Chapter Two

ALLOCATION AND SPATIAL DISTRIBUTION OF RESOURCES

A primary component of our approach is the spatial distribution of resources throughout the study area. To map the spatial distribution of gas and oil resources, the quantities of resources from different estimates must be allocated to spatially defined units. The units used in this study are derived from the "plays" defined by the U.S. Geological Survey. Plays are sets of known or postulated oil or gas accumulations sharing similar geologic, geographic, and temporal properties.[1] To improve upon the spatial resolution provided by published assessments of technically recoverable resources, we divided the published plays into subplays, then further divided each subplay into three areas corresponding to the locations of different resource categories (proved reserves, reserve appreciation, and undiscovered resources). A key step in our methodology is defining these subplays and resource areas and allocating resources from published assessments to them.[2]

This chapter discusses this process. We begin by describing the subplays defined for this work. Because the allocation procedure differs for the different published assessments, we then present the technically recoverable resource assessments used in this study. The assessments differ in the level of spatial resolution (regional, basin, or play level) at which different resources are defined. The allocation step entails distributing the total quantities of resource from each assessment to the subplays. Finally, we describe the three resource areas within each subplay and how they were defined.

SUBPLAY DEFINITION

The U.S. Geological Survey play definitions have come into common usage in discussing gas and oil resources and therefore form the basis for the resource units in this report. The U.S. Geological Survey defined 20 plays in the Greater Green River Basin. To provide a greater level of detail, most of these plays were divided into subplays in this study. A total of 50 plays and subplays (collectively referred to as subplays in this report) were defined. Subplays in conventional plays were defined on

[1]See the glossary for definitions of terms used in this report.

[2]RAND obtained the services of Energy and Environmental Analysis, Inc., to conduct subplay definition and resource allocation. More technical detail is provided in supplementary material available online at www.rand.org/publications/MR/MR1683.1. Resource areas within subplays were defined by RAND.

the basis of formation or geologic age interval. Subplays in tight sandstone plays were defined by depth interval within the formation. This subdivision into subplays is useful in capturing formation- and depth-specific production characteristics, drilling depths, and associated costs. A complete list of the plays and subplays defined in this analysis is given in the appendix.

TECHNICALLY RECOVERABLE RESOURCE ASSESSMENTS

Government and industry organizations estimate amounts of technically recoverable natural gas and oil resources in the United States. We have used two commonly accepted technically recoverable resource assessments in our analysis: the U.S. Geological Survey (U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995) and the National Petroleum Council (NPC) (1999) assessments. Both assessments include associated and nonassociated and conventional and nonconventional natural gas. Crude oil is assessed explicitly by the U.S. Geological Survey. The National Petroleum Council assessment of the oil resource used in this study is consistent with the associated-dissolved gas resources of National Petroleum Council (1999). The methodologies and results of these assessments are discussed in LaTourrette et al. (2002).

The National Petroleum Council presents two assessments. One is made assuming present technology capabilities (the "current technology" scenario), and one assuming future technology capabilities (the "advanced technology" scenario). The main difference between these scenarios is in the estimated ultimate recovery per well for undiscovered resources (see National Petroleum Council, 1999, for more details).

RESOURCE ALLOCATION

The U.S. Geological Survey and National Petroleum Council technically recoverable resource assessments allocate the different categories of resources and deposit types variously at the regional, basin, or play level of detail. All of these resources had to be allocated at the subplay level for this study. Because of this step, the resource allocations derived in this study are referred to as "USGS-based" and "NPC-inspired" to distinguish them from those agencies' assessments. The current technology and advanced technology scenarios from the National Petroleum Council assessment were allocated in the same manner. Assessments are summarized in Table 2.1.

Proved Reserves

Our analysis includes proved reserves, which have been added to the technically recoverable resource assessments. The proved reserve volumes represent the EIA Form-23 reserves allocated to individual producing properties in the IHS database (IHS Energy Group, 2002). We assign a proven reserve volume to each gas completion based on an analysis of recent annual production from the specific completion. The assignment of reserves uses a reserve-to-production ratio applied to recent annual production. The summation of all of the assigned reserves for Wyoming gas

Table 2.1

Technically Recoverable Resource Assessments Used in This Study

Resource	Category	USGS-Based	NPC-Inspired Current Technology	NPC-Inspired Advanced Technology
Natural gas (Tcf)	Proved reserves	6.6	6.6	6.6
	Reserve appreciation	8.8	30	30
	Undiscovered	130	97	122
	Total	145	134	159
Total liquids (MMbbl)[a]	Proved reserves	148	148	148
	Reserve appreciation	756	290	290
	Undiscovered	1,583	1,052	1,338
	Total	2,443	1,491	1,777

NOTE: MMbbl = million barrels.

[a]Includes crude oil plus natural gas liquids.

completions, for example, equals the EIA year-end reserves for that state. Gas reserves are evaluated on both a wet and a dry gas basis.

Reserve Appreciation

Assessments of reserve appreciation were made at the regional level. These regional assessments were allocated to basins and then plays in proportion to the distribution of proved reserves. Because of differences in the methodologies used in making these assessments, the U.S. Geological Survey reserve appreciation was allocated to conventional plays only, whereas the National Petroleum Council reserve appreciation was allocated to conventional and tight sandstone plays.

Undiscovered Conventional Resources

The U.S. Geological Survey assessment of undiscovered conventional resources was made at the play level, so these resources needed only to be reallocated to subplays. This allocation was made based on the volumes of new field discoveries in the individual subplays made since 1974.

The National Petroleum Council assessment of conventional gas was made at the regional level and so allocating to the subplay level required additional steps. The resource was first allocated to the basin level using the Potential Gas Committee's basin-level allocation. It was then allocated to subplays based on the existing productivity of the subplay's developed areas, the U.S. Geological Survey play assessments, and recent exploration activity. A portion of the conventional resource potential in the National Petroleum Council assessment is expected to be in low permeability formations and was therefore allocated to the tight sandstone subplays.

Undiscovered Tight Sandstone Resources

The majority of gas resources in the Greater Green River Basin are contained in tight sandstone formations. Depending on the technically recoverable resource assessment, gas in tight sandstone plays accounts for 70–95 percent or more of the undiscovered resources in the basin. Both the U.S. Geological Survey and the National Petroleum Council assessments of undiscovered tight sandstone resources were made at the play level. These resources were assigned to subplays based on historical well recoveries, drilling success rates, and well spacings.

Coalbed Methane Resources

Because coalbed methane is just beginning to be developed in the Greater Green River Basin, there is no adequate basis on which to subdivide the plays. This resource was therefore evaluated at the play level. The U.S. Geological Survey assessment was made at the play level and was used as is. The National Petroleum Council assessment and allocation were derived entirely from the U.S. Geological Survey values.

RESOURCE AREA DEFINITION

Three categories of resource were spatially distinguished in this analysis: proved reserves, reserve appreciation, and undiscovered resources. These resources were allocated to a producing area, an extension area, and a new field area within each subplay as shown in Table 2.2. Reserve appreciation potential, representing new production through the extension of existing fields, is assumed to occur both as infill within the producing area and as growth of an extension area surrounding the producing area. Producing, extension, and new field areas were defined in each subplay using GIS analysis, as described below.

Producing areas were defined based on the locations of successful wells. A well was assigned to a particular subplay if its position fell within the boundary of that subplay and its depth fell within the depth range for that subplay. Maps of successful wells in each subplay were created and contoured in terms of the number of wells per area. The producing area of a subplay was then defined as that area with a well density greater than 0.5 standard deviations above the mean density for the entire subplay. The producing area was not constrained to be a single contiguous area and in most cases consists of several discrete areas.[3] Well data used for this analysis were taken from Beeman et al. (1996). This dataset consists of 1/4 mile grid cells, with each cell assigned a value of no well, dry hole, or successful well based on the status of any wells located within it. A value of successful indicates that there is at least one suc-

Table 2.2

Spatial Assignment of Resource Categories

Resource Category	Resource Area
Proved reserves	Producing area

[3]The accuracy of the locations of producing areas derived with this method was qualitatively confirmed by a close agreement with published gas field locations.

Reserve appreciation	50% to producing area 50% to extension area
Undiscovered resources	New field area

cessful well in that cell. Because the surface projections of many subplays overlap, both location and depth of wells were used to assign wells to individual subplays.

Extension areas were defined as uniform buffers around the producing areas. The size of the extension area was estimated from the number of wells needed to extract half of the reserve appreciation resource (see Table 2.2) and the anticipated future well spacings. The number of wells was estimated from the amount of reserve appreciation resource and the estimated recovery per well. Well spacing was assumed to be 640 acres for conventional and 160 acres for tight sandstone and coalbed methane.[4]

The new field area was defined as the remainder of the subplay, and undiscovered resources were modeled as being homogeneously distributed throughout this new field area. This is a simplifying assumption made necessary because the location of undiscovered resources is, by definition, unknown. Thus, there is little justification for allocating undiscovered resources to particular areas within the new field area of a subplay. In reality, undiscovered resources will come online in discrete fields. This is well illustrated by the Jonah Field. The resource data used in this study predate the Jonah Field development and hence the reserves currently associated with that field are represented in our model as undiscovered resources distributed throughout the new field area of the Basin Margin Anticline play. The inability to predict locations of future fields is a limitation of any resource assessment. In our case, this shortcoming is tempered by dividing the basin into subplays and further subdividing resources among producing, extension, and new field areas within these subplays. As a result, the aerial extents of the new field areas are considerably smaller than the total play areas. In addition, subplays overlap each other extensively and the mapped distributions capture the spatial variability in resource concentration by summing the amounts in areas where subplays overlap.

The process described above was used to create maps of the producing, extension, and new field areas for each subplay. An example of such a map for Mesaverde subplay 2 is shown in Map 2.1 in the maps section. The map shows the study area and Mesaverde subplay 2, which is divided into producing, extension, and new field areas. Each of these areas is assigned a portion of the total technically recoverable resource base for the Greater Green River Basin through the allocation process described above. The sizes of the producing, extension, and new field area for each subplay and the gas and oil resources allocated to each subplay are shown in the appendix.

[4]Note that determining the size of the extension area is the only point in our analysis that utilizes well spacings. This influences the spatial distribution only. A tighter well spacing would reduce the size of the extension area. Cost estimates in the next chapter are based on estimated recoveries per well and total resources, which determines the number of wells independently of well spacing assumptions.

The total distribution of gas and oil resources and reserves in the Greater Green River Basin was generated by combining all of the individual subplay distributions and summing the amounts in the overlapping areas. The resulting distribution of technically recoverable gas for the USGS-based scenario is illustrated in Map 2.2. Distributions for other scenarios are also shown in the maps section. Map 2.2 shows the distribution and amount, in billion cubic feet (Bcf) per square mile, of natural gas throughout the study area. Tight sandstone subplays and the Deep Basin play were defined by townships; hence, some parts of the map show a checkerboard type pattern. This map shows that the gas resource is concentrated in certain parts of the basin, including the LaBarge Platform and Moxa Arch on the west and the Great Divide and Washakie Basins in the central region (see Figure 1.5 for locations).

The appendix lists 50 individual subplays defined for the economic analysis. Subplays in the conventional plays are "stacked" and have identical surface projections. As a result, they are not spatially resolved in a surface map of the area. This leaves 33 spatially distinct subplays in this analysis. Dividing each subplay into producing, extension, and new field areas results in 99 entirely independent spatial analysis units. However, most of the subplays overlap several others.[5] The net result is that thousands of individual spatial analysis units are used to generate the map shown in Map 2.2.

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[5]The subplays reside at different depths and hence do not actually intersect. However, their surface projections overlap extensively.