APPENDIX 8

PROVED RESERVES ESTIMATION AND FIELD BOUNDARY CONSTRUCTION

A8.1 SUMMARY

The Reserves and Production Division (RPD), Office of Oil and Gas, of the Energy Information Administration, estimated proved reserves of crude oil, natural gas and natural gas liquids on Federal lands located in selected geologic basins of the Rocky Mountain, Appalachian, Alaska, and Southeastern United States regions. This task involved attributing reported and imputed proved reserves to individual fields, developing field boundaries, and allocating these to Federal lands. The primary results are presented in a multi-layered GIS format accompanied by metadata compliant with the Federal Geographic Data Committee Metadata Standard. Most of the methods used were modified from those developed for the Phase I inventory in 2002. Some modifications were made to accommodate geological differences between the Phase I and Phase II basins, whereas other modifications represent the implementation of planned improvements.

To provide a fully consistent set of estimates the Phase I study areas were reprocessed using the modified methods. The updated Phase I results, which slightly differ from those previously published, are provided at the end of this appendix.

Four types of data obtained from a variety of sources were used for the project:

- Federal agencies
  - The 2001 Form EIA-23 Reserves Survey was the source for the bulk of the proved reserves estimates
  - The USGS was the source of well data for the state of Virginia (VA)
  - The Federal lands boundary data were provided by the Bureau of Land Management, Department of the Interior.
- State agencies (oil and gas regulatory agencies and geological surveys) provided well and production data either directly or via their websites.
- Commercial vendors
  - The IHS Energy Group Production Data set was a source of field names, reservoir names and 2001 production data for the states of Wyoming (WY), Utah (UT), Colorado (CO), Nebraska (NE), Mississippi (MS), Alabama (AL), Florida (FL) and Alaska (AK)
  - The IHS Well History Data set was a source of well locations for the states of WY, UT, NE and CO
  - PetroDataSource (PDS) was a source of well data for the states of FL, MS and Tennessee (TN)
  - HPDI was a source of well data for the states of West Virginia (WV) and Maryland (MD).

Several steps were involved in the collection and preparation phase:

- Identification of all wells, reservoirs and fields in the study areas
- Standardization of reservoir and field names to make them consistent from source to source
- Assigning field names to wells where they were missing
- Identification and standardization of well types
- Merging of the state, vendor, and Form EIA-23 survey data
- Identification and name editing of those fields that had wells located both inside and outside of the defined Phase II study areas and fields that crossed state boundaries.

To compare the fields and their proved reserves to Federal lands it was necessary to construct a boundary or outline for each field. Field boundaries were determined by placing reasonable and appropriate buffers around individual wells, followed by their union. Buffer size was based on well spacing as determined by measuring the distances between wells in a reservoir or field using the latitude and longitude of each well's spud point or surface location relative to those of neighboring wells (with the exception of Northern AK, where bottom-hole locations were used). For the Eastern states, wells within the same field were used to determine the appropriate buffer size because reservoir information was frequently absent or incomplete. Rules were developed on the basis of these measurements to determine which standard well spacing (buffer) should be used for each reservoir or field. After assigning the appropriate standard well spacing-based buffers to each field or reservoir, field boundary polygons were then generated using ESRI’s ArcGIS Version 8.3 software. A Visual Basic application was written to automate this process. The GIS mapping software performed these main steps:

- Selection of all wells with a specific field name
- Creation of a buffer around each well in the field using the assigned "buffer distance" (standard well spacing)
- Unioning of the buffers in each field to dissolve the inner boundaries of overlapping buffers
- Outputting of a boundary polygon (sometimes more than one polygon if one or more wells are located far from the other field wells) for each field.

Portions of field boundaries that extended outside of the defined Phase II study areas were clipped at the basin boundary and removed. For each field the fraction of total field area that was within the study area boundary was then calculated. This fraction was used to reduce the proved reserves for the field portion inside the study area boundary.

The outer margins of resultant multi-well field polygons often have a scalloped appearance. The polygons also often have small internal non-field “islands.” Numerous alternative methods were tested to identify and develop an algorithm which would adequately automate smoothing of scalloped-appearing field boundaries and fill in the small “islands” while acceptably limiting the polygon area increase. The resultant smoothing algorithm, automated by a Visual Basic application in ArcGIS, was applied to all field boundary polygons. Ninety-nine percent of the resultant smoothed outlines have areas that are less than 108 percent of the unsmoothed polygon areas.

Geographic comparison of the smoothed field boundary polygons to the Federal lands polygons was then performed, resulting in output of a Federal lands fraction for each field.

Proved reserves estimates submitted on the 2001 Form EIA-23 survey were used in the estimation process. For those fields in which only some of the operators reported on Form EIA-23, the minimum reserves-to-production ratio of those that had reported was multiplied by the production of non-reporting operators to impute the latter's proved reserves. For those fields (which were usually small) in which no operator had reported on Form EIA-23, regression equations were developed from other reported observations in the basin that were used to estimate proved reserves. The portion associated with Federal lands within the field was then computed using the Federal lands fraction. Each field was then assigned to a proved reserves size class sufficiently narrow to be useful for this inventory’s purposes while at the same time broad enough to ensure confidentiality of each Form EIA-23 respondent's proprietary estimates.

For the combined study areas proved Federal lands liquid reserves (crude oil plus condensate) were estimated to be 23.0 percent of total proved reserves with the individual percentages for ranging from 0.0 to 85.9 percent. Similarly, the proved Federal lands gas reserves were estimated to be 22.1 percent of total proved reserves with the individual percentages ranging from 0.0 to 96.1 percent. Also for the combined basins, Federal lands proved barrel-of-oil equivalent (BOE) reserves were estimated to be 22.3 percent of total proved reserves with the percentage for individual basins ranging from 0.0 to 93.6 percent.

A8.2 STUDY AREAS

The Phase II study areas and the states and counties pertinent to them are listed in Table A8-1. Their boundaries were provided by the USGS. All wells in the listed states and counties for which location information (in the form of latitude and longitude coordinates or projected coordinates) were available were selected if within the study area boundaries. Wells not located within the study area boundaries were discarded unless they were in a field that had wells located both inside and outside of the boundaries.

Table A8-1. Phase II Study Areas and Their State and County Affiliations

A8.3 DATA SOURCES

Three principal sources of data were used for this study:

- Federal Agency Data

  - The 2001 Form EIA-23 Survey files which contain field-by-field proved reserves estimates and production data as reported by large operators
  - A well data table with well spud point location (latitude and longitude), field name, and well type at time of completion for VA was obtained from the USGS (Robert Milici)
  - Federal lands boundary data were provided by the Bureau of Land Management, Department of the Interior.
- State Agency Data
  - Many of the oil and gas regulatory entities and the geological surveys of the producing US states have official websites where tables with the following data can be downloaded and/or queried: well spud point location (latitude and longitude), field name, and well type at time of completion. Several states also have online interactive web-mapping (webmapper) applications where wells can be viewed on a map and queries about them can be made. A few states have constructed their own oil and gas field boundary or outline files; these were used, where available, to check the reasonableness of the field boundaries constructed for this project. Oil and gas production data, usually annual by well, is available to download or query for some states. Links to the websites used in this study are listed in Table A8-2.

Table A8-2. Links to Websites Used in Phase II

  - Some data can't be downloaded from the state websites even though they can be queried online and must therefore be obtained directly from a state agency. Certain data were obtained from the listed state agencies (and contact persons) in Table A8-3.

Table A8-3. State Agencies Contacted

- Commercial Data
  - Well data tables with spud point location (latitude and longitude), field name, and well type at time of completion for the states of FL, MS, and TN were purchased from vendor PetroDataSource
  - Well data tables with spud point location (latitude and longitude), field name, and well type at time of completion for the states of WV and MD were purchased from vendor HPDI
  - IHS Production CDs were the source of production data at the well (for gas) or the lease (for oil) for crude oil, associated-dissolved gas, nonassociated gas, and condensate production in the Rocky Mountain states (CO, NE, UT, WY), the Black Warrior Basin states (AL, MS), FL, and AK
  - IHS Well History CDs were the source of spud point location (latitude and longitude thereof generated by Tobin International, Ltd.), field names, producing formation(s), and well type at the time of completion for the Rocky Mountain states (CO, NE, UT, WY) and Alaska.

A8.4 LIMITATIONS IMPOSED BY THE AVAILABLE DATA SOURCES

A variety of shortcomings and flaws in the available data impose unavoidable limitations either on what can be done or on the achievable level of accuracy. Chief among these are:

- Field and reservoir names are frequently non-standard as concerns their content and/or spelling. This makes accurate automated—and often even manual—matching of field and well records across data sources difficult and sometimes impossible. While standardized field codes are assigned and supported by EIA, most field names and their spellings are assigned by State agencies. When reporting well or production information for a field on which the state has not yet given an official name, the field operator is free to use any name or spelling.

  An additional factor was the demise of the American Association of Petroleum Geologists' (AAPG) Committee on Statistics of Drilling, which for many years performed an essential quality control function relative to U.S. well statistics and field and reservoir names. Staffed by industry volunteers the Committee was disbanded in 1986 and its files were turned over to the American Petroleum Institute (API), which that for many years maintained them absent the "in-the-field" quality control that the AAPG Committee had provided. Eventually this task was transferred to two competing commercial data vendors for continued maintenance and updating. Both recipient firms were subsumed into IHS Energy Group.

- Related to the field name problem is the problem of unknown and/or unassigned field names. This was most prevalent in the Appalachian Basin where thousands of wells exist that are not associated with field names. Such wells were assigned field names by proximity to existing fields and by determining producing formations in common with existing fields. This process involved viewing of mapped well locations and the use of automated programs that calculated distances from unknown wells to nearby wells associated with field names. After this there were still, especially in the Appalachian basin, wells that could not be assigned field names. These were assigned temporary names with Reserves and Production Division and county name as part of the name.

- Well misclassification is a perennial problem. For the most part it is caused by insufficient recursive quality control. For example, a new well may initially be classified as a wildcat well, which by definition has discovered a new field. Subsequent drilling of extension wells in this or an adjacent field may, over time connect the two adjacent fields. At this point both fields will shift to the field name of the earliest discovered of the two. This and other similar reclassifications occur frequently, but that fact often never filters backward, i.e., in this case to re-classification of the wildcat well type to extension or even development status.

- With the notable exception of fields located on the Outer Continental Shelf, the Federal government has access to subsurface data other than the well data available in state or vendor well files and state well log files. Because seismic data and interpretations, surface and subsurface geologic maps, and many well logs are proprietary data, in the context of this inventory, this limits what can be done concerning the construction of field boundaries to a purely geometric approach based on the buffering of well locations around their surface spud points (or bottom-hole locations for AK only).

- Many wells located in the Appalachian Basin were drilled and completed in the 1800's, long before there were laws to regulate them or any government or commercial organization tracking them. Digital records do not exist for many of the oldest wells and these are not represented in the field boundaries that resulted from this study unless they were producing relatively recently or were replaced with newer wells. The state geological surveys of OH, PA and KY are addressing this issue to varying extents by digitizing older field boundary maps and integrating them with digital well records in a GIS.

For these reasons, the resultant field boundaries are approximations, the accuracy of which, in the absence of adequate subsurface information, depends to a greater or lesser extent, on the professional judgment of the EIA RPD's petroleum geologists and engineers. *Collectively the field boundaries provided here are likely to be of sufficient accuracy for policy formulation concerning access to Federal onshore lands. In specific instances they may not be accurate enough for the application of policy and regulation.*

A8.5 PROCESS OVERVIEW

Figure A8-1 is a flow chart of the major steps followed in estimation of field-level proved reserves (on the left-hand side) and the construction of field boundaries (on the right-hand side), plus their merger into the final principal reserves product. The following discussion provides details for each of the indicated steps.

Figure A8-1. Phase II Process Flows

A8.6 QUALITY CHECKING AND COMBINATION OF DATA SOURCES FOR EACH STATE

Owing to different histories of tracking of oil and gas industry activity and to non-standardization, each state's data posed unique challenges relative to assembling the most complete and accurate well data set possible for use in constructing field boundaries. State agencies were a primary source of well data for all 16 of the producing states involved in the Phase II basins. These data were augmented with vendor well data in 11 of the 16 states (see Table A8-4).

Table A8-4. Well Data Sources by State for Phase II

A8.7 MERGING OF WELL DATA FILES

For Colorado, Wyoming, Utah, Nebraska, and Alaska, a well data set with locations was available from both a state agency and the vendor IHS. For those states an initial step was added that combined the IHS Annual Production data file (includes well location and type) with the IHS Well History file location and well type. The API well number, present in both files, was the common key for this merging process.

The IHS Well History records that did not match with IHS Production records were most often dry holes, injection wells or storage wells. If these did not match well records in other state or vendor files for that state, they were discarded. To create valid field boundaries only oil and gas wells were retained, whether or not they had recorded 2001 production data, excepting in Alaska where the injection wells were retained. The spud point location data in the IHS Well History file are Tobin International, Ltd's, most accurate coordinates and were used when available. If location information was not available in the IHS Well History file, the information in the IHS Production file was used.

For the states with multiple state and/or vendor sources, the available well data sets were merged using the API number of the well (or the state permit number if the API number was not available) as the common data field. The following rules and procedures were developed and used to merge the files:

A8.7.1 Preparation of Spud Point Location Information (Well Latitude and Longitude at The Surface)

For each state with multiple well data, the wells from each source were plotted on a map using the ArcGIS software. Location quality of the data sets was checked by looking for wells located far from a field’s core location, wells with locations out of state, and wells located in the wrong county. This information was used to determine which source of location coordinates was the best one to use as the primary source. If location information was not available from any source the well record was deleted from the data used for field boundary construction but was retained for merger with the Form EIA-23 database and subsequent use in the determination of production and reserve volumes.

Because more horizontal or highly deviated wells are increasingly being drilled in the U.S. onshore, it is better to use the latitude and longitude of a bottom-hole location (BHL) to locate wells rather than the surface spud-point location. Only the state of Alaska data had sufficient BHLs, so for all other states the spud point (surface) location was used.

West Virginia was one of the most problematic states for the data combination process, as EIA had four well data sources from two vendors and two state agencies.

Unfortunately, the data considered most reliable (from the WV Geologic and Economic Survey) were not complete inasmuch as the Survey would only provide EIA with well data for the 20 counties where Federal Land was believed to exist. It was therefore necessary to "mosaic" a well data set using the data deemed best from all four sources.

Some states such as Virginia provided spud point locations in a projected coordinate system such as state plane. For these data the latitude and longitude values were calculated in ArcGIS because the buffer calculation program required location coordinates in that format.

A8.7.2 Field and Reservoir Name Respelling and Renaming

Variation in field and reservoir names and spellings is common among the commercial data files and state sources. Names were altered as necessary to make them as consistent as possible across sources. To achieve better field boundaries it was assumed that the buffers created for wells should be calculated on a reservoir level where possible (otherwise on a field level) and that the field boundary would then be constructed by unioning of the reservoirs in the field. Reservoir names were only consistently available for the states of WY, CO, UT, NE, AK, MS, AL and FL.

Names carried on the IHS Production file were used when available because they were most consistent with the names in the EIA Field Code Master List. Otherwise names from the state files, non-IHS vendor files, or the IHS Well History file were used.

If a well did not have a legitimate *field* name associated with it, (e.g., the associated name was 'UNDESIGNATED', 'UNKNOWN', 'WILDCAT'), an RPD-assigned name incorporating identification of the well's county location was used to replace it (e.g. a new field name like "RPD_Washington_Cnty-1" was created). When records appeared not to have a legitimate *reservoir* name, (e.g., 'UNKNOWN', 'UNKNWN', 'WILDCAT'), "UNNAMED" was used as the reservoir name.

If a reservoir name was abbreviated, the full reservoir name was assigned. If a reservoir name was augmented by a layer/zone/horizon modifier (e.g. "11250 A Washita-Freder," "11300 Washita-Freder") the modifier was removed (e.g. all were changed to "Washita-Freder"). Most records did not contain horizon information so the zone name was used instead as the best available data for reservoir naming.

Some field names were changed based on information obtained from state data sets, state websites, and conversations with state agency personnel. A few states such as CO, UT, WY and MS have developed their own spatial data files of field boundaries. These are often digitized versions of geologic outlines originally drawn by hand on paper. When these outlines were overlaid on the field boundaries created in the present study some discrepancies were noted and investigated. The comparison resulted in additional field name edits in some instances.

A8.7.3 Missing Field Names

Well files for every state had records where the field name was missing or that contained values such as ‘UNKNOWN,’ ‘UNKNWN’ or ‘WILDCAT.’ For all areas except the Black Warrior and Appalachian Basins the field name data field for these wells was populated manually. Wells with missing field names were plotted on a map showing the outlines of all named fields. Unnamed field wells located within or in close proximity to a named field boundary were given the name of that field. Unnamed wells judged to be too far from named field outlines to be considered part of that field were given RPD field names as described in section (b) above.

A very large number of unnamed field wells existed in the Appalachian and Black Warrior basins, so a SAS program was created to automatically assign field names to wells depending on their distance from wells located in the nearest named fields. An interwell distance of 2700 feet for oil wells and 5300 feet for gas wells was used for a first pass assignment of such field names. If a well without a field name was within these distances to a well with a field name, it was assigned that field name. Second and third passes were made at 2 and 3 times these distances to assign field names and ‘grow’ a field from assigned wells to unassigned wells. Wells that did not meet these proximity criteria after the third pass were assigned an RPD field name as described in section (b) above.

A special edit was made for one KY field name. The KY Division of Oil and Gas assigns the field name CATRON CREEK to all wells in unnamed fields. CATRON CREEK is defined as only being a valid field name in Harlan Co., KY. So all CATRON CREEK wells not located in Harlan County, KY had to be reassigned new/substitute names via the SAS program.

The state of Ohio presented a particularly unique challenge because the state well files do not yet include field name as an attribute. The OH Geological Survey, however, has constructed a field boundary polygon layer incorporating older development areas that lack digital well control (as described in the Limitations section, item (4) above). A Visual Basic program was written to place each well in a field boundary polygon and write the polygon field name as a well file attribute. Due to overlapping of the polygons many wells fell into two or more polygons and were assigned from 2 to 5 field names. The 2 to 5 field names were then ordered by the distance between the well and each polygon center, the first having the shortest distance, the second the next shortest, etc. Since completion formation data was available for the OH well records, a series of programs was written that used the completion formation name to pick the most probable field name out of these 2 to 5 possible fields.

A8.7.4 Identification of Well Types for Later Buffering

Deciding which wells to include in the buffering process is critically important in the construction of field boundaries. All wells where type = oil or type = gas in at least one of the source datasets were retained and classified as oil or gas. Wells which were not of type = oil or type = gas in at least one source were classified as a dry hole, a CO_2 producer, or an injection well. Some states such as CO and WY have interactive online webmapping sites. These were used extensively to arbitrate well type discrepancies between data sets. Following final assignment of the well type only the positively identified oil and gas wells were retained for input to the well buffering process, with the exception of wells located in Northern AK. Since the wells drilled there as injectors had a significant impact on the field outlines, they were retained and buffered in Northern AK.

Some of the state well files mix dry holes which never produced (usually typed as “drilled and abandoned” or “D&A”) with former oil or gas producing wells that are now plugged and abandoned (typed as “P&A”). This makes the task of separating present and former producers from wells that never produced difficult and, emphasizes the importance of having good historical production data records.

A8.7.5 Merging of Non-IHS Production Data

Well-level production data from state or vendor sources other than IHS were merged to the well files by API number or by drilling permit number. Some states have incomplete production data. For example, NY only has gas production data at the individual well level; oil production data are at the lease level.

A8.8 CONSTRUCTION OF WELL BUFFERS

The procedure used to generate well buffers consisted of several development and application steps. Creation of oil and gas field boundaries was accomplished using ArcGIS 8.3 software and the methodologies developed by EIA for Phase I of the inventory which are documented in detail in the original Phase I report.

The basic method used to construct field boundaries was to buffer each well in a reservoir or a field with a circle. The radius of the circle was determined by analysis of the spacing pattern for the wells in each reservoir in a field if reservoir names were consistently available, or for the wells in each field if they were not. The resulting circular buffer polygons were then unioned into a single field boundary polygon set (note that if wells are far enough apart there can be more than one non-contiguous polygon per resultant single field boundary). Given the large volume of data involved this method was used because it most effectively utilizes the available information on the different reservoir spacing patterns present within a field and is relatively easy to perform on a large data set.

A8.8.1 Determination of Nominal Well Spacing and the Assignment of Buffer Radii

An analysis of the distances between wells in a reservoir or a field, calculated from their spud point locations (or their bottom-hole locations in Northern Alaska), was used to assign a standard well spacing unit to each reservoir or field. The same technique was used in Phase I of the inventory. Nearest neighbor inter-well separation distances were calculated separately for oil wells and gas wells. The upper and lower bounds of the observed spacing ranges are shown in the two left-hand columns of Table A8-5. The corresponding nominal standard well spacings (a geometric distribution) and buffer radii are shown in the two right-hand columns. The 75th percentile (P75) of the observed inter-well distance distribution was taken to be the observed inter-well distance. This statistic was selected because, as judged by the RPD project team, it yielded the best match to nominal well spacings in an extensive set of map trials done for Phase I. If the P75 distance fell within the corresponding interval shown in the two left-hand columns of the table then the corresponding nominal spacing was selected and its buffer size was initially assigned to every well in the reservoir (or field).

Table A8-5. Inter-Well Distance Ranges, Nominal Standard Well Spacings, and Buffer Radii

A8.8.2 Well Buffer Construction Rules Rules for the assignment of buffers were created to handle reservoirs (or fields if no reservoir names were available) that did not, for whatever reason, readily conform to a nominal spacing. The rules are based on well types and well counts

- For oil reservoirs the maximum spacing allowed was 160 acres, i.e. a buffer radius of 2,640 feet.
- If the reservoir had between 1 and 10 oil wells or the reservoir name was 'UNNAMED' a spacing of 160 acres was assigned.
- For gas reservoirs the maximum spacing allowed was 640 acres, i.e. a buffer radius of 5,280 feet.
- If the reservoir had only 1 gas well or the reservoir was named 'UNNAMED' a spacing of 640 acres was assigned.
- If a gas reservoir located in the Black Warrior Basin or a field located in the Appalachian Basin had 3 or fewer wells a spacing of 160 acres was assigned. If it had more than 3 wells and less than 10 wells the nominal spacing unit was used per Table A8-5 up to a maximum spacing of 160 acres.
- For coalbed methane wells a maximum spacing of 160 acres was assigned, i.e. a buffer radius of 2,640 feet.
- If the oil well count divided by the sum of the oil well count and the gas well count was less than or equal to 0.05 <u>and</u> if the oil well spacing was greater than the gas well spacing, the oil well spacing was set to the gas well spacing; otherwise, the original oil well spacing was retained.
- If the ratio of gas well count to the sum of the oil well count and the gas well count was less than or equal to 0.05 the gas well spacing was set to the oil well spacing for the field or reservoir; otherwise, the original gas well spacing was retained.

A8.9 CONSTRUCTION OF FIELD BOUNDARIES

A SAS file containing the oil and gas well data with field name attribute "Field" (and reservoir name attribute "Reservoir" if that data was available) was imported into ArcGIS as a dBase (.dbf) file. The wells were then plotted using the latitude/longitude information in the file and converted to a geodatabase point feature class file. The coordinate system used was UTM NAD27 with the following UTM zones for each study area: Denver Basin–Zone 14, Wyoming Thrust Belt–Zone 12, Florida Peninsula, Black Warrior Basin, and Appalachian Basin–Zone 16, and Northern Alaska–Zone 7.

Before field boundary construction the following procedure was performed to ensure that all wells in the fields of interest lay entirely inside the study area boundaries. Two dbf files were made for each state, one of all wells inside the study area and another of all wells outside the study area. SAS queries were performed on those files to identify, for each state, all field names that had wells both inside and outside the study areas. These fields were then researched to determine if they were fields that actually extended across the study area boundaries (e.g. Colville River Field in AK NPR-A, Speaker Field in CO Denver Basin) or if they were geographically separate fields (not in reservoir communication) with the same name in the same state. The latter situation is, for example, especially common in KY and TN. In instances of the latter case, county names were appended to the field names (e.g. CACTUS_Morgan vs. CACTUS_Garfield) so that they would be put into different fields when the field boundaries were constructed.

Well files for each state were built that included only those wells located inside the study area/basin boundaries and all well records for fields that extended across the study area boundaries (e.g. Colville River Field, AK as mentioned above). These files were then used to construct the field boundary polygons.

The Visual Basic for Applications (VBA) code implemented within ArcGIS for Phase I of the inventory was used to automatically create polygonal field boundaries from the buffered wells. The principal steps performed were:

- Select the "field name" attribute and “buffer distance” attribute from the well file. Select all wells with the first "field name" encountered.
- Create a buffer around each selected well using "buffer distance" (see Figure A8-2)
- Union the buffers.
- Dissolve the barriers between overlapping buffers.
- Iteratively perform the above steps for each unique "field name”.
- Output a polygon feature class with one polygon (often consisting of multiple polygon rings) for each field.
- Convert to a shapefile.

Figure A8-2. Buffering Process

Figures A8-3 and A8-4 show the buffered field boundary of a field with two reservoirs. Figure A8-3 displays buffers by reservoir: Reservoir A is composed of oil wells with 80 acre buffers while reservoir B contains oil wells with 160 acre buffers and gas wells with 640 acre buffers. The final product of the field boundary creation process with buffers for both reservoirs unioned into one polygon record is shown on Figure A8-4.

Figure A8-3. Field Buffers by Reservoir

Figure A8-4. Field Buffers by Field

A8.10 SMOOTHING OF THE FIELD BOUNDARIES

An artifact of the well buffer approach to field boundary construction is that multi-well field boundaries inevitably have an irregularly scalloped, botryoidal (grape cluster-like) appearance. Field boundaries tend to be much smoother than that in their natural reality. Other artificial results include small interior non-field “islands” and small separations between multiple polygon “rings” of a single field boundary (see Figure A8-5). It is probable that in most instances (1) the interior islands are legitimately part of the field area and should therefore be included in it, and (2) that the "outlier" polygons of a field should be joined with (i.e., bridged into) the main field boundary when the separation distance is sufficiently small. That is the way a geologist or petroleum engineer would subjectively draw the field boundary by hand based on only the well spud point location and well spacing information available (i.e., absent subsurface information). For Phase II the field boundary construction effort was therefore enhanced by development and inclusion of a methodological extension that both automatically and more closely approximates what a geologist or petroleum engineer would draw as the field boundary. To have a consistent set of field boundaries for all of the inventory phases this extended methodology was also applied to upgrade the Phase I study area/basin field boundaries.

Figure A8-5. Buffered Field Outline Issues

A Visual Basic application that could be implemented within ArcGIS to smooth the irregular boundaries and fill in the smaller spaces in an automatic, quick, systematic, consistent, and repeatable manner was developed. The guiding principles adhered to in development of the smoothing application were to (1) add field area to the concave indented portions to smooth the scalloped look, (2) not add or subtract area from the convex portions in order to maintain the well buffer spacing, (3) fill in the interior non-field “islands” that are smaller than the buffer size as these are very likely part of the actual field area, (4) join separated polygon “rings” of the same field by a “bridge” if they are sufficiently close together, and (5) minimize the concomitant increase in the field's area. A number of alternative smoothing techniques were considered, tested, and rejected before the implemented technique was selected. These included:

- Raster Filters: Buffered field boundaries were converted from vector (point-line-polygon) format to raster (pixel) format. A variety of neighborhood statistical operators (filters) were applied to the raster and then converted back to vector format. This approach was not satisfactory because it always added field area to the convex portions of boundaries.
- *Generalize* and *Smooth* methods: These two vector-based methods are built into the ArcGIS software. The *Generalize* method was not chosen because it consistently subtracts area from the convex portions of field boundaries. The

Smooth method results in inconsistent addition and subtraction of field area in the convex and concave portions of a field boundary, also not acceptable.

- Maximum angle technique: This technique first filled in and merged all interior non-field islands smaller in area than the maximum field buffer size. It then stepped along each vertex in a polygon and moved the vertex out until the angle formed by that vertex and the two vertices on either side of it was less than a maximum specified angle. Because moving one vertex out affects the angles of adjacent vertices, it required many iterations to get all angles to be less than the maximum allowed angle. Also, narrow fiord-like indentations in the field boundaries were particularly problematic with this technique and needed to be manually addressed prior to automated movement of the vertices. The increased complexity, human resource needs, longer processing time, and inconsistent handling of problems made this technique undesirable.

A technique based on tangent trapezoids was ultimately selected for field boundary smoothing because it focuses on how close wells in a field should be in order for their associated buffers to be unioned and is also simpler than the other tested techniques. It's begins by comparing the distance between each pair of wells within a field boundary to the average of the two wells' calculated buffer sizes. Three cases for the tangent trapezoid technique based on that relative distance are summarized in Figure A8-6. If the inter-well distance is less than or equal to two times the average buffer size, the buffers are either tangent (just touching) or overlapping (Figure A8-6a). When that is the case a trapezoid is constructed through both wells that extends to the full diameter of the buffers and is then unioned to the boundary polygon for that field. If the inter-well distance is between 2 to 2.5 times the average buffer size a trapezoid of one-half the buffer diameter is constructed and unioned to the boundary polygon for that field (Figure A8-6b). This thinner union of the well buffers reflects a higher uncertainty that the field is hydraulically connected in the subsurface within the space between the wells. If the inter-well distance is greater than 2.5 times the average buffer size no trapezoid is drawn and the field outline remains segmented (Figure A8-6c).

Figure A8-6. Tangent Trapezoid Smoothing Rules

In addition to filling in the concave boundary areas, the tangent trapezoid technique aptly handles the matter of interior non-field "islands," fiord-like indentations in the field boundary, and spaces between multiple polygon "rings" belonging to the same field. Figure A8-7 shows an example of a field boundary before and after smoothing via the tangent trapezoid technique. The ratio of smoothed boundary area to unsmoothed boundary area was calculated in each instance to ensure that field area additions were sufficiently minimized. The mean increase in field area from unsmoothed to smoothed boundaries was 4.2 percent for all basins combined. Less than 1 percent of all fields exceeded an 8 percent change, and only 0.02 percent of all fields had a 10 to 14 percent change.

Figure A8-7. Field Boundary Before and after Smoothing with Tangent Trapezoid Technique

Field boundary polygons that crossed study area boundaries were exported as a separate file, and were then clipped to the study area boundary polygon files. For each of these fields the ratio of field area after clipping (area inside basin) to total field area (area inside + area outside basin) was calculated as the attribute INBAS_FRC (in-basin fraction). The value of this attribute is 1 for fields located entirely inside a study area/basin and ranges from greater than zero to less than 1 for those fields that cross a study area/basin boundary. It was necessary to clip these fields before calculating the Federal land fraction because the BLM-provided Federal land coverages do not always extend far enough outside the study area to permit its calculation for the entire unclipped field boundaries. The attribute INBAS_FRC is later multiplied by the field reserves to derive field reserves located inside the study area/basin boundary.

A8.11 CALCULATION OF THE FEDERAL LANDS FRACTION WITHIN A FIELD'S BOUNDARY

The Federal land ownership coverages provided by the BLM, (one coverage per study area) were intersected with the field boundary outlines to ascertain the land ownership aspect of each field's area. A definition query was used to exclude land with private and state mineral ownership and then an automated procedure (developed for Phase I) was used to calculate the fraction of Federal land within each oil and gas field polygon. The procedure intersected the Federal land coverages with the field polygons and then populated a column in the field boundary polygon table “PctFedLand.”

A8.12 REVIEW AND QUALITY CONTROL OF THE RESULTING MAPS

Maps were printed at an appropriate scale for each study area to facilitate quality checking of the constructed field boundaries both before and after the smoothing algorithm was applied. These maps displayed the wells in the field and the field boundary polygons. They also showed selected field attributes such as state, county, basin, and percent Federal land. Figure A8-8 provides an example of a quality control map.

Figure A8-8. Black Warrior Basin Quality Check Map Showing Smoothed Field Outlines and Percent Federal Land

A8.13 FIELD-LEVEL PROVED RESERVES ESTIMATION

The conditioned state/vendor well history and production data were summed to the field/operator level and then merged with the field proved reserves estimates reported on Form EIA-23 by the largest operators. Fields were classified into four types for the purpose of reserves estimation:

- Fields with no 2001 production data or reserves estimate data
- Fields that were completely reported by both IHS and the EIA survey, with 2001 production and all operators in the fields being surveyed by EIA. The proved

reserves estimates submitted by the operators for these fields were used as reported.

- Fields that were partially reported and partially imputed. These fields are represented in both the IHS and EIA survey data by 2001 production volumes, but only part of the total field reserves estimate was reported to EIA because some operators in the field were not required to report proved reserves on Form EIA-23. The remainder of the field's proved reserves were therefore imputed by RPD by assigning the weighted average reserves-to-production ratio of the reporting operators to the non-reporting operators and multiplying it by the non-reporting operators' reported production volumes as taken from state/vendor data.
- Fields that were completely estimated based on vendor/state 2001 production data because the operators of these fields were not required to submit a Form EIA-23. Although these fields constitute a sizeable fraction of the total number of fields in the study areas, their aggregate proved reserves represent only a small portion of total proved reserves. The proved reserves and corresponding production data reported on the 2001 Form EIA-23 were used to develop predictive least squares regression equations quantitatively descriptive of their relationship. These equations were then used to estimate proved reserves for this class of fields based on the vendor/state production data available for them. The estimation equations were developed using SAS statistical software, one each for oil, associated-dissolved gas, non-associated gas, and condensate, for each basin, state (including fields both in-basin and outside-basin) and the United States as a whole. The form of the equation is:

$$\log_e(\textit{Proved Reserves}) = a + b \log_e(\textit{Production})$$

Table A8-6 lists the resulting regression parameters. For any field where reserves were imputed, the basin-level parameters were used if available, followed in their absence by state-level parameters if available, followed in the absence of both by US-level parameters. Where no parameter is listed in the table there was not sufficient data available for that basin or state to validly estimate the parameter.

Table A8-6. Regression Equation Parameters for the Estimation of Non-Reported Reserves

The resultant crude oil proved reserves estimates were then summed with the proved condensate reserves estimates to yield the proved liquid reserves estimates. Similarly, the proved associated-dissolved gas reserves estimates and the proved non-associated gas reserves estimates were summed to yield the total proved gas reserves estimates. Lastly, a gas-to-oil ratio of 6000 cubic feet per barrel was used to convert the total proved gas reserves to their oil equivalent, which was then summed with the proved liquid reserves estimates to yield the proved barrel-of-oil-equivalent reserves estimates.

For each of the four reserve types Table A8-7 summarizes by study area the number of fields, the basin field count, the barrel-of-oil-equivalent production, and the barrel-of-oil-equivalent proved reserves. The percentage of each reserve type in the study area/basin is also shown.

Table A8-7. Field count, BOE Production & BOE Reserves for Four Reserve Types in Each Study Area

A8.14 CALCULATION OF FEDERAL RESERVES

The Federal reserves for each field were estimated by multiplying the fraction of Federal land for each field (derived by GIS analysis as described above) by the proved reserves estimates for each product. This procedure assumes that the distribution of proved reserves per unit area within a field boundary is uniform. While that is never precisely the case, this procedure is sufficiently precise for a regional study such as this one.

A8.15 RESERVES CLASSIFICATION

In order to sufficiently protect the proprietary proved reserves data submitted to EIA, each field was then assigned to a gross reserves size class and a Federal reserves size class, by product, per the following classification scheme:

Class Number	Proved Liquid Reserves
0	Zero reserves (i.e., no recorded 2001 production)
1	Greater than zero but less than 10 Mbbls liquid
2	Greater than 10 but less than 100 Mbbls liquid
3	Greater than 100 but less than 1000 Mbbls liquid
4	Greater than 1000 but less than 10,000 Mbbls liquid
5	Greater than 10,000 Mbbls liquid

Class Number	Proved Gas Reserves
0	Zero reserves (i.e., no recorded 2001 production)
1	Greater than zero but less than 10 MMCF gas
4	Greater than 10 but less than 100 MMCF gas
5	Greater than 100 but less than 1000 MMCF gas
4	Greater than 1000 but less than 10,000 MMCF gas
5	Greater than 10,000 but less than 100,000 MMCF gas
6	Greater than 100,000 MMcf gas

Class Number	Proved Barrel-of-Oil Equivalent Reserves
0	Zero reserves (i.e., no recorded 2001 production)
1	Greater than zero but less than 10 MBOE
2	Greater than 10 but less than 100 MBOE
3	Greater than 100 but less than 1000 MBOE
4	Greater than 1000 but less than 10,000 MBOE

5 Greater than 10,000 but less than 10,0000 MBOE
6 Greater than 10,0000 MBOE

Note: M=1,000; MM=1,000,000; bbls=barrel; cf=cubic feet

A8.16 MERGING OF PROVED RESERVES CLASSES WITH FIELD BOUNDARIES AND FRACTION OF FEDERAL LAND

A GIS file was produced that contains the intersection of the Federal land coverages with the field boundaries. Owing to the existence of multiple federal land parcels within each field boundary, the resultant boundary polygons were then dissolved on the attribute "field" to union the data into one polygon record per field. A table with the reserves classes by field (range 0 to 6) and the field name was then joined to the shapefile associated with the field boundary shapefile. The latter was then converted to coverage format and thence to interchange file format (.e00).

For all study areas except the Appalachian Basin there was good correspondence between the production file and the map file with Federal land percentages. Owing to the poor condition of field names in the Appalachian Basin there was less correspondence between these files; there were approximately 1200 Appalachian Basin fields that had map locations but no 2001 production data. All of these fields were assigned to reserve class zero although because of faulty or incomplete field names some of them might properly belong to other fields for which there were 2001 production data. Approximately 130 fields appeared to have 2001 production but there were no available location data. These fields, which together accounted for less than 1 percent of the liquids production and approximately 1.5 percent of the gas production in the Appalachian Basin, were assumed not to be on Federal land because that was more likely to be the case in this basin.

A8.17 SUMMARY OF RESULTS

GIS is clearly the information conveyance method of choice where both analysis of Federal lands policy and regulations and their application are concerned. The primary proved reserves result is therefore a GIS layer containing field boundary polygons attributed with field name and a proved reserves size class for each field product. Unfortunately, none of this very detailed information can be usefully conveyed on a piece of paper this size. You have to use a GIS workstation to view it and a wide-format printer to print it at a size where the detail can be distinguished. Therefore, in lieu of a close look at the reserves results, summary statistics are provided by study area in Table A8-8.

Table A8-8. Summary of 2001 Federal Lands Proved Reserves by Study Area

A8.18 SUMMARY OF UPDATED PHASE 1 RESULTS

The land status files provided by the Department of the Interior for the Phase I study areas have been updated since the original work was done in 2002 and EIA has incrementally improved its field boundary construction process. For the purpose of maintaining a consistent set of estimates, the Phase I study areas were reprocessed to reflect these changes. Specifically:

1) The field outlines were smoothed using the algorithm described in the appendix documentation for Phase II.

2) Portions of field outlines that extended outside of the defined basin boundary were clipped to the basin boundary.

3) The projection for the GIS files of all basins except the Montana Thrust Belt were changed from UTM-12/NAD27 to UTM-13/NAD27.

Taken together these changes only very slightly impacted the Federal reserves totals and percentages, the updated version of which is shown in Table A8-9.

Table A8-9. Summary of Updated 2001 Federal Lands Proved Reserves by Phase I Study Area