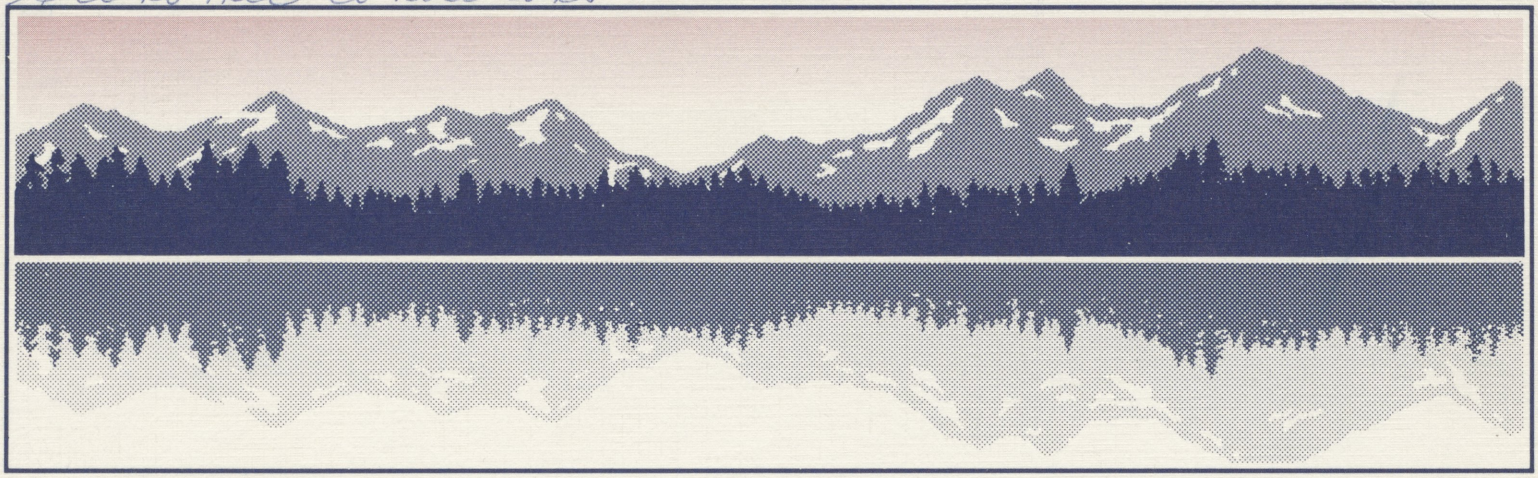

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HOUSING FORECASTS IN THE PACIFIC NORTHWEST:

A DISAGGREGATE APPROACH

by

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* The Bonneville Power Administration (Bonneville) and the Northwest Power Planning Council (Council) combined their forecasting efforts for 1988 and produced a joint forecast of long-term electricity use in the Pacific Northwest. During this process it became clear that the old methodologies for producing housing forecasts would not handle new demands for model inputs. The staff of Bonneville and the Council formed a joint workgroup to develop a new methodology for a more rigorous and flexible housing forecast. The authors of this report are the members of that workgroup.

Don Hoffard and Mark Farah of Bonneville and Terry Morlan of the Council directed the joint forecasting efforts. Nora Miller of the Council provided invaluable programming support.

This paper documents a new methodology. Comments and reviews are welcome and appreciated. Please contact Deborah Kitchin at the Council, (503) 222-5161, or Peter West at Bonneville, (503) 230-5824.

HOUSING FORECASTS IN THE PACIFIC NORTHWEST

The Bonneville Power Administration (Bonneville) and the Northwest Power Planning Council (Council) produce 20-year forecasts of regional electricity demand. These forecasts help map the Region's energy future and are used to evaluate resources, design programs, develop strategies and objectives, and define requirements. About one-third of the current and expected demand for electricity is for household use. The single most important factor influencing this residential demand is the number of housing units. This paper focuses on how Bonneville and the Council construct housing forecasts. Following an overview of what is required of a housing forecast, the paper details methodologies, assumptions, and results.

OVERVIEW

Housing forecasts have two fundamental and overlapping uses for Bonneville and the Council. The first is for the forecasts of electricity use for the next 20 years. The forecasts are important for resource assessment, acquisition, and management, and for transmission expansion, maintenance, and policy. This is a focus on the demand side; that is, it defines the levels of electricity use that will exist. The second use of the housing forecasts is for program design for conservation, weatherization, and new building standards. This is a focus on the supply side; that is, it defines what is likely to be available as an acquired resource from conservation. Both of these require a look at what types of housing will be built in the future, how much will be built, how long the current stocks of housing will last, and what will be the characteristics of the future housing stock.

Housing in the Pacific Northwest is forecast at a disaggregate level. The forecast considers three housing types (single family, multifamily, and manufactured homes) for two utility areas (public and private) for each state in the Bonneville service area (Idaho, Oregon, Washington, and the 16 counties in western Montana). Further, the stock of housing for each of these categories is specified for annual vintages beginning in 1900.

First, the forecasts take the historical housing stock by type and vintage and calculate how much of this survives over the forecast period. Projections of new construction by type are then added to the remaining stock each year to arrive at a new estimate of housing stock for each forecast year. The projections of new construction are composed of additions and replacements. Replacements are calculated from the non-surviving stock, and additions are calculated from the growth in population and households. Additions and replacements will also reflect expected shifts in the mix of new housing due to consumer preferences, land use patterns, economic conditions, and income growth.

This methodology does not forecast housing starts or permits. Electricity demand in the residential sector is based on a forecast of occupied housing units. The model assumes a longterm equilibrium approach with excess demand and supply expected to balance out over the longrun. As a consequence, occupied housing stock in any forecast year is equal to the total number of households forecast for that year.

HOUSING STOCK

In terms of electricity use, housing can be broken into three relevant categories: single family, multifamily, and manufactured homes. The single family category includes the traditional one-family detached home and both attached and detached structures with up to four units. Multifamily is defined as structures with five or more units. Manufactured homes includes houseboats, prebuilt homes assembled onsite, prebuilt homes trucked or towed to a site or installation, and miscellaneous other housing types.

The 1980 U.S. Census of Housing is used to define the base stock of housing for the states in the Region. In 1980, the Region's housing stock was 77.7 percent single family, 14.4 percent multifamily, and 7.9 percent other and manufactured.

In addition to housing by type and state, the stock is also categorized by vintage. The 1980 Census provides estimates of housing by decade from 1939 to 1980. Homes built before 1940 comprised 21.8 percent of the housing stock. The biggest increase in the housing stock came in the 1970s, with these homes accounting for 32.7 percent of the 1980 stock.

The following charts illustrate the composition of the 1980 stock by decade. Chart one shows the decade-by-decade shares for the total stock in the Pacific Northwest. As noted in the text, the homes built during the 1970s represent the largest proportion of the total stock. Housing built prior to the 1940s represents the second largest portion of the total stock. More than half the housing stock was either built before 1940 or after 1969.

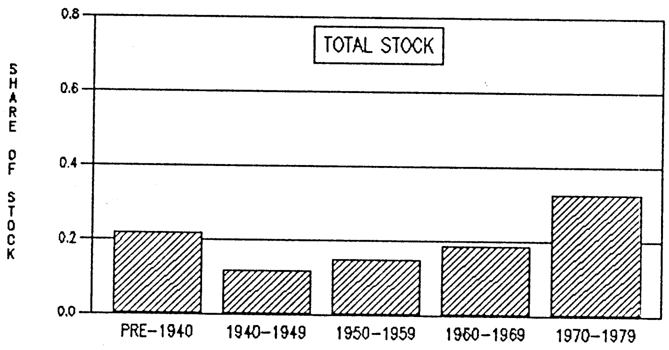


Chart 1

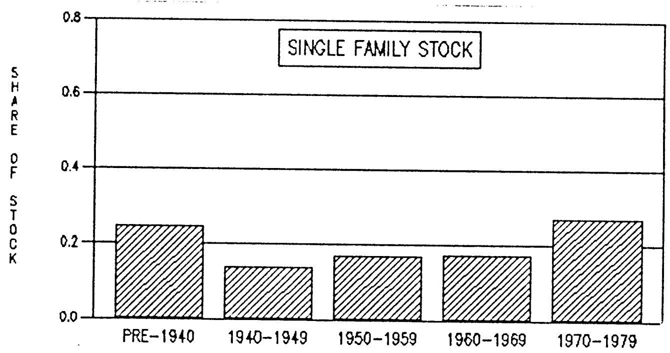


Chart 2

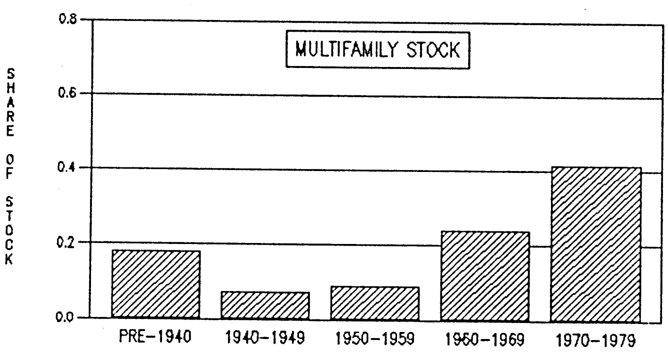


Chart 3

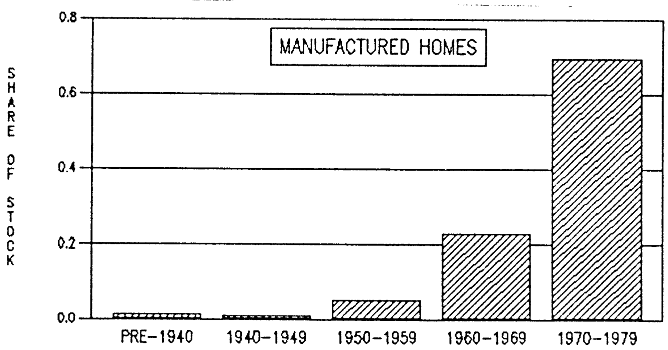


Chart 4

Chart two gives a breakdown of single family homes by the decade in which they were built. Single family construction is more stable from decade to decade than is construction of multifamily and manufactured housing. Single family construction comprises more than 75 percent of the total residential construction prior to 1980. The decade-by-decade shares for total housing (Chart One) tend to mirror those for single family homes.

Charts three and four show decade-by-decade construction of multifamily and manufactured homes. These charts illustrate the dramatic increase in the number of these types of units. To a large degree, the major expansion of the regional economy and its population during the 1970s was serviced by multifamily structures and manufactured housing.

The decade-by-decade estimates from the census are used as control totals for disaggregating the stock into yearly vintages. Secondary data from surveys sponsored by Bonneville are matched with the Census data to give year-by-year estimates of housing stock by type from 1900 to 1980 for each state in the Region.

The stock, as characterized by type, vintage, and state, is also divided into two additional categories based on utility type. The overall regional forecast of electricity is composed of separate forecasts for public and investor-owned (private) utilities. The separate utility-area forecasts are used to define some of Bonneville's Federal requirements under the 1980 Regional Power Act. Actual counts of residential customers by type of utility and housing type for each state are used to share out the historical data.

The actual forecast of the housing stock begins in 1981. Without intercensal estimates, annual housing stock in the 1980s is estimated. Intercensal estimates of population and households are used as proxies in determining historical growth in housing from 1981 to 1987. A special study done by the Census on households for 1981 to 1986 is used to help define the growth in the housing stock by state and by utility. For the 16 counties in western Montana, growth was estimated from population changes. This growth in households during the 1980s, plus the expected replacements of existing stock are used to estimate a base series for calibrating electric load forecasts through 1987.

The following sections explain how the housing stock is adjusted for new construction to account for additions, replacements, and other changes to the stock over time.

NEW CONSTRUCTION

The housing forecast deals with stock and new construction. The forecast of the stock of housing simply represents the sum of the previous year's stock plus new construction in the current year. Net new construction is the key component in the housing forecast, since it defines how the stock will grow and change over time.

As noted earlier, new construction is defined as the sum of additions to the housing stock and replacements of the current stock. Additions are simply the new housing units required to accommodate the growth in regional households over time. Replacements are new constructions required to replace homes that are retired from the stock due to age, demolition, destruction, and other factors. Retirements are subtracted from additions and replacements to arrive at net new construction.

Additions rely on a projection of households for each state. The household forecast is based on population growth and expected patterns for household formation. It is assumed that each household will occupy a housing unit of some type. Thus total new households equals total additions to the housing stock, as defined here. This assumption disregards vacancy rates and other supply factors. The focus for new additions is on the demand side.

The total number of additions are disaggregated into the three housing types for each state using marginal shares. These shares are listed in the Table One.

The marginal shares in Table One are based on an analysis of the change in housing stock from decade to decade and on current permits and completion data for actual new construction. These shares reflect changing economics, demographics, technology, and consumer tastes and preferences. The ranges (high, medium-high, medium, medium low, and low) reflect the uncertainties in future trends, conditions, and technologies. The marginal shares play a key role in adjusting the mix of housing types for the overall housing stock in the forecast.

Table One
New Construction Shares by Type, 1988-2010
(Percent)

Type of Homes	High	Medium-High	Medium	Medium-Low	Low
Single Family	76.2	66.7	62.4	58.0	48.0
Multifamily	13.9	17.4	19.8	22.2	29.7
Manufactured	9.9	15.9	17.8	19.8	22.3

In 1980 single family homes comprised about 78 percent of the housing stock, multifamily structures were about 14 percent of the total, and manufactured homes accounted for the remaining 8 percent. In comparison to these historical values, the marginal shares listed in Table One are lower for single family homes and higher for the other two categories. The consequence is that the proportion of single family homes will decrease over the forecast as the rate of new additions falls below the historical share. Of course, this also means that the relative shares of multifamily and manufactured homes will increase through the forecast period.

Given a household forecast and the marginal shares, the formula for deriving net new additions is:

$$\text{Additions}_{ijt} = (\text{Households}_{it} - \text{Households}_{it}\text{-}1) * \text{Marginal Share}_j$$

where, i = state
j = housing type
t = forecast year

Replacements comprise the second part of new construction and are a function of the number of homes retired from the existing housing stock. As the housing stock ages through time, some homes are retired from the stock because of age. Others are demolished due to natural causes or modified to accommodate other types of building activity. Forecasts of replacements begin by calculating a statistical probability of survival for each vintage and for each housing type. This statistical survival function represents an average aging trend for a particular housing type. The estimated survival function varies over time and allows for different rates of retirements for different housing types.

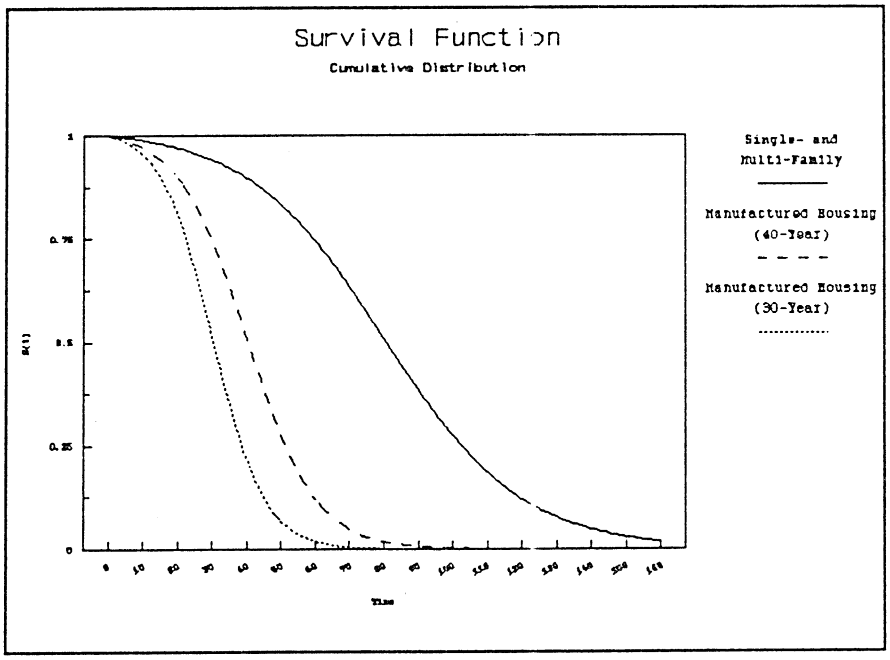
The survival function estimates a relationship between the cumulative probability of a house surviving to a given year and its age in that year. The general form of the survival function is:

$$\text{Survival Probability}_{vt} = 1 - (1/(1 + e **(a-b(t-v))))$$

where, v = original construction year, vintage
t = forecast year
a = 4
b = .05 for 80-year average life spans, or
.10 for 40-year average life spans, or
.133 for 30-year average life spans.

There are three separate survival functions estimated and defined in the forecast. The first is based on an average life of 80 years for single-family and multifamily housing. For manufactured homes built between

1900-1979 an average life of 30 years is assumed. For manufactured homes built after 1979 an average life span of 40 years is assumed. Graph One displays the survival functions. The shape of these functions imply a greater probability of survival in the early years, but as homes age over time, the likelihood of survival begins to decrease.



Graph 1

Given the assumed average life spans and the asymptotic character of the survival functions, nearly all the manufactured homes are retired after they reach 80 years of age. More than 99 percent of all single family and multifamily units are retired by the time they have aged 160 years.

An important empirical question arises as to the level of disaggregation appropriate for estimating a survival function. In theory, a separate function could exist for each individual housing unit based upon a number of variables such as geographic location, housing type, vintage, market value, etc. However, the empirical data seems to support specifying only the three functions illustrated in Graph One.

Appendix A addresses further issues and alternative functional forms for the survival curves.

Given a probability of survival, estimating the number of retirements is analogous to computing expected values. Retirements will equal the change in cumulative probabilities of survival for each vintage times the number of units of that vintage for a given year. Stated in terms of a retirement methodology, the expected number of retirements for a particular vintage and housing type:

$$\text{Retirements}_{ijtv} = \text{Housing Stock}_{ijtv} * (\text{Survival Probability}_{vt} - \text{Survival Probability}_{vt-1})$$

where,
- i = state
- j = housing type
- t = time
- v = vintage

As noted earlier, disaggregating the stock into vintages is accomplished by matching the Census counts with the survey data from the Pacific Northwest Residential Energy Consumption Survey of 1983 (PNWRES).

PNWRES collected data on the year of construction for 2,737 houses in the Pacific Northwest. The census data, with a larger regional coverage, are used as a control to split the housing stock into the decade of construction. The PNWRES data, with more detailed data on construction dates, are used to split the stock within each decade.

An advantage of accounting for the age distribution in estimating replacements is that it allows anomalies in historical housing construction to be considered. For example, an unusually large amount of housing construction occurred during the 1970s. Therefore, it is reasonable to expect there will also be a large number of retirements as houses of these vintages reach the end of their useful lifetimes. The methodology allows this bulge in the age distribution to move through time and affect replacement rates.

The number of retirements is summed across types and vintages to get a total number of retirements for any forecast year. This total is then disaggregated into housing types using the marginal shares defined earlier. This last step yields the number of replacements for the new construction forecast.

The calculation of replacements takes the form:

$$\text{Replacements}_{ijt} = \left(\sum_{v}^{V} \sum_{j}^{J} \text{Retirements}_{ijtv} \right) * \text{Marginal Share}_j$$

where, i = state
j = housing type
t = time
v = vintage

Retirements equal replacements in total, only. The marginal shares and the average life spans allow for differing rates of retirements and replacements among housing types. In fact, the marginal shares in Table One have the effect of retiring more single family homes than are actually replaced.

Housing Stock is adjusted over time based on new construction. This year's stock is a function of last year's stock, new additions, new replacements, and retirements. The final form for the stock adjustment is:

$$\text{Stock}_{ijt} = \text{Stock}_{ijt-1} + \text{Additions}_{ijt} + \text{Replacements}_{ijt} - \text{Retirements}_{ijt}$$

where, i = state
j = housing type
t = time

The last three factors in this formula define net new construction.

As mentioned in the beginning, Bonneville and the Council have used this housing methodology to forecast stock and new construction from 1981 to 2010. A forecast has just been completed and the results of this are summarized in the following section. These results illustrate the meaning and use of the methodologies outlined above.

FORECAST RESULTS

For the medium case the total housing stock increases at an average annual rate of 1.6 percent from 1988 to 2010. This yearly growth translates into a total increase of 1,414,800 units or 42.0 percent by 2010. Single family homes increase at an average annual rate of 1.4 percent, but show an actual decline in its overall share of the total housing stock. Single family homes are 77.7 percent of the stock in 1980 and drop to 71.0 percent by

2010. Single family homes will still be the single largest housing category in the forecast, but demographic, economic, and technological changes will shift the mix toward more manufactured and multifamily housing.

Again for the medium case, shares of multifamily housing increase from 14.4 percent in 1980 to 18.3 percent in 2010. Multifamily housing increases from 427,900 units in 1980 to 876,600 units in 2010. Manufactured housing increases its share of total housing from 7.9 percent in 1980 to 10.7 percent in 2010. The number of manufactured homes in 2010 nearly doubles from the amount in 1980 and represents a significant increase in this type of housing.

Tables Two and Three, below, summarize these forecasts of housing stock and illustrate how new construction affects the forecasts. Table Two shows the average annual growth rates for the range of forecasts developed by Bonneville and the Council. Table Three shows the shift in the composition of the housing stock over the forecast for all the ranges. This table illustrates the effect that the marginal shares have on the stocks of housing over time.

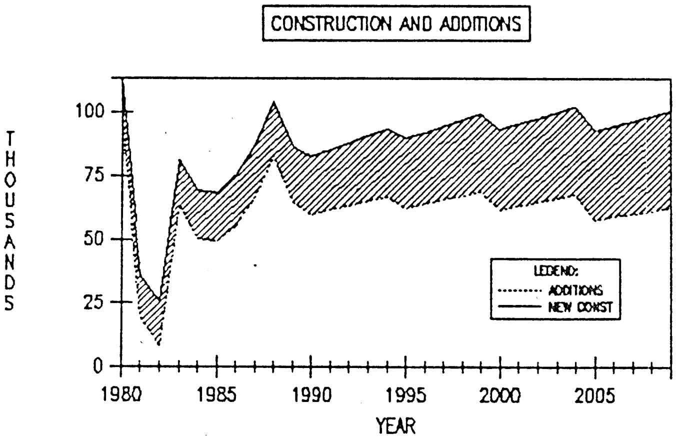
Table Two
Housing Stock Growth
Average Annual Rate of Change (%)
1988-2010

	High	Medium-High	Medium	Medium-Low	Low
Total Stock	2.8	2.0	1.6	1.3	0.4
Single Family (1-4 units)	2.9	1.8	1.4	1.0	0.1
Multifamily (5 and more)	2.7	2.4	2.3	2.2	1.4
Manufactured Home	2.2	2.6	2.3	2.1	0.6

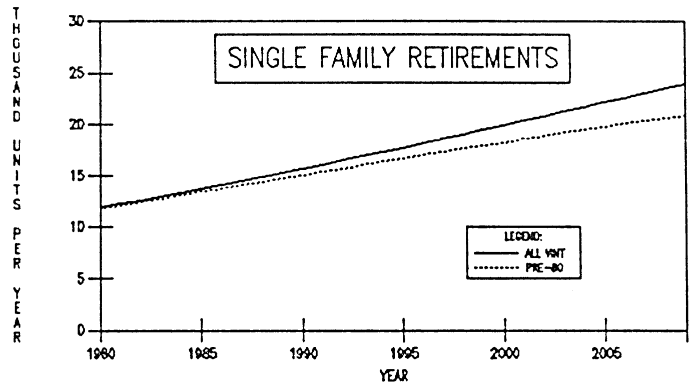
Table Three
Changes in Composition
Percent of Occupied Stock by Type
1988 - 2010

	1980	High	High	Medium Medium	Low	Medium Low
Single Family (1-4 units)	77.7	77.0	72.5	71.0	69.7	69.4
Multifamily	14.4	15.2	17.2	18.3	19.2	20.7
Manufactured Home 7.9	7.8	10.3	10.7	11.1	9.9	

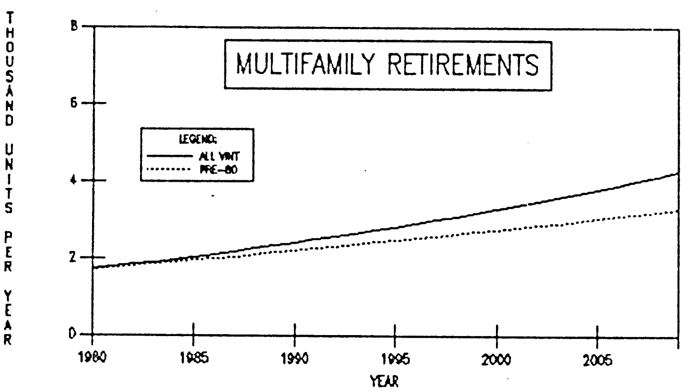
New Construction is forecast as a composite of retirements, replacements, and new additions. Graph Two breaks out the construction forecast by its components. Overall, new construction averages about 94,300 units per year in the medium case. The graph shows total new construction as the sum of additions and replacements. The dotted line represents the additions and the shaded area shows the number of replacements. The ratio of additions to replacements varies by year and scenario, but additions average 68 percent of new construction and replacements average 32 percent.



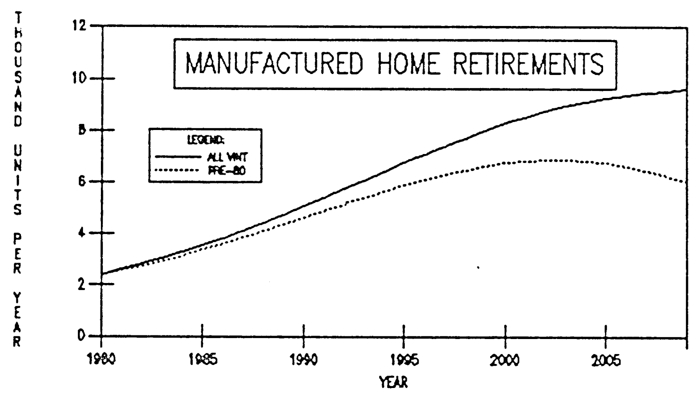
Graph 2



Graph 3



Graph 4



Graph 5

Graph Two illustrates the relative impacts of the household forecasts and the estimated survival functions. The forecast of additions is directly related to the shape and size of the household forecast and generally makes up the largest part of new construction. The replacements portion of new construction is relatively small in the early part of the forecast but grows significantly by 2010. The replacements are a function of the age structure of housing stock and the expected survival rates. By the end of the forecast period significant amounts of the pre-1940 stock are being retired and the post-1970 stock is beginning to show noticeable amounts of replacements.

The growing levels of replacements can be illustrated in the next series of graphs. Graphs Three, Four, and Five show the number of retirements for each housing type. These graphs show the total number of retirements along with those due to just the pre-1980 stock. The number of retirements grows significantly for all housing types over the forecast. This growth is what leads to the increasing amount of replacements in the new construction forecasts (reference Graph Two, again).

These last three graphs also reveal the impacts of the survival functions and the vintage mix of the housing stock. For all housing types, the number of retirements of post-1980 stock are relatively minor until the mid-1990s period. After 1995 the number of retirements of the post-1980 stock begins to grow significantly faster than the number of retirements of the pre-1980 stock. This is especially true for manufactured homes.

The large numbers of manufactured homes built in the 1960s and 1970s are more than half gone by the year 2000. This results from assuming an average life of 30 years for manufactured homes built before 1980. As the large stock of 1960s and 1970s vintages are increasingly retired from the stock the relative proportion of post-1980 retirements grows. This pattern for manufactured housing is likely to be repeated for multifamily housing for the period beyond 2010, since both housing types have shown the same historical growth. However, it will take longer for retirements of multifamily structures to exhibit a leveling pattern since the average life of these units is more than double that for manufactured housing.

Because single family stock and additions tend to be relatively more even across decades, the retirements will be more linear and exhibit less of the leveling pattern than for the other housing types. There will, of course, be periods of increasing retirements when a large stock of similar vintages are retired from the stock and replaced.

SUMMARY

As the results indicate, the overall housing forecasts are driven by the household forecasts. However, the forecasts are also sensitive to assumptions about the average lifetime for a surviving structure, the expected adjustments to the mix of housing (marginal shares), and the age structure of the base stock of housing (the disaggregation into vintages). Uncertainties about the overall size of the housing stock and changes in the housing mix are addressed in Bonneville's and the Council's forecasting processes through the use of a range of alternate growth scenarios. The average lifetimes and underlying age structures of the housing stock can be addressed through better historical data.

With some modifications, the methodology outlined here could be applied to sub-state and county levels. However, the uncertainties around the assumptions at the regional level could easily overwhelm small area forecasts and provide counterintuitive results. Extreme care should be taken when scaling down this methodology to make sure the assumptions are customized to the empirical and historical experience of the locality.

Census data and County records can define the housing stock and the various vintages at the county level. Given this assessment of housing by type and vintage and the average life of a structure, a PC spreadsheet is all that is needed to estimate survivals and replacements over a forecast period. Local permits data, land use practices, and preferences can be the bases for estimating marginal shares by type of structure for new replacements and additions. However, the key to this sort of application is likely to be the forecast of population and household growth for the future, if the area is growing.

At a more local level and for applications outside of residential demand forecasting, accommodations should be made for vacancies. Further, in vacation areas the methodology should account for non-resident ownerships and second homes.

The methodology presented in this paper address a disaggregate forecast of housing over the longer term. This forecast does not factor in business cycles or market disruptions. It is a tool for a general analysis for long term planning and should not be used to assess current market conditions or to prepare short term analyses.

APPENDIX A

Technical Considerations for Survival and Replacement Functions

Some alternative functional forms exist for the replacement function which maintain the hypothesized "S" shape. These alternatives allow more control over the underlying assumptions and perhaps, a replacement function that more accurately matches the data. Two general functional forms are examined here. In both cases a constraint is placed on the model such that the probability of replacement (P) is not less than zero and not greater than one hundred percent. A second constraint is also imposed such that at the limiting age of a house, the maximum lifetime, (L) the cumulative probability of replacement is one hundred percent.

The general form of the first equation is:

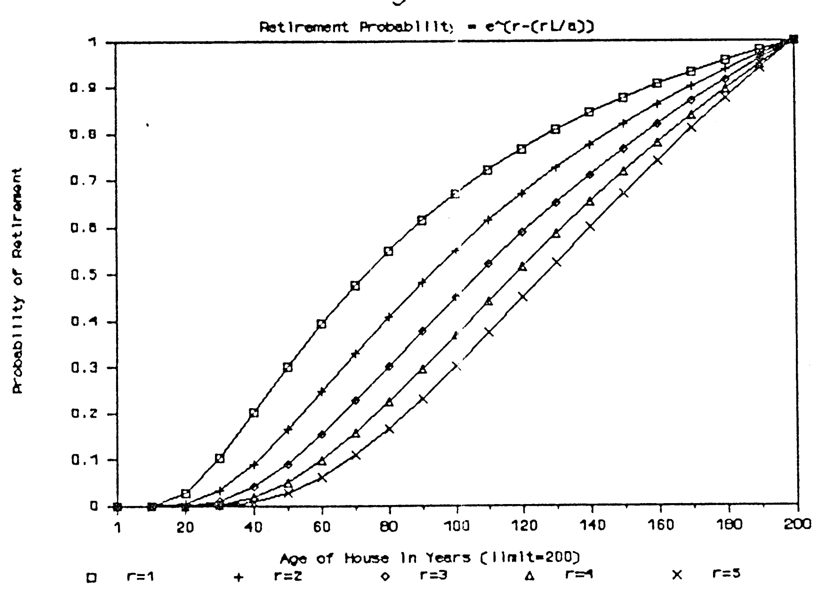
$$P = e^{**}(k1-(k2/t))$$

where, t = time,
k1, k2 = estimated parameters.

By respecifying the equation as $P = e^{**}(r-(rL/a))$, where a is the age of the house and r is the parameter estimated by the analyst to shape the curve, the equation satisfies the constraints. At the age limit (L), the probability of retirement equals e raised to the power of zero, or 100 percent. In turn the probability of retirement will approach zero for newer houses as the age of the structure approaches zero. The line estimated by this curve will have a asymptote at zero, reach one (100 percent) at the age limit set by the analyst and vary its shape depending upon r. It will always be symmetric with respect to time.

Figure 1 shows a graph of this function with r values ranging from one to five and a 200-year limit.

Figure 1



The second formulation relaxes the constraint of symmetry over time. This alternative form is a weighted average of an exponential growth function and an inverse exponential (or decay) function. The relative weights for each function will vary over time. There are two parameters to vary in this formulation: the rates of growth and decay in the functions themselves and the rate of change in the relative weighting between the growth and decay functions. The general form is an exponential function and can be specified as: P = (100**(1/r)) * ((a/L)/r).

When r is greater than one the equation estimates an exponential growth and when r is less than one the equation estimates an exponential decay function. By solving the equation twice, once with r greater than one and once with the inverse of r, two lines are estimated which represent the mirror image of each other. As r becomes larger the rate of change for both functions will increase and the spread between the functions is greater.

If a weighted average of these two lines is computed with the weight gradually shifting from the growth to the decay function over time, then the desired "S" shape over time will be computed. As the exponential form given above is constrained to shift between zero and one over time, it can also be used to derive the relative weights. The general equation is again solved for all ages with a selected value of w substituted for r. The weight for the growth function at any age equals the probability associated with that age; and the weight for the exponential decay is simply one minus the probability. There is no a priori reason why the parameters r and w need to be the same. This allows the analyst to vary two parameters: r, the rate of growth/decay and w, the rate of change in relative weights. In essence, the parameter r varies the vertical slope of the curve, and the parameter w varies the horizontal slope which relaxes the constraint of time symmetry.

To summarize, the general functional form, specified in the preceding paragraph, is solved for all ages (a) up to the limit (L). First it is solved with the parameter r set by the analyst and second with the inverse of r. Larger initial values of r will produce greater rates of change — a wider spread between the growth and decay function. Next, the same general equation is solved with the parameter w specified by the analyst to determine the rate of change in relative weight from the growth to the decay function. By defining the general equation to be the function, f, the complete functional form is given as:

$$[f(w)*f(r)] + [(1-f(w))*f(1/r)]$$

Figures 2.1 to 2.4, which follow, show the results for combinations of r and w with values of two and three.

Several additional issues arise in a more rigorous treatment of the estimation of the replacement function. One such issue is the treatment of houses which had not been demolished before the time of the study. Such data introduces "right censored" observations into the analysis. Replacement data are limited in that significant replacement probabilities can be expected for over one hundred years and complete data for this time span are not available. The limited amount of data and the relatively long time between data generations did not permit rigorous testing of alternative functional forms for the replacement function.

Statistical techniques have been developed to deal with the above data problem. These techniques generally involve estimation of a "hazard function" which is the ratio of the first derivative of the replacement function to the survival function. The ratio is then estimated as one of several probability density functions. If the data can be handled in such a rigorous manner, then statistical tests can be performed to determine if replacement functions for different categories of data such as housing type or vintage are significantly different. Such a further extension of the model would incorporate explanatory variables other than time in the determination of the probability of replacement.

Figure 2.1

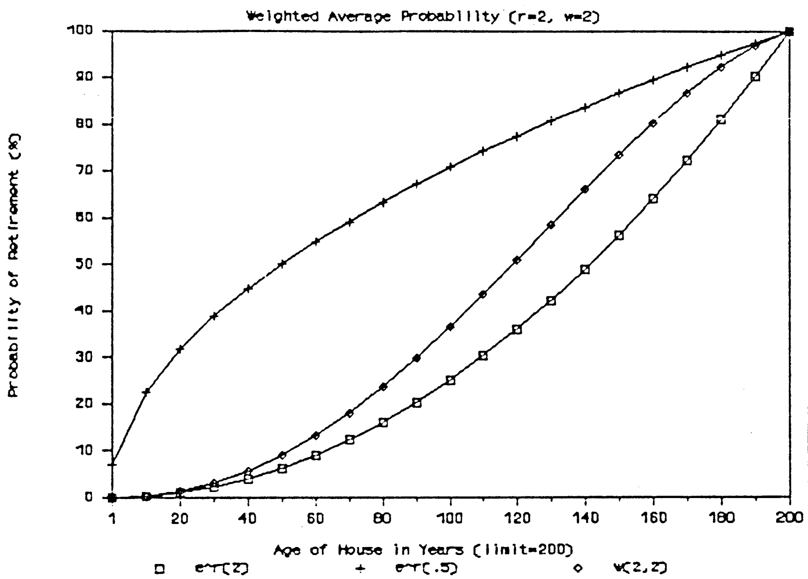


Figure 2.2

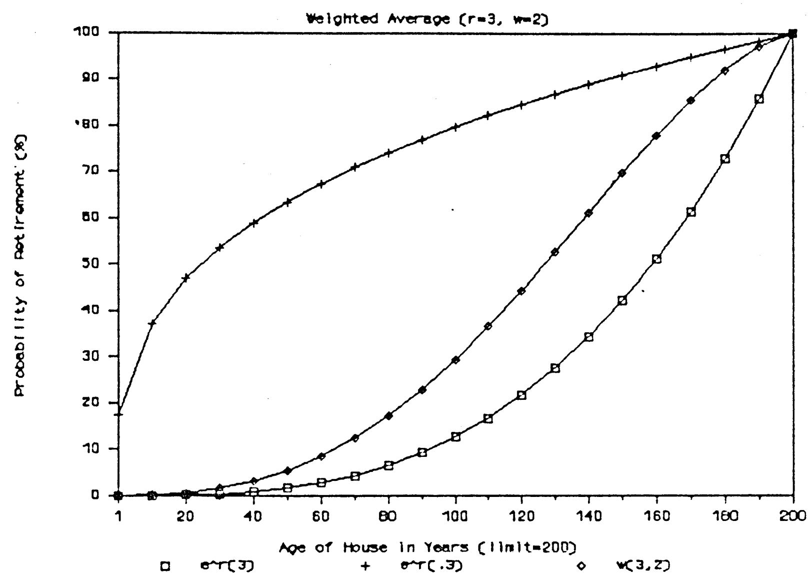


Figure 2.3

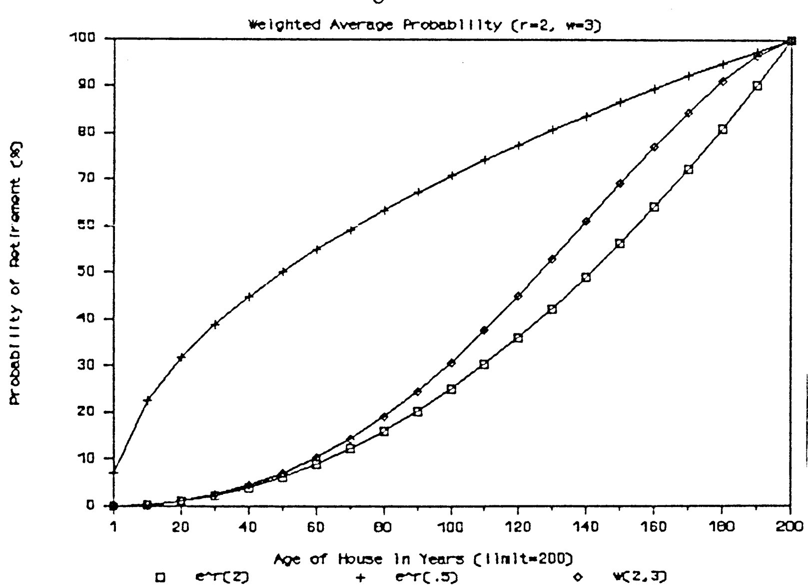


Figure 2.4