THE WILDERNESS SOCIETY

ECOLOGY AND ECONOMICS RESEARCH DEPARTMENT

ANALYSIS OF HABITAT FRAGMENTATION FROM OIL AND GAS DEVELOPMENT AND ITS IMPACT ON WILDLIFE:

A FRAMEWORK FOR PUBLIC LAND MANAGEMENT PLANNING

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Our mission:

To protect wilderness and to inspire Americans to care for our wild places.

PURPOSE

This brief is submitted as part of the NEPA process for this land management proposal. It is intended to:

- Identify habitat and wildlife impacts that must be analyzed in the plan,
- Demonstrate the potential impacts on wildlife of habitat fragmentation from oil and gas development at various well-pad densities, and
- Offer methodologies to assist the Bureau of Land Management (BLM) to fulfill its responsibility to analyze the direct, indirect, and cumulative impacts on wildlife of proposed oil and gas development in the management plan.

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INTRODUCTION

This document is structured around the following topics:

- **<u>Legislative and Administrative Requirements for Scientific Analysis.</u>**
  We review the legislative and administrative obligations the BLM has to assess the environmental consequences of proposed oil and gas development activities.

- **<u>The Science of Habitat Fragmentation and Wildlife Impacts from Oil and Gas Development.</u>**
  We describe the current state of knowledge of the direct, indirect, and cumulative impacts of roads and similar development on wildlife and their habitats. We also describe easily computed spatial metrics that can be used to meaningfully assess the degree and impact of habitat fragmentation.

- **<u>A Methodology for Analyzing Habitat Fragmentation and Wildlife Impacts.</u>**
  We describe an analytical framework that uses geographic information systems (GIS) to aid in examining the direct, indirect, and cumulative impacts of proposed oil and gas development alternatives.

- **<u>Results of an Analysis Applying our Methodology to a Hypothetical Landscape.</u>**
  We discuss the results of a habitat fragmentation analysis simulating the development of an oil and gas field to progressively higher well-pad densities over time.

- **<u>Conclusions and Recommendations for Oil and Gas Management Planning.</u>**
  We draw conclusions from the results of our hypothetical analysis and make specific recommendations regarding the analyses the BLM should conduct and the consideration that should be given to the effects that different levels of oil and gas development have on wildlife.

The methodology presented here provides a necessary, but by no means sufficient, framework for the evaluation of proposed land management decisions regarding oil and gas development. Fragmentation impacts are only one facet of the total ecological impact of such decisions. In order to fully evaluate the merits of different land management alternatives a complete set of ecological and socioeconomic analyses must be conducted and interpreted.

While we present both an analytical framework and results from a hypothetical analysis using that framework, we emphasize the importance of the BLM using the framework to conduct site-specific analyses wherever planning is taking place. The charts and numeric results of our sample analysis (including the charts in Appendix A) can give a preliminary estimate of the minimum potential fragmentation impacts of development on wildlife and their habitats. In this sense, these sample results may be useful in the early stages of planning to help focus the BLM's own analyses, but they are not intended to be a substitute for those site-specific analyses.

LEGISLATIVE AND ADMINISTRATIVE REQUIREMENTS FOR SCIENTIFIC ANALYSIS

The BLM has a responsibility to manage the landscape for wildlife, energy development, and many other purposes. The Federal Land Policy and Management Act (FLPMA) requires the BLM to "manage the public lands under principles of multiple use and sustained yield," in a manner that will "minimize adverse impacts on the natural, environmental, scientific, cultural, and other resources and values (including fish and wildlife habitat) of the public lands involved."[1] FLPMA also requires the BLM to inventory its lands and their resources and values, and then take this inventory into account when preparing land use plans.[2] Through management plans, the BLM can and should protect wildlife (as well as scenic values, recreation opportunities, and wilderness character) on the public lands by prescribing various management actions, including the exclusion or limitation of certain uses of the public lands.[3] This is necessary and consistent with FLPMA's definition of multiple use, which identifies the importance of wildlife (in addition to other values) and requires the BLM to consider the relative values of these resources but "not necessarily to [choose] the combination of uses that will give the greatest economic return."[4]

The National Environmental Policy Act (NEPA) requires the BLM to take a "hard look" at the potential environmental consequences of a proposed action, such as a resource management plan or oil and gas development project, so that the BLM must assess impacts and effects that include: "ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic, historic, cultural, economic, social, or health, whether direct, indirect, or cumulative."[5] NEPA's hard look at environmental consequences must be based on "accurate scientific information" of "high quality."[6] Essentially, NEPA "ensures that the agency, in reaching its decision, will have available and will carefully consider detailed information concerning significant environmental impacts."[7] The Data Quality Act and the BLM's interpreting guidance expand on this obligation, requiring that "influential information" (information that is expected to lead to a "clear and substantial" change or effect on important public policies and private sector decisions as they relate to federal public lands and resources issues, such as that information contained in or used to develop a resource management or major oil and gas development project) use the "best available science and supporting studies conducted in accordance with sound and objective scientific practices."[8]

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[1] 43 U.S.C. §1732.
[2] 43 U.S.C. §§ 1711(a), 1712(a).
[3] *See* 43 U.S.C. § 1712(e).
[4] 43 U.S.C. § 1702(c).
[5] 40 C.F.R. § 1508.8.
[6] 40 C.F.R. § 1502.15.
[7] Robertson v. Methow Valley Citizens Council, 490 U.S. 332, 349 (1989).
[8] Treasury and General Government Appropriations Act for Fiscal Year 2001, Pub.L.No. 106-554, § 515. *See also,* Bureau of Land Management "Information Quality Guidelines," available at http://www.blm.gov/nhp/efoia/data_quality/guidelines.pdf.

NEPA also requires that the BLM conduct its environmental impact analysis based upon an adequate and accurate description of the environment that will be affected by the proposed action under consideration—the "affected environment."[9] The affected environment represents the baseline conditions against which impacts are assessed. The importance of accurate baseline data has been emphasized by courts, which have found that "a baseline against which to compare predictions of the effects of the proposed action and reasonable alternatives is critical to the NEPA process."[10]

It is important that the BLM continue to update data on the distribution and quality of wildlife habitat, in order to establish an accurate baseline and determine necessary management actions to preserve and enhance habitat. In the context of managing oil and gas development, the agency can best fulfill its obligation to evaluate the impacts of potential management decisions, then select a course of action based on the best available science, by using both field monitoring and spatial analysis to make the assessments called for under NEPA, FLPMA, and the Data Quality Act. Specifically, the BLM should evaluate the effects on wildlife (and natural and cultural resources) of habitat fragmentation from the existing and proposed network of roads and well pads, and only permit development in a manner that will not cause significant damage to wildlife habitat, using the techniques discussed below.

THE SCIENCE OF HABITAT FRAGMENTATION AND WILDLIFE IMPACTS FROM OIL AND GAS DEVELOPMENT

Impacts of Habitat Fragmentation

Oil and gas development creates a complex network of roads, well pads, pipelines, pumping stations, and other infrastructure across a landscape. Roads are widely recognized by the scientific community as having a range of direct, indirect, and cumulative effects on wildlife and their habitats (Trombulak and Frissell 2000, Gucinski et al. 2001, Gaines et al. 2003, Wisdom et al. 2004a, Wisdom et al. 2004b, New Mexico Department of Game and Fish 2005). Increasingly, studies are demonstrating many of the negative effects on wildlife specific to oil and gas development (Colorado Department of Wildlife et al. 2008, Wyoming Game and Fish Department 2004, Confluence Consulting 2005, Holloran 2005, Sawyer et al. 2006, Berger et al. 2006). These negative effects range from direct removal of habitat to long-term displacement of species from preferred habitat. Direct effects can be measured by calculating the physical dimensions of the development feature (e.g., roads or well pads). Indirect and cumulative effects on wildlife are often assessed through analysis of habitat fragmentation.

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[9] 40 C.F.R. § 1502.15.
[10] Half Moon Bay Fisherman's Marketing Ass'n v. Carlucci, 857 F.2d 505, 510 (9th Cir. 1988) ("without establishing . . . baseline conditions . . . there is simply no way to determine what effect [an action] will have on the environment, and consequently, no way to comply with NEPA.").

Habitat fragmentation has been defined as the "creation of a complex mosaic of spatial and successional habitats from formerly contiguous habitat" (Lehmkuhl and Ruggiero 1991). Habitat fragmentation alters the distribution of wildlife species across the landscape and affects many of their life functions such as feeding, courtship, breeding, and migration. Transportation networks and similar infrastructure are one of the most significant causes of habitat fragmentation, and negatively impact wildlife well beyond the surface area disturbed by an actual road or oil/gas well pad (Wyoming Game and Fish Department 2004). The hundreds of scientific papers covered in the literature reviews cited in the previous paragraph illustrate the preponderance of evidence that routes ranging from narrow dirt tracks to paved roads can and do have adverse affects on wildlife. In fact, habitat fragmentation from roads and other human infrastructure has been identified as one of the greatest threats to biological diversity worldwide (Wilcove 1987). This volume of science simply cannot be ignored in a major land management planning effort.

Measures of Habitat Fragmentation

To quantitatively assess the impacts of habitat fragmentation on wildlife, we need two things: a way to measure fragmentation, and a way to tie various degrees of fragmentation to their impacts on wildlife. Many measures of fragmentation are available—McGarigal and Marks (1995) present dozens—and each has its advantages and disadvantages. Other publications illustrate the importance of such metrics for landscape-level planning (Leitao and Ahern 2002) and measuring the indirect and cumulative impacts of development on wildlife (Theobald et al. 1997, Thomson et al. 2005). In federal land management planning, where transparency and public involvement are important, metrics that are easily computed and easily understood are desirable. The ability to tie these metrics to wildlife impacts comes from the biological literature, which contains an increasing number of references to easily computed fragmentation metrics and values for those metrics at which various wildlife impacts have been recorded. Table 1 contains examples of these indicator values for a few important wildlife species present in oil and gas development areas across the West. This is only a sample, and BLM staff should search the scientific literature for the latest and most appropriate values associated with species of local importance whenever land management planning is undertaken.

Species	Indicator Value	Impact/Observation/Recommendation	Reference
Sagebrush-obligate birds	328 foot distance to nearest road	Within this distance the density of sagebrush-obligate birds drops by 50 percent regardless of the amount of activity on the road.	Ingelfinger 2001
Greater Sage-Grouse	< 5 producing wells within 1.9 miles of a lek	No impact on lek attendance by males was observed.	Holloran 2005
	5-15 producing wells within 1.9 miles of a lek	Medium impact on lek attendance by males was observed.	
	> 15 producing wells within 1.9 miles radius of a lek	Heavy impact on lek attendance by males was observed.	
	2 mile radius around a lek	Well density within this distance of a lek was observed to be one-third lower for active leks than for inactive leks.	Naugle et al. 2006
	3.4 mile radius around a lek	No surface occupancy (NSO), no new road construction, and seasonal closure of existing roads are recommended within this distance of a lek.	Braun 2006
	4 mile radius around a lek	Minimum disturbance is recommended within this distance of a lek.	Northwest Colorado Greater Sage-Grouse Working Group 2006
	4 mile radius around a lek	NSO designation for areas within this distance of leks is scientifically supported when nesting and brood rearing maps are not available.	Colorado Department of Wildlife 2008
	1 well pad/mi^2 pad density	Measurable negative impacts on breeding populations are observed at this density.	
Elk	1 mi/mi^2 road density	Road density above which habitat effectiveness is eliminated in non-forested landscapes	Lyon 1979
Mule Deer	328 foot distance to nearest road	Distance from a road at which deer are observed to exhibit avoidance in shrub landscape.	Rost and Bailey 1979
	436 foot distance to nearest road	Female deer on winter range move away from humans on snowmobiles.	Freddy et al. 1986
	627 foot distance to nearest road	Female deer on winter range move away from humans on foot.	
	1,096 foot distance to nearest road	Female deer on winter range alert to humans on foot.	
	1,542 foot distance to nearest road	Female deer on winter range alert to humans on snowmobiles.	
	1.6, 1.9, and 2.3 miles from well pads	Minimum distances from well pads at which deer are most likely to occur over three years of progressive oil and gas development.	Sawyer et al. 2006
Pronghorn	0.6 mile distance to nearest road	Distance from a maintained road at which pronghorn exhibit avoidance.	Ockenfels et al. 1994
	1 mi/mi^2 road density	Road density at which negative impacts were acknowledged to occur.	BLM 1999
Bighorn Sheep	433 foot distance to nearest road	Sheep flee from human activity on roads at this distance.	Papouchis et al. 2001
	1,191 foot distance to nearest road	Sheep alert to human activity on roads at this distance.	

Table 1. Fragmentation Indicator Values for Selected Wildlife Species.

A sampling of road density, distance-to-nearest-road-or-well-pad, or related values at which indirect and cumulative impacts on wildlife occur.

We recommend the use of two fragmentation metrics that are both easy to compute and easy to understand: road density and distance to nearest road or well pad.

Road density is the total length of road per unit area (e.g., miles per square mile). It can be computed by dividing the entire study area into a grid of areas (cells) appropriately sized[11] for the total size of the study area, and assigning to each cell the total length of road in the surrounding circular one-square-mile area. Figure 1 is an illustration of this concept. Feature dimensions, especially cell size, are exaggerated for clarity.

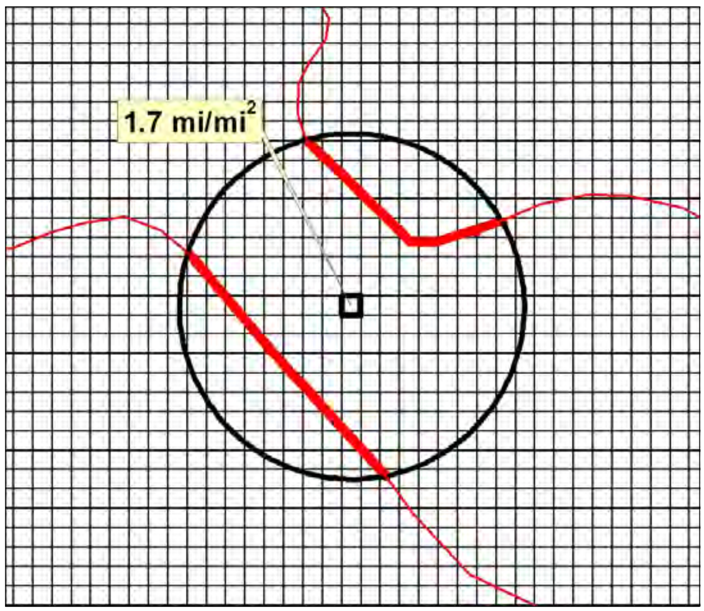

Figure 1. Illustration of Road Density Metric.
Road density is computed for each grid cell in the study area using a GIS tool that totals the length of road in the circular one square mile area surrounding the cell and assigns that value to the cell. With total road length measured in miles, road density has units of miles per square mile. This figure illustrates the one-square-mile circle, the central cell being processed, and the roads (red/bold within the circle) whose lengths are being summed to give the cell's road-density value.

Distance to nearest road is the distance from any place in the study area to the nearest road (or other fragmenting feature—in this document we also include the distance to the nearest well pad in this metric). It can be computed by dividing the entire study area into a grid of areas (cells), again appropriately sized for the total size of the study area, and assigning to each cell the distance between the center of that cell and the center of the nearest cell with a road in it. Figure 2 illustrates this concept—again, with feature dimensions exaggerated for clarity.

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[11] There are no hard and fast rules for selecting an appropriate cell size. Analysts must balance the desire for a small cell that gives fine resolution and smooth visual display against the desire for a larger cell that reduces computer processing time.

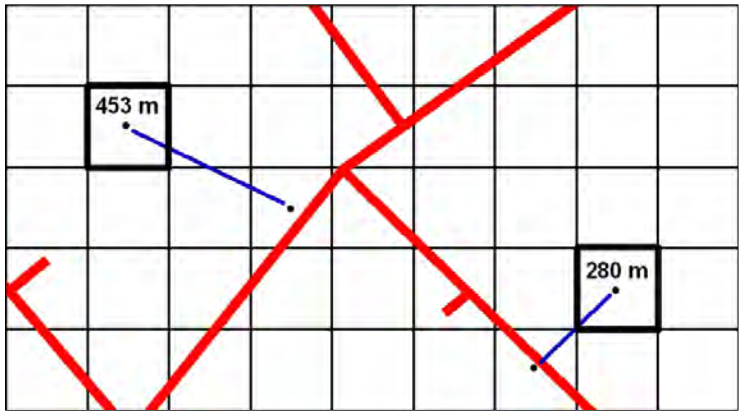

Figure 2. Illustration of Distance-to-Nearest-Road Metric.
Distance to nearest road is computed for each grid cell in the study area using a GIS tool that measures the distance from the cell's center to the center of the nearest roaded cell and assigns that value to the cell. This figure shows cell centers for two sample cells as points, roads as bold red lines, and the distance between cell centers as thinner blue lines.

A METHODOLOGY FOR ANALYZING HABITAT FRAGMENTATION AND WILDLIFE IMPACTS

Authorization of oil and gas development on federal land requires the BLM to examine the direct, indirect, and cumulative impacts of the proposed development and a range of management alternatives. This assessment necessarily includes looking at levels of reasonably foreseeable development under the alternatives (see e.g., Instruction Memorandum 2004-089). In order to evaluate likely effects and select the appropriate alternative in terms of both development and impacts to other resources such as wildlife habitat, the agency should assess a range of well-pad densities and specifically determine acceptable levels. In the absence of such comprehensive analyses, fields can develop faster than originally expected without the agency having considered the potential effects of, for instance, full-field development with infill, and put in place specific limitations. The result is development density, and destruction of wildlife habitat, exceeding anything considered during the plan approval process.

For example, in the Jonah Field in Wyoming, original predictions in 1998 were for drilling of 500 wells over 15 to 20 years with a maximum well density[12] of one well per 80 acres. Within five years, however, an additional 500 wells

[12] The BLM sometimes uses the term *spacing* to describe the distribution of well pads on the surface of the land. This term can be confusing—both because it was originally developed to describe the number of drill holes needed to drain a certain reservoir (this is downhole spacing) and because terms like *increasing spacing* may be interpreted either as placing pads farther apart or as increasing the number of pads per square mile. For these reasons, we use the term *well-pad density* to describe the surface distribution of well pads.

were drilled and a well density of one well per 40 acres had been approved. Most recently, the infill project for this field resulted in the approval of 3,100 more wells, with a well density averaging one well per 10 acres and ranging as high as one well per 5 acres in some parts of the field. While all of these step-wise increases were approved by BLM, the agency's decision-making would have been better informed by an analysis made at the outset that examined the degree of habitat fragmentation likely to result from different levels of development. This would have assisted in setting limits on acceptable development, and would also have limited industry expectations. Performing such an analysis and putting limitations on the degree of habitat fragmentation that will be allowed is important for responsible land management.

The BLM is already recognizing the potential for using GIS analysis to evaluate development impacts. For instance, the Record of Decision (ROD) for the Resource Management Plan Amendment for Federal Fluids Mineral Leasing and Development in Sierra and Otero Counties (New Mexico) sets out two limitations to protect Chihuahuan Desert Grasslands: restricting surface disturbance to 5 percent of a leasehold at one time and limiting total surface disturbance to 1,589 acres over the life of the RMP Amendment. The ROD states that both limitations will be monitored and enforced using GIS technology. (See ROD, p. 12, available at http://www.blm.gov/pgdata/etc/medialib/blm/nm/field_offices/las_cruces/las_cruces_planning/white_sands__otero0/docs_white_sands_.Par.82039.File.dat/PRINTABLEROD-LCFO-FINAL_text.pdf.)

To demonstrate an analytical framework for the analysis of fragmentation, and to provide estimates of the fragmentation effects of oil and gas development on wildlife, we have simulated the incremental development of an oil and gas field, from low well-pad density to high, on a hypothetical 28,120-acre site. The seven well-pad densities analyzed were chosen to match densities commonly discussed in BLM management plans: one pad per 640 acres, 320 acres, 160 acres, 80 acres, 40 acres, 20 acres, and 10 acres. These densities, respectively, are equivalent to 1 pad per square mile (mi^2), 2 pads/mi^2, 4 pads/mi^2, 8 pads/mi^2, 16 pads/mi^2, 32 pads/mi^2, and 64 pads/mi^2 (the BLM and others sometimes use pads/mi^2 in reference to what they call well-pad spacing). Throughout this analysis we express well-pad density using one or the other of these units, choosing the most appropriate for the context. We refer to each simulation of a stage of incremental development as a development scenario.

Scenario Development and Assumptions

The first step in creating development scenarios for analysis was to define the set of roads we assumed to be present before any oil and gas development. The number of roads in the pre-development landscape has an effect on the magnitude of change in fragmentation metrics from the pre-development condition to the first stage (and a few subsequent stages) of oil and gas development. The change in fragmentation between the pre-development condition and the first few development stages is smaller when pre-development roadedness is higher because the landscape is already relatively fragmented before well pads and connecting roads are added. The impact of pre-development roadedness decreases as development continues, because the number of well pads on the landscape becomes the driver in the total number and distribution of roads. We chose to create a relatively small initial road system in an effort to remain conservative in our depiction of fragmentation effects.

The pre-development road centerline dataset was digitized on-screen using ArcGIS (ArcInfo) 9.2[13]. Road centerlines were converted to a new dataset representing the actual width of road rights-of-way (the assumed area of direct disturbance) by buffering the centerlines by 20 feet on each side—giving a total width of 40 feet[14].

Development of the oil and gas field was simulated through an iterative process, involving three steps for each stage of development:

1) **Randomly place the number of well pads necessary to achieve the desired well-pad density.** We did this using tools available in CommunityViz 3.2 (Scenario 360),[15] software designed to work as an extension of ArcGIS. We chose to represent well pads as 4-acre squares[16] and to restrict placement of new well pads so that they not overlap with existing well pads and/or roads present in the preceding stage of development. For the first stage of oil and gas development, this exclusion area is the dataset representing the set of 40-foot-wide roads defined for the pre-development landscape.

2) **Manually create road centerline segments, through on-screen digitizing, to connect the newly placed well pads to the existing road system**. We maintained a single roads dataset, with new road segments being added at each stage of simulated oil and gas development. Dataset attributes were maintained to allow identification of the complete road network associated with each development stage. When digitizing road segments, we assumed no restrictions on road routing (e.g., no topographic limitations). As new road centerlines were added, they were often routed along the edge of existing well pads in an effort to minimize fragmentation as measured by the distance-to-nearest-road-or-well-pad metric. However, this practice may slightly increase fragmentation as measured by the road-density metric because a road segment can be slightly longer than the shortest distance between its end points. No effort was made to quantify these effects.

3) **Convert road centerlines to a dataset representing road width, and combine this with the well-pad dataset associated with the current development stage.** This created a dataset representing the area directly disturbed by roads and well pads. As for the pre-development road system, road width was set to 40 feet. For the next stage of development, the combined road/pad dataset was fed back into step 1 above, as the area which the next set of well pads must not overlap.

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[13] Manufactured by ESRI (Environmental Systems Research Institute), Redlands, CA.

[14] The 40-foot width is based on the average initial width of direct disturbance used in the Draft Environmental Impact Statement for the Pinedale Resource Management Plan from the BLM's Pinedale Resource Area in Wyoming. We selected this width as a representative example of the way that the agency measures impacts in an area where the BLM is regularly addressing oil and gas development.

[15] Manufactured by Placeways, LLC, Boulder, CO.

[16] The 4-acre well pad size is the area of direct disturbance projected for one well pad with a single well in the Reasonably Foreseeable Development document for the Little Snake Resource Area Management Plan in Colorado.

This process was repeated seven times to create representations of the road and well-pad infrastructure associated with a pre-development condition and seven hypothetical stages of oil and gas development. Figure 3 presents a pictorial view of these eight development scenarios.

For the pre-development condition and each of the development stages, measurements were made of the area of direct disturbance, road density, and distance to nearest road or well pad using the techniques described in the previous section of this document. The grid cell size chosen was 33 feet—providing good resolution as well as good GIS processing times. Fragmentation metrics were calculated for the entire 28,120-acre study area, but the results presented below are those associated with only the center 20,000-acre analysis area (the lighter shaded interior area in Figure 3). This was done in order to avoid including erroneous results that may naturally arise when processing data near the edge of the full 28,120-acre area.

Conservative Estimates

The results presented here are conservative estimates of the actual degree of habitat fragmentation and its impacts on wildlife for several reasons. First, these hypothetical scenarios consider the effects of roads and well pads but not of pipelines, pumping stations, and other infrastructure associated with oil and gas development. Second, our road networks do not include closed loops, which commonly occur in real oil and gas developments and increase the overall miles of road and degree of fragmentation. Third, our assumption of no topographic influences on road construction yields a shorter road network than in most real landscapes. Fourth, we assume few roads in the pre-development scenario, but in real landscapes throughout the West the number of roads existing prior to oil and gas development varies greatly, and many areas have pre-development road networks significantly larger than that used in this analysis. Where pre-development road networks are larger, the total degree of fragmentation will be greater, particularly in the early stages of development. Fifth, we assumed a well-pad size of only 4 acres, which is substantially smaller than frequently proposed sizes ranging from 4 to 160 acres depending on the number of wells per pad. Sixth and finally, our analysis of the effect of well pads on Greater Sage-Grouse leks, in which we assume one well per pad, underestimates the impact resulting when more than one well occupies a single pad. Taken together, these factors suggest that the degree of habitat fragmentation and the associated impacts on wildlife from oil and gas development in real landscapes will be even greater than those presented in this document.

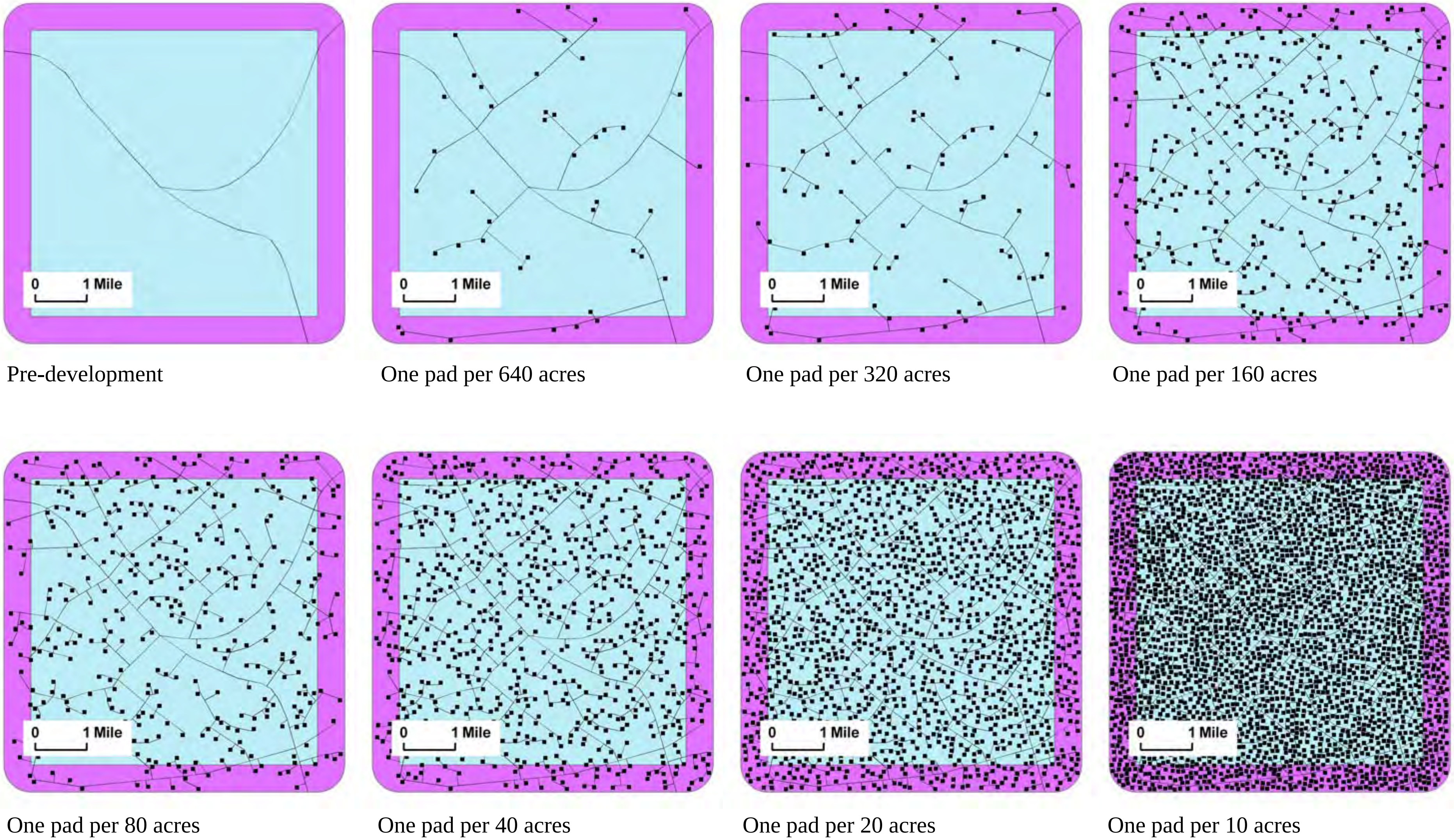


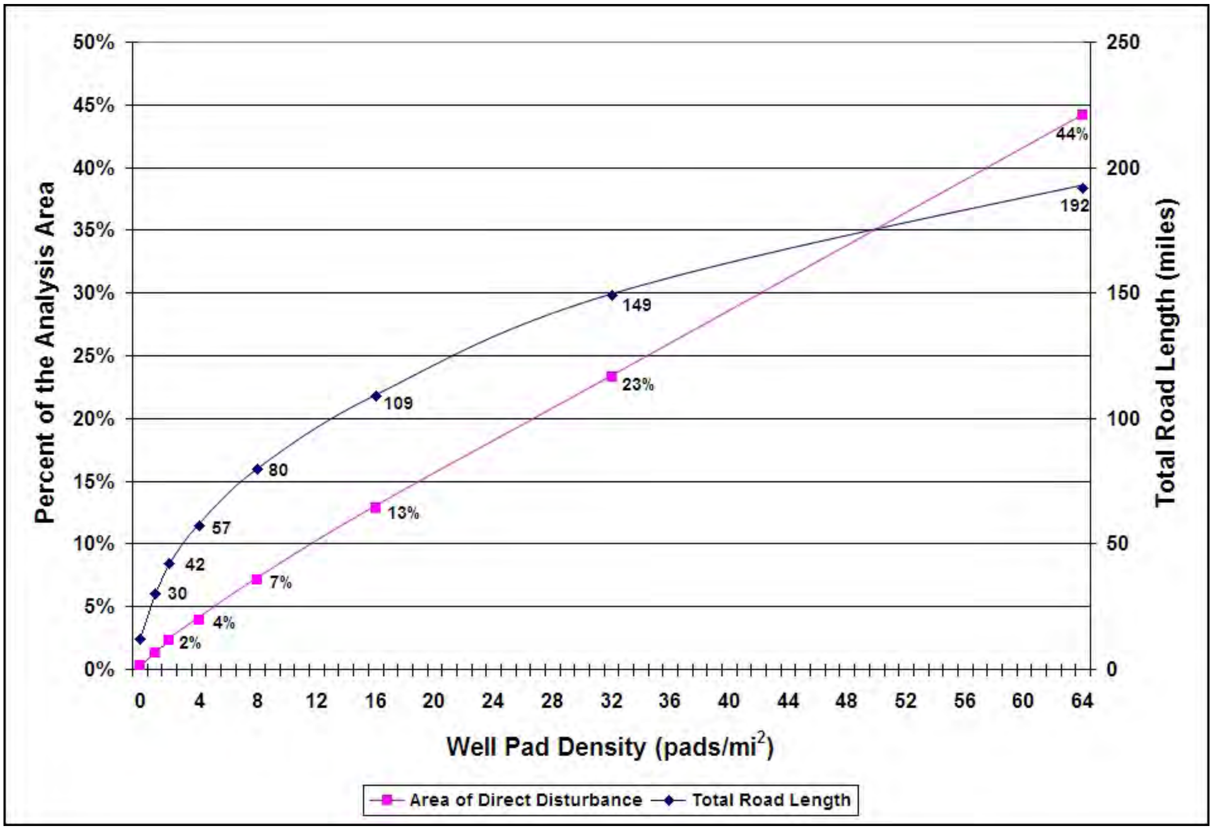
Figure 3. Eight Stages of Simulated Oil and Gas Development.

This series of maps shows the area of direct disturbance from well pads and roads for eight development scenarios. With the pre-development scenario serving as the base condition, each new scenario is created by randomly adding square 4-acre well pads to the previous scenario and connecting them to the growing network of 40-foot-wide roads. Fragmentation metrics are reported for the center 20,000-acre analysis area (blue/lighter shaded) in order to avoid errors that naturally occur as a result of data processing near the edge of the study area.

Results of an Analysis Applying Our Methodology to a Hypothetical Landscape

Measuring Direct Disturbance

Simple measures of direct disturbance from oil and gas development include total miles of road and total combined road and well-pad area. The graph and table in Figure 4 summarize these measures of direct disturbance for our eight oil and gas field development scenarios. The total area of direct disturbance increases approximately linearly as well-pad density increases. This is expected since the number of well pads (and hence, total well-pad area) doubles as well-pad density doubles. Total road length behaves differently, increasing more rapidly in the early stages of development. Again, though, this is expected, since, in the earlier stages of development, the random placement of a few well pads in our relatively unroaded area will likely require the construction of long roads to connect the well pads to the existing road system. In the later stages of field development, new well pads are likely to be placed near existing roads, and even the larger number of roads needed does not offset the significantly shorter length of each road. This relatively more rapid increase in total road length in the early stages of field development has implications for the indirect impacts of habitat fragmentation, as measured by road density and distance to nearest road or well pad (as shown in the next section).



Well-Pad Density (acres/pad)	Well-Pad Density (pads/mi²)	Total Road System Length (miles)	Total Area Directly Impacted (acres)	Percent of Study Area Directly Impacted
Pre-development	0	12	59	<1%
640	1	30	271	1%
320	2	42	459	2%
160	4	57	793	4%
80	8	80	1,429	7%
40	16	109	2,579	13%
20	32	149	4,661	23%
10	64	192	8,830	44%

Figure 4. Measures of Direct Disturbance for Eight Development Scenarios.
This table and graph show the growth of the area of direct disturbance in our oil and gas field development simulation. While the area of direct disturbance, driven by the increasing well-pad area, increases linearly, total road system length increases more rapidly in the earlier stages of field development.

Measuring Indirect and Cumulative Impacts

Road Density

Road density, when calculated spatially, may be assessed visually by mapping. Figure 5 shows the patterns of road density across the landscape at the different well-pad densities used in our simulation. Using GIS, these data can be displayed with wildlife habitat boundaries such as seasonal range, breeding and rearing habitat, migration paths, and other data for individual species to give a visual sense of road density specifically within these habitats. GIS technology can also combine the road-density and habitat information to give quantitative results within key habitats.

Mean road density—the area-weighted average of individual road-density grid values for the analysis area—can be measured and plotted against well-pad density for each development scenario as shown in Figure 6. This graph shows that the *rate* of increase in road density is higher at earlier stages of development than at later stages. This is consistent with the rate of growth in total road system length and suggests the high relative impact of initial development and the importance of maintaining undeveloped areas.

The utility of spatial road-density computations is increased by tying them to the biological literature on wildlife impacts of fragmentation. To make this connection we plotted the cumulative area distribution of road density for each development scenario (Figure 7). This yielded a series of curves showing the percentage of the landscape at or below any given road density, which can indicate how much of the landscape will likely remain as viable habitat (i.e., below some road-density indicator value obtained from wildlife field research). For instance, Lyon (1979) found that a road density of 1 mi/mi^2 will eliminate elk habitat effectiveness in non-forested landscapes. To help us understand how the percentage of the landscape with road density below this value changes with increasing oil and gas development, we can superimpose a line corresponding to a road density value of 1 mi/mi^2 (the vertical dashed line in Figure 7) and read the proportion of unimpacted area directly from the chart for each development density (dashed horizontal lines). This reveals that even at the lowest development density—one well pad per 640 acres—just 50 percent of the landscape has a road density less than Lyon’s (1979) indicator for loss of habitat effectiveness. At the 320- and 160-acre densities, this proportion falls to 36 percent and 15 percent respectively. At even higher well-pad densities, virtually none of the landscape meets Lyon’s criterion. Wherever oil and gas development is planned, assessments of this type should be done for all potentially impacted local species for which road-density indicator values are available in the biological literature.

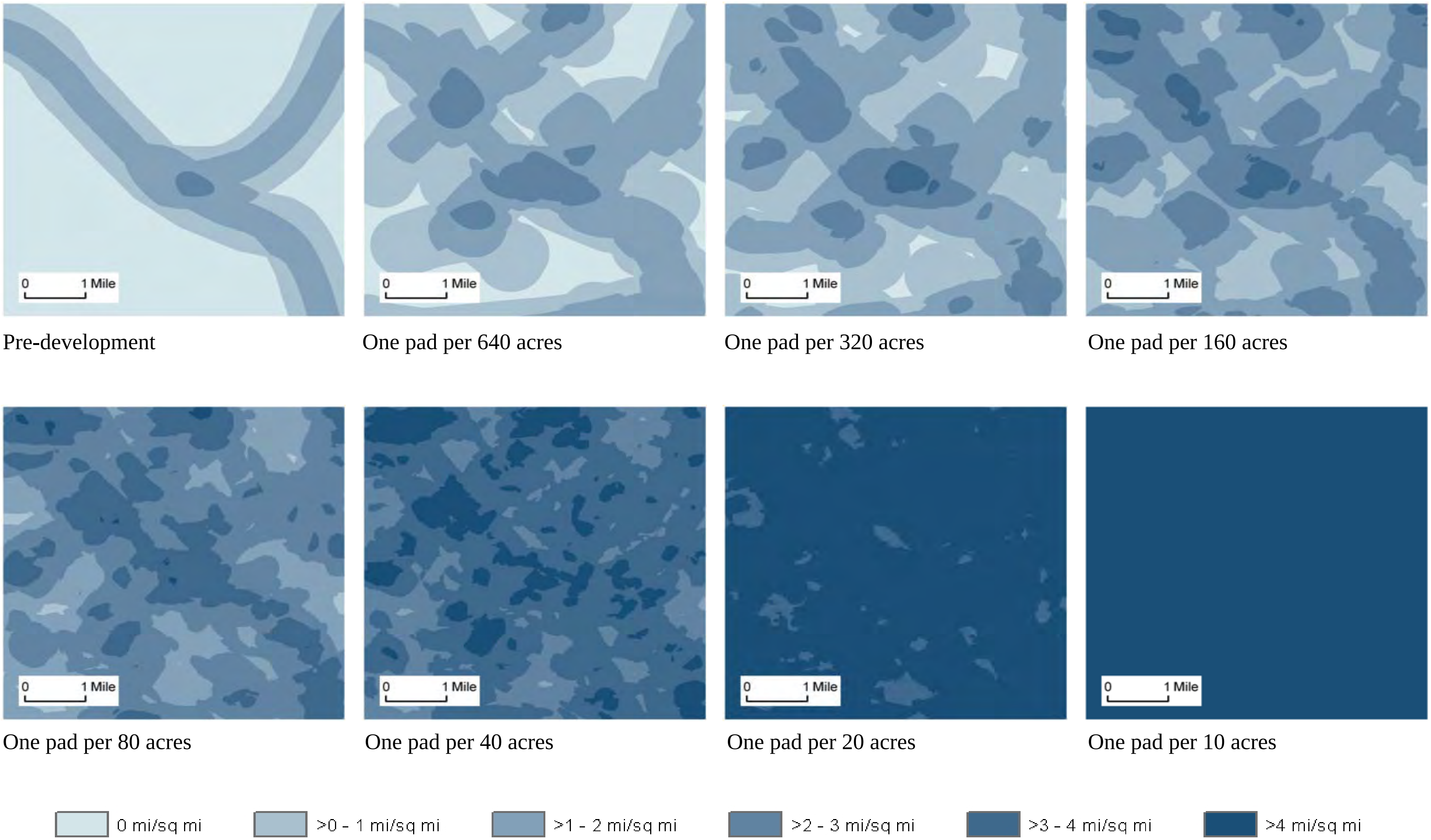
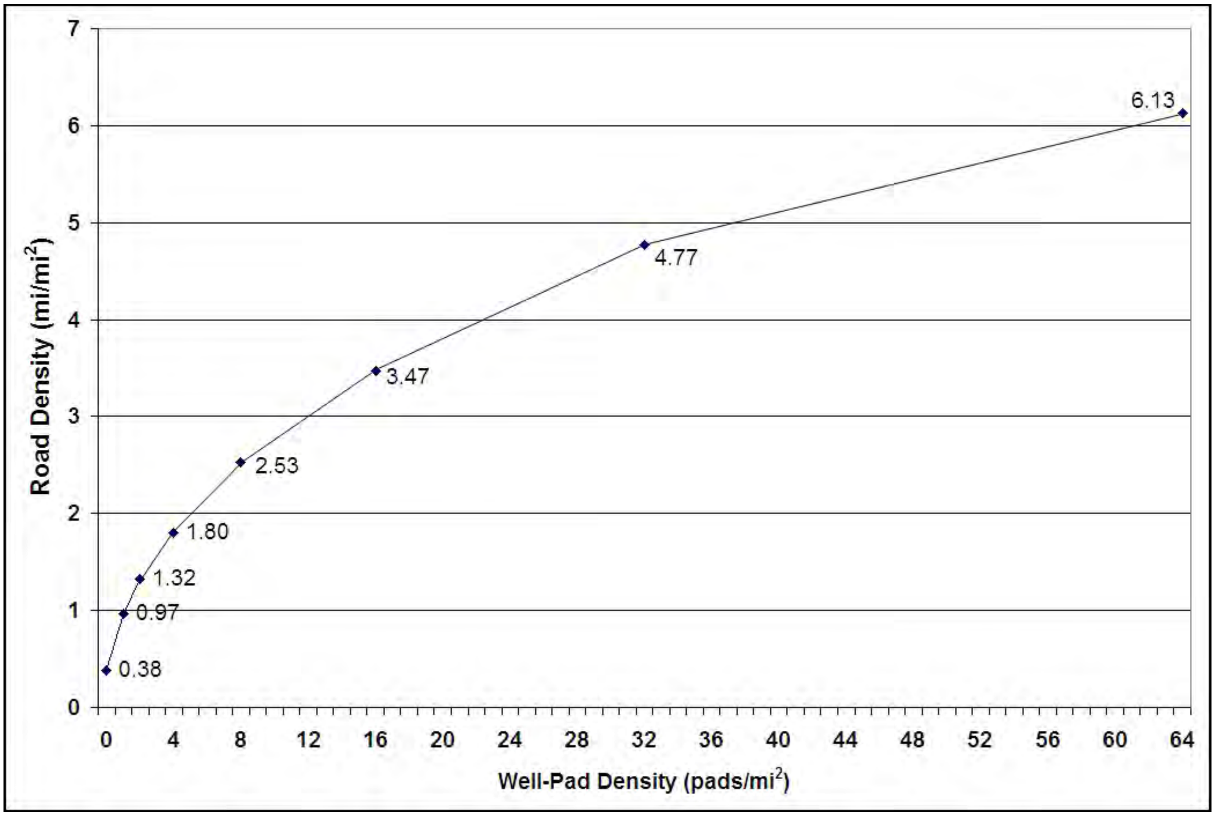


Figure 5. Maps of Road Density for Eight Oil and Gas Development Scenarios.



Well-Pad Density (acres per pad)	Well-Pad Density (pads/mi^2)	Mean Road Density (mi/mi^2)	Change in Mean Road Density	Rate of Change in Road Density
Pre-development	0	0.38	--	--
640	1	0.97	0.59[17]	0.59[17]
320	2	1.32	0.35	0.35
160	4	1.80	0.48	0.24
80	8	2.53	0.73	0.18
40	16	3.47	0.94	0.12
20	32	4.77	1.30	0.08
10	64	6.13	1.36	0.04

Figure 6. Mean Road Density for Eight Development Scenarios.

This graph and table show that the rate of change in road density (computed as the change in mean road density divided by the change in pad density) occurs most rapidly at lower development densities. This indicates the high relative impact of initial development, and emphasizes the importance of maintaining undeveloped areas.

[17] Note that the magnitude of the change in road density from the pre-development condition to a well-pad density of 1 pad/mi^2 is dependent on our assumption of a relatively small pre-development road system. With a more extensive pre-development road system this change in mean road density would be smaller. The size of the pre-development road system has an effect on the magnitude of change between subsequent development stages as well, but the effect decreases as development density increases.

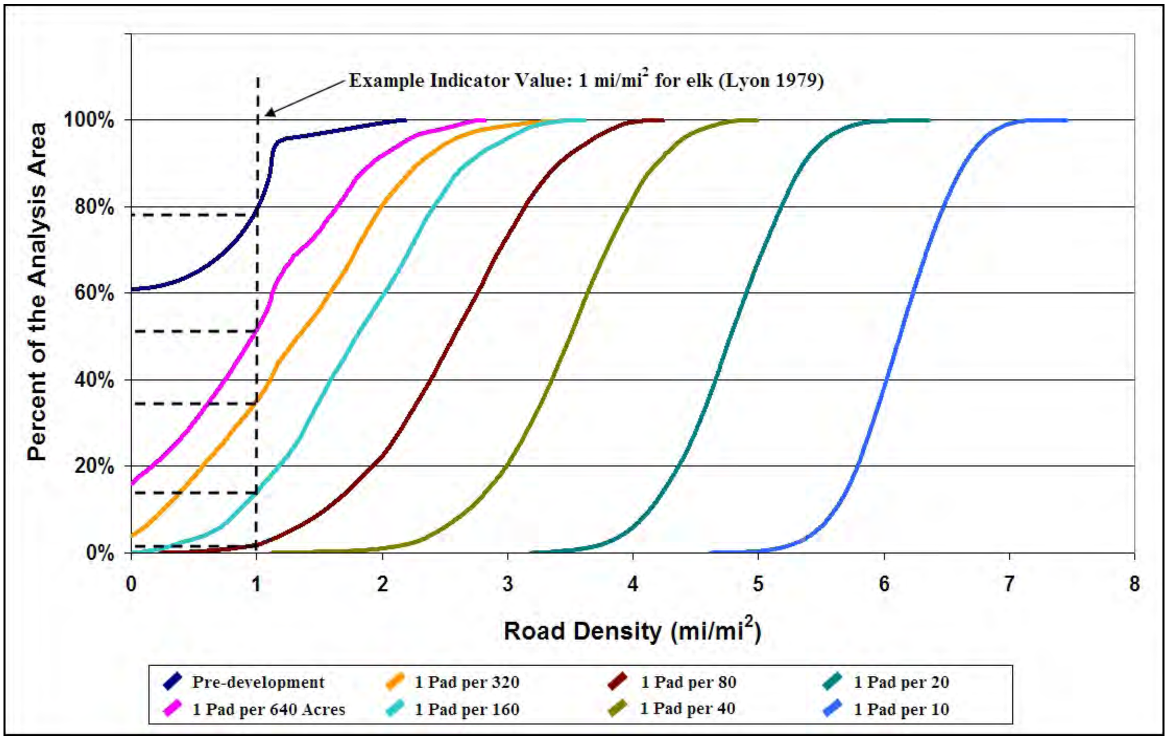


Figure 7. Proportion of Analysis Area at or Below a Road Density for Eight Development Scenarios. These curves show the proportion of the analysis area at or below a given road density for each development scenario. The curves can be examined in relation to wildlife indicator values found in the scientific literature (such as in Table 1) to assess the likely impact of different oil and gas development densities on wildlife species. This example shows that, even at the lowest oil and gas development densities, relatively high percentages of the landscape exceed Lyon's (1979) indicator value for loss of elk habitat effectiveness in open landscapes.

Distance to Nearest Road or Well Pad

Distance to nearest road or well pad, when calculated spatially, may also be assessed visually by mapping. Figure 8 shows the patterns of proximity to roads and well pads across the landscape at the different well-pad densities analyzed in our simulation. The treatment and use of the distance-to-nearest-road-or-well-pad metric is similar to that described for road density above. Using GIS, the distance-to-nearest-road-or-well-pad data can be displayed with wildlife habitat boundaries such as seasonal range, breeding and rearing habitat, migration paths, and other data for individual species to give a visual sense of road and well-pad proximity specifically within these habitats. GIS analysis can also combine the distance-to-nearest-road-or-well-pad and habitat data to give quantitative results within sensitive habitats.

The mean distance to nearest road or well pad—the area-weighted average of the values of individual grid cells for the analysis area—can be measured and plotted against the density of well pads across the landscape for each development scenario (Figure 9). As was the case with road density, the *rate* of decrease in distance-to-nearest-road-or-well-pad values is higher at earlier stages of development than at later stages, implying that the relative rate of impact from development is higher at lower development densities and suggesting the importance of maintaining undeveloped areas.

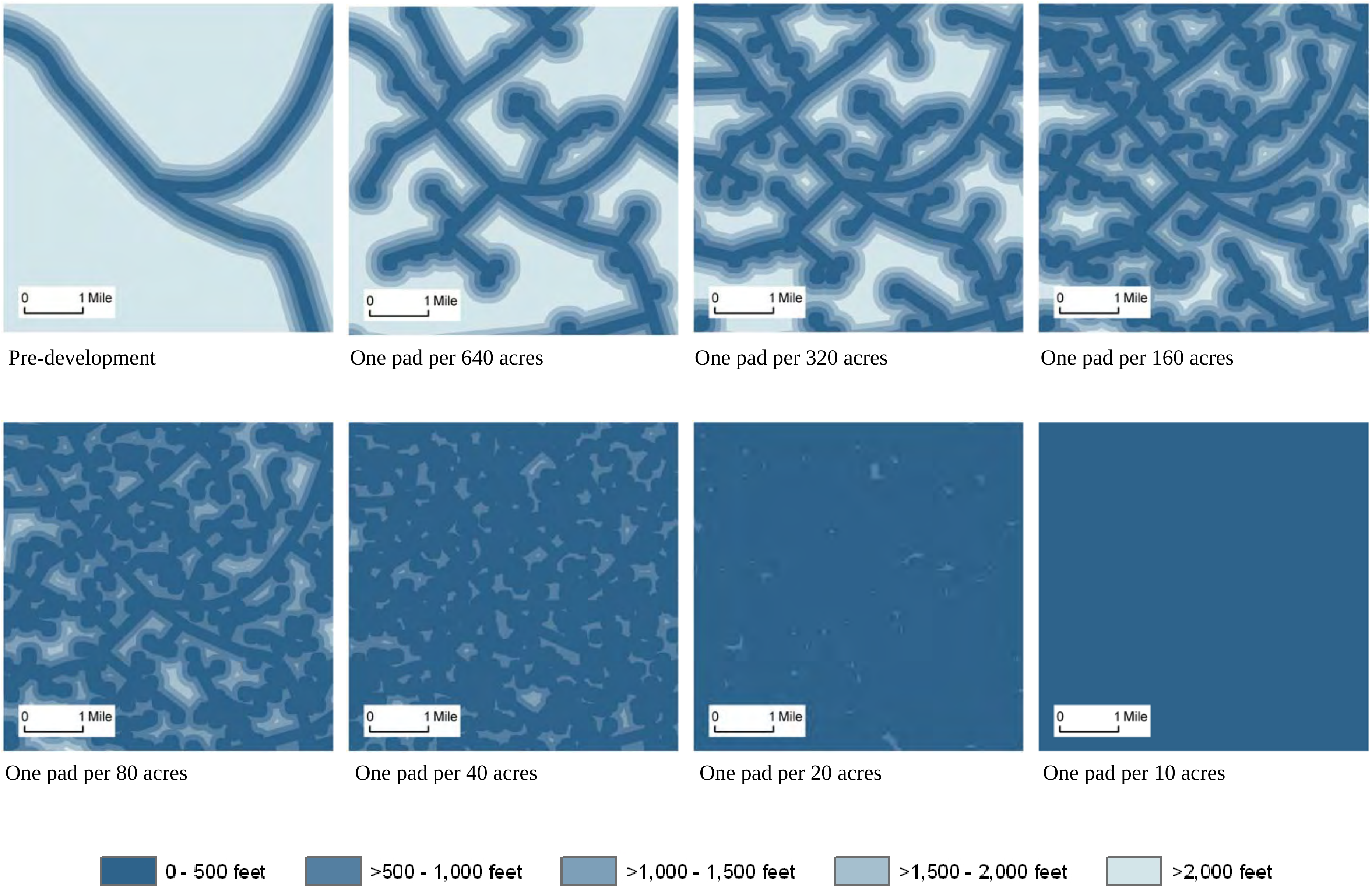
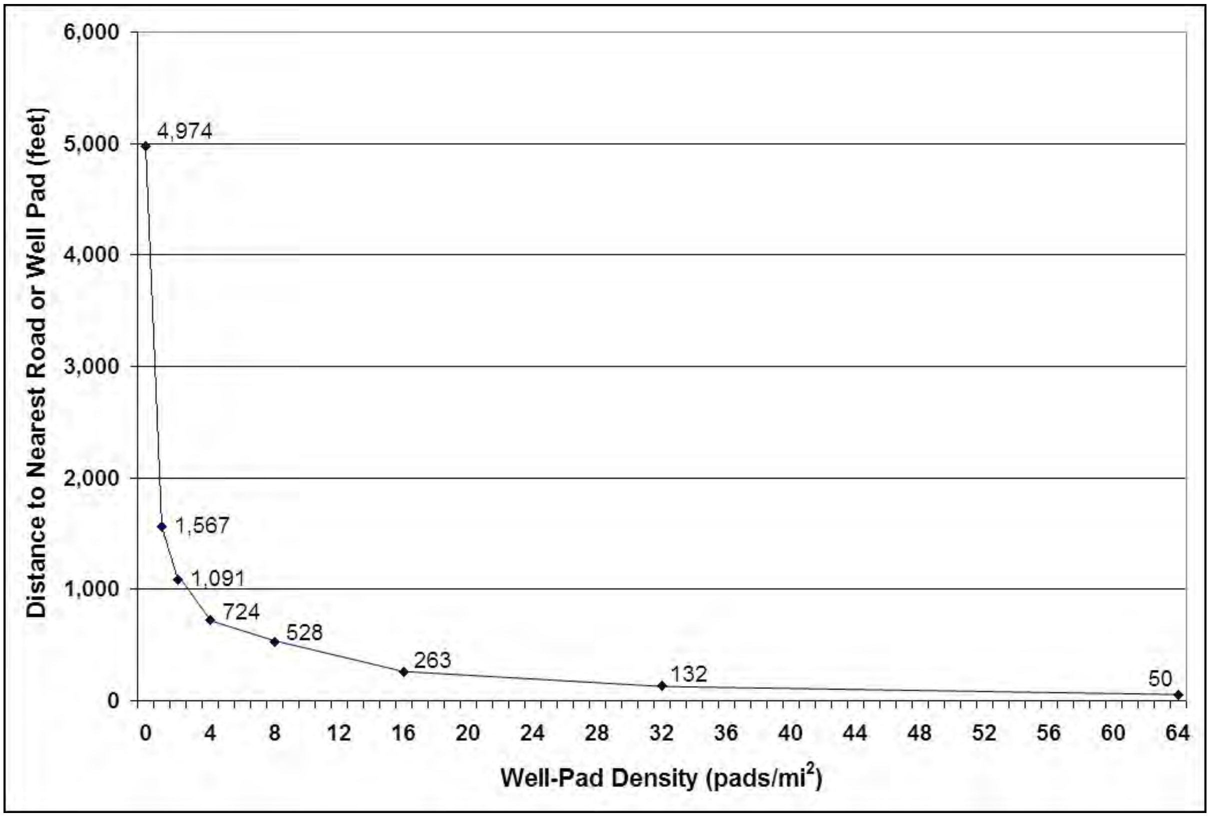


Figure 8. Maps of Distance to Nearest Road or Well Pad for Eight Oil and Gas Development Scenarios.



Well-Pad Density (acres per pad)	Well-Pad Density (pads/mi^2)	Mean Distance to Nearest Road or Pad (feet)	Change in Mean Distance to Nearest Road or Pad	Rate of Change in Distance to Nearest Road or Pad
Pre-development		4,974	--	--
640	1	1,567	3,407[18]	3,407[18]
320	2	1,091	476	476
160	4	724	367	184
80	8	528	196	49
40	16	263	265	33
20	32	132	131	8
10	64	50	82	3

Figure 9. Mean Distance to Nearest Road or Well Pad for Eight Development Scenarios.
This graph and table show that the rate of change in the distance to nearest road or well pad (computed as the change in mean distance to nearest road or well pad divided by the change in pad density) occurs most rapidly at lower development densities. This indicates the high relative impact of initial development, and emphasizes the importance of maintaining undeveloped areas.

Just as was the case with road density, the utility of spatial distance-to-nearest-road-or-well-pad computations is increased by tying them to the biological literature on wildlife impacts of fragmentation. To make this connection we

[18] As noted above for road density, the magnitude of the change in distance to nearest road or well pad from the pre-development condition to a well-pad density of 1 pad/mi^2 is dependent on our assumption of a relatively small pre-development road system. With a more extensive pre-development road system this change in mean distance would be smaller. The size of the pre-development road system has an effect on the magnitude of change between subsequent development stages as well, but the effect decreases as development density increases.

plotted the cumulative area distribution of distance to nearest road or well pad for each development scenario (Figure 10). This yielded a series of curves showing the percentage of the landscape beyond any given distance to a road or well pad, which can indicate how much of the landscape will likely remain as viable habitat (i.e., beyond some distance-to-nearest-road indicator value obtained from wildlife field research) at any given development density. For example, Ingelfinger (2001) found that the density of sagebrush-obligate birds drops by 50 percent within 328 feet of a road, regardless of the amount of activity on the road. To help us understand how the percentage of the landscape beyond this distance from the nearest road or well pad changes with increasing oil and gas development, we can superimpose a line representing this indicator value (the dashed vertical line in Figure 10) and read the proportion of unimpacted area directly from the chart for each development density (horizontal dashed lines). This exercise shows that at a well-pad density of just one pad per 80 acres, less than 55 percent of the landscape is beyond Ingelfinger's distance. The proportion of unimpacted area drops rapidly from there as development continues. Wherever oil and gas development is planned, assessments of this type should be done for all the potentially impacted local species for which distance-to-nearest-road-or-well-pad indicator values are available in the biological literature.

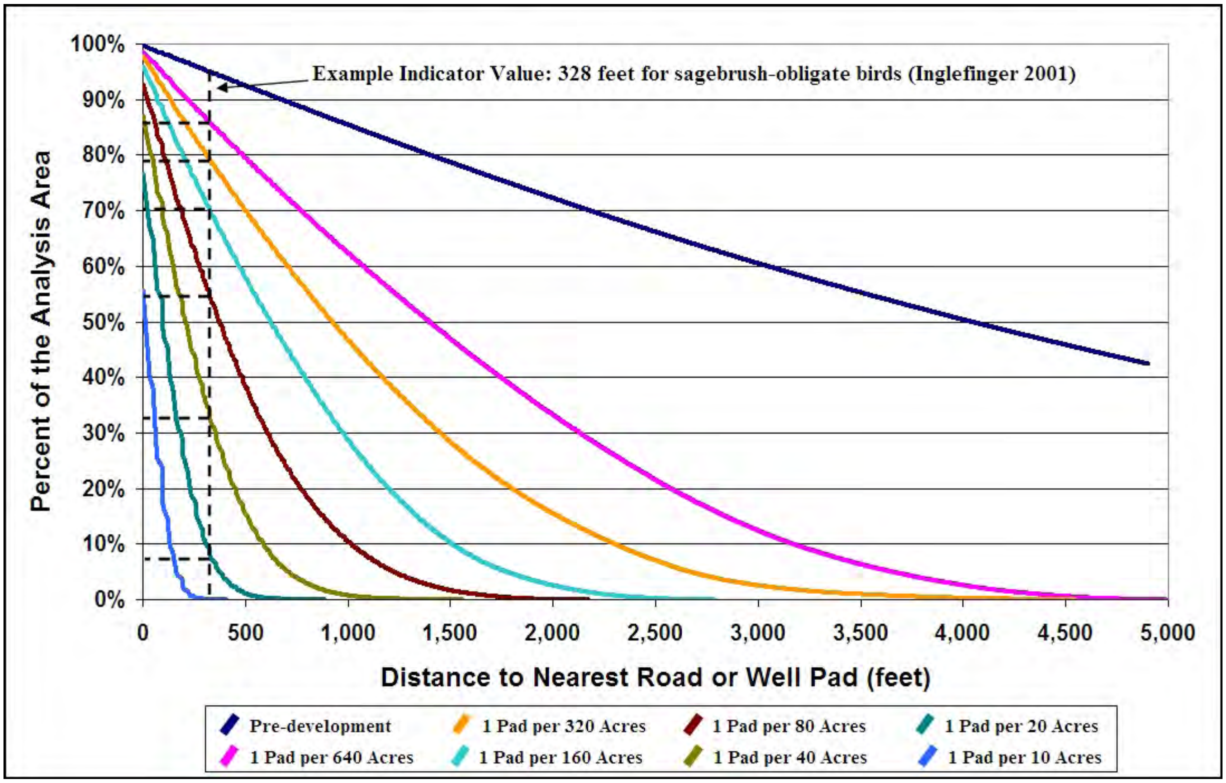


Figure 10. Proportion of Analysis Area Beyond a Distance of a Road or Well Pad for Eight Development Scenarios. These curves show the proportion of the analysis area beyond a given distance to the nearest road or well pad for each development scenario. The curves can be examined in relation to wildlife indicator values found in the scientific literature (such as in Table 1) to assess the likely impact of different oil and gas development densities on wildlife species. This example shows that, even at relatively low well-pad densities, significant percentages of the study area are close enough to roads or well pads to show the 50 percent reduction in the density of sagebrush-obligate birds reported by Ingelfinger (2001).

Special Case: Greater Sage-Grouse

A variety of fragmentation indicator values for different wildlife species may be found in the scientific literature, and these will necessitate application of different GIS processes to properly assess and represent them. We mention a special case of indicator values for Greater Sage-Grouse because of the presence of this species in so many oil and gas development areas across the West, its at-risk status, and the many state and federal agency efforts underway to protect it. Such efforts include the Greater Sage-Grouse Comprehensive Conservation Strategy from the Western Association of Wildlife Agencies (Stiver et al. 2006), a review of the latest science on Greater Sage-Grouse by the wildlife agencies of Colorado, Montana, North Dakota, Utah, and Wyoming (Colorado Department of Wildlife et al. 2008), and the Colorado Greater Sage-Grouse Conservation Plan (Colorado Greater Sage-Grouse Conservation Plan Steering Committee 2008).

Several studies have examined Greater Sage-Grouse lek use in relation to the proximity of those leks to oil and gas wells, and recommended corresponding management actions. Braun (2006) recommends no surface occupancy (NSO), no new road construction, and seasonal closure of existing roads within 3.4 miles of Greater Sage-Grouse leks. Holloran (2005) considered lek attendance by males in relation to the number of producing wells within 1.9 miles of a lek, finding no measurable impact for fewer than 5 wells, moderate decline in male attendance for 5 to 15 wells, and significant decline for more than 15 wells within 1.9 miles of a lek. GIS buffer tools can identify the area within any radius of each lek, while GIS neighborhood analysis can be used to compute the number of wells within a specified distance for each lek. The BLM will likely have lek location data with which to perform these analyses, yielding the site-specific information needed for planning.

In the hypothetical landscape we used in our analysis, where lek locations cannot be known, we can only perform the neighborhood analysis for all grid cells in the analysis area and provide a general sense of the likelihood of development impacts on Greater Sage-Grouse lek use: the higher the proportion of the landscape exceeding the indicator values, the higher the proportion of leks likely to be impacted. The results of this analysis are summarized in Figure 11, which shows that only the one-pad-per-square-mile development scenario yielded even as much as 10 percent of the analysis area in Holloran's no-impact class (fewer than 5 wells within 1.9 miles). In the two-pads-per-square-mile development scenario, 35 percent of the analysis area was in the medium-impact class. For all other development scenarios virtually no portion of the analysis area fell outside of the high-impact class. These results suggest that substantial impacts on Greater Sage-Grouse must be acknowledged for oil and gas development in or near the bird's breeding habitat, a conclusion that is supported by the findings of a report recently released by the wildlife agencies of five western states (Colorado Department of Wildlife et al. 2008).

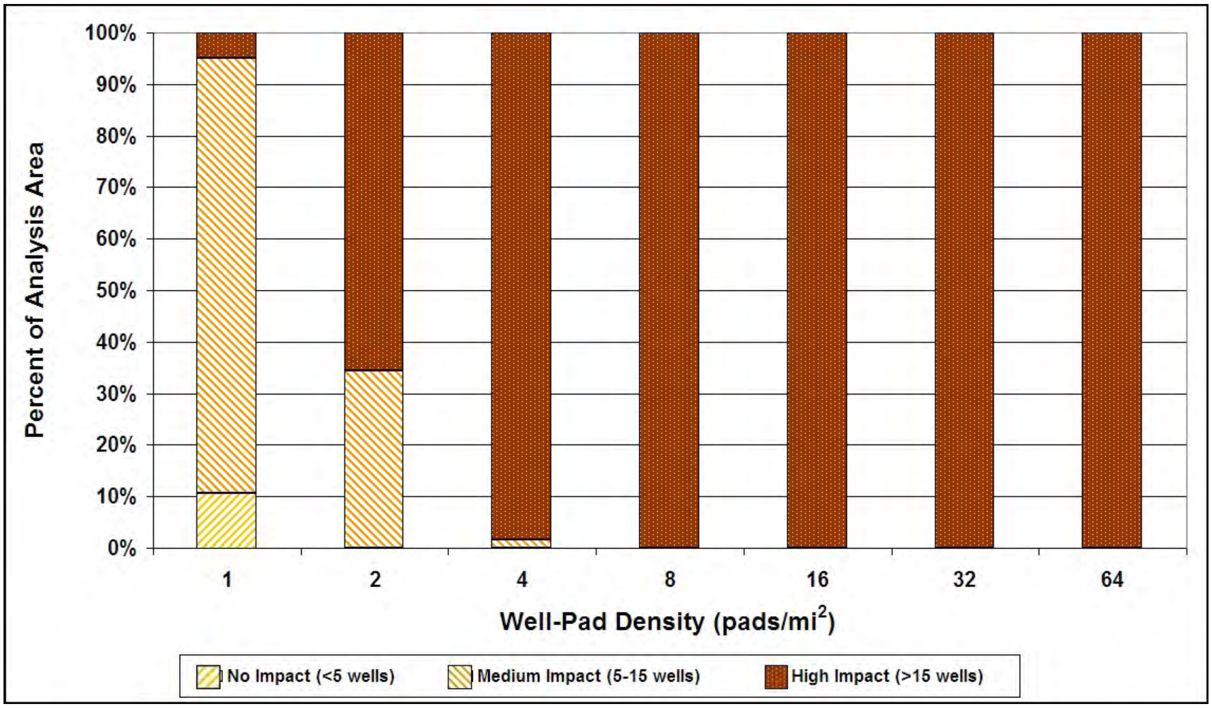


Figure 11. Distribution of Analysis Area Among Three Sage-Grouse Lek Impact Classes Identified by Holloran (2005) This analysis (based on Holloran 2005) of the number of well pads within 1.9 miles of a possible Greater Sage-Grouse lek shows that even the lowest oil and gas development densities are likely to have significant impact on lek attendance. It is important to note that, because Holloran's study considered the number of actual wells, and our analysis considers well pads, our measure of impact will be an underestimate when pads contain more than one well.

CONCLUSIONS AND RECOMMENDATIONS FOR OIL AND GAS MANAGEMENT PLANNING

Conclusions

The following conclusions arising from our analysis have direct implications for management planning for oil and gas development:

1. **Substantial scientific research is available indicating that the roads, well pads, and associated activities cause direct, indirect, and cumulative impacts on wildlife.**
   Indicators of indirect and cumulative impacts of development on wildlife and habitat can and should be collected from a survey of scientific literature relevant to species found in the resource planning area. There is abundant evidence in peer reviewed literature of negative impacts from roads and well pads, including reductions in particular wildlife functions (e.g., breeding, foraging), reductions in overall habitat use or effectiveness, and complete abandonment of habitat. Sufficient research may not yet be available to provide detailed wildlife response models for all species for different road densities or distance-to-nearest-road-or-well-pad values. However, there are adequate indicator values for specific metrics for many wildlife species, including key species of concern for the BLM, to allow the agency to assess threats from oil and gas development.

2. **Landscape analysis using GIS is necessary to take advantage of the best science regarding indicators of direct, indirect, and cumulative impacts.**

   Because the discussion of indirect and cumulative impacts due to roads and well pads is by its very nature spatial, it requires a means of analysis that can incorporate spatial measures such as (but not limited to) road density or distance to nearest road or well pad. Because GIS technology is readily available and is not costly to use, GIS analysis is an accessible way of meeting this requirement.

3. **Habitat fragmentation and negative impacts on wildlife occur at low well-pad densities and increase most rapidly at low well-pad densities.**

   Based on scientific literature, road density and distance-to-nearest-road-or-well-pad values indicating potential negative impacts on wildlife can be reached quickly, at relatively low oil and gas development densities. Looking at the wildlife indicator values presented in this document (Table 1) and many others in the biological literature, along with the graphs in Figures 7 and 10, it is apparent that significant negative effects on wildlife occur over a substantial portion of a landscape even at the lower well-pad densities characteristic of the early stages of development in a gas or oil field. Further, the rate at which road density increases and distance to nearest road or well pad decreases is higher at lower well-pad densities than at higher densities (Figures 6 and 9). This suggests that landscape-level planning for infrastructure development and analysis of wildlife impacts need to be done prior to initial development of a field. Where development has already occurred, the existing impacts on local wildlife species must be measured and acknowledged, and the cumulative impacts from additional development must be assessed.

   The fact that wildlife impacts for some species occur over a substantial portion of a landscape at low well-pad densities suggests that portions of a landscape that contain habitat for threatened and endangered species, unique habitats, species valued for hunting and recreational pursuits, and other species of concern should remain free from oil and gas development.

4. **The charts and numeric results of our sample analysis, together with relevant indicator values in the biological literature, can help guide the BLM, but they are no substitute for site-specific analyses.**

   The graphs in Figures 7, 10, and 11 may be used to estimate the minimum percent of a landscape reaching a given indicator value from the biological literature at a given level of development. The cumulative area distribution curves in Figure 7 give the percent of a landscape at or below any given road-density value for each well-pad density. The cumulative area distribution curves in Figure 10 give the percent of a landscape beyond any given distance-to-nearest-road-or-well-pad value for each well-pad density.

   For a view of how these curves might be used in management planning, consider a situation where a BLM planning alternative proposes a well-pad density of one pad per 160 acres and the latest biological literature suggests that habitat use by a species of concern in the development area declines by 50 percent at road densities above one mile per square mile. Placing a vertical line at one mile per square mile on the graph in Figure 7 allows

BLM staff to estimate that under this alternative no more than 15 percent of the development area will provide habitat exhibiting less than a 50 percent decline in use by that species. If Greater Sage-Grouse are present in the planning area, Figure 11 suggests (based on research by Holloran 2005) that the one pad per 160 acres alternative will result in highly detrimental impacts for this species over 98 percent of the planning area. These same figures can also be used to estimate habitat fragmentation impacts for other indicator values reported in the scientific literature. Their value lies in their ability to provide a quick, preliminary estimate of the magnitude of habitat fragmentation impacts for potential development alternatives. Complete spatial analyses of the specific landscape for which oil and gas development plans are being made must still be done using techniques such as those we suggest above in order to help develop and evaluate the alternatives finally proposed.

Recommendations

By applying the methodology and assessing the fragmentation metrics we have described here, the BLM can better fulfill its obligations to evaluate the direct, indirect, and cumulative impacts of various management alternatives. Therefore, we formally request that the following actions be taken for any NEPA analysis of impacts from proposed oil and gas development:

1. **Conduct a spatial analysis of the direct, indirect, and cumulative impacts on wildlife of all proposed oil and gas development alternatives.**

   This step is necessary to demonstrate the use of the best available science and fulfill the BLM's legal obligations in evaluating alternatives in a draft resource management plan and draft EIS. The best available GIS data layers for wildlife habitat boundaries and status information for species potentially threatened by oil and gas development should be assembled. The latest biological literature on the impacts of road networks, oil and gas infrastructure, and related activities on local species should be collected. All infrastructure elements proposed or reasonably anticipated under each management alternative should be considered, and their combined impact on wildlife and habitat assessed. A spatial development simulation should be generated for the entire planning unit for each development alternative. These should incorporate, spatially and quantitatively, all existing and proposed infrastructure to accurately represent the construction of elements from the Reasonably Foreseeable Development Scenario (RFD) and the particular plan alternative. The analysis should yield the location and acreage or percent area where selected species of concern could be adversely affected by oil and gas development (with maps if possible). The results of this analysis should be reflected in each management alternative in the draft management plan and draft EIS, and reflect indirect and cumulative impacts in addition to direct surface disturbance. Efforts should be made to craft and select management plan alternatives that minimize the acreage of the planning area likely to experience direct, indirect, and cumulative impacts based on these results. The graphs and charts in this document (and included in Appendix A) can be used to help shape proposed alternatives and focus the analysis of them, but they cannot take the place of those analyses.

2. **Assess the habitat fragmentation effects of oil and gas development for maximum well-pad development densities.**

It is not uncommon for oil and gas field development to proceed much faster than the BLM anticipates, and for well and/or pad densities to quickly exceed those assessed during planning processes. A full range of development densities should be included in the EIS so that fragmentation effects are fully anticipated, understood, and controlled.

3. **Include oil and gas field development options that leave areas of threatened habitats undeveloped.**
   Because our results indicate that substantial impacts occur even at lower levels of oil and gas development, the BLM needs to consider means for leaving important wildlife habitat undeveloped. Clearly one option is to prescribe no surface occupancy (NSO) in particularly rare or sensitive habitat areas. Other management options available to the BLM include directional drilling to allow access to areas of NSO from adjacent lands. Phased development and cluster development, singly or in combination, can be implemented to allow some areas to be developed intensely while other areas are temporarily left undeveloped. This requires strict guidelines that prevent additional development until after the original development area has been reclaimed, keeping a specific portion of the landscape in large undeveloped patches and development clustered in limited areas.
4. **Conduct landscape-scale analyses to evaluate impacts and provide sound ecological protection for a landscape's wildlife, habitat, and other ecological resources.**
   The importance and complexity of using the best available science to plan at the landscape scale is increasingly recognized by scientists (Leitao and Ahern 2002, Szaro et al. 2005, Noss 2007). Many ecological functions such as the seasonal migrations of wildlife, connectivity required to prevent genetic isolation, and natural disturbances affecting wildlife habitat occur across broad landscapes. Indicators of wildlife impacts are spatial in nature and should be considered in a landscape context. Consequently, decision-making about oil and gas development and conservation of natural resources must be made at the landscape scale using spatial analysis of projected well-pad densities and other field development infrastructure.
5. **Use GIS technology to evaluate the impacts of oil and gas development on wildlife.**
   GIS is the best approach for this analysis because it is readily available and not costly. The analyses of direct, indirect, and cumulative impacts described above can be done with ArcGIS software that is already standard within the BLM and with its contractors. As mentioned earlier in this document, GIS is, in fact, already being used by the BLM for impact assessment in some locations (e.g., Las Cruces District, New Mexico). The automated placement of well pads (or other structures) in the simulation of step-wise development of oil and gas fields requires an ArcGIS software extension (CommunityViz) that is beginning to be used in some BLM offices. The GIS analyses suggested in this document are straightforward and do not require advanced modeling or scripting skills; further, the GIS data required for these analyses are already in the possession of most BLM offices. A modest investment of time (a tiny fraction of the total resources invested in BLM resource management plans) in carrying out these GIS analyses could substantially improve the NEPA compliance of resource management plans involving oil and gas development.
6. **Use landscape analysis techniques to improve public engagement.**
   In addition to helping the BLM meet its legal requirements under FLPMA, NEPA, and the Data Quality Act to use

the best available data and science, landscape analysis improves the ability of many constituencies and stakeholders to understand and engage in the land management planning process. The GIS inputs and results can be mapped to graphically illustrate an area's existing resources and threats to those resources under different management alternatives. For instance, maps can be made that display data on the location of elk critical winter range overlaying data showing where road density thresholds for significant impacts on elk will be exceeded under different management alternatives.

7. **Encourage research on habitat fragmentation indicators for wildlife of local importance.**
   Because of its authority over oil and gas management actions and the need for increased scientific understanding of wildlife responses to roads, well pads, and related infrastructure, the BLM should encourage field research monitoring the impacts of these on wildlife by wildlife agencies and research institutions.

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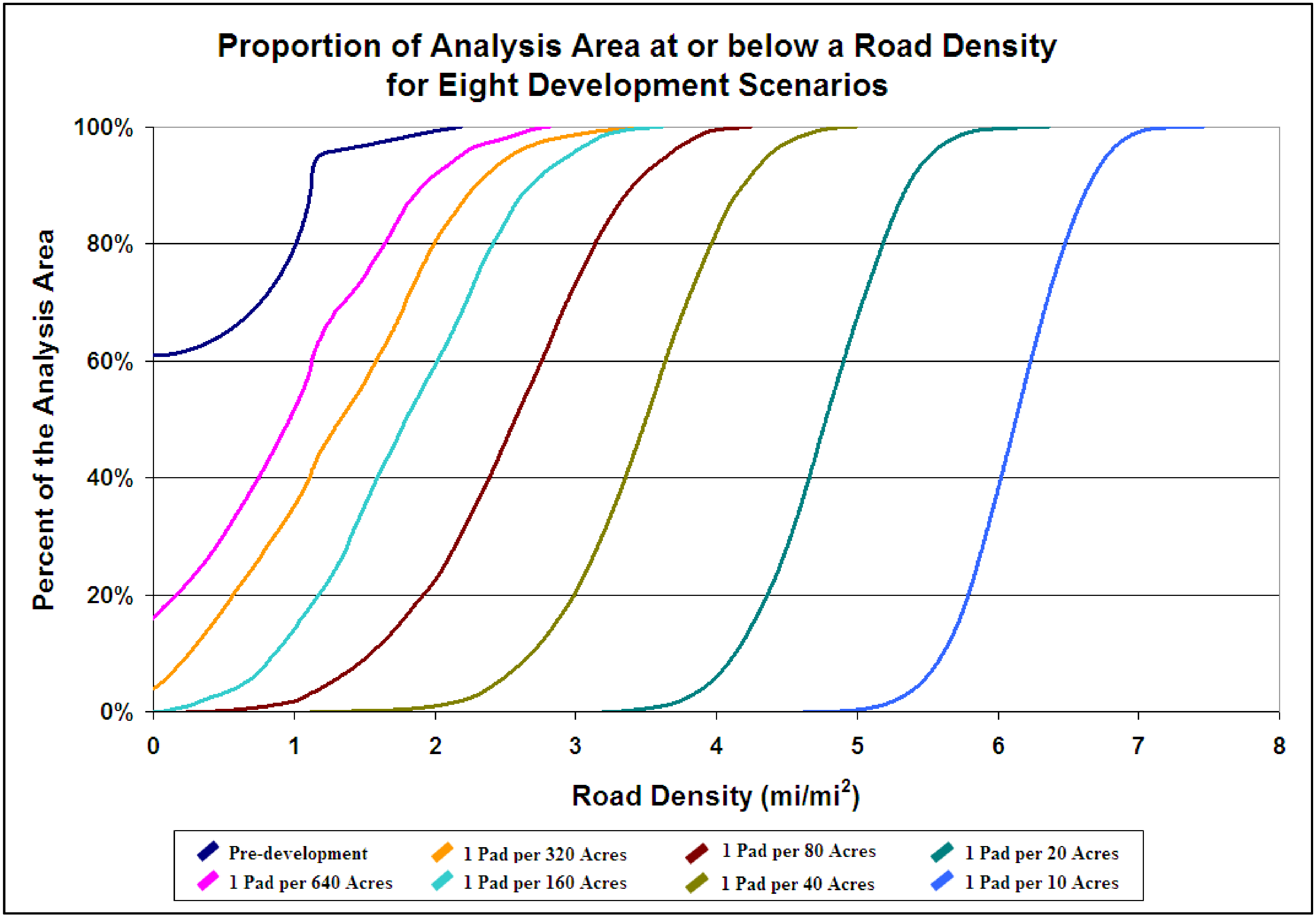
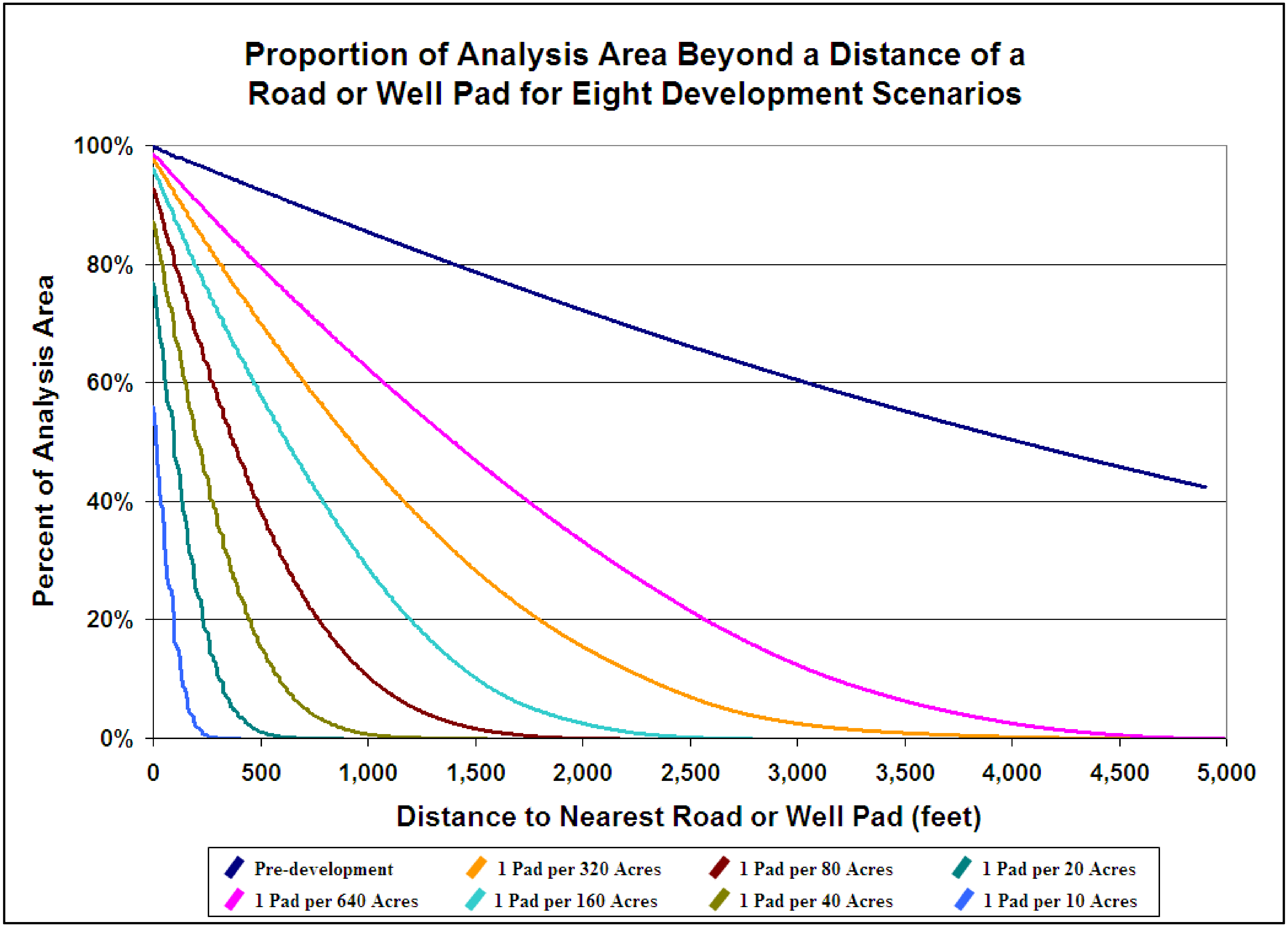
Appendix A: Graphical Tools for Preliminary Landscape Analysis

This appendix provides copies of the cumulative area distribution graphs for road density and distance to nearest road or well pad for eight common oil and gas development densities (originally presented in Figures 7 and 10 respectively). These graphs are intended to be used to plot indicator values found through a literature review for wildlife species in a planned oil and gas development area. The first graph allows the user to estimate what percent of the landscape has road density lower than a road-density indicator value found in the biological literature—the portion of the landscape likely to remain unaffected (or less affected) by a given level of development. The second graph allows the user to determine what percent of the landscape is farther from the nearest road or well pad than a distance-to-nearest-road indicator value—the portion of the landscape likely to remain unaffected (or less affected) by a given level of development.

As stated in the main body of this document, the value of these graphs lies in their utility as a coarse screen that can give a quick sense of the magnitude of habitat fragmentation impacts for potential development alternatives. Complete spatial analyses of the specific landscape for which oil and gas development plans are being made must still be done using techniques such as those we suggest in the main text in order to help develop and evaluate the alternatives finally proposed.


Proportion of Analysis Area at or below a Road Density
for Eight Development Scenarios
Percent of the Analysis Area
100%
80%
60%
40%
20%
0%
0
1
2
3
4
5
6
7
8
Road Density (mi/mi2)
Pre-development
1 Pad per 640 Acres
1 Pad per 320 Acres
1 Pad per 160 Acres
1 Pad per 80 Acres
1 Pad per 40 Acres
1 Pad per 20 Acres
1 Pad per 10 Acres


Proportion of Analysis Area Beyond a Distance of a
Road or Well Pad for Eight Development Scenarios
Percent of Analysis Area
100%
80%
60%
40%
20%
0%
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
5,000
Distance to Nearest Road or Well Pad (feet)
Pre-development
1 Pad per 320 Acres
1 Pad per 80 Acres
1 Pad per 20 Acres
1 Pad per 640 Acres
1 Pad per 160 Acres
1 Pad per 40 Acres
1 Pad per 10 Acres