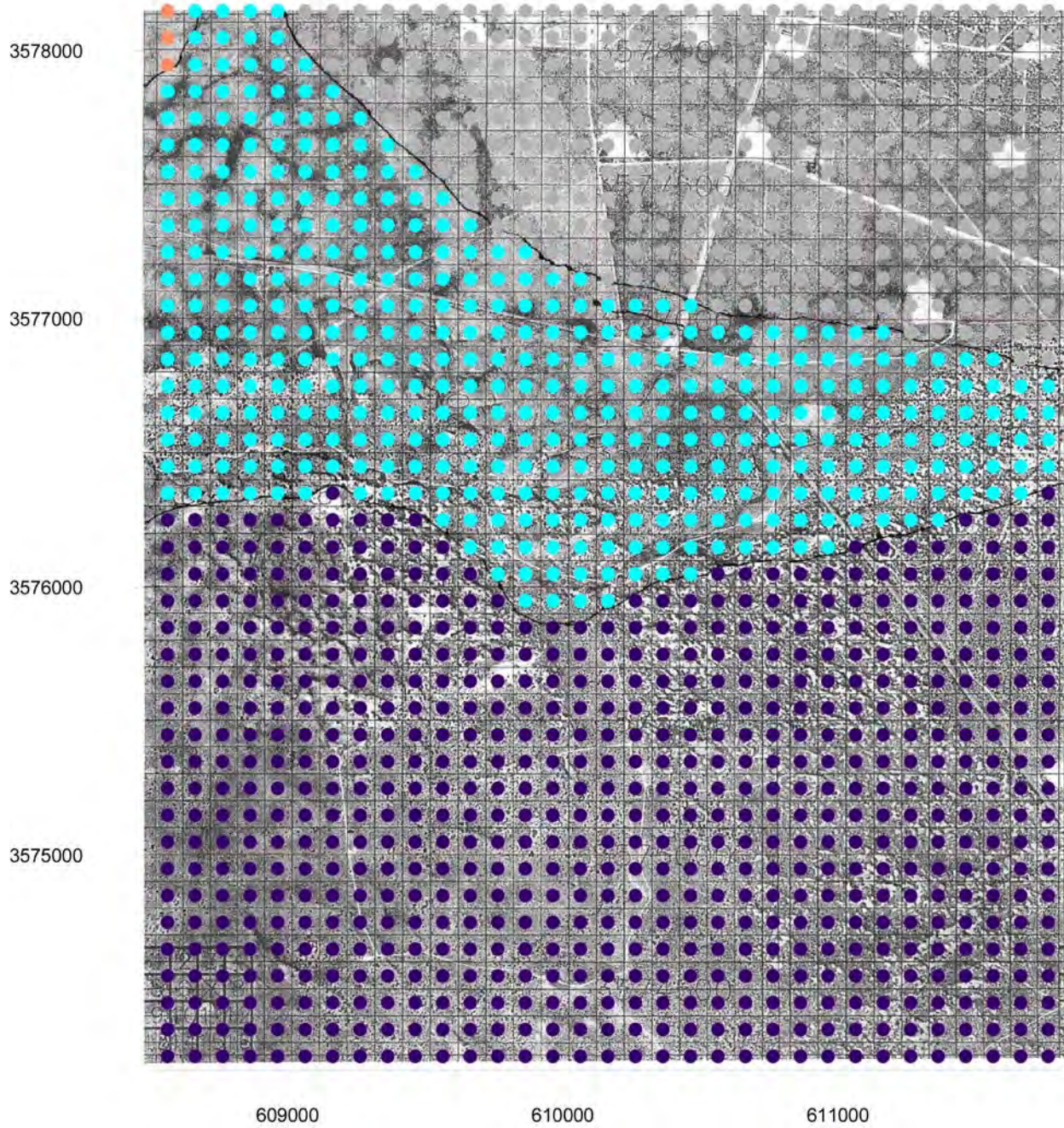## AP-114 Task 1B
Page 4 Check

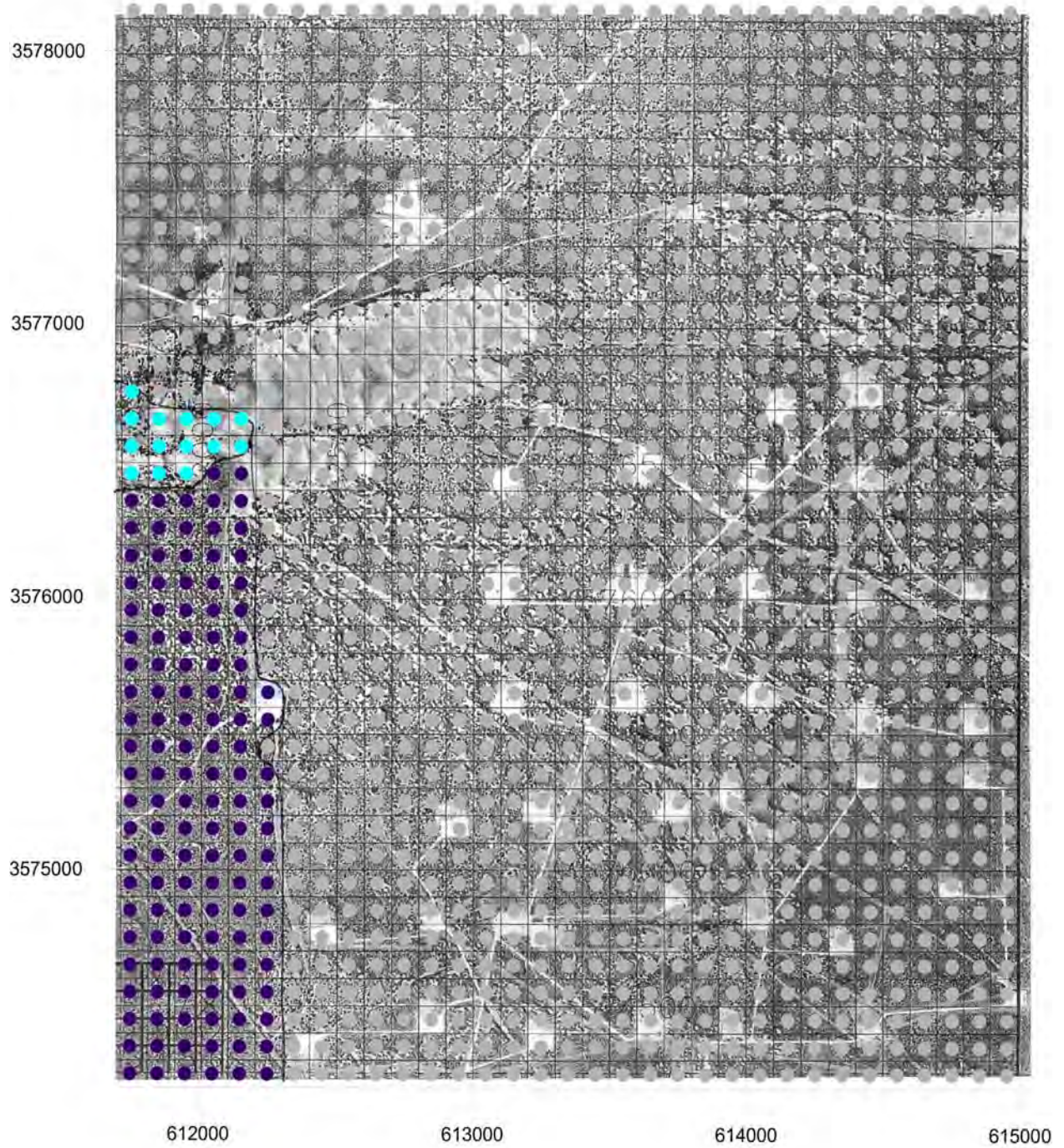# AP-114 Task 1B
Page 5 Check

AP-114 Task 1B
Page 6 Check
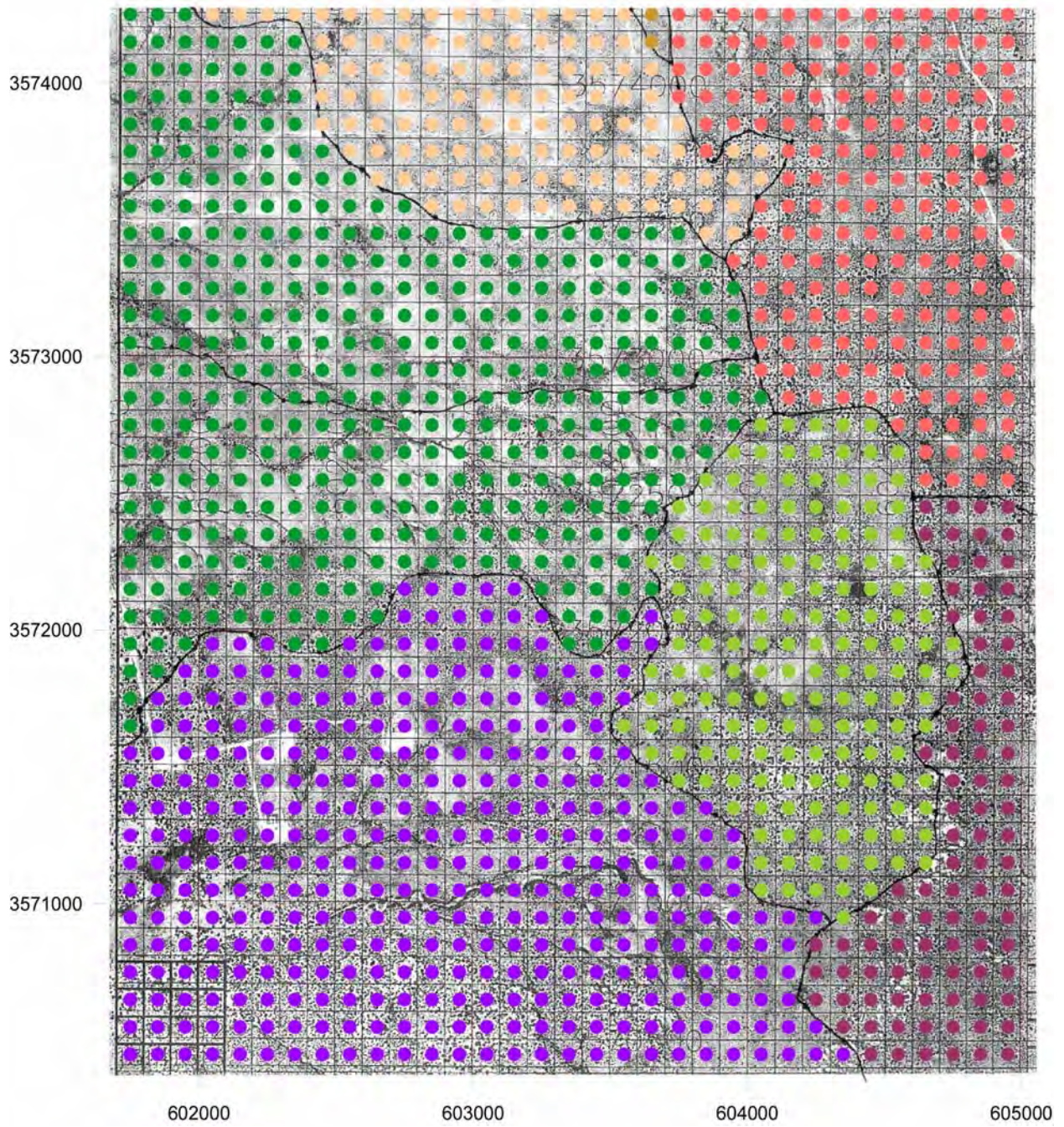
AP-114 Task 1B
Page 7 Check

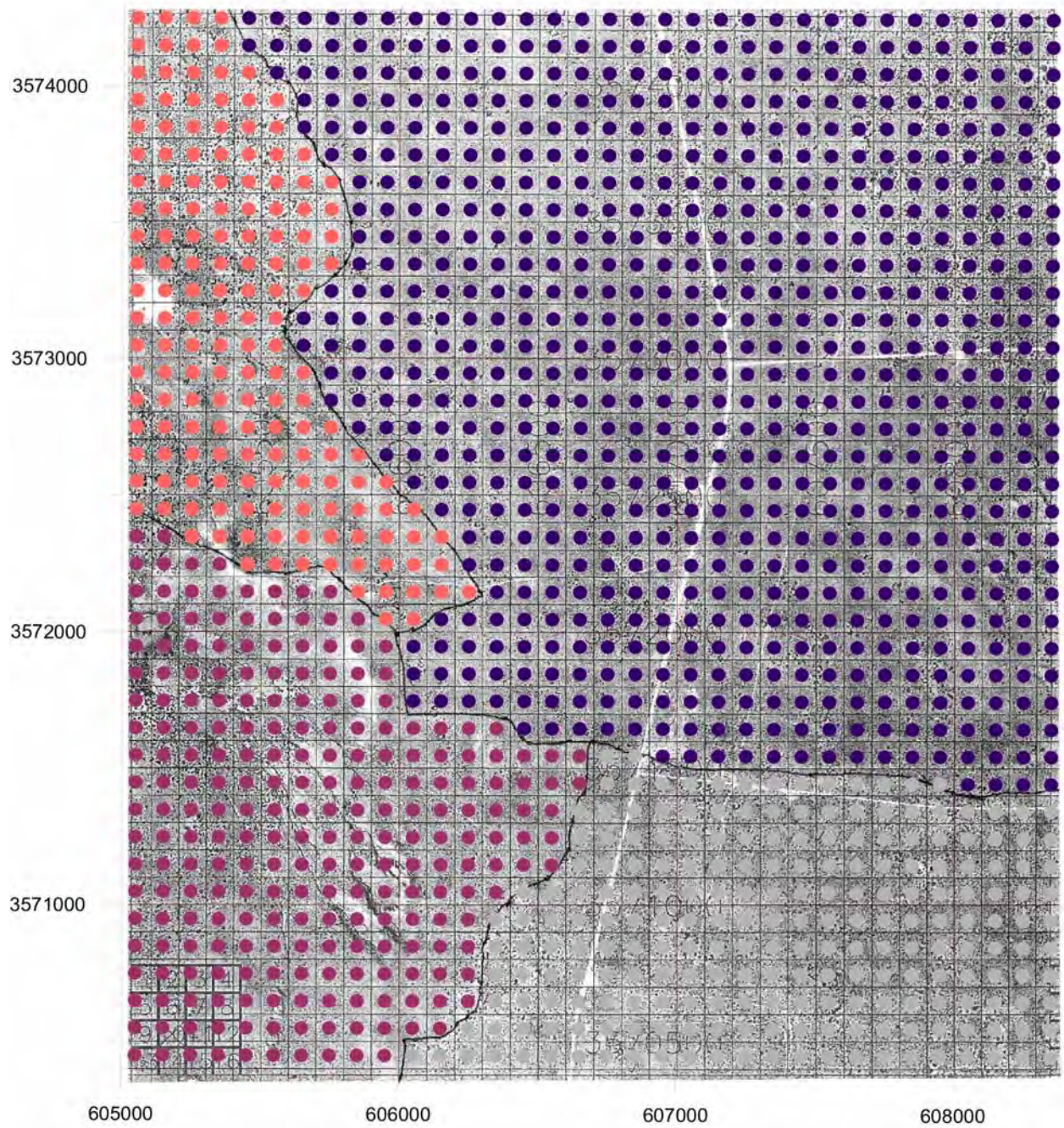## AP-114 Task 1B
Page 8 Check
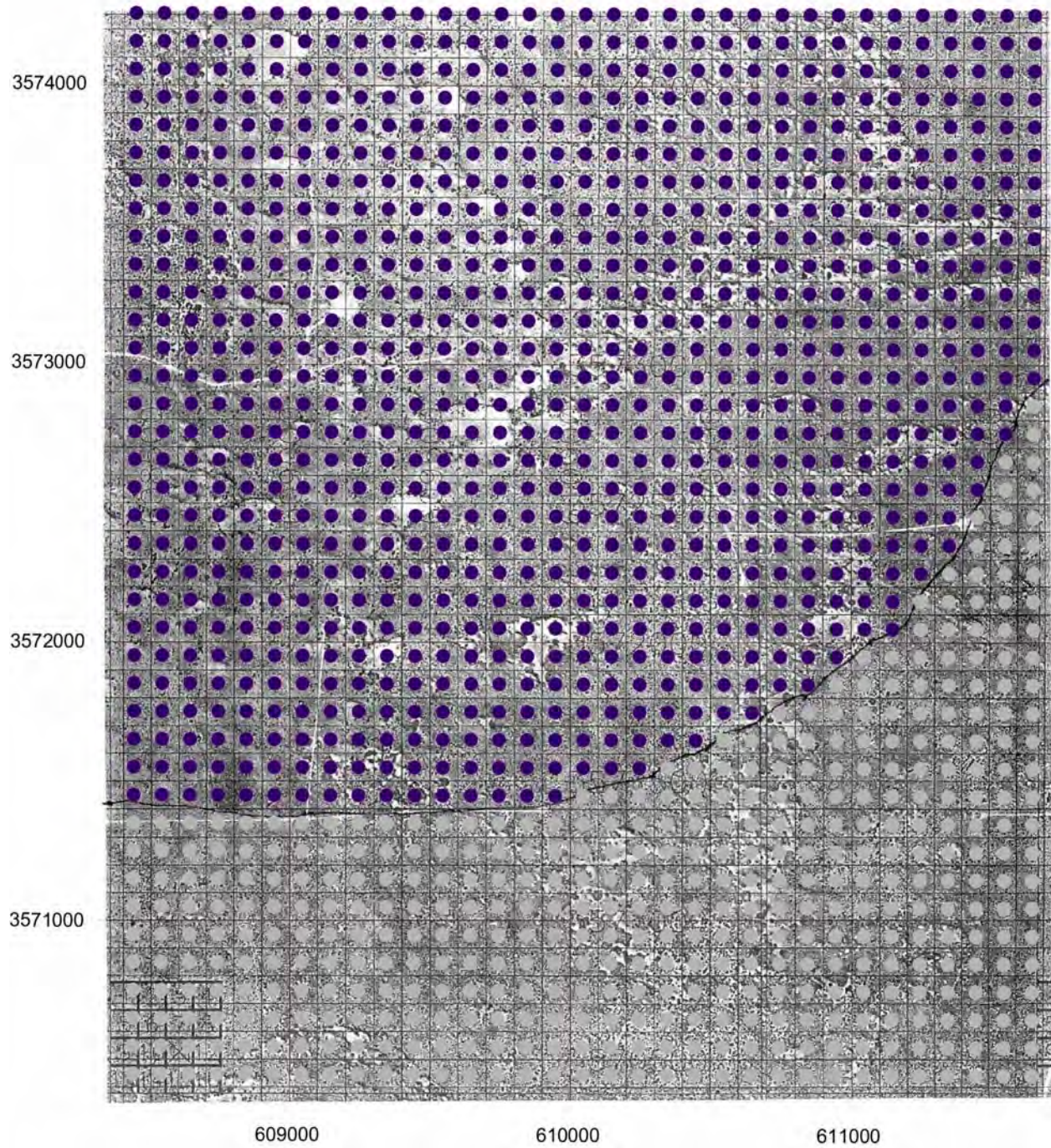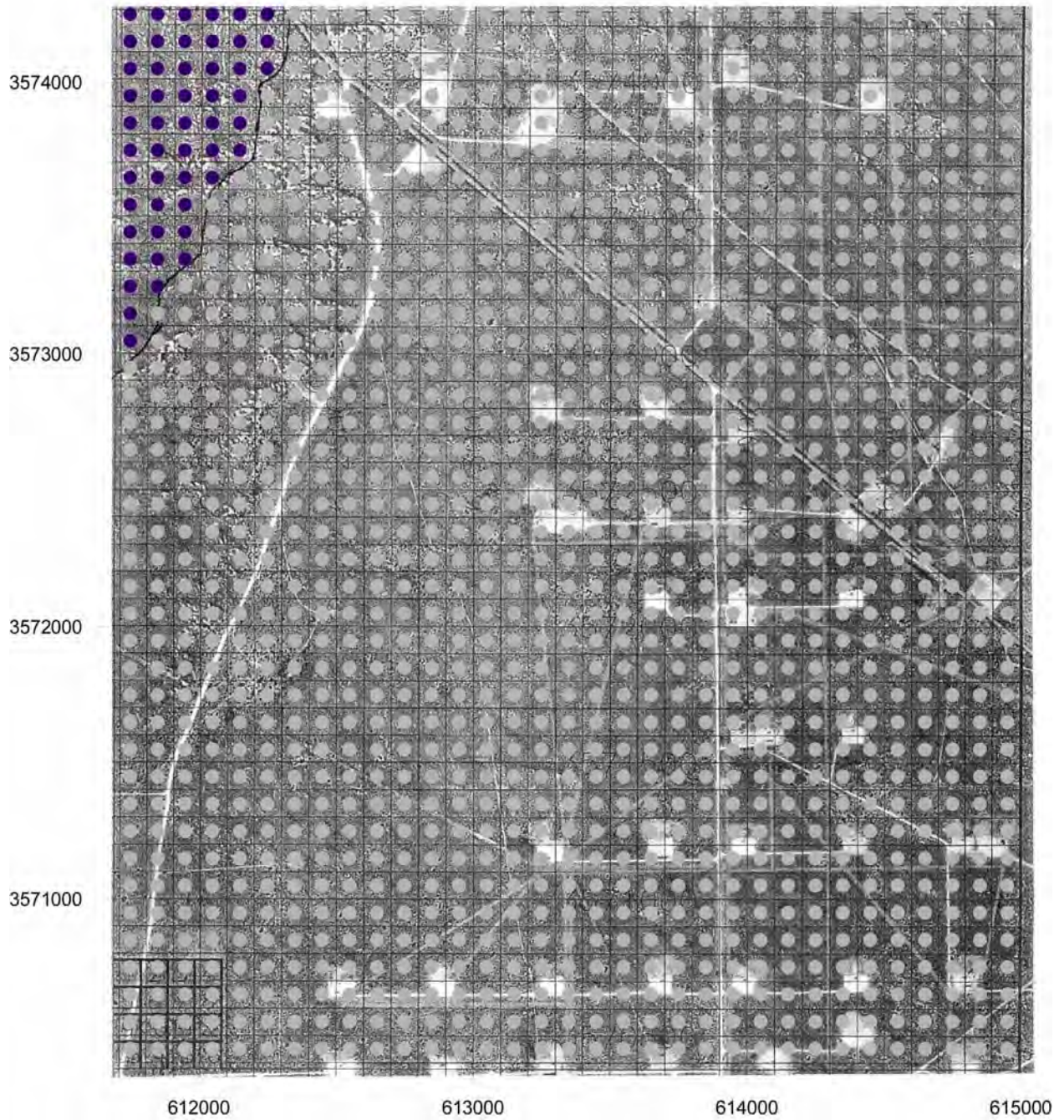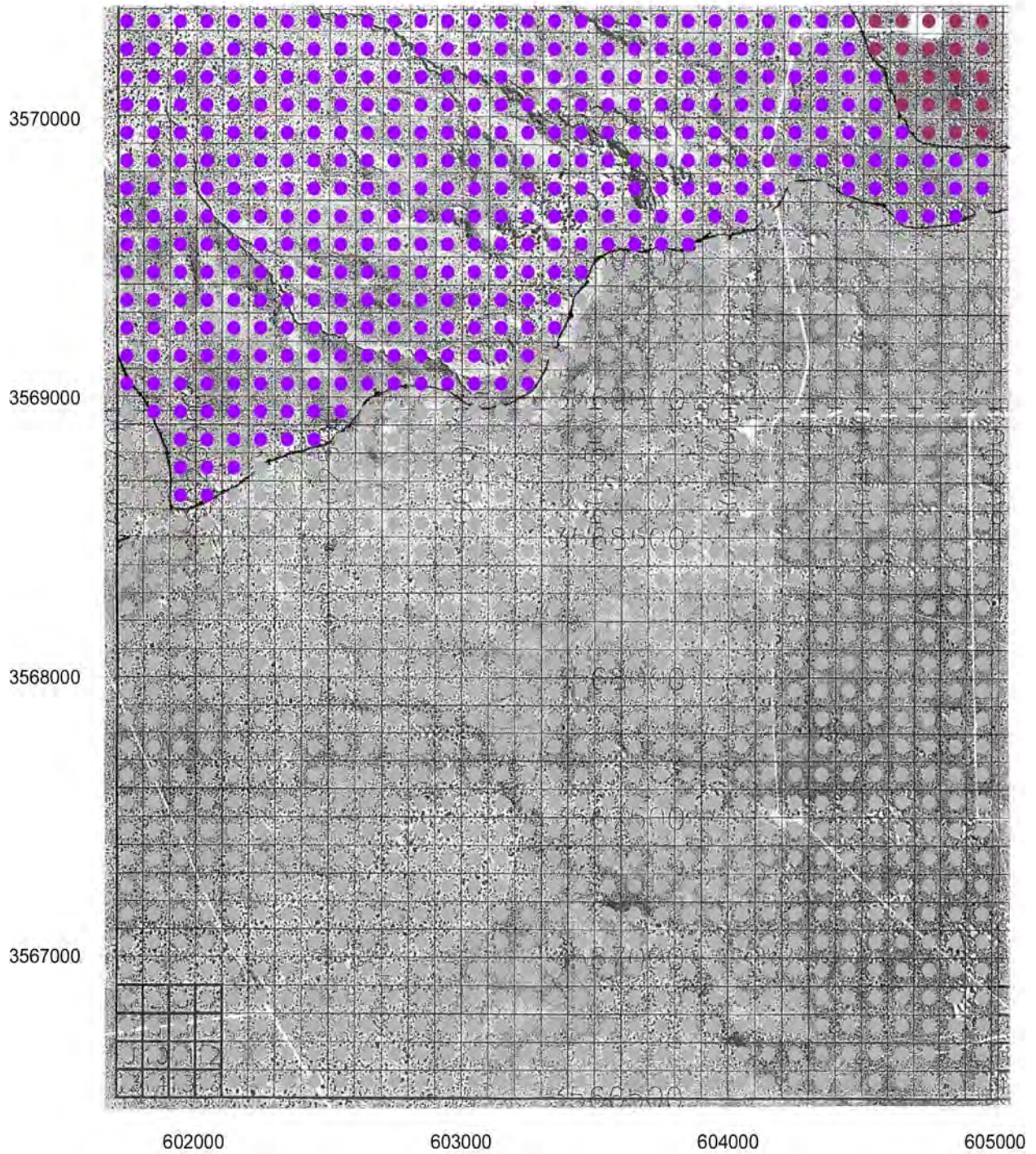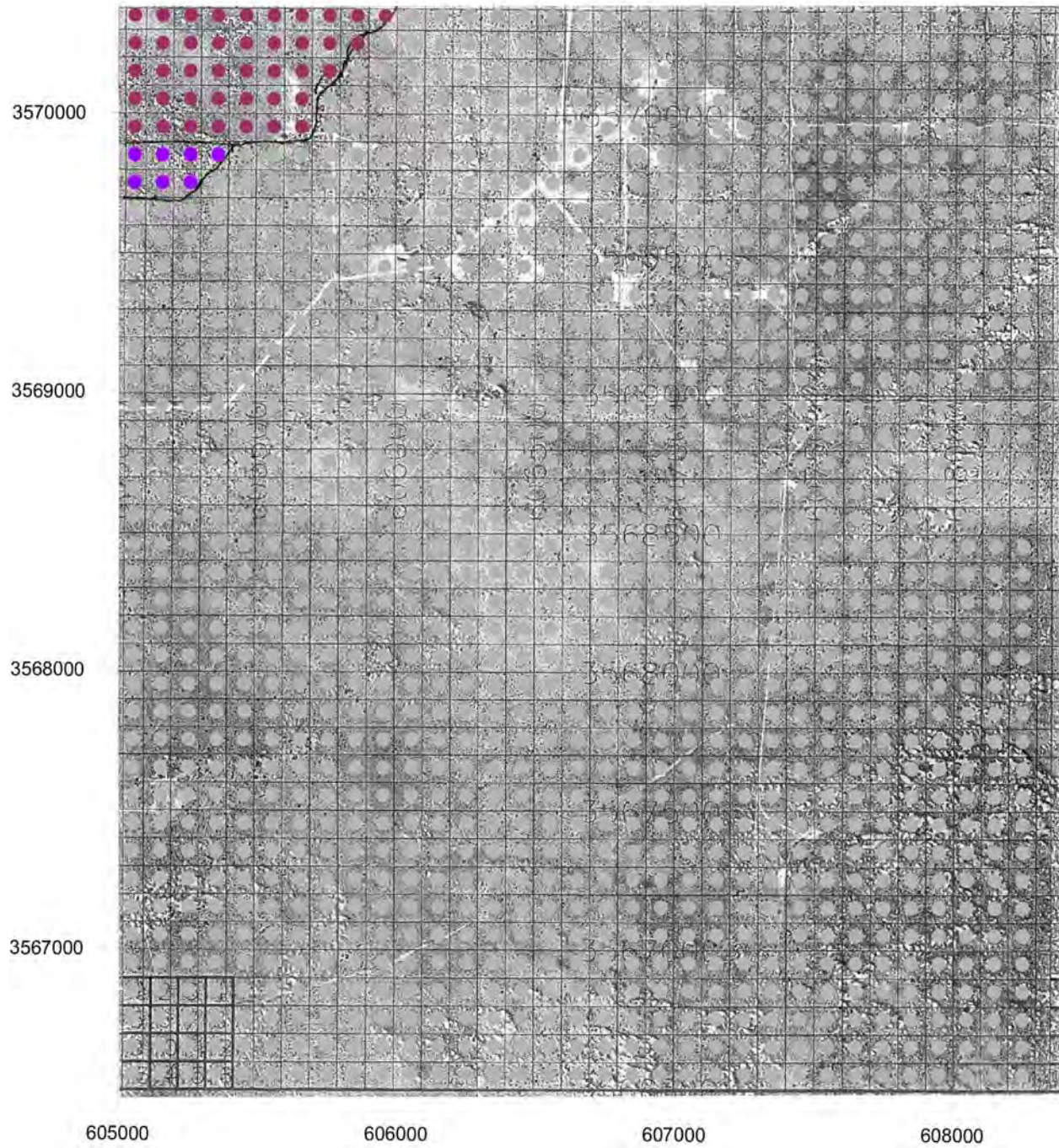
AP-114 Task 1B
Page 9 Check

AP-114 Task 1B
Page 10 Check

AP-114 Task 1B
Page 11 Check

AP-114 Task 1B
Page 12 Check

AP-114 Task 1B
Page 13 Check

AP-114 Task 1B
Page 14 Check

AP-114 Task 1B
Page 15 Check
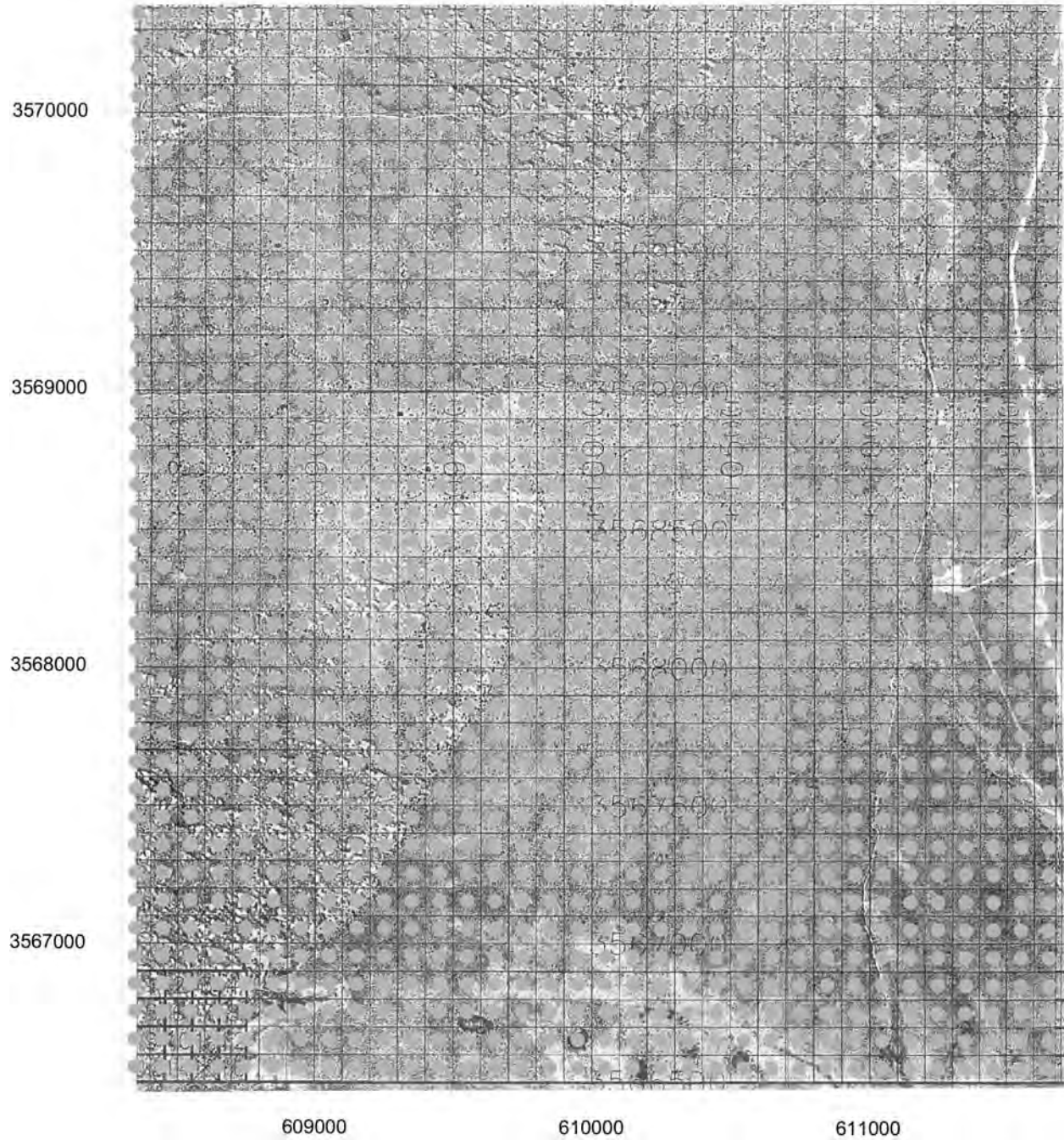
AP-114 Task 1B
Page 16 Check
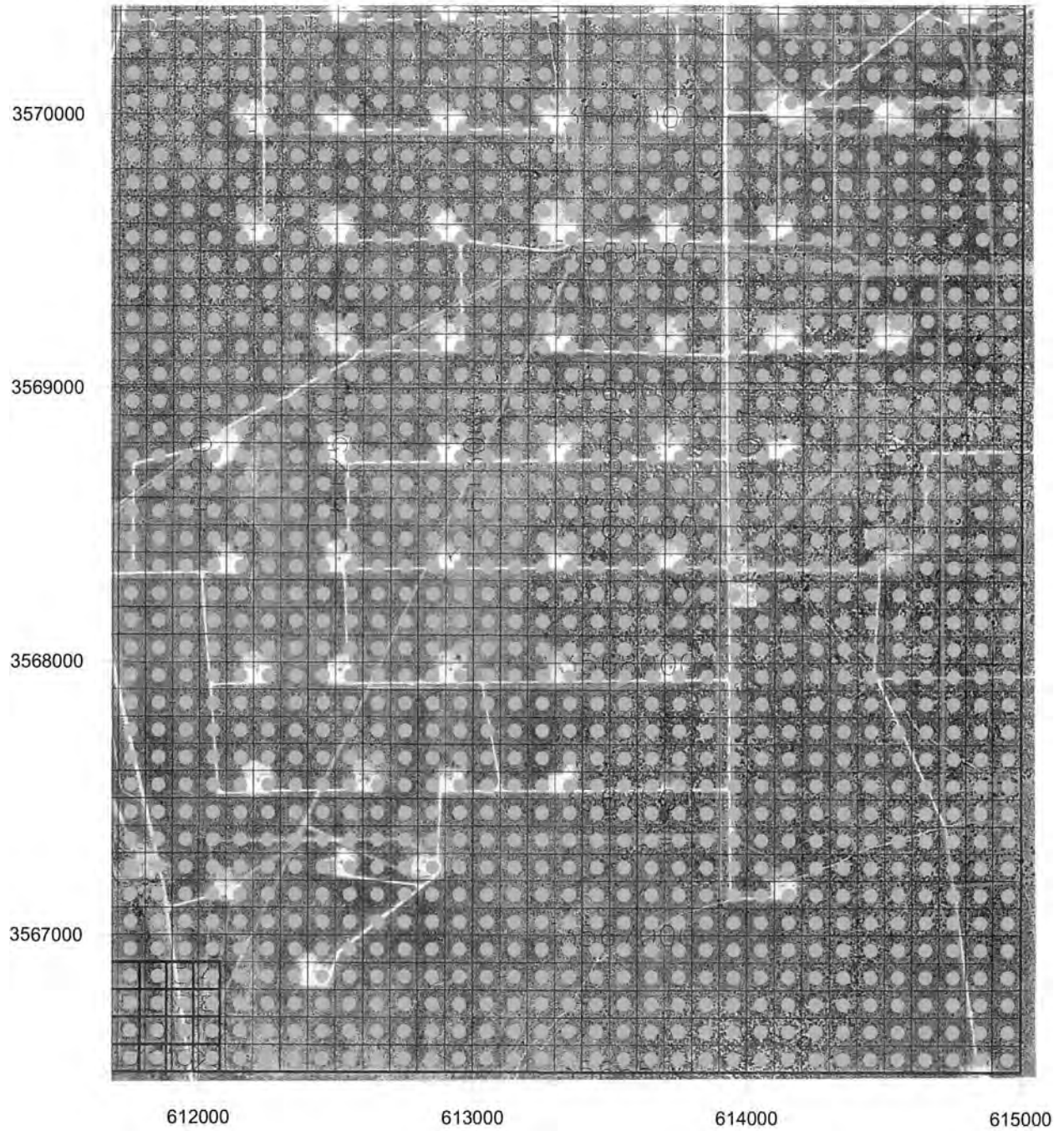
Appendix B

For

Analysis Report
Task 1B of AP-114
Identify Possible Area of Recharge to the Culebra West and South of WIPP

**(AP-114: Analysis Plan for Evaluation and Recalibration of Culebra Transmissivity Fields)**

Task Number 1.4.1.1

**Report Date: November 15, 2005**

Visualization of Values Assigned for Elements

The data in table AP-114 Task 1B.xls (Excel® 2002) has been plotted using Grapher® 5.0 for each of the five elements identified for Task 1B. The basic information, as explained in the text, was recorded as a number in the data table to represent different parts to each element. There is no intrinsic meaning to the numbers used to represent parts of the element, nor do the colors to represent them in the following graphs have any specific meaning, other than to help differentiate the elements visually.

Element 1 Drainage Basins
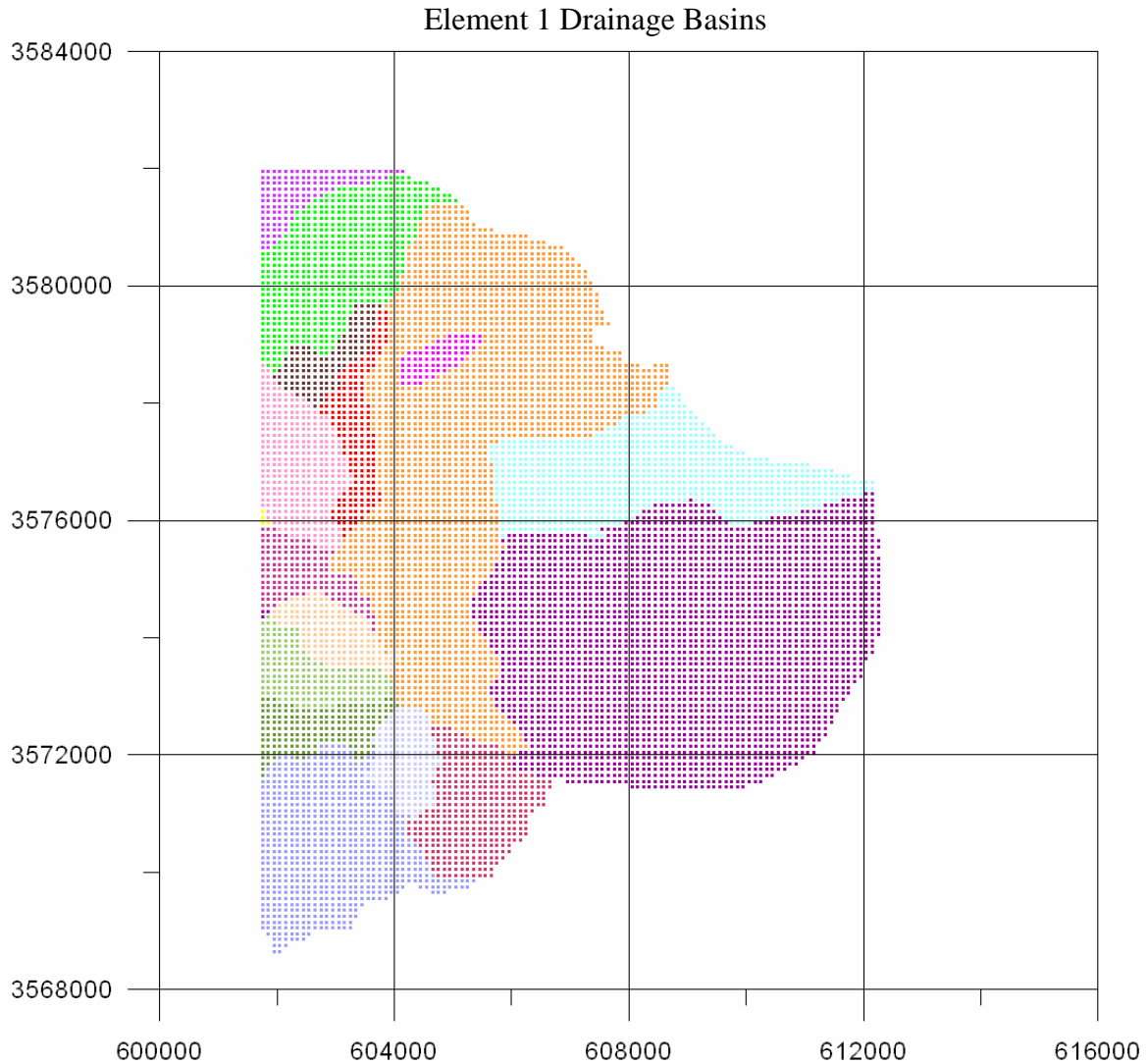
There are seventeen defined drainage basins within the study area (data table values 1 through 17). The "default" value of 0 represents the area (uncolored here) where drainage basins were not defined at this scale because there is very little that can be defined as surface drainage and there is little topographic differentiation. The colors have no significance other than being different for each basin.

Element 2 Culebra Confinement
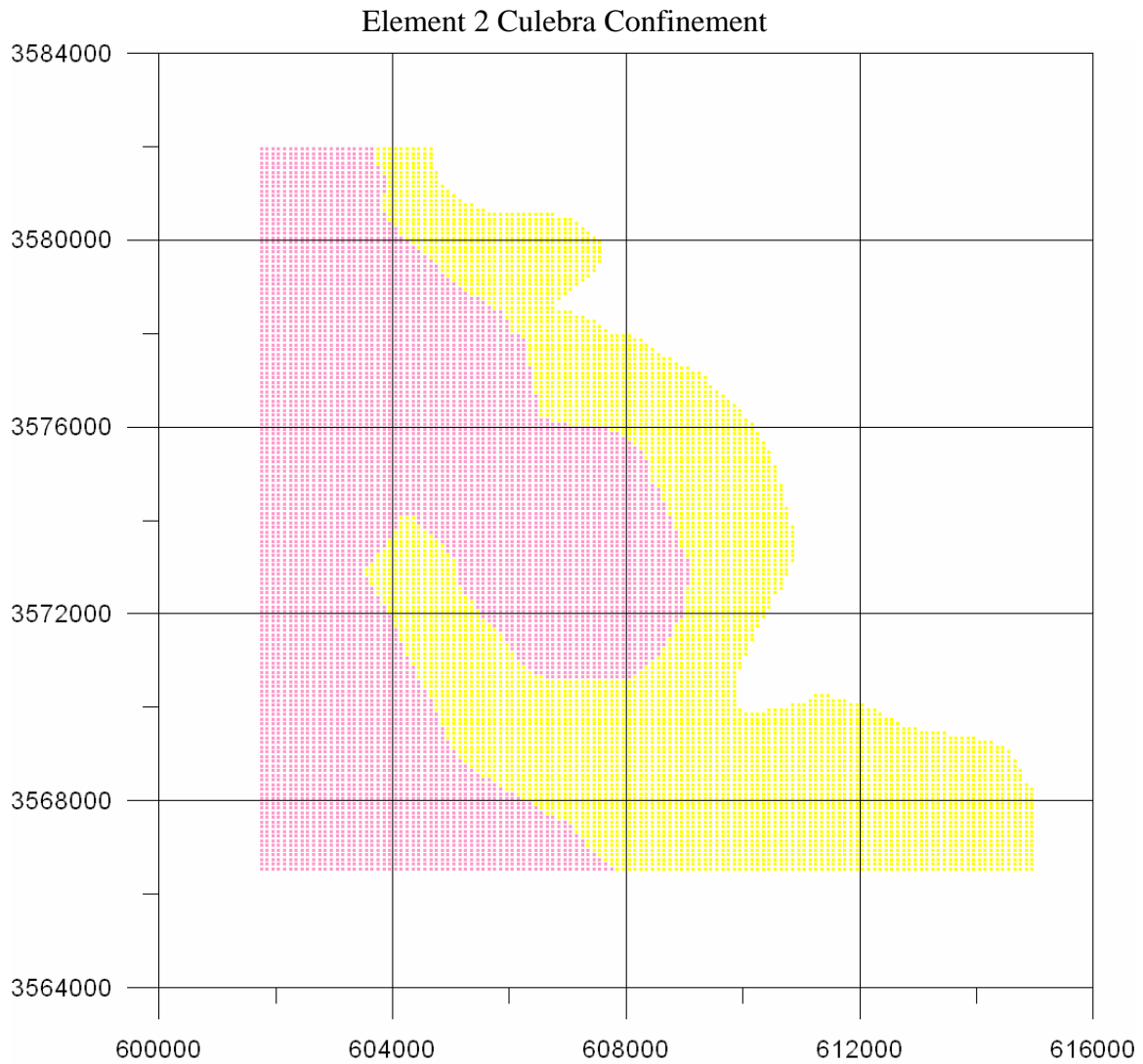
Three zones were differentiated that are generally considered confined, transitional, and unconfined.

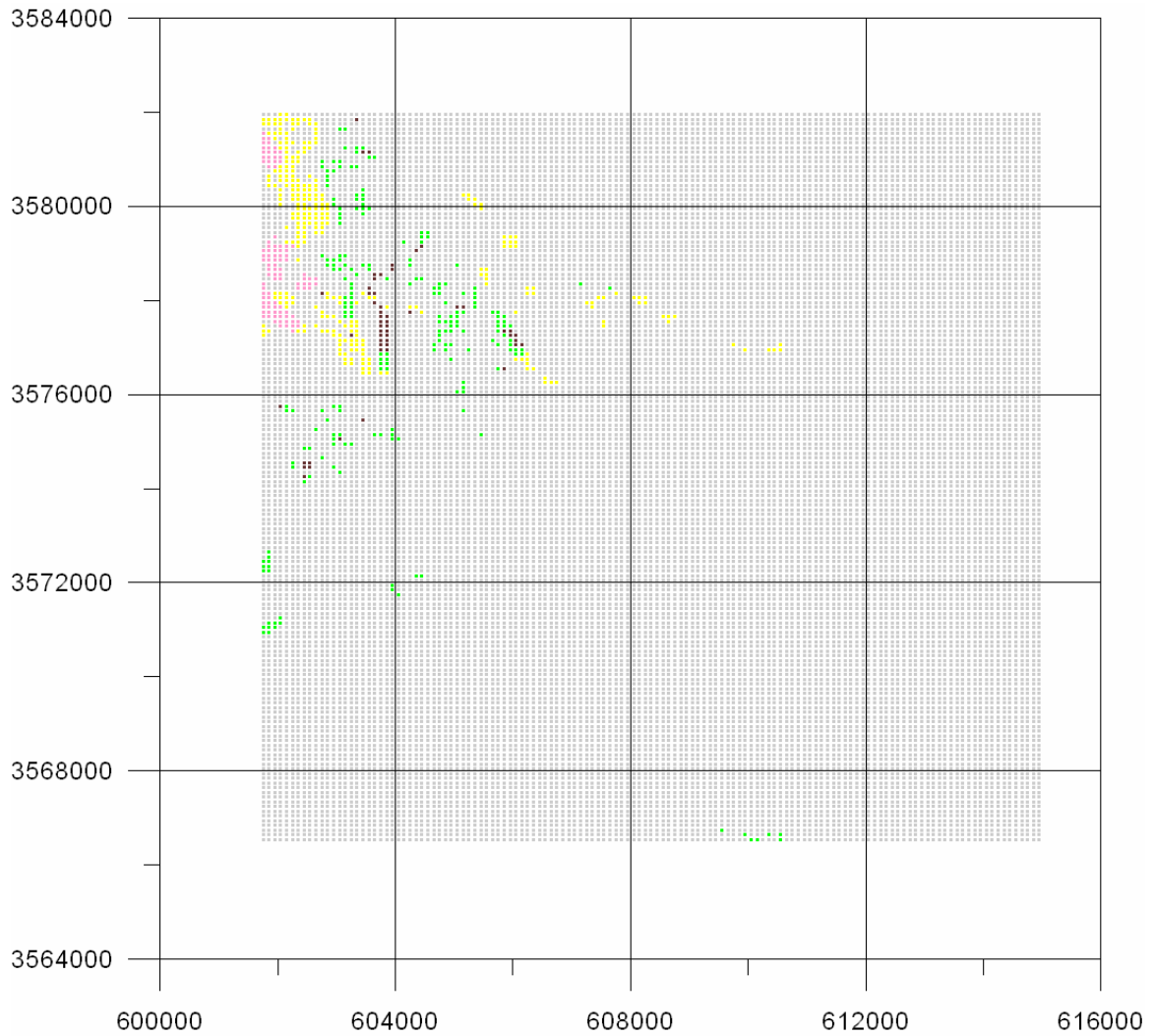| Key to Colors and Data Values for Culebra Confinement		
Data Table Value	Culebra Characteristic	Color Equivalent
0	Confined	None (white)
1	Transitional	Yellow
2	Unconfined	Pink

Element 3 Drainage Channels
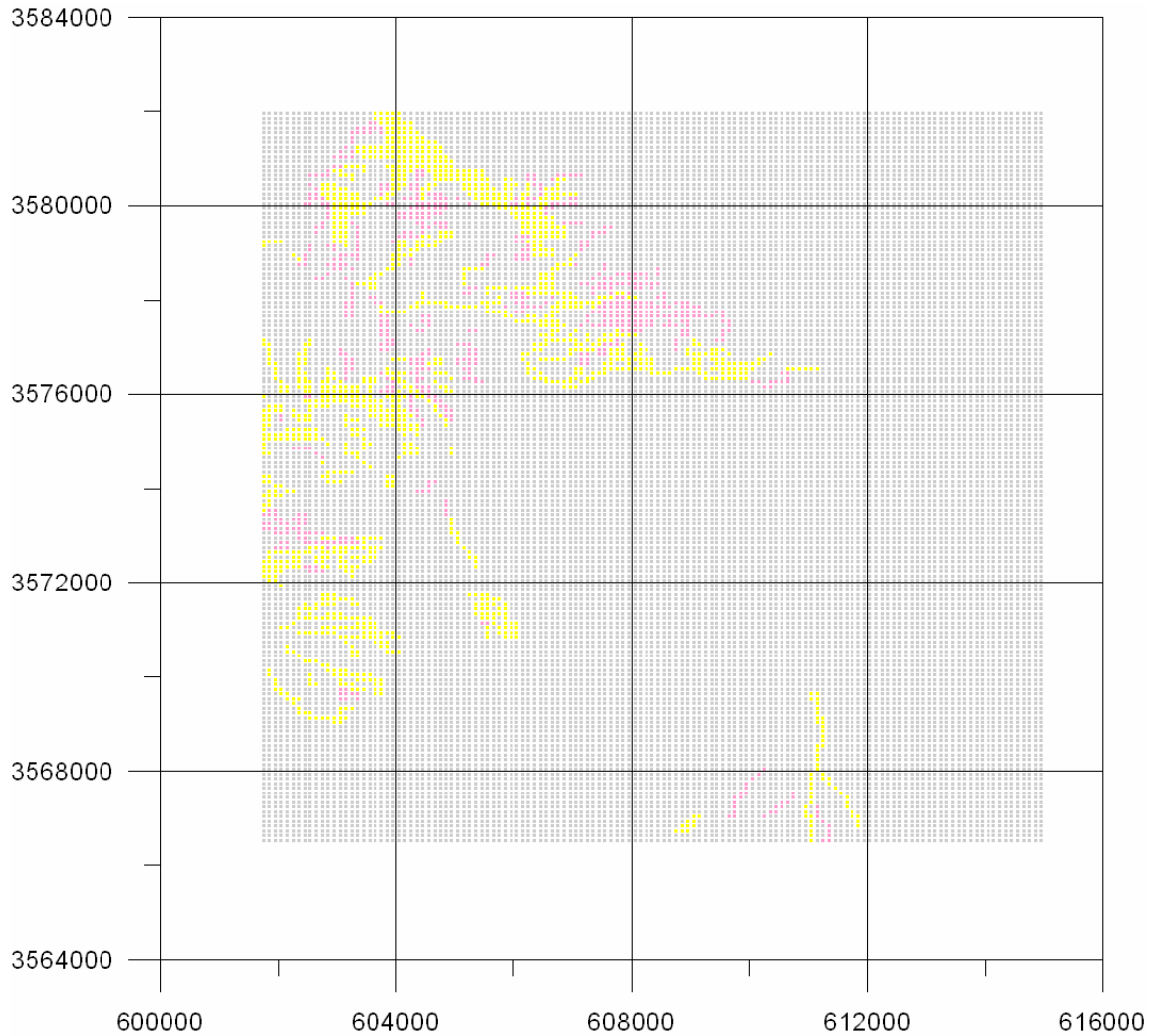
Most of the area covered by the study has no significant development of drainage channels. This is represented here with small gray dots.

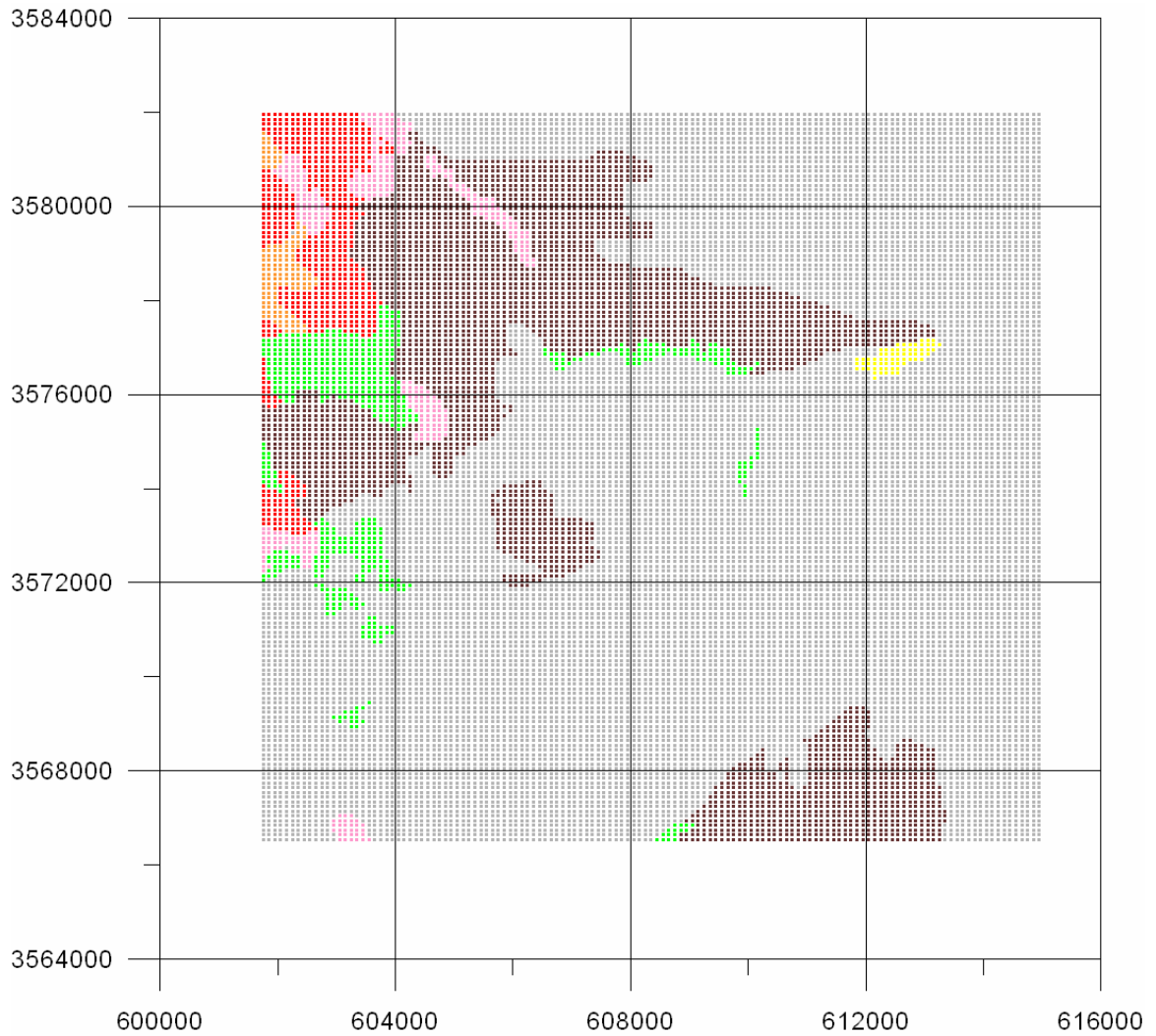| Key to Colors and Data Values for Drainage Channels		
Data Table Value	Drainage Characteristic	Color Equivalent
0	No significant channels	Gray
1	Open channels, little vegetation	Yellow
2	Channels or arroyos with significant vegetation	Pink

Element 4 Points and Areas of Potential Recharge

Sand, sand dunes, and Mescalero caliche blanket large areas without visible points or areas that focus recharge. These are coded with small gray dots to contrast with other areas.

Key to Colors and Data Values for Points or Areas of Recharge		
Data Table Value	Recharge Characteristic	Color Equivalent
0	No specific points or areas	Gray (small dots)
1	Vegetated lows or collection points	Yellow
2	Brine lakes and adjacent marshy areas	Pink
3	Karst valleys or broader karst features	Green
4	Sinkholes, caves, and dolines	Dark Brown

Element 5 Curve Number

Key to Colors and Data Values for Curve Numbers			
Data Table Value	Curve Number	Soil Characteristics (See US Department of Agriculture, 1986)	Color Equivalent
0	55	A soils, fair vegetation	Gray (small dots)
1	63	A soils, poor vegetation	Yellow
2	72	B soils, fair ground cover	Pink
3	81	C soils, fair ground cover	Green
4	86	D soils, fair ground cover	Dark Brown
5	88	D soils, poor ground cover	Red
6	0?	Brine Lakes	Orange