Projecting County-Level Populations Under Three Future Scenarios

A Technical Document Supporting the Forest Service 2010 RPA Assessment

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August 2010

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Abstract

County-level population projections from 2010 to 2060 are developed under three national population growth scenarios for reporting in the 2010 Renewable Resources Planning Act (RPA) Assessment. These population growth scenarios are tied to global futures scenarios defined by the Intergovernmental Panel on Climate Change (IPCC), a program within the United Nations Environment Programme. The first of these scenarios, the A1/Census scenario, is equivalent to the current official U.S. Bureau of Census national projection, which, at the writing of this paper, extended to 2050. The second scenario, A2, is a higher population growth future, and the B2 scenario is a lower population growth future. The methodology for developing projections to 2060 is to disaggregate the above-mentioned national growth scenarios by using county shares of national population growth obtained from the Woods & Poole Economics Inc. projections of county populations from 2010 to 2030. A1/Census county projections from 2035 to 2060 are based on a recursive approach that extends past growth to project future growth, with adjustments to assure national additivity across counties and growth-dampening for the highest growth counties. The A2 and B2 county populations for 2010 to 2060 are derived from the A1/Census county projection shares.

Keywords: Climate change scenarios, county population projections, growth extrapolation, population trends, Resources Planning Act, U.S. population projections.

Introduction

In 1974, the Forest and Rangeland Renewable Resources Planning Act (RPA) was passed by Congress to require decennial assessments of the state of the Nation's forest and range resources (U.S. Forest Service 2001). This Act and the requirement of decennial assessments were prompted by the need for reliable, up-to-date information for setting policies, laws, management plans, and managing use of these resources. Originally, the emphasis was on supply and demand aspects of forest and range resources, but more recently the emphasis has expanded to include concerns about resource condition, ecosystem health, social relationships, and sustainability. Resource specialists, usually Forest Service research scientists, provide the technical expertise and data for several resource areas, such as timber, wildlife and fish, water, outdoor recreation and wilderness, range forage, minerals, and land base. A 5-year update, usually provided between each of the required decennial RPA Assessments, focuses on what has changed.

The RPA team of scientists prepared for the 2010 assessment by constructing models that forecast future trends in resource condition and demand. Future population projections were important to most of those modeling efforts. Because the RPA Assessment is on a 50-year time horizon, population projections to 2060 were needed for modeling and forecasting forest and range trends. The Bureau of Census provides national population projections to 2050 (U.S. Bureau of Census 2004), but those projections are not disaggregated to regional, State, and local scales. To have spatial definition, the planning for the 2010 RPA Assessment had to include specification to use county-level data where possible. Woods & Poole Economics Inc. (2006), an independent firm specializing in long-term county economic and demographic projections, provides county-level population projections, but those extend only to 2030. The primary problem addressed by this project was how to link Intergovernmental Panel on Climate Change (IPCC) scenarios, official U.S. Bureau of Census population projections, Woods & Poole Economics county projections, and a system for adjusting local growth or decline.

The objective of this paper is to provide methods and rationales for projecting county-level population from population at a base date of Dec 31, 2006, through 2060, based on (1) U.S. Bureau of Census national population projections to 2050, (2) the Woods & Poole county population projections to 2030, and (3) three selected IPCC population growth scenarios for the United States. The three population growth scenarios selected for the overall 2010 RPA Assessment represent a range of assumptions about possible future social, economic, and green house gas emission trends. The 2010 RPA Assessment modeling and forecasting builds upon the futures assumed under the three selected IPCC scenarios, including population futures.

Methodology

The *three population growth scenarios* framed within the IPCC scenarios (Nakicenovic and others 2000) are referred to as (1) the current status A1/Census, (2) high population A2, and (3) low population B2. In this paper, these scenario names will be used in shortened forms (fig. 1).

Let

P_i^{A1} = the national population in year *i* based on the A1/Census scenario,

P_i^{A2} = the national population in year *i* based on the A2 scenario, and

P_i^{B2} = the national population in year *i* based on the B2 scenario.

These population scenarios each consist of eleven 5-year population projections from the base date to 2060. These projections are obviously unknown, but considered as given upon which county-level population projections are disaggregated. An initial known population for Dec. 31, 2006, is also given and ties the three scenarios to a common, truly known origin. The United States has 3,141 counties, some of them actually municipalities, but this paper lists 3,140 counties, because there is no projection data available for Colorado's Broomfield County, which was formerly part of another larger county and only recently added to the Bureau of Census county listings (see the 2006 estimates data in U.S. Census Bureau, Estimates Program, Counties: http://www.census.gov/popest/counties/counties.html). The analysis in this paper considers the land area and population in Broomfield County as part of its former county.

National Population Projections for the Three Scenarios

The first step in the analysis was to develop *national projections* representing updates of the three original IPCC population projection scenarios. This step was based on the most currently available official U.S. Bureau of Census projection curve (U.S. Bureau of Census 2004). This official U.S. Bureau of Census national projection for 2000 to 2050 was substituted for the original IPCC A1 scenario. Scenarios A2 and B2 were computed from the A1/Census projections to maintain the proportionate relationship between the original A1, A2, and B2 IPCC population growth scenarios. The original IPCC A1 was considerably lower than the newer 2004 Census projection because it was based on the 1990 U.S. Census. The necessary adjustment was roughly equivalent to a simple upward shift of the IPCC A1 population change curve. The three population projection growth curves were given a common base population equivalent to the estimated Census population as of Dec. 31, 2006 (fig. 1).

A1/Census County Populations (2010 to 2030)

The A1/Census national projections from 2010 to 2030 were disaggregated to county level as the next step in the analysis. Woods & Poole county-level projections were used as the basis for this disaggregation. The Woods & Poole projections extend only to 2030, while the A1/Census national projection extends to 2050. From the Woods & Poole county projections for 2010 to 2030, we calculated *county shares* (proportions) of the Woods & Poole national total to disaggregate the A1/Census national population to county level for year *i* (*i* =2010, 2015, 2020, 2025, and 2030). Thus

P_i^{WP} = Woods & Poole national population in year *i* and

$C_{i,j}^{WP}$ = Woods & Poole population for county *j* in year *i*.

The Woods & Poole share for county *j* in year *i* is simply the ratio of the county population over the Woods & Poole national population, which is defined as

$$S_{i,j}^{WP} = \frac{C_{i,j}^{WP}}{P_i^{WP}} \qquad (1)$$

To obtain the A1/Census county populations, the shares defined by equation (1) are multiplied by the A1/Census national population, yielding the disaggregated county-level populations

$$C_{i,j}^{A1} = S_{i,j}^{WP}\, P_i^{A1} \qquad (2)$$

for year *i* and county *j* =1, 2, 3, …, 3,140.

A1/Census County Populations (2035 to 2060)

The A1/Census county populations are projected from 2035 to 2060 by adjusting the previous 5- to 10-year absolute growth for a given county such that the sum of the projections across all counties equals the A1/Census projected national total for that year. This *additivity adjustment* factor is required because the growth in the previous 5- to 10-year period may not necessarily be equal to the growth in the next period. A recursive population growth relationship is developed beginning at 2035 and is based on the 2030 county population obtained from the Woods & Poole shares (as explained previously). Execution of this system begins by projecting the 2035 A1/Census population for county *j* by defining the previous 5- to 10-year growth as

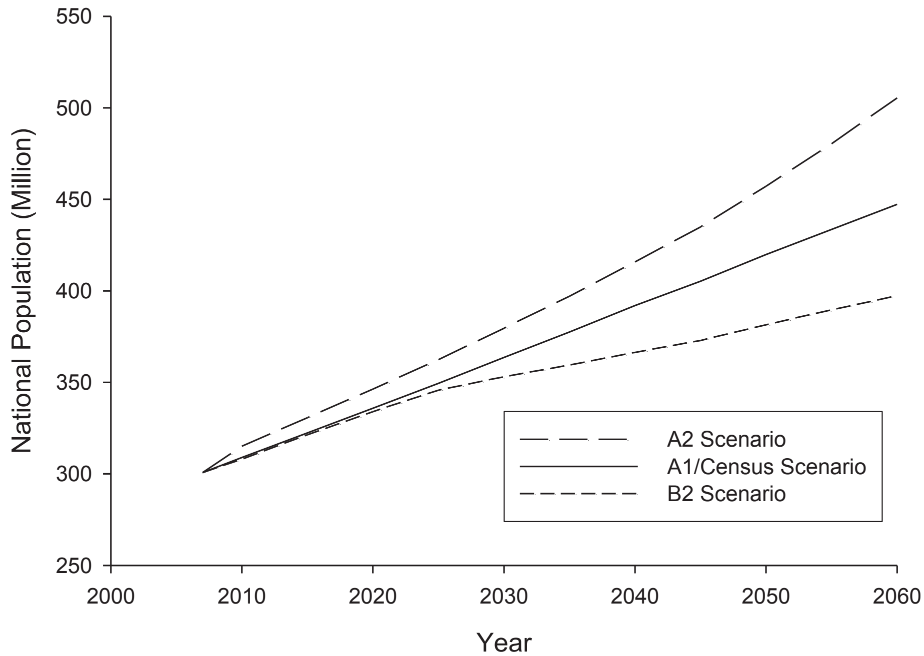

Figure 1—National population projections for the three climate change scenarios used for the 2010 RPA Assessment. The current population trend is the A1/Census scenario. A high population scenario is A2, while a low population scenario is B2.

$$G_{2035,j}^{A1} = C_{2030,j}^{A1} - C_{2025,j}^{A1} \quad (3)$$

Then the county-level population in 2035 is

$$C_{2035,j}^{A1} = C_{2030,j}^{A1} + \left(1 + A_{2035}\right) G_{2035,j}^{A1} \quad (4a)$$

if the growth during 2025 to 2030 is positive[1], or as

$$C_{2035,j}^{A1} = C_{2030,j}^{A1} + \left(1 - A_{2035}\right) G_{2035,j}^{A1} \quad (4b)$$

if the growth is negative. A_{2035} is the unknown additivity adjustment factor for year *i*. Note that if A_{2035} is positive, then all increasing counties have their growth increased by this proportion and all negative counties have their growth (actually decline in population) decreased (actually increase in population) by the same proportion. This assumption seems reasonable, i.e., that both increasing and decreasing counties should be adjusted with the same proportional adjustment.

Negative A_{2035} can also occur and is defined as a decrease in the population change rate. It is important to note that this adjustment is only on the change in county population between 2030 and 2035 and not on the total county population in 2035. This ensures that increasing (by population) counties will remain increasing and decreasing counties will remain decreasing after adjustment. If the additivity adjustment factor was developed for application to the total county population, it is possible to lose this constraint on how each county's future population will change over the entire projection period.

The additivity adjustment factor is unknown, but can be obtained by equating the A1/Census national population in 2035 to the sum of the increasing and decreasing county populations in 2035. Thus, summing equation (4a) over all increasing *p* counties with equation (4b) over all decreasing *n* counties ($p+n$ = 3,140), we have

$$\sum_{j=1}^{3140} C_{2035,j}^{A1} = \sum_{j}^{p} \left[C_{2030,j}^{A1} + \left(1 + A_{2035}\right) G_{2035,j}^{A1}\right] + \sum_{j}^{n} \left[C_{2030,j}^{A1} + \left(1 - A_{2035}\right) G_{2035,j}^{A1}\right] \quad (5)$$

Taking the summation sign through the brackets on the right hand side of equation (5) yields

$$\sum_{j=1}^{3140} C_{2035,j}^{A1} = \sum_{j}^{p} C_{2030,j}^{A1} + \sum_{j}^{p} G_{2035,j}^{A1} + \sum_{j}^{p} A_{2035} G_{2035,j}^{A1} + \sum_{j}^{n} C_{2030,j}^{A1} + \sum_{j}^{n} G_{2035,j}^{A1} - \sum_{j}^{n} A_{2035} G_{2035,j}^{A1} \quad (6)$$

[1]A 5-year growth of zero is considered positive growth.

and rearranging gives

$$\sum_{j=1}^{3140} C^{A1}_{2035,j} - \sum_{j}^{p} C^{A1}_{2030,j} - \sum_{j}^{n} C^{A1}_{2030,j} = \sum_{j}^{p} G^{A1}_{2035,j} + \sum_{j}^{p} A_{2035} G^{A1}_{2035,j} + \sum_{j}^{n} G^{A1}_{2035,j} - \sum_{j}^{n} A_{2035} G^{A1}_{2035,j} \quad (7)$$

The left side of equation (7) is the A1/Census national population in 2035 minus that in 2030, which simplifies to

$$P^{A1}_{2035} - P^{A1}_{2030} = \sum_{j}^{p} G^{A1}_{2035,j} + \sum_{j}^{p} A_{2035} G^{A1}_{2035,j} + \sum_{j}^{n} G^{A1}_{2035,j} - \sum_{j}^{n} A_{2035} G^{A1}_{2035,j} \quad (8)$$

Combining terms on the right side yields

$$P^{A1}_{2035} - P^{A1}_{2030} = \left[\sum_{j}^{p} G^{A1}_{2035,j} + \sum_{j}^{n} G^{A1}_{2035,j} \right] + A_{2035} \left[\sum_{j}^{p} G^{A1}_{2035,j} - \sum_{j}^{n} G^{A1}_{2035,j} \right] \quad (9)$$

Solving for A_{2035} we have

$$A_{2035} = \frac{P^{A1}_{2035} - P^{A1}_{2030} - \left[\sum_{j}^{p} G^{A1}_{2035,j} + \sum_{j}^{n} G^{A1}_{2035,j} \right]}{\left[\sum_{j}^{p} G^{A1}_{2035,j} - \sum_{j}^{n} G^{A1}_{2035,j} \right]} \quad (10)$$

Thus, given the A1/Census county level populations $C^{A1}_{2025,j}$ and $C^{A1}_{2030,j}$, then obtaining $G^{A1}_{2035,j}$ from equation 3, A_{2035} is calculated using equation (10). Substituting A_{2035} into equation (4a) or (4b) yields the projected 2035 A1/Census county-level population $C^{A1}_{2035,j}$.

The system of equations (3), (4a), (4b), and (10) is defined for projecting A1/Census county-level populations for 2035. This could be extended for subsequent 5-year periods by a recursive relationship for any year i (i =2035, 2040, 2045, 2050, 2055, and 2060) by using the following generalized system of equations

$$G^{A1}_{i,j} = C^{A1}_{i-5,j} - C^{A1}_{i-10,j} \quad (11a)$$

$$C^{A1}_{i,j} = C^{A1}_{i-5,j} + (1 + A_i) G^{A1}_{i,j} \quad (11b)$$

$$(\text{ if } G^{A1}_{i,j} \geq 0)$$

$$C^{A1}_{i,j} = C^{A1}_{i-5,j} + (1 - A_i) G^{A1}_{i,j} \quad (11c)$$

$$(\text{ if } G^{A1}_{i,j} < 0)$$

$$A_i = \frac{P^{A1}_{i} - P^{A1}_{i-5} - \left[\sum_{j}^{p} G^{A1}_{i,j} + \sum_{j}^{n} G^{A1}_{i,j} \right]}{\left[\sum_{j}^{p} G^{A1}_{i,j} - \sum_{j}^{n} G^{A1}_{i,j} \right]} \quad (11d)$$

High-density counties with high rates of growth exhibited explosive populations, while high-density counties with high rates of negative growth tended toward extinction. This result is because the system developed is very simplistic and does not take into account natural density dependent mechanisms that normally control such drastic population changes. Thus, a modification was developed to help alleviate this problem by *dampening such extreme continued growth increases or decreases*. All counties were characterized by their population density at the previous 5-year time period

$$DEN_{i,j} = \frac{C^{A1}_{i-5,j}}{Area_j} \quad (12)$$

and their density growth rate (growth per square mile)

$$DGR_{i,j} = \frac{G^{A1}_{i,j}}{Area_j} \quad (13)$$

where

$AREA_j$ = area (square miles) in county j.

Three fast increasing groups and three fast decreasing groups were defined based on each county's percentile rank for the $DEN_{i,j}$ and $DGR_{i,j}$ criteria. These groups were then assigned dampening factors $D_{i,j}$ that would adjust their growth slightly by decreasing positive growth and decreasing negative growth. Experimentation with the cut points for these groups, the dampening factors, and the population projections that they produced lead to the final criteria shown in table 1.

The development of the generalized system of equations that incorporates the dampening factor is analogous to that previously presented by equations (3) through (11d) with only slight modification. Defining growth as in equation (11a)

$$G^{A1}_{i,j} = C^{A1}_{i-5,j} - C^{A1}_{i-10,j} \quad (14a)$$

the A1/Census county populations are now defined as

$$C^{A1}_{i,j} = C^{A1}_{i-5,j} + (1 + A_i) D_{i,j} G^{A1}_{i,j} \quad (14b)$$

$$(\text{ if } G^{A1}_{i,j} \geq 0)$$

$$C^{A1}_{i,j} = C^{A1}_{i-5,j} + (1 - A_i) D_{i,j} G^{A1}_{i,j} \quad (14c)$$

$$(\text{ if } G^{A1}_{i,j} < 0)$$

The same derivation as shown in equations (5) to (10) could be employed to yield the dampened additivity factor defined as

$$A_i = \frac{P^{A1}_{i} - P^{A1}_{i-5} - \left[\sum_{j}^{p} D_{i,j} G^{A1}_{i,j} + \sum_{j}^{n} D_{i,j} G^{A1}_{i,j} \right]}{\left[\sum_{j}^{p} D_{i,j} G^{A1}_{i,j} - \sum_{j}^{n} D_{i,j} G^{A1}_{i,j} \right]} \quad (14d)$$

An example of the effect of dampening on high-density increasing populations is shown in figure 2. An example of dampening decreasing population is shown in figure 3.

The *effect of the additivity and dampening adjustment factors* is explored by projecting the A1/Census county populations and comparing their sums to the A1/Census national projections. When the additivity and dampening factors are not used, the sum of the projected county populations are very close to the A1/Census national projections but not equal to them (column 3, table 2). The additivity adjustment corrects this (column 4, table 2). The need for the additivity adjustment is more pronounced when dampening is used. Dampening without the additivity ajustment diverges from the A1/Census national projections, being about 4 percent (18,496,000) low at 2060 (column 6, table 2). Additivity corrects this, providing identical projected populations to that of the A1/Census national projections (column 7, table 2).

A2 and B2 County Populations (2010 to 2060)

The county population projections for the A2 and B2 scenarios are obtained directly from the county shares from the A1/Census county projections using the additivity adjustment and dampening methodology outlined by equations (14a) to (14d). The approach was to apply the exact same methods used to disaggregate A1/Census in order to disaggregate the earlier derived A2 and B2 national projections. Using this approach, the proportionate relationship between projected total national population for the A1/Census, A2, and B2 scenarios was preserved. This assures that the three scenario projections for a single county will not unexpectedly cross, which could occasionally occur if not thus constrained. Figure 4 illustrates the three scenarios for an increasing county and a decreasing county.

The A1/Census share for county *j* in year *i* is simply the ratio of the projected county population over the projected national population, which is defined as

$$S_{ij}^{A1} = \frac{C_{i,j}^{A1}}{P_i^{A1}} \qquad (15)$$

To obtain the A2 county populations, these shares defined by equation (15) are multiplied by the A2 national population, yielding the disaggregated A2 county-level populations

$$C_{i,j}^{A2} = S_{i,j}^{A1} P_i^{A2} \qquad (16)$$

Similarly, the B2 county populations are defined as

$$C_{i,j}^{B2} = S_{i,j}^{A1} P_i^{B2} \qquad (17)$$

The A2 and B2 county populations defined by equations (16) and (17) are for all years 2010, 2015, …, 2060. The Woods & Poole shares $S_{i,j}^{WP}$ could have been used for years 2010–2030 if desired because $S_{i,j}^{WP} = S_{i,j}^{A1}$ up to 2030. However, it was easier to be consistent and simply use the calculated A1/Census shares for all three scenarios and all years from 2010 to 2060.

Table 1—Criteria used to form the three density increasing groups (HI, MI, and LI) and the three density decreasing groups (HD, MD, and LD)

Group	Density $DEN_{i,j}$	Density Growth Rate $DGR_{i,j}$	Dampening Factor $D_{i,j}$	2035	2040	2045	2050	2055	2060
HI[1]	$D_{i,j} \geq 95$	$DGR_{i,j} \geq 95$	0.85	99	103	111	113	117	121
MI[2]	$90 \leq D_{i,j} < 95$	$DGR_{i,j} \geq 90$	0.90	122	123	123	125	127	130
LI[3]	$85 \leq D_{i,j} < 90$	$DGR_{i,j} \geq 85$	0.94	120	123	124	127	130	133
HD[4]	$D_{i,j} \geq 90$	$DGR_{i,j} \leq 10$	0.94	34	34	33	32	32	32
MD[5]	$80 \leq D_{i,j} < 90$	$DGR_{i,j} \leq 20$	0.96	29	24	24	24	23	22
LD[6]	$70 \leq D_{i,j} < 80$	$DGR_{i,j} \leq 30$	0.98	21	26	27	28	29	30

[1] HI = high density increasing group.
[2] MI = medium density increasing group.
[3] LI = low density increasing group.
[4] HD = high density decreasing group.
[5] MD = medium density decreasing group.
[6] LD = low density decreasing group.

Note: The cut point values for $DEN_{i,j}$ and $DGR_{i,j}$ are percentile rankings among all 3,140 counties. All counties that do not fall into one of these six groups are not dampened ($D_{i,j}$ = 1.0). The number of counties in each of the groups is shown for each year of the projection.

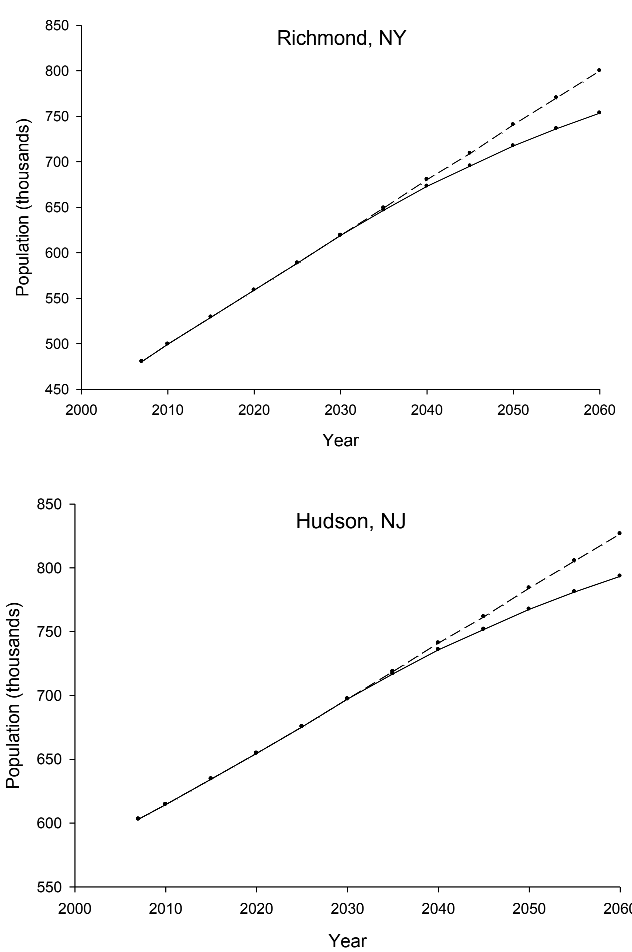

Figure 2—Increasing populations undampened (dashed line) and dampened (solid line).

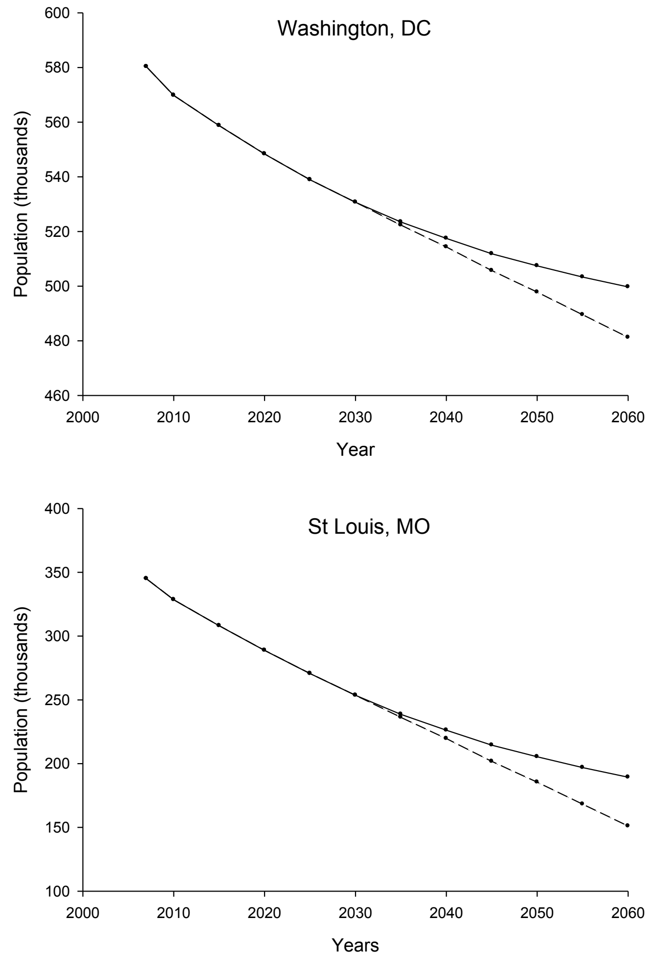

Figure 3—Decreasing populations undampened (dashed line) and dampened (solid line).

Table 2—The A1/Census population and the projected populations with and without the additivity factor and dampening

Column 1	Column 2 A1/Census Population	Column 3 Projected Population	Column 4 Projected Population	Column 5 Additivity Factor	Column 6 Projected Population	Column 7 Projected Population	Column 8 Additivity Factor
Additivity Factor	-	No	Yes	Yes	No	Yes	Yes
Dampened	-	No	No	No	Yes	Yes	Yes
	thousands						
Dec312006	300,716	300,716	300,716	-	300,716	300,716	-
2010	308,936	308,936	308,936	-	308,936	308,936	-
2015	322,366	322,366	322,366	-	322,366	322,366	-
2020	335,805	335,805	335,805	-	335,805	335,805	-
2025	349,439	349,439	349,439	-	349,439	349,439	-
2030	363,584	363,584	363,584	-	363,584	363,584	-
2035	377,474	377,730	377,474	-0.0171	376,587	377,474	0.0646
2040	391,946	391,875	391,946	0.0397	388,608	391,946	0.1207
2045	405,254	406,020	405,254	-0.0765	399,739	405,254	-0.0065
2050	419,854	420,165	419,854	0.0916	410,096	419,854	0.1714
2055	433,581	434,311	433,581	-0.0570	419,755	433,581	0.0077
2060	447,308	448,456	447,308	0.0000	428,812	447,308	0.0654

Note: The additivity factor is given for those projections which use the additivity factor.

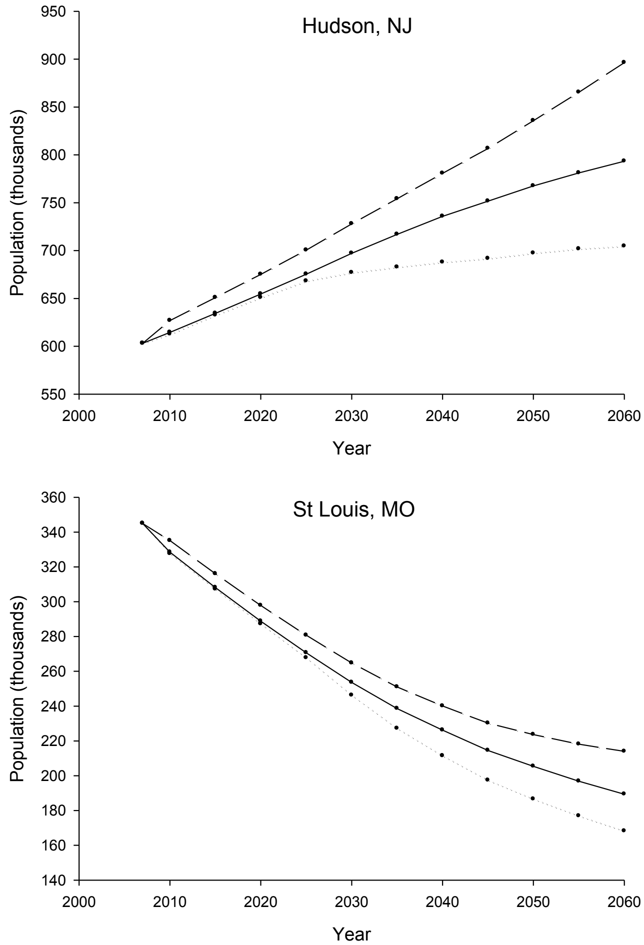

Figure 4—Population projections for the dampened and additivity adjusted A1/Census (solid line), and fitted A2 (dashed line) and B2 (dotted line) scenarios.

Conclusion

The scenario-based county population projection methodology developed for the 2010 RPA Assessment is very simple, but it is built on a consistent, recursive set of equations that ensures several desirable properties (see http://www.fs.fed.us/research/rpa/ for the specific county projections). Primary among these desirable properties is consistency in treatment across spatial and time dimensions. The three national scenario projections at the root of the resulting county population projections are based on selected IPCC scenarios for the United States. The most current Census projection was used as the best available substitute for the original A1 IPCC scenario. The A2 and B2 scenario substitutes were derived from A1 by maintaining the proportionate relationships between the original A1, A2, and B2 IPCC national population growth curves.

Individual county shares of national population for the A1/Census scenario for projection years to 2030 were obtained from Woods & Poole Economics Inc., CEDDS (Complete Economic and Demographic Data Source) data base. These shares were used to produce county-level estimates of the A1/Census scenario from 2010 to 2030 by disaggregating the national A1/Census scenario. Subsequent A1/Census population projections to 2060 were produced by a recursive approach that applied a dampening factor to modify extreme growth rates, along with an additivity adjustment to ensure that county populations sum to the national total for each scenario and each projection year. The additivity adjustment was applied to county growth to ensure that increasing or decreasing population counties will continue a consistent future trend.

The A2 and B2 scenario population projections for individual counties were then calculated in the same manner as A1/Census population projections. A2 and B2 national population projections used to substitute for the original IPCC projections were calculated to retain the relative proportional relationship between the original three scenarios. This also assured that scenario projection curves for counties did not cross at any point in the projection period. The effect of the additivity and dampening adjustments was evaluated using line graphs to visually inspect results as well as frequency tabulations of scenario projection differences at county level to detect crossing or merging curves.

Acknowledgments

We thank Guy Robertson of the U.S. Forest Service for offering feedback at the initiation of our research and Gary T. Green and Warren A. Brown of the University of Georgia for reviewing an earlier version of this manuscript.

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County-level population projections from 2010 to 2060 are developed under three national population growth scenarios for reporting in the 2010 Renewable Resources Planning Act (RPA) Assessment. These population growth scenarios are tied to global futures scenarios defined by the Intergovernmental Panel on Climate Change (IPCC), a program within the United Nations Environment Programme. The first of these scenarios, the A1/Census scenario, is equivalent to the current official U.S. Bureau of Census national projection, which, at the writing of this paper, extended to 2050. The second scenario, A2, is a higher population growth future, and the B2 scenario is a lower population growth future. The methodology for developing projections to 2060 is to disaggregate the above-mentioned national growth scenarios by using county shares of national population growth obtained from the Woods & Poole Economics Inc. projections of county populations from 2010 to 2030. A1/Census county projections from 2035 to 2060 are based on a recursive approach that extends past growth to project future growth, with adjustments to assure national additivity across counties and growth-dampening for the highest growth counties. The A2 and B2 county populations for 2010 to 2060 are derived from the A1/Census county projection shares.

Keywords: Climate change scenarios, county population projections, growth extrapolation, population trends, Resources Planning Act, U.S. population projections.

United States Department of Agriculture

Forest Service

Southern Research Station

e-General Technical Report SRS-128

August 2010