# Continuous Mortality Investigation

# User guide to version 1.1 of the CMI Library of Mortality Projections

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**Contents**



**It remains the responsibility of any actuary or other person using a projection of future mortality to ensure that it is appropriate for the particular purpose to which it is put, regardless of whether the projection is contained within the library.**

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## 1 Background

The CMI has in recent years incorporated projections of future mortality into its published mortality tables that have been extensively used by UK actuaries in pricing and valuing life insurance and pension scheme risks.

During its work on the "00" Series tables, the CMI undertook extensive research into mortality projections but came to the conclusion that it was unable to present a single view of the future, as had been attempted with preceding mortality tables. The final "00" Series tables adopted by the UK Actuarial Profession with effect from 1 September 2006 did not contain any projections. It soon became clear that the absence of projections left a gap that has caused much debate, both within the Profession and between the Profession and interested external stakeholders.

The CMI - and the Actuarial Profession as a whole - recognised the need to make the CMI's recent work more accessible to actuaries. As a result, the CMI formed a Task Force which produced a draft "library" of mortality projections which was published, together with CMI Working Paper 27, in July 2007. Meetings to discuss the library were held in Edinburgh on 18 July and at Staple Inn Hall on 20 July and 26 July.

The Task Force invited feedback on all aspects of the library of mortality projections and Working Paper 27. Over 40 responses were received from a variety of individuals and companies. The Task Force considered all the comments received, together with points made in discussion at the various meetings, and whether – and how – these should be reflected in the initial library. The feedback and the task force's response are documented in CMI Working Paper 30, which the CMI published simultaneously with version 1.0 of the library and a user guide to the library in November 2007.
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The CMI always envisaged that the library would be a "living document" and that further projections might be added in time. (Future updates were discussed in Working Paper 27 and are also addressed in section 9 of the user guide.) Consequently a small group was established to oversee the future management of the library, comprising: Gordon Sharp (Chair), Kevin Armstrong (also a member of the CMI Life Office Mortality Committee) and Brian Wilson (CMI SAPS Mortality Committee), with Dave Grimshaw as Secretary.

Version 1.1 of the library was released in March 2009 containing 15 additional projections; these have been generated using three models – P-Spline age-period, P-Spline age-cohort and Lee Carter – applied to five new datasets: ONS data to 2006 and to 2007 for both Males and Females, and CMI Assured Lives data to 2006 for Males only. For all these projections, the same age ranges and knot spacings have been used as for the projections using data to 2005 contained in version 1.0 of the library.

The user guide has now been updated in order to document the contents of version 1.1 of the library.

Additional background information on the changes incorporated in version 1.1 of the library is contained in Working Paper 37.

Please note that as the changes made from version 1.0 of the library are limited to additional years of data, the CMI is not undertaking a consultation exercise on version 1.1 of the library.

Any comments on the library of mortality projections can be sent via e-mail to projections@cmib.org.uk or in writing to: Dave Grimshaw, CMI, Cheapside House, 138 Cheapside, London, EC2V 6BW. Such comments will be considered for future work.

# 2 The library of projections

Considerable work has been undertaken in the area of mortality projections in recent years, much of it of a highly technical nature. The CMI has published the library of projections in the hope that it will provide a useful reference source for actuaries working in this area.

It also aims to establish a well-defined vocabulary for mortality projections; the need for this arises, for example, from:

- Scheme Funding discussions between employers and trustees, and
- Life offices' communications with rating agencies, analysts, shareholders and others.

The CMI believes that each of the projections within the library is sufficiently well-defined that it can be uniquely identified. In addition within this document we seek to indicate where divergences from these projections need to be disclosed, for clarity, and in some cases suggest how this should be done.

**It is very important to note that none of the projections is recommended for any particular situation and their inclusion in the library does not imply suitability.**

**Furthermore the fact that any particular projection is *not* included in the library does not imply that it is unsuitable.**

**Provision of the library does not take away the need for individual actuaries to use their judgement and make recommendations best suited to the firm or scheme.**

Version 1.1 of the library of projections is contained in a series of spreadsheets (referred to in this user guide as "volumes"). The projections in the library are summarised in the table in Appendix A. This section seeks to explain how they can be used. More details on the derivation of the different projections are set out in subsequent sections of this paper.

The CMI does not intend that these projections should form part of the "00" Series or "S1" Series of mortality tables. Each of the projections contained within the library could – in theory – be used with any assumption of base mortality, i.e. projections are not uniquely associated with a particular base table as was the case with projections such as those contained within the "92" Series tables. It is, though, for the actuary to ensure the suitability of any particular projection in conjunction with the particular base table that is used as the starting point for a projection.

Each sheet within each spreadsheet contains a different projection (except the first page of each spreadsheet entitled "Notes"). The following points apply to all these projections:

- Each sheet contains a two-way table of cumulative mortality reduction factors, by age and calendar year.
- These cumulative reduction factors can be defined as:

  $$RF(x,t) = q_{x,t} / q_{x,0}$$

  where x is the age, t is the elapsed time from the Start Year.
- Thus each sheet starts from values of 100% in the Start Year and subsequent columns show the cumulative reduction factor to the year in question.
- The ONS 2004-based Population Projections commence in 2004 and the ONS 2006-based Population Projections in 2006.

- All the other projections in the library commence in 1992. The improvements between 1992 and 2005 in each sheet are a mixture of projected values and actual values, as follows:
  - For the Original “92” Series, all of the figures are projections.
  - For other projections where the Base Year is later than 1992 (e.g. P-spline projections using data to 2004) then the figures between 1992 and the Base Year are smoothed actual improvements, with the smoothing coming from the relevant model. Actual smoothed improvements are indicated by shading within the library itself.
  - The Interim Cohort Projections are an adaptation of the “92” Series projections that reflect actual smoothed improvements up to 1999 for one particular cohort only (see section 3 for more detail).
- In all cases, the projections in the library are shown to 2130, regardless of the length of the projection period used to derive the projection.

***Naming convention***

One of the aims of the library is to produce a standardised terminology for use between actuaries. The projections included in the library are not intended to include every projection that an actuary might consider it appropriate to use, nor does it seek to prescribe methods by which projections should be derived. However it is intended that if the naming convention is used, as a form of shorthand descriptor, then the projection should be used as set out in the library and in this document, or calculated in a consistent manner where indicated. Any departure from this should be specifically noted.

In an attempt to keep the proposed names brief, the names assigned to the P-spline and Lee-Carter projections intentionally do not include all aspects of the derivation of the projection. For example, the names of these projections do not currently state the age range that has been used; however it is intended that if projections are produced using a different age range to that indicated in the library, this would need to be specifically disclosed.

***Age and year definitions***

For each projection, “age” is defined as “age exact” as in base tables of mortality produced by the CMI. There is no precise definition of the calendar period to which CMI base tables relate. The "00" Series tables, for example, are based on data from calendar years 1999 to 2002. The actual point to which mortality rates graduated from this dataset apply depends on how data volumes are spread over the quadrennium and how experience varies over the quadrennium. However in order that the projections contained in the library can be used consistently, we have assumed that the mortality rates apply to lives attaining each particular age $x$ at 30 June 2000.

A consistent approach should be taken with earlier CMI-produced tables, such as the "92" Series.

As discussed in section 8 of Working Paper 35, the mortality rates in the “S1” Series SAPS tables are deemed to apply to a life attaining age $x$ exact on 1 September 2002. The CMI considers it would be spurious accuracy to interpolate between the years of improvement in projections from the library when combined with a Series 1 base table, especially given the arbitrary nature of the designated date. Consequently, application of a projection from the library from (say) year $T$ to year $T+1$ should be applied identically whether to a “00” Series table (with a designated date of 30 June 2000) or a “S1” Series table (with a designated date of 1 September 2002), or disclose what has been done,

Note that this means that the same improvement rate (from year *T* to year *T+1*) is being applied regardless of whether the year is from 30 June (for a “00” Series table) or from 1 September (for an “S1” Series table).

If an actuary is using a base mortality assumption derived from other than a CMI table, they will need to have due regard to the definition of that table with regard to age and calendar year, but should convert it to “age exact at 30 June” if it is then being projected using a projection from the library, or based on one from the library, or disclose what has been done.

Example 1: “00” Series table
If one applies the medium cohort projection (sheet 4 of volume 1) to a base mortality assumption of 100% PNML00, then the generated mortality rates for a male aged 65 exact at 30/6/2000 would be:

| **Age** | **Year** | **Derivation** | **Rate** |
|---|---|---|---|
| 65 | 30/6/2000 – 30/6/2001 | “00” Series tables based on age exact and assumed to relate to 30/6/2000, hence $q_{65}$ at 30/6/2000 can be read from the table as $q_{65}$ = 0.012853 | 0.012853 |
| 66 | 30/6/2001 – 30/6/2002 | Base table value of $q_{66}$ taken to be 0.014141;<br>Improvement from 30/6/2000 to 30/6/2001 =<br>1 - 65.6255/68.4657 = 4.1484%;<br>Adjusted value of $q_{66}$ = 0.014141 * (1 – 0.041484) | 0.013554 |
| 67 | 30/6/2002 – 30/6/2003 | Base table value of $q_{67}$ assumed to be 0.015689;<br>Improvement from 30/6/2000 to 30/6/2002 =<br>1 - 62.2531/67.7614 = 8.1290%;<br>Adjusted value of $q_{67}$ = 0.015689 * (1 – 0.08129) | 0.014414 |

(NB we have followed the CMI convention that mortality rates are rounded to 6 d.p throughout. Rounded values of the improvements from the library are shown in these examples but, in practice, we would expect actuaries to use the numbers direct from the library, i.e. in unrounded form.)

If mortality rates at age 65 are required as at 31 December 2000 using a "00" Series base table, for example, rather than at 30 June 2000 then (unless otherwise disclosed) it is necessary to incorporate an allowance for improvements during that half-year and the derivation of the rate at age 65 using the medium cohort projection will become:

- “00” Series tables based on age exact and assumed to relate to 30/6/2000;
- Need to allow for improvements for half-a-year between 30/6/2000 and 31/12/2000;
- Improvement from 30/6/2000 to 30/6/2001 at age 65 = 1 - 66.4489/69.1763 = 3.9427%;
- Improvement from 30/6/2000 to 31/12/2000 assumed to be 1 - [(1 – 0.039427) ^ (184 / 365)] = 2.0074%;
- Hence $q_{65}$ at 31/12/2000 can be estimated as $q_{65}$ * (1-0.020074) = 0.012595.

Example 2: “S1” Series table
If one applies the medium cohort projection with a 1% minimum (sheet 2 of volume 2) to a base mortality assumption of 100% S1PFL, then the generated mortality rates for a female aged 60 exact at 1/9/2002 would be:

| Age | Year | Derivation | Rate |
|---|---|---|---|
| 60 | 1/9/2002 – 1/9/2003 | "S1" Series tables based on age exact and assumed to relate to 1/9/2002, hence $q_{60}$ at 1/9/2002 can be read from the table as $q_{60}$ = 0.006115 | 0.006115 |
| 61 | 1/9/2003 – 1/9/2004 | Base table value of $q_{61}$ taken to be 0.006422;<br>Improvement from 1/9/2002 to 1/9/2003 =<br>1 - 65.5926/67.6713 = 3.0717%;<br>Adjusted value of $q_{61}$ = 0.006422 * (1 – 0.030717) | 0.006225 |
| 62 | 1/9/2004 – 1/9/2005 | Base table value of $q_{62}$ assumed to be 0.006808;<br>Improvement from 1/9/2002 to 1/9/2004 =<br>1 - 63.0536/66.9230 = 5.7819%;<br>Adjusted value of $q_{67}$ = 0. 006808 * (1 – 0.057819) | 0.006414 |

If mortality rates at age 60 are required as at 31 December 2002 using a "S1" Series base table, for example, rather than at 1 September 2002 then (unless otherwise disclosed) it is necessary to incorporate an allowance for improvements during that part-year and the derivation of the rate at age 60 using the medium cohort projection with a 1% minimum will become:

- "S1" Series tables based on age exact and assumed to relate to 1/9/2002;
- Need to allow for improvements for four months between 1/9/2002 and 31/12/2002;
- Improvement from 1/9/2002 to 1/9/2003 at age 60 = 1 - 66.0063/68.1890 = 3.2009%;
- Improvement from 1/9/2002 to 31/12/2002 assumed to be 1 - [(1 – 0.032009) ^ (121 / 365)] = 1.0727%;
- Hence $q_{60}$ at 31/12/2002 can be estimated as $q_{60}$ * (1-0.010727) = 0.006049.

***Limiting Age***

All of the projections within the library assume a limiting age of 120, i.e. that $q_{120}$ = 1, throughout the period of the projection. This, and the assumptions at ages 90 to 119 more generally, are considered further in section 8 below.

***Differential smoking or health status***

It is common practice to differentiate between smokers and non-smokers for certain assurances and similar practice is now being applied to annuity pricing. All of the projections within the library have been derived from data that is not differentiated by smoker status and actuaries will need to give additional consideration to whether modification is required for smoker-differentiated business. Similar considerations also apply in respect of substandard lives, especially if these constitute a significant part of the portfolio.

***ONS classification of deaths***

The ONS data used in v1.0 of the library (and earlier CMI research into P-spline and Lee-Carter) classified deaths on an Occurrence basis for the years 1993-2005, with a Registration basis used for all earlier years.

The ONS has now moved to classification of deaths on a Registration basis for all years, so the 1961-2006 and 1961-2007 datasets give us previously unused Registration death data for 1993 onwards.

The projections included in version 1.1 of the library that use the ONS datasets to 2006 and 2007 are therefore inconsistent with those that were included in version 1.0 using data to

2003, 2004 and 2005. The CMI has not amended these earlier projections within version 1.1 of the library, however the impact of the data change is illustrated for the 1961-2005 dataset in Working Paper 37.

# 3 Previously-published tables of projections

***The original "92" Series***

Full details of the projections that were incorporated in the "92" Series tables are contained in section 6 of CMI Report No. 17.

In brief, the Committee sought to reflect recent trends in observed experience, with particular attention to the period 1975-1994. Despite differences between the various CMI investigations, it was decided to use a single projection. In particular this applied to females as well as males, even though no clear pattern could be discerned in recent female improvements.

The model adopted to allow for mortality improvement was essentially the same as that used for the "80" Series tables (see section 4.3 of CMI Report No. 10) whereby at each age the rate of mortality is assumed to decrease exponentially to a limiting value. For the "92" Series, the speed of convergence to the limit depended on age (in contrast to the "80" Series).

The model assumed that the long-term rate of mortality at each age will be a percentage of the rate in 1992, with the percentage equal to 13% at ages up to and including 60, 100% at ages 110 and over, and increasing linearly between.

In addition, the model assumed that a fraction of the total fall in the rate of mortality at each age will occur in the first 20 years. This fraction was set to 0.55 for ages up to and including 60, 0.29 at age 110, and reducing linearly between.

These values were chosen as a 'best fit' to male experience over 1975-1994, although the choice of age 110, above which there were no increases, was arbitrary.

***The Interim Cohort Projections***

Full details of these projections are contained in CMI Working Paper 1, published in 2002.

The "92" Series projections were quickly found to understate the level of mortality improvements that were actually occurring in the CMI experience and evidence had emerged of a "cohort effect", present in both population and CMI data. The CMI responded by publishing Working Paper 1, containing the "interim cohort projections" late in 2002.

Based on improvements in mortality to 1999, these tables offered an ad hoc adjustment to the original "92" Series projections. Key points in these adjustments are:

- The adjustment was in respect of one cohort only, born either side of 1926.
- This cohort was assumed to exhibit a faster rate of improvement than the original "92" Series projections for an arbitrary period – to 2010 for the "Short Cohort" projection, 2020 for the "Medium Cohort" projection and 2040 for the "Long Cohort" projection.
- The annual rates of improvement from 1993-1999 were based on smoothed actual rates of improvement during that period.
- From 2001, the improvement rates were assumed to reduce linearly to zero at the end of the cohort period.
- The rates of improvement were subject to minimum values of the improvements in the original "92" Series.

- Initially the cohort was taken to include years of birth between 1910 and 1942. After 2000, the ‘width’ of the cohort effect was reduced so that by the end of the cohort period it included only one year, which relates to lives born in 1926.

***ONS 2004-based National Population Projections***[1]

More details of these projections are contained in “National population projections 2004-based”. This publication also contains useful background on recent trends in population mortality.

Key points underlying the approach to future improvements in mortality within the 2004-based population projections are:

- It was assumed that the then current rates of improvements converge by age and tend to long-term “target” rates of improvement over the first 25 years of the projections (i.e. to 2029). The target rates were assumed to apply in 2029 and all years thereafter
- For the principal projections, this long-term target was 1% p.a. applicable to $m_x$ for all ages, for both genders and the different countries of the UK; broadly equivalent to the average annual rate of improvement over the whole of the 20th century.
- The transition from the assumed rates of mortality improvement by age and gender for the first year of the projection to the target rate is more rapid at first for males, and less rapid for females. These transitions are illustrated in Table 7.2 of the “National population projections” paper and partially in the table overleaf.
- Note that for males, there are two sets of improvement factors; one applicable to England, Wales and Northern Ireland and one applicable to Scotland, since differing rates of improvement in the first year of the projection are assumed for males in Scotland, compared to the other countries, at some ages, and that different transition rates apply thereafter.
- For females, the same improvement factors and transition rates apply in each of the constituent countries and hence in the UK overall.
- Cohort effects were recognised in that the transitions for those born before 1960 (i.e. those shaded in the table below) were projected by cohort, that is, diagonally downwards in the projection.
- For generations born since 1960 (not shaded), there was little evidence of generation effects for these cohorts and the transitions in mortality rates were therefore projected by calendar year, that is, horizontally in the projection.
- The initial rates of mortality improvement by age and gender for 2004 were estimated by analysing past data.  The initial rates of improvement for ages 90 and over should be regarded as less ‘robust’ than those for younger ages because:
  - official single year of age population estimates were not available for ages 90 and over so historical mortality rates at these oldest ages had to be estimated, and
  - the resulting estimated initial rates of improvement at ages 90 and over were further adjusted to ensure that the future mortality rates produced from them looked plausible compared to those for younger ages, and between males and females.

[1] Following the Government's acceptance of the recommendations of the Morris review, responsibility for the production of the official population projections for the UK and its constituent countries was transferred from the Government Actuary's Department (GAD) to the Office for National Statistics (ONS) with effect from 31 January 2006.

- "Variant" projections were also prepared, where the long-term target is 2% p.a. or 0% p.a. These were referred to as "High life expectancy" and "Low life expectancy" projections. As the "National population projections" paper states "These are intended as plausible alternative scenarios and not to represent upper or lower limits…" Adjustments were also made to the assumed rates of improvement in 2004-5 for these variants to reflect uncertainty about the then current rates of improvement.

Assumed percentage reduction in central death rates, $m_x$, for selected ages between selected consecutive calendar years in the projection period and the total reduction in $m_x$ over 25 years for the principal projections

| Age | 2004-05 | 2011-12 | 2021-22 | 2028-29 | Reduction over 25 years |
|---|---|---|---|---|---|
| **Males (England, Wales and Northern Ireland)** | | | | | |
| 22 | 3.31 | 2.38 | 1.36 | 1.00 | 38.7 |
| 32 | 1.86 | 1.52 | 1.14 | 1.00 | 28.8 |
| 42 | 1.48 | 1.28 | 1.08 | 1.00 | 25.9 |
| 52 | 0.80 | 0.75 | 0.93 | 1.00 | 16.0 |
| 62 | 1.87 | 2.19 | 0.93 | 1.00 | 28.5 |
| 72 | 5.01 | 2.31 | 1.32 | 1.00 | 41.3 |
| 82 | 3.22 | 2.86 | 1.35 | 1.00 | 41.2 |
| 92 | 1.47 | 2.25 | 1.49 | 1.00 | 33.7 |
| | | | | | |
| **Males (Scotland)** | | | | | |
| 22 | 2.61 | 1.96 | 1.25 | 1.00 | 34.0 |
| 32 | 1.12 | 1.07 | 1.02 | 1.00 | 23.1 |
| 42 | 0.87 | 0.92 | 0.98 | 1.00 | 21.2 |
| 52 | 0.80 | 0.75 | 0.93 | 1.00 | 16.0 |
| 62 | 1.53 | 2.19 | 0.93 | 1.00 | 27.4 |
| 72 | 5.01 | 2.24 | 1.32 | 1.00 | 40.8 |
| 82 | 3.22 | 2.86 | 1.33 | 1.00 | 41.2 |
| 92 | 1.47 | 2.25 | 1.49 | 1.00 | 33.7 |
| | | | | | |
| **Females (UK and constituent countries)** | | | | | |
| 22 | 2.47 | 2.15 | 1.62 | 1.00 | 37.5 |
| 32 | 0.58 | 0.67 | 0.82 | 1.00 | 17.3 |
| 42 | 1.97 | 1.76 | 1.41 | 1.00 | 32.6 |
| 52 | 1.42 | 0.83 | 0.91 | 1.00 | 19.7 |
| 62 | 1.30 | 1.81 | 0.91 | 1.00 | 25.5 |
| 72 | 4.37 | 2.07 | 1.44 | 1.00 | 39.5 |
| 82 | 2.01 | 2.61 | 1.58 | 1.00 | 40.6 |
| 92 | 0.30 | 1.56 | 1.87 | 1.00 | 30.1 |

The ONS 2004-based projections included in the library relate to:

- Males (England, Wales and Northern Ireland only), Males (Scotland only) and Females (UK and constituent countries); and
- Principal, High life expectancy and Low life expectancy projections

These projections had not previously been published in age- and year-specific form and the CMI is grateful to the ONS for its permission to include these within the library.

Note that the improvement factors were derived from an analysis of UK data; these were used as input data for the projections for each constituent country (with adjustment for Scottish males). The improvement factors may differ from those derived from the published projected mortality rates at UK level since the latter were 'back calculated' from aggregated projected numbers of deaths and mid year populations for each individual country and, as a result, are less smooth than the input assumptions which have been used to create the projections for the library.

Note also that the target rates used in the 2004-based projections after 2029 apply to improvements in $m_x$ whereas we have expressed improvements in the library in the form of improvements in $q_x$. The improvements in the library after 2029 are therefore slightly lower than the target rates, with the difference increasing with age.

A further point to note is that the ONS projections assumed that everyone dies when they reach age 120.5. Given that the library uses an age definition of 'age exact', we have made the assumption that $q_{120}$=1 in incorporating the ONS 2004-based projections into the library.

***ONS 2006-based National Population Projections***

More details of these projections are contained in "National population projections 2006-based".

Our understanding is that most of the key points outlined above in relation to the 2004-based projections apply also to future improvements in mortality within the 2006-based population projections, except of course replacing "2004" with "2006" and "2029" with "2031".

A key difference is that, although the long-term "target" rate of improvement after the first 25 years of the projections (i.e. in and after 2031) is 1% p.a. (in $m_x$, for the principal projections) at most ages, it is assumed that those born in the years 1923 to 1940 will continue to experience higher rates of mortality improvement in the future. The target rates of improvement in and after 2031 rise from 1% p.a. for those born before 1923 to a peak of 2.5% p.a. for those born in 1931 and then declining back to 1% p.a. for those born in 1941 or later.

A second difference is that the target rates for those born in 1911 and earlier were assumed to reduce from 1% p.a. for those born in 1911 to 0.1% p.a. for those born in 1902 and earlier.

Note that for the variant projections, the long-term target rates of improvement were assumed to be 1% p.a. higher or 1% p.a. lower than those assumed for the principal projections. For the avoidance of doubt, this means that the prolonged "cohort effect" applied in the principal projection applies also to these variants with peak rates of improvement for those born in 1931 of 3.5% p.a. and 1.5% p.a. respectively. These variants are again referred to as "High life expectancy" and "Low life expectancy" projections.

Note that the ONS High life expectancy variants extend to age 124.5. This feature has NOT been replicated in the projections included within the library where, as noted previously, we have retained the assumption of $q_{120}$=1 throughout. The significance of this assumption is discussed further in section 8.

A summary table of rates of improvement in the principal projections corresponding to that provided earlier for the 2004-based projections is given below.

Assumed percentage reduction in central death rates, $m_x$, for selected ages between selected consecutive calendar years in the projection period and the total reduction in $m_x$ over 25 years for the principal projections

| Age | 2006-07 | 2011-12 | 2021-22 | 2030-31 | Reduction over 25 years |
|---|---|---|---|---|---|
| **Males (England, Wales and Northern Ireland)** | | | | | |
| 22 | 5.12 | 3.90 | 1.95 | 1.00 | 49.2 |
| 32 | 3.04 | 2.44 | 1.47 | 1.00 | 36.9 |
| 42 | 1.64 | 1.45 | 1.15 | 1.00 | 27.1 |
| 52 | 0.58 | 1.00 | 1.00 | 1.00 | 20.7 |
| 62 | 2.61 | 3.03 | 1.00 | 1.00 | 33.1 |
| 72 | 5.40 | 2.79 | 1.66 | 1.00 | 41.7 |
| 82 | 3.32 | 3.90 | 1.65 | 1.00 | 46.9 |
| 92 | 1.93 | 2.78 | 2.89 | 1.20 | 44.8 |
| | | | | | |
| **Males (Scotland)** | | | | | |
| 22 | 5.12 | 3.90 | 1.95 | 1.00 | 49.2 |
| 32 | 2.05 | 1.74 | 1.24 | 1.00 | 30.2 |
| 42 | 1.37 | 1.26 | 1.09 | 1.00 | 25.1 |
| 52 | 0.58 | 0.82 | 0.94 | 1.00 | 19.3 |
| 62 | 2.34 | 3.03 | 0.94 | 1.00 | 32.5 |
| 72 | 5.19 | 2.66 | 1.66 | 1.00 | 40.6 |
| 82 | 3.32 | 3.78 | 1.61 | 1.00 | 46.3 |
| 92 | 1.93 | 2.78 | 2.85 | 1.20 | 44.7 |
| | | | | | |
| **Females (UK and constituent countries)** | | | | | |
| 22 | 2.62 | 2.38 | 1.82 | 1.00 | 38.9 |
| 32 | 1.41 | 1.35 | 1.21 | 1.00 | 26.8 |
| 42 | 2.62 | 2.38 | 1.82 | 1.00 | 38.8 |
| 52 | 1.48 | 1.20 | 1.12 | 1.00 | 24.8 |
| 62 | 2.07 | 2.27 | 1.12 | 1.00 | 31.6 |
| 72 | 4.95 | 2.11 | 1.75 | 1.00 | 39.9 |
| 82 | 2.34 | 3.16 | 1.70 | 1.00 | 45.4 |
| 92 | 0.99 | 2.14 | 2.85 | 1.20 | 42.7 |

The ONS 2006-based projections included in the library relate to:

- Males (England, Wales and Northern Ireland only), Males (Scotland only) and Females (UK); and
- Principal, High life expectancy and Low life expectancy projections

The CMI is grateful to the ONS for its permission to include these within the library and, especially, for making them available so soon after their official publication.

The notes at the end of the description of the 2004-based projections apply also to the 2006-based projections.

# 4 Adjusted Interim Cohort Projections

In the absence of any formal successor to the Interim Cohort Projections, some actuaries have modified these projections to make them more suitable for their use. This is entirely appropriate.

One consequence of the informal application of such modifications is that they are not necessarily undertaken in a consistent manner. The CMI has therefore included some variations that it understands are currently being used within the library to try to establish consistency of practice. As with other projections within the library, their inclusion should not be taken to infer that they are in any way recommended by the CMI.

***Applying a minimum value***

This modification seeks to apply a minimum improvement rate at all ages and calendar years to the mortality improvements in the Interim Cohort Projections. In their end-2005 and end-2006 FSA Returns a number of UK insurance companies adopted such an approach, using a variety of different minimum values.

Within the library we have included one illustrative projection to an otherwise unadjusted cohort projection – based on applying a 1.00% minimum improvement rate to the $q_x$ from the Medium Cohort projection. This should not be taken to imply that 1% is a recommended minimum. Other minima can be used, denoted by changing the value in the name of the projection, but should be calculated in a consistent manner to the example unless specifically noted otherwise.

Imposing a minimum value is relatively straightforward at most ages. From the cumulative reduction factors for the original projection, derive the annual rate of improvement for each age and calendar year. Any rates below the required minimum are replaced with the minimum value and the cumulative reduction factors are then re-calculated.

However the imposition of a minimum value to the cohort projections could be done in a variety of ways at older ages, although the overall financial impact of the different approaches is unlikely to be material. This arises because the original "92" Series projections (and, in most cases, the interim cohort projections) assume no improvements above age 110. Hence this assumption could be retained, even if the minimum improvement is applied elsewhere. If this is not done, then consideration of the limiting age is required. In many cases the underlying tables (and certainly those published recently by the CMI) use a limiting age of 120, as noted in section 2. Applying improvements to $q_{120}$ will extend the table beyond that age and this may cause systems issues.

For the purposes of the illustrative projection in the library, the CMI has assumed that the minimum value does apply above age 110 but that the limiting age of 120 is retained. If users state that they are applying a different minimum value to a cohort projection, they should either do so in a consistent manner or explicitly state the approach they have adopted.

It is also worth noting that a minimum rate of improvement can also be applied to any other projection in the library, but it has only been illustrated with the specific projections described in this section.

***Using a percentage of the cohort projections***
This modification uses a percentage of the mortality improvements in the Interim Cohort Projections.

Within the library we have included one illustrative projection – based on using 90% of the Medium Cohort projection. This should not be taken to imply that 90% is a recommended adjustment. Other figures can be used, to adjust the relevant cohort projection up or down, but should be applied in a consistent manner to the example and can be denoted by changing the value in the name of the projection.

For the purposes of the illustrative projection in the library, the CMI has assumed that the approach to applying the percentage is as follows. From the original projection, derive the annual rate of improvement for each age and calendar year. Apply the required percentage and the cumulative reduction factors are then re-calculated.

Note that this approach applies the relevant percentage to all of the improvement rates within the projection, not just those rates that were uplifted by the Interim Cohort Projections from the original "92" Series projections.

Unlike the imposition of a minimum value to the cohort projections (see preceding section), the application of a percentage does not give rise to particular issues at older ages, as applying a percentage maintains the assumptions of no improvements above age 110 and the limiting age of 120.

***Blending two cohort projections***
This modification uses a mixture of the mortality improvements in two of the Interim Cohort Projections.

Within the library we have included one illustrative projection – based on using an average of the Medium Cohort projection and the Long Cohort projection. Other mixtures can be used but should be applied in a consistent manner to the example and can be denoted by changing the name of the projection.

For the purposes of the illustrative projection in the library, the CMI has assumed that this modification is applied by deriving the annual rate of improvement for each age and calendar year for each of the original projections, averaging these and then re-calculating the cumulative reduction factors.

Note that this approach (like the application of a percentage) does not give rise to particular issues at older ages.

***Blending two cohort projections and applying a minimum value***
To illustrate this combination of adjustments, the library includes an example of a minimum value (1.5% p.a.) applied to an average of the Medium Cohort projection and the Long Cohort projection. This has been calculated assuming that the blending of the projections is undertaken BEFORE the minimum is applied. Any divergence from this practice should be specifically disclosed.

***Using a percentage of the cohort projections and applying a minimum value***

To illustrate this combination of adjustments, the library includes an example of a minimum value (2.5% p.a.) applied to 120% of the Long Cohort projection. This has been calculated assuming that the percentage adjustment to the projection is undertaken BEFORE the minimum is applied. Any divergence from this practice should be specifically disclosed.

# 5 P-spline projections

More details of the Penalised Spline (or P-spline) projection methodology are contained in Working Paper 15 and Working Paper 20:

- Working Paper 15 sets out the CMI Mortality Projections Working Party's work towards developing stochastic methodologies. Section 2.3 gives a brief description of the P-spline model.
- Working Paper 20 provides practical advice on using the P-spline model, gives examples based on the P-spline methodology and discusses various features of the model.

Both papers contain further useful references.

Key points to note regarding the P-spline model are summarised below:

- The P-spline model is an example of a non-parametric smoothing model. It is a local model that fits cubic splines to the data, and was used to model the CMI Permanent Assurances Lives dataset in CMI Working Paper 1 that introduced the Interim Cohort Projections.
- A 2-dimensional model can be fitted to mortality data using either the age and calendar year (age-period) dimensions or the age and year of birth (age-cohort) dimensions.
- Coefficients of the model are selected using a maximum likelihood approach subject to a penalty being imposed. The penalty acts to ensure that there is an appropriate balance between the level of smoothness and goodness of fit.
- The use of the penalty also enables the model to be used to generate projections, extrapolating recent trends in the data.
- P-spline age-period and age-cohort models are both able to identify cohort effects, if they exist, in the region of the data. However, the age-period model will only project the stronger cohort effects into the future. Examples of cohort features in projections using the age-period and age-cohort models are shown in Appendix E of Working Paper 20.
- The P-spline model generates standard deviations which can be used to generate percentiles to reflect parameter uncertainty. This is considered further below.

***P-spline projections included in the library***

A number of applications of the P-spline model are included in the library. These illustrate the impact of using:

- Age-period and age-cohort versions of the model;
- CMI Permanent Assurances Lives and ONS (England and Wales) datasets for males. For females only the ONS (England and Wales) dataset has been used;
- Data to 2003, 2004, 2005 and 2006, thus illustrating the impact of adding an additional year's data. For the ONS datasets only, projections are also included using 2007 data.

All of the projections have been generated using the CMI's illustrative software and in all cases the $50^{th}$ percentile projection has been included in the library. This can be considered as a best estimate from the model.

As noted in section 2, the projections using the ONS datasets use a different classification of deaths for 2006 and 2007 to the projections included in version 1.0 of the library using data to 2003, 2004 and 2005.

Further details of the method and parameters used to generate the projections are contained in Appendix B.

***Calculating percentiles from the library***

For each P-spline projection in the library, as well as the 50th percentile projection we have included two-way tables of the fitted log $\mu$'s and corresponding standard errors generated by the CMI's illustrative software. The figures have been provided for the age range used to generate the projections. Actuaries can use the log $\mu$'s and standard errors to calculate the improvements for alternative percentiles.

In order to calculate the projected improvements for any given percentile for a dataset:

- Calculate the percentile $\mu$'s by taking the exponential of the log $\mu$'s, adjusted to reflect the required percentile. The adjustment to the log $\mu$'s is as follows: log $\mu$ + Z x S.E. where Z is the standard normal value corresponding to the percentile and S.E. is the relevant standard error.
- Calculate the percentile $q$'s:
  - For CMI data, the formula is: $q(x) = 1- \exp(- (\mu(x, t) + \mu(x+1, t)) / 2)$. Please note that the formula differs for $q(90)$, as we do not have a value of $\mu(91, t)$ , so have assumed that $q(90,t) = 1-\exp(-\mu(90, t))$.
  - For ONS data, the formula is: $q(x, t) = 1- \exp(-\mu(x, t))$.
- The cumulative reduction factors in $q(x, t)$ can then be calculated.

Actuaries may find it helpful to check their calculations using the 50th percentile projection included in the library and the annuity values provided below; however you should note that the library has been generated using Office 2007. We understand that consistent figures are produced in Excel 2003, but that Excel 2002 (and earlier versions) returns different values for the normal variable, and may produce marginally different values (see e.g. http://www.louisepryor.com/showTopic.do?topic=43).

The table below provides sample annuity values to allow users to check their application of percentiles to a P-spline projection. The projection and the percentiles chosen are purely illustrative. The basis is consistent with that used in section 7 below.

| **Males** | **Annuity values for a life aged *x* exact on 1 July 2007 assuming base mortality of 100% PCMA00 and interest at 5% p.a.** | | | | | |
|---|---|---|---|---|---|---|
| **Projection** | $_{20\|}\ddot{a}_{45}$ | $_{10\|}\ddot{a}_{55}$ | $\ddot{a}_{60}$ | $\ddot{a}_{65}$ | $\ddot{a}_{70}$ | $\ddot{a}_{80}$ |
| | | | | | | |
| PSAC_Male_ONS_EW_2005_2.5 | 6.162 | 9.330 | 15.950 | 14.267 | 12.256 | 7.770 |
| PSAC_Male_ONS_EW_2005_97.5 | 5.378 | 8.289 | 14.874 | 13.255 | 11.391 | 7.325 |

# 6 Lee-Carter projections

More details of the Lee-Carter projection methodology are contained in Working Paper 15 and Working Paper 25:

- Working Paper 15 sets out the CMI Mortality Projections Working Party's work towards developing stochastic methodologies. Section 2.2 gives a brief description of the Lee-Carter model.
- Working Paper 25 provides practical advice on using the Lee-Carter model, gives examples based on the Lee-Carter methodology and discusses various features of the model.

Both papers contain further useful references.

Key points to note regarding the Lee-Carter model are summarised below:

- The Lee-Carter model is a bilinear model in age ($x$) and time ($t$) of the following form:
  $$\log \mu(x, t) = a(x) + b(x)\, k(t) + z(x, t)$$
- The force of mortality, $\mu(x, t)$, in the region of the data is derived by fitting the model to the mortality data and obtaining estimates of the parameters. The components of the model describe:
  - the average level of mortality over time for a particular age, $a(x)$;
  - the overall change in mortality over time, $k(t)$;
  - the pattern of deviations by age from the overall level of changes in mortality, $b(x)$; and
  - the random errors (stochastic innovations), $z(x, t)$.
- The parameters are selected to fit the model to the data using a maximum likelihood approach. To achieve a unique choice of parameters, some constraints on the parameters are required. These are usually $\sum_x b(x) = 1$ and $\sum_t k(t) = 0$.
- Projected $\mu(x, t)$ are obtained by projecting $k(t)$ forward. If this is done by fitting a time-series model, such as an ARIMA (Auto-Regressive Integrated Moving Average) process, then stochastic projections are generated.
- If the stochastic error is excluded, then a unique central projection of the average projected $\mu(x, t)$ is generated. This is the method that has been used to generate the projections in the library.
- Allowing for the stochastic error will generate sample paths for the projected $\mu(x, t)$. These are random unless the generation is controlled, by using a non-random seed. As the number of scenarios increases the mean of the projected mortality rates will tend towards the central projection.
- Generating $\mu(x, t)$ in this way has no regard for parameter risk. This can be introduced using a technique known as parametric bootstrapping (see Appendix C for a brief description) and generating a number of synthetic datasets. Each synthetic dataset is used as a basis for a simulation of $\mu(x, t)$.
- The Lee-Carter model does not smooth the volatility in mortality rates across calendar years to the same extent as the P-Spline model. This may make it more difficult to identify features in the region of the data and the structure of the model means that cohort features are not projected into the future.

***Lee-Carter projections included in the library***

A number of applications of the Lee-Carter model are included in the library. As for the P-spline projections, these illustrate the impact of using:

- CMI Permanent Assurances Lives and ONS (England and Wales) datasets for males. For females, only the ONS (England and Wales) dataset has been used;
- Data to 2003, 2004, 2005 and 2006, thus illustrating the impact of adding an additional year's data. For the ONS datasets only, projections are also included using 2007 data.

All of the projections have been generated using the CMI's illustrative software and in all cases the central projection has been included in the library. This can be considered as a best estimate from the model and is generated without any allowance for uncertainty. This is considered further, along with illustrations of allowance for some of the uncertainty inherent in any projection of future mortality below.

As noted in section 2, the projections using the ONS datasets use a different classification of deaths for 2006 and 2007 to the projections included in version 1.0 of the library using data to 2003, 2004 and 2005.

Further details of the method by which the projections included in the library have been generated is summarised in Appendix C.

***Illustrating Uncertainty***

The Lee-Carter model generates sample paths, which may be considered advantageous if one wishes to incorporate these with economic scenarios in a combined model. These sample paths reflect both parameter uncertainty and stochastic uncertainty and can also be used to generate percentiles but, as explained in Appendix C, this can be done in different ways:

- The mortality rates at each age could be ranked to generate the required confidence interval but these rates would arise from different sample paths.
- Assumptions can be made as to base mortality and interest rates to calculate an annuity value for each sample path, which can then be ranked to generate confidence intervals. This approach produces much narrower confidence intervals than ranking mortality rates. This approach was adopted in Working Paper 25, except that the 50$^{th}$ percentile values were based on the mean annuity value, not the ranking.

# 7 Illustrative values

Working Paper 27 contained a brief discussion on possible approaches to illustrating the choice of projection. Many other approaches were suggested in responses and these are documented in Working Paper 30. In this section we use just two approaches – annuity values and expectations of life – to illustrate the projections in version 1.1 of the library.

The tables below set out illustrative annuity due values over a range of ages for the year of use 2007. Values for complete expectation of life at various ages are also shown for 2007 and for age 65 in 2017 and 2027. In order to provide a comparison influenced purely by the future projection, all these values have been calculated using the same assumptions regarding base mortality, namely 100% of PCMA00 or PCFA00 in 2007, for males and females respectively. An interest rate of 5% has been used in calculating all the annuity values. Note that the interest rate and base mortality have been chosen to illustrate the difference in the projections and should not be interpreted as representative assumptions.

Note that:

- The values are different from those in Working Paper 27, which were calculated as at 2005 and allowed for improvements in mortality between 2000 and 2005. In addition, some of the values in Working Paper 27 were based on projections derived from inconsistent data (see “Errata to CMI Working Papers 20, 25 and 27 on Mortality Projections”).
- The values below assume a base mortality assumption of 100% of PCMA00 or PCFA00 in 2007, with no explicit allowance for improvements between 2000 and 2007.
- The PCMA00 and PCFA00 base tables only provide values of $q_x$ for ages 50 and above in CMI Working Paper 22. For the younger ages we used the extensions to younger ages provided in CMI Working Paper 26.

In each case, a two-way table of $q_x$ was produced by applying improvement factors from version 1.1 of the library. The values of $q_x$ have been rounded to 6 decimal places, as is normal practice in the CMI Tables Program (STP).

For comparison purposes, values are also shown using just the base mortality and interest (and no projection) and also showing annual compound rates of improvement from 1% to 5% p.a. These projections are marked by an asterisk (*) to indicate that they are not included within version 1.1 of the library.

| **Males** | **Annuity values for a life aged *x* exact on 1 July 2007 assuming base mortality of 100% PCMA00 and interest at 5% p.a.** | | | | | |
|---|---|---|---|---|---|---|
| **Projection** | $_{20\|}\ddot{a}_{45}$ | $_{10\|}\ddot{a}_{55}$ | $\ddot{a}_{60}$ | $\ddot{a}_{65}$ | $\ddot{a}_{70}$ | $\ddot{a}_{80}$ |
| | | | | | | |
| 0% p.a. improvement* | 3.944 | 6.796 | 13.441 | 11.944 | 10.245 | 6.762 |
| 1% p.a. improvement* | 4.325 | 7.207 | 13.842 | 12.311 | 10.560 | 6.946 |
| 2% p.a. improvement* | 4.736 | 7.659 | 14.285 | 12.719 | 10.912 | 7.151 |
| 3% p.a. improvement* | 5.171 | 8.154 | 14.778 | 13.177 | 11.307 | 7.380 |
| 4% p.a. improvement* | 5.593 | 8.674 | 15.311 | 13.684 | 11.752 | 7.640 |
| 5% p.a. improvement* | 5.962 | 9.181 | 15.856 | 14.223 | 12.240 | 7.932 |
| | | | | | | |
| "92" Series | 4.392 | 7.255 | 13.864 | 12.300 | 10.522 | 6.884 |
| Short Cohort | 4.394 | 7.258 | 13.867 | 12.305 | 10.528 | 6.894 |
| Medium Cohort | 4.440 | 7.335 | 13.968 | 12.437 | 10.707 | 7.104 |
| Long Cohort | 4.570 | 7.551 | 14.248 | 12.805 | 11.169 | 7.414 |
| Medium Cohort_1% minimum | 4.517 | 7.410 | 14.039 | 12.501 | 10.761 | 7.134 |
| 90%_Medium Cohort | 4.393 | 7.282 | 13.915 | 12.387 | 10.660 | 7.069 |
| Average(MC_LC) | 4.503 | 7.441 | 14.105 | 12.617 | 10.932 | 7.254 |
| Average(MC_LC)_1.5% minimum | 4.671 | 7.598 | 14.242 | 12.719 | 10.988 | 7.277 |
| 120% Long Cohort 2.5% minimum | 5.086 | 8.090 | 14.753 | 13.232 | 11.487 | 7.603 |
| ONS_2004_Male_EWNI_Principal | 4.473 | 7.503 | 14.190 | 12.727 | 11.004 | 7.137 |
| ONS_2004_Male_EWNI_HLE | 4.769 | 7.803 | 14.468 | 12.967 | 11.195 | 7.224 |
| ONS_2004_Male_EWNI_LLE | 4.196 | 7.228 | 13.936 | 12.508 | 10.830 | 7.057 |
| ONS_2004_Male_S_Principal | 4.467 | 7.493 | 14.177 | 12.722 | 11.005 | 7.137 |
| ONS_2004_Male_S_HLE | 4.764 | 7.793 | 14.455 | 12.962 | 11.196 | 7.224 |
| ONS_2004_Male_S_LLE | 4.190 | 7.217 | 13.923 | 12.503 | 10.830 | 7.057 |
| ONS_2006_Male_EWNI_Principal | 4.611 | 7.717 | 14.429 | 13.001 | 11.304 | 7.237 |
| ONS_2006_Male_EWNI_HLE | 4.891 | 7.998 | 14.687 | 13.223 | 11.479 | 7.307 |
| ONS_2006_Male_EWNI_LLE | 4.349 | 7.459 | 14.192 | 12.798 | 11.144 | 7.171 |
| ONS_2006_Male_S_Principal | 4.598 | 7.697 | 14.401 | 12.976 | 11.283 | 7.237 |
| ONS_2006_Male_S_HLE | 4.878 | 7.978 | 14.660 | 13.198 | 11.458 | 7.307 |
| ONS_2006_Male_S_LLE | 4.335 | 7.438 | 14.164 | 12.773 | 11.123 | 7.172 |
| PSAP_Male_Ass_2003_50 | 4.956 | 7.917 | 14.531 | 12.925 | 11.053 | 7.159 |
| PSAP_Male_Ass_2004_50 | 4.931 | 7.885 | 14.498 | 12.894 | 11.027 | 7.146 |
| PSAP_Male_Ass_2005_50 | 4.993 | 7.955 | 14.567 | 12.959 | 11.085 | 7.186 |
| PSAP_Male_Ass_2006_50 | 5.224 | 8.234 | 14.852 | 13.229 | 11.318 | 7.311 |
| PSAP_Male_ONS_EW_2003_50 | 3.962 | 6.832 | 13.488 | 11.998 | 10.284 | 6.696 |
| PSAP_Male_ONS_EW_2004_50 | 5.600 | 8.690 | 15.341 | 13.749 | 11.884 | 7.830 |
| PSAP_Male_ONS_EW_2005_50 | 5.588 | 8.699 | 15.368 | 13.792 | 11.933 | 7.799 |
| PSAP_Male_ONS_EW_2006_50 | 5.890 | 9.222 | 15.993 | 14.468 | 12.566 | 8.125 |
| PSAP_Male_ONS_EW_2007_50 | 5.327 | 8.408 | 15.082 | 13.512 | 11.625 | 7.476 |
| PSAC_Male_Ass_2003_50 | 5.061 | 7.982 | 14.568 | 12.933 | 11.038 | 7.137 |
| PSAC_Male_Ass_2004_50 | 5.046 | 7.964 | 14.550 | 12.916 | 11.025 | 7.132 |
| PSAC_Male_Ass_2005_50 | 5.083 | 8.007 | 14.593 | 12.958 | 11.064 | 7.161 |
| PSAC_Male_Ass_2006_50 | 5.253 | 8.211 | 14.800 | 13.151 | 11.229 | 7.249 |
| PSAC_Male_ONS_EW_2003_50 | 5.499 | 8.355 | 14.906 | 13.245 | 11.340 | 7.193 |
| PSAC_Male_ONS_EW_2004_50 | 5.751 | 8.757 | 15.354 | 13.697 | 11.772 | 7.532 |
| PSAC_Male_ONS_EW_2005_50 | 5.824 | 8.834 | 15.416 | 13.749 | 11.803 | 7.534 |
| PSAC_Male_ONS_EW_2006_50 | 5.749 | 8.670 | 15.267 | 13.640 | 11.762 | 7.535 |
| PSAC_Male_ONS_EW_2007_50 | 5.637 | 8.527 | 15.106 | 13.475 | 11.600 | 7.391 |
| | | | | | | |

| Males | Annuity values for a life aged *x* exact on 1 July 2007 assuming base mortality of 100% PCMA00 and interest at 5% p.a. | | | | | |
|---|---|---|---|---|---|---|
| **Projection** | $_{20\|}\ddot{a}_{45}$ | $_{10\|}\ddot{a}_{55}$ | $\ddot{a}_{60}$ | $\ddot{a}_{65}$ | $\ddot{a}_{70}$ | $\ddot{a}_{80}$ |
| | | | | | | |
| LC_Male_Ass_2003_Central | 4.475 | 7.345 | 13.959 | 12.399 | 10.618 | 6.958 |
| LC_Male_Ass_2004_Central | 4.478 | 7.347 | 13.961 | 12.401 | 10.619 | 6.957 |
| LC_Male_Ass_2005_Central | 4.497 | 7.369 | 13.982 | 12.419 | 10.634 | 6.966 |
| LC_Male_Ass_2006_Central | 4.545 | 7.420 | 14.031 | 12.463 | 10.671 | 6.986 |
| LC_Male_ONS_EW_2003_Central | 4.441 | 7.306 | 13.916 | 12.351 | 10.566 | 6.912 |
| LC_Male_ONS_EW_2004_Central | 4.469 | 7.337 | 13.946 | 12.377 | 10.587 | 6.923 |
| LC_Male_ONS_EW_2005_Central | 4.482 | 7.351 | 13.960 | 12.389 | 10.596 | 6.925 |
| LC_Male_ONS_EW_2006_Central | 4.496 | 7.369 | 13.977 | 12.406 | 10.611 | 6.933 |
| LC_Male_ONS_EW_2007_Central | 4.502 | 7.375 | 13.983 | 12.410 | 10.613 | 6.932 |

| Males | Complete expectation of life for a life aged 65 exact on 1 July | | Complete expectation of life for a life aged *x* exact on 1 July 2007 assuming base mortality of 100% PCMA00 | | | |
|---|---|---|---|---|---|---|
| **Projection** | **2027** | **2017** | $e_{60}$ | $e_{65}$ | $e_{70}$ | $e_{80}$ |
| | | | | | | |
| 0% p.a. improvement* | 18.401 | 18.401 | 22.523 | 18.401 | 14.504 | 8.118 |
| 1% p.a. improvement* | 21.356 | 20.456 | 24.090 | 19.584 | 15.351 | 8.479 |
| 2% p.a. improvement* | 25.316 | 23.111 | 26.074 | 21.057 | 16.386 | 8.905 |
| 3% p.a. improvement* | 30.535 | 26.612 | 28.662 | 22.951 | 17.691 | 9.416 |
| 4% p.a. improvement* | 36.370 | 30.890 | 31.903 | 25.351 | 19.343 | 10.043 |
| 5% p.a. improvement* | 41.729 | 35.441 | 35.565 | 28.185 | 21.351 | 10.811 |
| | | | | | | |
| “92” Series | 20.729 | 20.147 | 23.905 | 19.389 | 15.161 | 8.337 |
| Short Cohort | 20.743 | 20.160 | 23.918 | 19.403 | 15.175 | 8.352 |
| Medium Cohort | 21.193 | 20.602 | 24.336 | 19.832 | 15.628 | 8.710 |
| Long Cohort | 22.601 | 21.973 | 25.631 | 21.153 | 16.941 | 9.346 |
| Medium Cohort_1% minimum | 22.175 | 21.189 | 24.749 | 20.130 | 15.833 | 8.791 |
| 90%_Medium Cohort | 20.916 | 20.379 | 24.151 | 19.685 | 15.512 | 8.650 |
| Average(MC_LC) | 21.870 | 21.260 | 24.957 | 20.465 | 16.256 | 9.014 |
| Average(MC_LC)_1.5% minimum | 23.964 | 22.441 | 25.727 | 20.939 | 16.489 | 9.083 |
| 120% Long Cohort 2.5% minimum | 28.946 | 25.883 | 28.357 | 23.000 | 18.066 | 9.779 |
| ONS_2004_Male_EWNI_Principal | 22.629 | 21.779 | 25.338 | 20.789 | 16.405 | 8.824 |
| ONS_2004_Male_EWNI _HLE | 25.640 | 23.665 | 26.667 | 21.719 | 17.009 | 9.013 |
| ONS_2004_Male_EWNI _LLE | 20.236 | 20.236 | 24.234 | 20.003 | 15.885 | 8.654 |
| ONS_2004_Male_S_Principal | 22.598 | 21.746 | 25.303 | 20.778 | 16.406 | 8.825 |
| ONS_2004_Male_S _HLE | 25.615 | 23.635 | 26.633 | 21.709 | 17.010 | 9.014 |
| ONS_2004_Male_S _LLE | 20.204 | 20.204 | 24.200 | 19.992 | 15.885 | 8.655 |
| ONS_2006_Male_EWNI_Principal | 23.837 | 22.931 | 26.375 | 21.754 | 17.255 | 9.016 |
| ONS_2006_Male_EWNI _HLE | 26.908 | 24.842 | 27.711 | 22.685 | 17.852 | 9.174 |
| ONS_2006_Male_EWNI _LLE | 21.385 | 21.367 | 25.265 | 20.968 | 16.741 | 8.873 |
| ONS_2006_Male_S_Principal | 23.752 | 22.844 | 26.286 | 21.687 | 17.209 | 9.017 |
| ONS_2006_Male_S _HLE | 26.830 | 24.756 | 27.621 | 22.616 | 17.805 | 9.175 |
| ONS_2006_Male_S _LLE | 21.298 | 21.280 | 25.177 | 20.902 | 16.696 | 8.873 |
| PSAP_Male_Ass_2003_50 | 27.846 | 24.659 | 27.148 | 21.748 | 16.758 | 8.914 |
| PSAP_Male_Ass_2004_50 | 27.464 | 24.413 | 26.971 | 21.622 | 16.676 | 8.887 |

| **Males** | **Complete expectation of life for a life aged 65 exact on 1 July** | | **Complete expectation of life for a life aged *x* exact on 1 July 2007 assuming base mortality of 100% PCMA00** | | | |
|---|---|---|---|---|---|---|
| **Projection** | **2027** | **2017** | $\mathbf{e_{60}}$ | $\mathbf{e_{65}}$ | $\mathbf{e_{70}}$ | $\mathbf{e_{80}}$ |
| | | | | | | |
| PSAP_Male_Ass_2005_50 | 28.276 | 24.936 | 27.348 | 21.897 | 16.869 | 8.973 |
| PSAP_Male_Ass_2006_50 | 31.552 | 27.140 | 28.959 | 23.062 | 17.652 | 9.251 |
| PSAP_Male_ONS_EW_2003_50 | 18.152 | 18.358 | 22.568 | 18.455 | 14.502 | 7.989 |
| PSAP_Male_ONS_EW_2004_50 | 36.293 | 30.998 | 32.053 | 25.630 | 19.768 | 10.463 |
| PSAP_Male_ONS_EW_2005_50 | 36.751 | 31.427 | 32.455 | 25.988 | 20.034 | 10.429 |
| PSAP_Male_ONS_EW_2006_50 | 43.121 | 37.166 | 37.237 | 29.903 | 22.883 | 11.386 |
| PSAP_Male_ONS_EW_2007_50 | 34.157 | 29.343 | 30.768 | 24.604 | 18.846 | 9.678 |
| PSAC_Male_Ass_2003_50 | 28.809 | 24.964 | 27.260 | 21.742 | 16.699 | 8.869 |
| PSAC_Male_Ass_2004_50 | 28.612 | 24.840 | 27.173 | 21.681 | 16.662 | 8.858 |
| PSAC_Male_Ass_2005_50 | 29.121 | 25.177 | 27.418 | 21.863 | 16.793 | 8.919 |
| PSAC_Male_Ass_2006_50 | 31.553 | 26.773 | 28.565 | 22.680 | 17.336 | 9.113 |
| PSAC_Male_ONS_EW_2003_50 | 36.642 | 29.252 | 29.975 | 23.544 | 17.869 | 9.049 |
| PSAC_Male_ONS_EW_2004_50 | 40.088 | 32.573 | 32.722 | 25.721 | 19.496 | 9.817 |
| PSAC_Male_ONS_EW_2005_50 | 41.219 | 33.313 | 33.198 | 26.019 | 19.646 | 9.829 |
| PSAC_Male_ONS_EW_2006_50 | 40.620 | 32.164 | 32.267 | 25.422 | 19.397 | 9.817 |
| PSAC_Male_ONS_EW_2007_50 | 38.665 | 30.766 | 31.191 | 24.584 | 18.747 | 9.474 |
| LC_Male_Ass_2003_Central | 22.076 | 20.939 | 24.449 | 19.810 | 15.476 | 8.497 |
| LC_Male_Ass_2004_Central | 22.079 | 20.942 | 24.451 | 19.811 | 15.475 | 8.494 |
| LC_Male_Ass_2005_Central | 22.254 | 21.061 | 24.541 | 19.877 | 15.521 | 8.514 |
| LC_Male_Ass_2006_Central | 22.626 | 21.318 | 24.736 | 20.020 | 15.621 | 8.553 |
| LC_Male_ONS_EW_2003_Central | 21.610 | 20.616 | 24.200 | 19.603 | 15.307 | 8.403 |
| LC_Male_ONS_EW_2004_Central | 21.821 | 20.764 | 24.313 | 19.685 | 15.364 | 8.424 |
| LC_Male_ONS_EW_2005_Central | 21.916 | 20.831 | 24.362 | 19.720 | 15.385 | 8.428 |
| LC_Male_ONS_EW_2006_Central | 22.030 | 20.913 | 24.427 | 19.770 | 15.421 | 8.442 |
| LC_Male_ONS_EW_2007_Central | 22.105 | 20.960 | 24.455 | 19.788 | 15.430 | 8.443 |

| **Females** | **Annuity values for a life aged *x* exact on 1 July 2007 assuming base mortality of 100% PCFA00 and interest at 5% p.a.** | | | | | |
|---|---|---|---|---|---|---|
| **Projection** | $_{20\|}\ddot{a}_{45}$ | $_{10\|}\ddot{a}_{55}$ | $\ddot{a}_{60}$ | $\ddot{a}_{65}$ | $\ddot{a}_{70}$ | $\ddot{a}_{80}$ |
| | | | | | | |
| 0% p.a. improvement* | 4.466 | 7.565 | 14.359 | 12.903 | 11.240 | 7.716 |
| 1% p.a. improvement* | 4.830 | 7.972 | 14.766 | 13.287 | 11.580 | 7.930 |
| 2% p.a. improvement* | 5.218 | 8.414 | 15.211 | 13.710 | 11.956 | 8.168 |
| 3% p.a. improvement* | 5.620 | 8.891 | 15.699 | 14.179 | 12.378 | 8.434 |
| 4% p.a. improvement* | 5.997 | 9.379 | 16.217 | 14.690 | 12.845 | 8.734 |
| 5% p.a. improvement* | 6.314 | 9.841 | 16.731 | 15.221 | 13.349 | 9.070 |
| | | | | | | |
| “92” Series | 4.841 | 7.965 | 14.741 | 13.239 | 11.512 | 7.847 |
| Short Cohort | 4.843 | 7.968 | 14.745 | 13.244 | 11.518 | 7.856 |
| Medium Cohort | 4.889 | 8.045 | 14.845 | 13.375 | 11.694 | 8.062 |
| Long Cohort | 5.026 | 8.272 | 15.139 | 13.758 | 12.173 | 8.415 |
| Medium Cohort_1% minimum | 4.981 | 8.139 | 14.937 | 13.460 | 11.768 | 8.109 |
| 90%_Medium Cohort | 4.850 | 7.999 | 14.798 | 13.329 | 11.648 | 8.028 |
| Average(MC_LC) | 4.957 | 8.157 | 14.990 | 13.564 | 11.929 | 8.234 |
| Average(MC_LC)_1.5% minimum | 5.138 | 8.335 | 15.149 | 13.689 | 12.006 | 8.271 |
| 120% Long Cohort 2.5% minimum | 5.532 | 8.817 | 15.660 | 14.211 | 12.523 | 8.634 |
| ONS_2004_Female_UK_Principal | 4.964 | 8.220 | 15.067 | 13.669 | 11.994 | 8.020 |
| ONS_2004_Female_UK_HLE | 5.195 | 8.448 | 15.273 | 13.843 | 12.129 | 8.077 |
| ONS_2004_Female_UK_LLE | 4.747 | 8.011 | 14.877 | 13.509 | 11.869 | 7.965 |
| ONS_2006_Female_UK_Principal | 5.078 | 8.386 | 15.256 | 13.871 | 12.231 | 8.124 |
| ONS_2006_Female_UK_HLE | 5.295 | 8.597 | 15.446 | 14.030 | 12.353 | 8.170 |
| ONS_2006_Female_UK_LLE | 4.874 | 8.192 | 15.082 | 13.725 | 12.118 | 8.079 |
| PSAP_Female_ONS_EW_2003_50 | 4.081 | 7.118 | 13.903 | 12.453 | 10.801 | 7.343 |
| PSAP_Female_ONS_EW_2004_50 | 5.368 | 8.607 | 15.419 | 13.924 | 12.158 | 8.270 |
| PSAP_Female_ONS_EW_2005_50 | 5.310 | 8.535 | 15.351 | 13.876 | 12.140 | 8.282 |
| PSAP_Female_ONS_EW_2006_50 | 6.431 | 10.026 | 16.963 | 15.538 | 13.784 | 9.645 |
| PSAP_Female_ONS_EW_2007_50 | 5.821 | 9.186 | 16.065 | 14.646 | 12.945 | 8.997 |
| PSAC_Female_ONS_EW_2003_50 | 5.367 | 8.597 | 15.401 | 13.888 | 12.085 | 8.102 |
| PSAC_Female_ONS_EW_2004_50 | 5.676 | 9.008 | 15.846 | 14.346 | 12.534 | 8.438 |
| PSAC_Female_ONS_EW_2005_50 | 5.741 | 9.082 | 15.924 | 14.420 | 12.611 | 8.449 |
| PSAC_Female_ONS_EW_2006_50 | 5.822 | 9.216 | 16.089 | 14.612 | 12.819 | 8.633 |
| PSAC_Female_ONS_EW_2007_50 | 5.703 | 9.041 | 15.887 | 14.395 | 12.597 | 8.480 |
| LC_Female_ONS_EW_2003_Central | 4.905 | 8.051 | 14.842 | 13.354 | 11.630 | 7.933 |
| LC_Female_ONS_EW_2004_Central | 4.930 | 8.079 | 14.871 | 13.381 | 11.654 | 7.948 |
| LC_Female_ONS_EW_2005_Central | 4.938 | 8.086 | 14.876 | 13.384 | 11.655 | 7.944 |
| LC_Female_ONS_EW_2006_Central | 4.956 | 8.108 | 14.899 | 13.407 | 11.676 | 7.960 |
| LC_Female_ONS_EW_2007_Central | 4.957 | 8.108 | 14.897 | 13.403 | 11.670 | 7.953 |

| **Females** | **Complete expectation of life for a life aged 65 exact on 1 July** | | **Complete expectation of life for a life aged *x* exact on 1 July 2007 assuming base mortality of 100% PCFA00** | | | |
|---|---|---|---|---|---|---|
| **Projection** | **2027** | **2017** | $e_{60}$ | $e_{65}$ | $e_{70}$ | $e_{80}$ |
| | | | | | | |
| 0% p.a. improvement* | 20.853 | 20.853 | 25.264 | 20.853 | 16.677 | 9.675 |
| 1% p.a. improvement* | 23.989 | 23.088 | 27.026 | 22.211 | 17.672 | 10.123 |
| 2% p.a. improvement* | 28.123 | 25.946 | 29.240 | 23.892 | 18.885 | 10.651 |
| 3% p.a. improvement* | 33.400 | 29.642 | 32.089 | 26.033 | 20.406 | 11.287 |
| 4% p.a. improvement* | 39.039 | 33.998 | 35.557 | 28.689 | 22.305 | 12.064 |
| 5% p.a. improvement* | 43.981 | 38.436 | 39.323 | 31.725 | 24.555 | 13.008 |
| | | | | | | |
| "92" Series | 23.040 | 22.528 | 26.626 | 21.860 | 17.369 | 9.923 |
| Short Cohort | 23.053 | 22.541 | 26.639 | 21.873 | 17.383 | 9.938 |
| Medium Cohort | 23.506 | 22.993 | 27.078 | 22.321 | 17.849 | 10.302 |
| Long Cohort | 25.032 | 24.495 | 28.530 | 23.790 | 19.305 | 11.061 |
| Medium Cohort_1% minimum | 24.710 | 23.752 | 27.640 | 22.738 | 18.145 | 10.429 |
| 90%_Medium Cohort | 23.249 | 22.781 | 26.896 | 22.173 | 17.731 | 10.239 |
| Average(MC_LC) | 24.246 | 23.720 | 27.780 | 23.031 | 18.552 | 10.667 |
| Average(MC_LC)_1.5% minimum | 26.618 | 25.126 | 28.748 | 23.655 | 18.888 | 10.778 |
| 120% Long Cohort 2.5% minimum | 31.696 | 28.755 | 31.625 | 25.942 | 20.660 | 11.602 |
| ONS_2004_Female_UK_Principal | 25.114 | 24.286 | 28.176 | 23.368 | 18.686 | 10.277 |
| ONS_2004_Female_UK_HLE | 27.724 | 25.868 | 29.284 | 24.121 | 19.157 | 10.411 |
| ONS_2004_Female_UK_LLE | 22.993 | 22.967 | 27.239 | 22.720 | 18.271 | 10.153 |
| ONS_2006_Female_UK_Principal | 26.199 | 25.302 | 29.102 | 24.192 | 19.438 | 10.492 |
| ONS_2006_Female_UK_HLE | 28.840 | 26.885 | 30.201 | 24.931 | 19.895 | 10.603 |
| ONS_2006_Female_UK_LLE | 24.054 | 23.986 | 28.175 | 23.557 | 19.037 | 10.389 |
| PSAP_Female_ONS_EW_2003_50 | 17.615 | 18.504 | 23.406 | 19.344 | 15.465 | 8.952 |
| PSAP_Female_ONS_EW_2004_50 | 30.643 | 27.695 | 30.591 | 24.924 | 19.617 | 10.902 |
| PSAP_Female_ONS_EW_2005_50 | 29.925 | 27.224 | 30.252 | 24.726 | 19.541 | 10.916 |
| PSAP_Female_ONS_EW_2006_50 | 46.933 | 41.425 | 41.941 | 34.222 | 26.896 | 14.689 |
| PSAP_Female_ONS_EW_2007_50 | 38.674 | 33.792 | 35.519 | 29.067 | 23.018 | 12.817 |
| PSAC_Female_ONS_EW_2003_50 | 31.076 | 27.777 | 30.526 | 24.750 | 19.336 | 10.532 |
| PSAC_Female_ONS_EW_2004_50 | 35.513 | 31.264 | 33.364 | 27.015 | 21.054 | 11.337 |
| PSAC_Female_ONS_EW_2005_50 | 36.508 | 31.982 | 33.924 | 27.442 | 21.377 | 11.388 |
| PSAC_Female_ONS_EW_2006_50 | 37.751 | 33.198 | 35.034 | 28.441 | 22.217 | 11.854 |
| PSAC_Female_ONS_EW_2007_50 | 35.857 | 31.549 | 33.622 | 27.260 | 21.288 | 11.445 |
| LC_Female_ONS_EW_2003_Central | 24.429 | 23.401 | 27.266 | 22.378 | 17.770 | 10.117 |
| LC_Female_ONS_EW_2004_Central | 24.632 | 23.549 | 27.384 | 22.470 | 17.837 | 10.147 |
| LC_Female_ONS_EW_2005_Central | 24.677 | 23.577 | 27.402 | 22.477 | 17.837 | 10.140 |
| LC_Female_ONS_EW_2006_Central | 24.823 | 23.687 | 27.495 | 22.552 | 17.894 | 10.171 |
| LC_Female_ONS_EW_2007_Central | 24.833 | 23.687 | 27.488 | 22.541 | 17.881 | 10.159 |

## 8 Alternative assumptions at the oldest ages

Assumptions at very old ages are hugely uncertain, as there is very limited data to assess current rates of mortality, let alone interpret rates of improvement. In Working Paper 27, we drew attention to the commonly-used assumption of a limiting age of 120 but for many projections used a single approach to the assumptions that apply above age 90 more generally. With hindsight, the CMI recognised that the use of a single assumption (which, for many of the projections, was that the same improvements apply at these older ages as at the highest age within the projection) did not convey the range of approaches that could be legitimately taken in dealing with an area of extreme data shortage.

Whilst the CMI has retained the original assumptions for the projections in version 1.1 of the library, this section is intended to illustrate the uncertainty generated by these assumptions using alternative scenarios.

***The Limiting Age***

As noted in section 2, it has been the practice within recent CMI mortality tables to assume a limiting age of 120, i.e. that $q_{120} = 1$. There is very little data (within either the CMI or ONS datasets) to justify this practice explicitly, although the rarity to date of survivors beyond that age is perhaps justification in itself for base mortality assumptions.

This was a very convenient assumption, for practical purposes, adopted for version 1.0 of the library. The CMI remains comfortable with this assumption for 2009 and it has been retained for all the projections within version 1.1 of the library. However it is important to recognise that there is less justification for this assumption when future mortality improvements are taken into account, especially for example if considering a high-improvement scenario within a stress test. Indeed, as noted previously, the ONS 2006-based projections use a higher limiting age in the "High Life Expectancy" variant. Actuaries should therefore consider whether it is appropriate to retain this assumption in their particular situation.

In particular, some of the projections in the library imply quite significant rates of improvement in mortality at age 119, resulting in an unrealistic increase in mortality rates between ages 119 and 120. In order to illustrate this, consider the projection PSAC_Male_ONS_EW_2005_50, combined with a base mortality assumption (in 2007) of 100% of PCMA00. The base table contains a value of $q_{119} = 0.620322$ (and $q_{120} = 1$). By the end of the projection period in the library (2130), the value of $q_{119}$ has reduced to 0.000137 yet within the library, $q_{120}$ still equals 1.

In order to illustrate the sensitivity of results to this assumption, let us consider alternative scenarios. First, let us retain our initial assumption that the value of $q_{120}$ (and older ages) in 2007 is 1, but that in subsequent years the mortality rates improve at the same rates as at the oldest age within the projection (which we previously also applied up to age 119). Note that this has the impact of removing the assumption of a limiting age in the years after 2007 (although of course the proportion assumed to survive to such ages is minute initially). The results of this alternative scenario (labelled "Scenario 1") are compared to the complete expectation of life and annuity values from those in section 7 in the table below.

A second alternative is to suppose that the value of $q_{120}$ in 2007 is 0.65, which is much more reasonable in comparison with the graduated table at the immediately preceding ages. Further assume that $q_{121} = 0.70$, etc so that the limiting age in 2007 is 127 (i.e. $q_{127} = 1$) and that, as above, in subsequent years the mortality rates improve at the same rates as improvements at the oldest age within the projection. This is labelled "Scenario 2" in the table below.

***Ages 90 to 119***

As noted above, the assumption used in many of the projections in the library that the improvements at ages 90 to 119 (or at 91 to 119) are the same as the improvements at age 89 (or 90) is also highly arbitrary.

An alternative scenario is to assume that the rates of improvement reduce linearly from those applicable to the highest age in the projection to zero at age 119 (NB we have assumed the reduction applies vertically down a calendar year rather than, say, diagonally down a cohort). An immediate corollary of this is that the "step" in mortality rates between ages only widens gradually and in particular the "step" between age 119 and age 120 remains constant throughout. The base table contains values of $q_{118}$ = 0.602053, $q_{119}$ = 0.620322 (and $q_{120}$ = 1). By the end of the projection period in the library (2130), under this alternative scenario, the value of $q_{118}$ has only reduced to 0.581989, whilst the values of $q_{119}$ and $q_{120}$ remain equal to 0.620322 and 1, respectively. This is labelled "Scenario 3" in the table below.

Note that care may be required if an approach at older ages similar to that in Scenario 3 is used in conjunction with applying a minimum value to a projection, and that the order of the steps could have considerable impact.

All figures in the table below are for males and assume:

Base mortality = 100% PCMA00
Projection = PSAC_Male_ONS_EW_2005_50
Interest = 5% p.a. (for the annuity values)

| | **Annuity values for a life aged *x* exact on 1 July 2007** | | | | | |
|---|---|---|---|---|---|---|
| | $_{20\|}\ddot{a}_{45}$ | $_{10\|}\ddot{a}_{55}$ | $\ddot{a}_{60}$ | $\ddot{a}_{65}$ | $\ddot{a}_{70}$ | $\ddot{a}_{80}$ |
| | | | | | | |
| Base Scenario | 5.824 | 8.833 | 15.416 | 13.749 | 11.803 | 7.534 |
| | | | | | | |
| Scenario 1 | 6.023 | 8.994 | 15.535 | 13.823 | 11.842 | 7.539 |
| | | | | | | |
| Scenario 2 | 6.025 | 8.998 | 15.540 | 13.828 | 11.846 | 7.540 |
| | | | | | | |
| Scenario 3 | 5.405 | 8.415 | 15.037 | 13.428 | 11.549 | 7.395 |

| | Complete expectation of life for a life aged 65 exact on 1 July | | Complete expectation of life for a life aged *x* exact on 1 July 2007 | | | |
|---|---|---|---|---|---|---|
| | **2027** | **2017** | **$e_{60}$** | **$e_{65}$** | **$e_{70}$** | **$e_{80}$** |
| | | | | | | |
| Base Scenario | 41.219 | 33.313 | 33.198 | 26.019 | 19.646 | 9.829 |
| | | | | | | |
| Scenario 1 | 63.546 | 45.377 | 39.967 | 29.376 | 20.975 | 9.925 |
| | | | | | | |
| Scenario 2 | 63.826 | 45.729 | 40.267 | 29.600 | 21.107 | 9.946 |
| | | | | | | |
| Scenario 3 | 30.839 | 27.278 | 29.267 | 23.485 | 18.130 | 9.368 |

The impact of allowing mortality improvements at ages 120 and above (Scenario 1) is significant, especially for the deferred annuity values illustrated. In contrast the incremental effect of varying the assumptions regarding the level of mortality in 2007 at ages above 120 (Scenario 2) is very small.

The significance of the assumptions regarding mortality improvements between ages 90 and 119 is illustrated by Scenario 3, which effectively assumes that the limiting age of 120 persists for the foreseeable future, with very little improvement in mortality at the immediately preceding ages, and hence illustrates the process of "rectangularisation" of survival curves that has been referred to by many commentators.

At the older ages shown in the table above, the effect of Scenario 3 is to reduce annuity values by around 2%, but again the more significant impact is on the deferred annuity values.

Note that we have intentionally chosen the projection PSAC_Male_ONS_EW_2005_50 to illustrate the impact of varying the assumptions at older ages for effect, as it is one of the projections within the library illustrating the most rapid rates of future improvements. Other projections demonstrate much lower sensitivity to these assumptions. For example, the LC_Male_ONS_EW_2005_50 projection produces much lower rates of future improvements and demonstrates minimal variation under Scenarios 1 and 2 from the Base Scenario, and a very small reduction under Scenario 3. This is unsurprising when one considers that the value of $q_{119}$ has reduced to 0.232780 by the end of the projection period in the library (2130), in contrast to the value of 0.000137 noted earlier for the PSAC_Male_ONS_EW_2005_50 projection.

The CMI would like to emphasise that these alternative scenarios for mortality rates at the very old ages have been included to illustrate the significance of these assumptions. The CMI does not consider that the assumptions at these ages used in the library itself are necessarily more likely to be borne out in practice than the alternative approaches outlined in this section. There is of course a plethora of other alternatives that could also be considered.

# 9 Future updates

The CMI is not committing to any specified review dates for the library. However it will be appropriate to supplement the library from time-to-time:

- To incorporate subsequent years' data, as has been done for version 1.1 of the library;
- To incorporate experience from a new dataset, e.g. from the CMI SAPS investigation, when there is sufficient data;
- To incorporate new "intuitive" projections, in the light of likely or actual medical advances; or
- If future work on projection methodologies indicates that a new methodology is worthy of inclusion, e.g. the Lee-Carter Age-Period-Cohort model or one or more of the family of Cairns-Blake-Dowd models.

In addition to the specific models, other methodologies are regularly being developed. For example see the LifeMetrics paper which comments on the relative merits of a number of methodologies. The CMI is keen to contribute to further research within the Profession into methodologies but does not anticipate leading such research.

Working Paper 27 contained draft criteria to govern the inclusion of projections within the library. These have been amended, but the CMI does not intend that the criteria below should be viewed as either prescriptive requirements or a complete set, however we suggest that new projections should be:

- A worthwhile addition to what is already contained in the library;
- Publicly available;
- Clearly described and documented;
- 'Road-tested' on different datasets and for different time-periods; and
- Adequately exposed to the Actuarial Profession for discussion.

It may of course be appropriate to revise this approach and these criteria over time.

The process by which the CMI supplements the library may depend on the extent and impact of the new projections. For example:

- A minor change, such as adding projections based on subsequent data, may be incorporated without prior consultation;
- In contrast incorporating new projections generated from a "new" methodology is likely to only be done after consultation, perhaps by means of a Working Paper.

Whilst adding an additional year's data may be considered a routine update, comparison of the figures in section 7 shows that it can have a substantial impact on Lee-Carter and, especially, P-spline projections. Actuaries making use of projections based on the latest year's data should not do so without due care, given the volatility of some projections to new data.

Note that as none of the projections in the library is "recommended", there is unlikely to be a corresponding need to "withdraw" projections.

## References


CMI Report No. 10: Graduation of the 1979-82 Mortality Experience - the "80" Series (May 1990)

CMI Report No. 17: Graduation of the 1991-94 Mortality Experience - the "92" Series Standard Tables (June 1999)

CMI Working Paper 1: An interim basis for adjusting the "92" Series mortality projections for cohort effects (December 2002)

CMI Working Paper 15: Projecting Future Mortality: Towards a proposal for a stochastic methodology (July 2005)

CMI Working Paper 20: Stochastic Projection Methodologies: Further progress and P-Spline model features, example results and implication (Revised version, November 2007)

CMI Working Paper 22: The Graduation of the CMI 1999-2002 Mortality Experience: Final "00" Series Mortality Tables – Annuitants and Pensioners (August 2006)

CMI Working Paper 25: Stochastic projection methodologies: Lee-Carter model features, example results and implications (Revised version, November 2007)

CMI Working Paper 26: Extensions to Younger Ages of the "00" Series Pensioner Tables of Mortality (April 2007)

CMI Working Paper 27: The "library" of Mortality Projections (July 2007)

CMI Working Paper 30: The CMI Library of Mortality Projections (November 2007)

"Errata to CMI Working Papers 20, 25 and 27 on Mortality Projections" CMI (November 2007)

CMI Working Paper 35: The graduations of the CMI Self-Administered Pension Schemes 2000-2006 mortality experience. Final "S1" Series of Mortality Tables (October 2008)

CMI Working Paper 37: Version 1.1 of the CMI Library of Mortality Projections (March 2009)

National population projections 2004-based (GAD, Series PP2 No 25, 2006) available from http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=4611&Pos=&ColRank=1&Rank=256 or http://www.gad.gov.uk/Publications/Demography_and_Statistics_Publications_Archive.asp

National Population Projections 2006-based (ONS, Series PP2 No 26, 2008) available from http://www.gad.gov.uk/Publications/Demography_and_Statistics_Publications_Archive.asp

Pensions Institute Discussion Paper: PI-0701 – A quantitative comparison of stochastic mortality models using data from England & Wales and the United States – Andrew J.G. Cairns, David Blake, Kevin Dowd, Guy D. Coughlan, David Epstein, Alen Ong and Igor Balevich (March 2007). lifeMetrics available via http://www.jpmorgan.com/pages/jpmorgan/investbk/solutions/lifemetrics


All the CMI documents (and the Library itself) are available from:
http://www.actuaries.org.uk/knowledge/cmi

## Appendix A: Full list of projections in version 1.1 of the library

The full list of projections included in version 1.1 of the library is shown below:

| Projection | Sheet in spreadsheet | Base Year |
|---|---|---|
| **Volume 1: Previously-published Projections** | | |
| Original “92” Series | 2 | 1992 |
| Short Cohort | 3 | 1992 |
| Medium Cohort | 4 | 1992 |
| Long Cohort | 5 | 1992 |
| ONS_2004_Male_EWNI_Principal | 6 | 2004 |
| ONS_2004_Male_EWNI_High life expectancy | 7 | 2004 |
| ONS_2004_Male_EWNI_Low life expectancy | 8 | 2004 |
| ONS_2004_Male_S_Principal | 9 | 2004 |
| ONS_2004_Male_S_High life expectancy | 10 | 2004 |
| ONS_2004_Male_S_Low life expectancy | 11 | 2004 |
| ONS_2004_Female_UK_Principal | 12 | 2004 |
| ONS_2004_Female_UK_High life expectancy | 13 | 2004 |
| ONS_2004_Female_UK_Low life expectancy | 14 | 2004 |
| ONS_2006_Male_EWNI_Principal | 15 | 2006 |
| ONS_2006_Male_EWNI_High life expectancy | 16 | 2006 |
| ONS_2006_Male_EWNI_Low life expectancy | 17 | 2006 |
| ONS_2006_Male_S_Principal | 18 | 2006 |
| ONS_2006_Male_S_High life expectancy | 19 | 2006 |
| ONS_2006_Male_S_Low life expectancy | 20 | 2006 |
| ONS_2006_Female_UK_Principal | 21 | 2006 |
| ONS_2006_Female_UK_High life expectancy | 22 | 2006 |
| ONS_2006_Female_UK_Low life expectancy | 23 | 2006 |
| **Volume 2: Adjusted Cohort Projections** | | |
| Medium Cohort_1% minimum | 2 | 1992 |
| 90% Medium Cohort | 3 | 1992 |
| 50% Medium Cohort_50% Long Cohort | 4 | 1992 |
| (50% Medium Cohort_50% Long Cohort)_1.5% minimum | 5 | 1992 |
| (120% Long Cohort)_2.5% minimum | 6 | 1992 |
| **Volume 3: P-spline Age-Period Projections** | | |
| PSAP_Male_Ass_2003_50 | 2 | 2003 |
| PSAP_Male_Ass_2004_50 | 3 | 2004 |
| PSAP_Male_Ass_2005_50 | 4 | 2005 |
| PSAP_Male_ONS_EW_2003_50 | 5 | 2003 |
| PSAP_Male_ONS_EW_2004_50 | 6 | 2004 |
| PSAP_Male_ONS_EW_2005_50 | 7 | 2005 |
| PSAP_Female_ONS_EW_2003_50 | 8 | 2003 |
| PSAP_Female_ONS_EW_2004_50 | 9 | 2004 |
| PSAP_Female_ONS_EW_2005_50 | 10 | 2005 |

| Projection | Sheet in spreadsheet | Base Year |
|---|---|---|
| **Volume 4: P-spline Age-Cohort Projections** | | |
| PSAC_Male_Ass_2003_50 | 2 | 2003 |
| PSAC_Male_Ass_2004_50 | 3 | 2004 |
| PSAC_Male_Ass_2005_50 | 4 | 2005 |
| PSAC_Male_ONS_EW_2003_50 | 5 | 2003 |
| PSAC_Male_ONS_EW_2004_50 | 6 | 2004 |
| PSAC_Male_ONS_EW_2005_50 | 7 | 2005 |
| PSAC_Female_ONS_EW_2003_50 | 8 | 2003 |
| PSAC_Female_ONS_EW_2004_50 | 9 | 2004 |
| PSAC_Female_ONS_EW_2005_50 | 10 | 2005 |
| | | |
| **Volume 5: Lee-Carter Projections** | | |
| LC_Male_Ass_2003_Central | 2 | 2003 |
| LC_Male_Ass_2004_Central | 3 | 2004 |
| LC_Male_Ass_2005_Central | 4 | 2005 |
| LC_Male_ONS_EW_2003_Central | 5 | 2003 |
| LC_Male_ONS_EW_2004_Central | 6 | 2004 |
| LC_Male_ONS_EW_2005_Central | 7 | 2005 |
| LC_Female_ONS_EW_2003_Central | 8 | 2003 |
| LC_Female_ONS_EW_2004_Central | 9 | 2004 |
| LC_Female_ONS_EW_2005_Central | 10 | 2005 |
| | | |
| **Volume 6: Additional Projections in version 1.1** | | |
| PSAP_Male_Ass_2006_50 | 2 | 2006 |
| PSAP_Male_ONS_EW_2006_50 | 3 | 2006 |
| PSAP_Male_ONS_EW_2007_50 | 4 | 2007 |
| PSAP_Female_ONS_EW_2006_50 | 5 | 2006 |
| PSAP_Female_ONS_EW_2007_50 | 6 | 2006 |
| PSAC_Male_Ass_2006_50 | 7 | 2007 |
| PSAC_Male_ONS_EW_2006_50 | 8 | 2006 |
| PSAC_Male_ONS_EW_2007_50 | 9 | 2006 |
| PSAC_Female_ONS_EW_2006_50 | 10 | 2007 |
| PSAC_Female_ONS_EW_2007_50 | 11 | 2006 |
| LC_Male_Ass_2006_Central | 12 | 2006 |
| LC_Male_ONS_EW_2006_Central | 13 | 2007 |
| LC_Male_ONS_EW_2007_Central | 14 | 2006 |
| LC_Female_ONS_EW_2006_Central | 15 | 2006 |
| LC_Female_ONS_EW_2007_Central | 16 | 2007 |

Note that volumes 1 to 5 above are unchanged from version 1.0 of the library. All the additional projections in version 1.1 are contained in volume 6.

## Appendix B: Generating the P-spline projections in v1.1 of the library

### *Choice of dataset*

- The P-spline model requires age-specific data for successive years; a minimum of 20 years was suggested in Working Paper 20. Additionally, for the age-ranges fitted, a large amount of data is required in each year of observation.
- The only UK datasets, available to the CMI, that satisfy these criteria are the ONS England and Wales population (males and females) dataset and the CMI Permanent Assurances Lives (males) dataset. These were the datasets used to illustrate the P-spline methodology in Working Paper 20.
- Datasets may be subject to retrospective adjustment. Ordinarily the projections in the library use the original dataset. For example, the CMI dataset for the projections based on data to 2003 used in Working Paper 20 was based on data collected to 2003. The CMI Permanent Assurances Lives dataset has subsequently been amended reflecting revisions to the 1947-2003 data that arose during the processing of 2004 data but the projections in the library using CMI data to 2003 all use the original 1947-2003 dataset. If projections are undertaken using a more recent dataset with the last year's/years' data removed, this should be specifically disclosed.
- As noted in section 2, the projections using the ONS datasets use a different classification of deaths for 2006 and 2007 to the projections included in version 1.0 of the library using data to 2003, 2004 and 2005.
- Note that whilst the CMI will be aware of such changes in its own datasets, it may not necessarily always have access to the first available ONS dataset.

### *Method of generating P-spline projections*

- The P-spline model fits forces of mortality (i.e. $\mu_x$) to the data. The age definition of the exposure and deaths for each of the datasets and the age ($x$) to which the fitted $\mu_x$ apply is as follows:

| **Dataset** | **Age Definition** | **$\mu_x$ Estimate** |
|---|---|---|
| ONS | Age last birthday | $\mu_{x+½}$ |
| CMI Permanent Assurances Lives | Age nearest | $\mu_x$ |

- Mean values of $\mu_{x,t}$ are produced for each age $x$ and year $t$ within the fitted region of the dataset and in the region of the projection.
- The $\mu_{x,t}$ can be used to estimate the values of the $q_{x,t}$ and from these the calendar year improvements can be determined for each age.
- For ages above 90 for the CMI Permanent Assurances Lives data and above 89 for the ONS data, the improvements are assumed to equal the improvements at ages 90 and 89, respectively, whilst $q_{120}$ is assumed to equal 1.
- The library provides projected improvements to 2130. These have been derived from mean values of $\mu_{x,t}$ using the following approach:
    - For the CMI Permanent Assurances Lives data, values for $q_{x,t}$ were estimated as:

      $$q_{x,t} = 1- \exp \{- ½ (\mu_{x,t} + \mu_{x+1,t}) \}$$

    - For the ONS data, values for $q_{x,t}$ were estimated as:

      $$q_{x,t} = 1- \exp \{- \mu_{x+½,t} \}$$

    - The cumulative reduction for a particular year $t$ has been calculated as $q_{x,t} / q_{x,0}$, where $q_{x,0}$ is the mortality rate for 1992.

- The parameters used to generate the projections are shown below.
- The positioning of knots has followed the convention outlined in Sections 7.9-7.10 of Working Paper 20. This explains that the knots have been positioned at both corners of the leading edge of the data. In practice, this means that:
  - For the age-period model, knots are positioned at the highest age in the age dimension and in the final year of the dataset in the period dimension. The data is curtailed at younger ages, if necessary, so that a knot is also positioned at the lowest age.
  - For the age-cohort model, knots are positioned at the highest age in the age dimension and, in the cohort dimension, on the cohort consistent with this age in the last year of the dataset. The data is again curtailed at younger ages, if necessary, so that a knot is also positioned at the lowest age.

***Calculating percentiles for P-Spline projections***

- The P-Spline model produces mean values for log $\mu_{x,t}$ and corresponding standard deviations for the log $\mu_{x,t}$, $\hat{s}_{x,t}$.
- A set of $\mu_{x,t}$ relating to a particular percentile can be calculated by applying the standard normal variable ($Z$), for the percentile in question, to the standard deviations and using this to adjust the mean $\mu_{x,t}$. This process is summarised by the following equation:

$$\mu_{x,t} = \exp\{\log(\mu_{x,t}) + Z \times \hat{s}_{x,t}\}$$

- These may be used to illustrate some of the uncertainty inherent in any projection of future mortality (see section 5 for more details).

***Parameters used to generate the projections***

We have used cubic B-splines and a penalty order of 2 for all our fits. In all cases we have produced projections for 130 years (Note that the models produced projections for 130 years, e.g. to 2133 for 2003 base year projections, but the projected improvements included in the library are only provided up until 2130. Changing the length of the projection period may alter the fit produced.)

*Age-Cohort model*
For datasets fitted using the age-cohort model the following parameters were used:

| | **Permanent Assurances Lives Males** | **ONS (E&W) Males** | **ONS (E&W) Females** |
|---|---|---|---|
| Order of B-spline | 3 | 3 | 3 |
| Penalty order | 2 | 2 | 2 |
| Calendar Year range | 1947-2003/4/5/6 | 1961-2003/4/5/6/7 | 1961-2003/4/5/6/7 |
| Age range | 21-90 | 21-89 | 24-89 |
| Knot spacing:<br>- age dimension<br>- cohort dimension | <br>Every 3 years<br>Every 3 years | <br>Every 4 years<br>Every 4 years | <br>Every 5 years<br>Every 5 years |
| Fixed knot positions:<br>- age dimension<br>- cohort dimension | <br>90<br>Last year of data less 90 | <br>89<br>Last year of data less 89 | <br>89<br>Last year of data less 89 |
| Minimum for penalty:<br>- age dimension<br>- cohort dimension | <br>0.0001<br>0.0001 | <br>0.0001<br>0.0001 | <br>0.0001<br>0.0001 |
| Starting point for penalty:<br>- age dimension<br>- cohort dimension | <br>100<br>100 | <br>100<br>100 | <br>100<br>100 |
| Projection Period | 130 years | 130 years | 130 years |
| Classification of Deaths | Date of Settlement | Projections to 2003/4/5 use :<br>Date of Registration for 1961-1992 and Date of Occurrence for 1993-2003/4/5<br><br>Projections to 2006/7 use:<br>Date of Registration for 1961-2006/7 | |

*Age-period model*

For datasets fitted using the age-period model the following parameters were used:

| | **Permanent Assurances Lives Males** | **ONS (E&W) Males** | | **ONS (E&W) Females** |
|---|---|---|---|---|
| Order of B-spline | 3 | 3 | 3 | 3 |
| Penalty order | 2 | 2 | 2 | 2 |
| Calendar Year range | 1947-2003/4/5/6 | 1961-2003 | 1961-2004/5/6/7 | 1961-2003/4/5/6/7 |
| Age range | 22-90 | 23-89 | 24-89 | 23-89 |
| Knot spacing:<br>- age dimension<br>- period dimension | <br>Every 4 years<br>Every 4 years | <br>Every 6 years<br>Every 6 years | <br>Every 5 years<br>Every 5 years | <br>Every 6 years<br>Every 6 years |
| Fixed knot positions:<br>- age dimension<br>- period dimension | <br>90<br>Last year of data | <br>89<br>Last year of data | | <br>89<br>Last year of data |
| Minimum for penalty:<br>- age dimension<br>- period dimension | <br>0.0001<br>0.0001 | <br>0.0001<br>0.0001 | | <br>0.0001<br>0.0001 |
| Starting point for penalty:<br>- age dimension<br>- period dimension | <br>100<br>100 | <br>100<br>100 | | <br>100<br>100 |
| Projection Period | 130 years | 130 years | | 130 years |
| Classification of Deaths | Date of Settlement | Projections to 2003/4/5 use :<br>Date of Registration for 1961-1992 and<br>Date of Occurrence for 1993-2003/4/5<br><br>Projections to 2006/7 use:<br>Date of Registration for 1961-2006/7 | | |

For the projection using male ONS data to 2004 generated using the age-period model it was not possible to use the same parameters as those used for the projections with data to 2003. A fit was obtained by altering the knot spacing (to every 5 years) but other ways of achieving this may be possible. The same parameterisation was used for projections using data to 2005, 2006 and 2007.

## Appendix C: Generating the Lee-Carter projections in v1.1 of the library

### *Choice of dataset*

- The data requirements for the Lee-Carter model are similar to those for the P-Spline model (described in Appendix B). However, the minimum number of successive calendar years covered by the data can be adjusted depending on the width of the age range being fitted. If a narrower age range is used then fewer than 20 calendar years of data are required.
- The same datasets have been used to illustrate the Lee-Carter methodology in Working Paper 25 and to generate the projections in the library as were used for the P-Spline projections.
- As noted in Appendix B for the P-spline projections, datasets may be subject to retrospective adjustment. Ordinarily the projections in the library use the original dataset. For example, the CMI dataset for the projections in the library and in Working Paper 25 does not reflect revisions to the 1947-2003 data that arose during the processing of 2004 data. If projections are undertaken using a more recent dataset with the last year's/years' data removed, this should be specifically disclosed.
- As noted in section 2, the projections using the ONS datasets use a different classification of deaths for 2006 and 2007 to the projections included in version 1.0 of the library using data to 2003, 2004 and 2005.
- Note that whilst the CMI will be aware of such changes in its own datasets, it may not necessarily always have access to the first available ONS dataset.

### *Method of generating Lee-Carter projections*

- The Lee-Carter model fits forces of mortality (i.e. $\mu_x$) to the data. The ages included in the datasets are specified below.
- Values of $\mu_{x,t}$ are produced for each age $x$ and year $t$ within the fitted region of the dataset and in the region of the projection.
- The $\mu_{x,t}$ can be used to estimate the values of the $q_{x,t}$ and from these the calendar year improvements can be determined for each age.
- For ages above 90 for the CMI Permanent Assurances Lives data and above 89 for the ONS data the improvements are assumed to equal the improvements at ages 90 and 89, respectively and $q_{120}$ is assumed to equal 1.
- The library provides cumulative reduction factors to 2130. These have been derived from the central projection of $\mu_{x,t}$.
- In addition to the central projections, it is possible to calculate projected improvements for particular percentiles, i.e. 97.5$^{th}$ percentile (see section 6 for a brief explanation).

### *Parametric bootstrapping*

The process of parametric bootstrapping generates each synthetic dataset using the following steps:

- Fit the Lee-Carter model to the data and calculate the $\mu(x, t)$.
- Use the $\mu(x, t)$ and the exposure data to determine the number of expected deaths, based on the Lee-Carter fit.
- Compare the actual deaths against the expected deaths to obtain deviance residuals for each age and year.

- For each age, randomly reallocate the deviance residuals across the years.
- Use the reassigned deviance residuals to simulate the number of deaths for each age and year.
- Re-fit the Lee-Carter model to the simulated deaths and the actual exposures and fit a time-series to the $k(t)$ parameters.
- Use the fitted parameters to generate $\mu'(x, t)$ in the region of the dataset and the time-series to generate projected $\mu'(x, t)$. The $\mu'(x, t)$ form a simulation.

***Calculating percentiles for Lee-Carter projections***

- The percentiles for the Lee-Carter projections are determined from the scenarios generated.
- The $q_{x,t}$ can be calculated for each scenario. Percentiles could be generated by ordering the mortality rates from all the scenarios, for each age and year, and selecting those corresponding to a particular percentile. The volatility of the mortality rates projected using Lee-Carter means that confidence intervals around the mortality rates would be very wide.
- The approach used in Working Paper 25 was to assume a base table of $q_{x,0}$, reflecting actual experience in year zero [both "92" Series and "00" Series base tables were used] and an interest rate [4.5%] to calculate annuity values for each age and year, for each of 1,000 scenarios. The mean of these values is the figure shown in Working Paper 25 as the 50$^{th}$ percentile value.
- Values for other percentiles were generated by ordering the annuity values from all the scenarios for each age and selecting the value corresponding to that particular percentile.
- The resulting confidence intervals are much narrower than those around the projected mortality rates.

It is important to note that using the method adopted for Working Paper 25 necessitates assumptions regarding interest rates and base mortality and different assumptions could result in a different ranking of the scenarios, and hence different confidence intervals. Furthermore the ranking of the scenarios will differ according to the start age of the annuity.

For these reasons we have not included projected mortality rates, other than the central projection, within the library. Actuaries wishing to illustrate uncertainty by means of ranking scenarios using the Lee-Carter method will need to specify details of how these have been obtained if it is intended that another actuary should be able to reproduce them.

***Parameters used to generate the projections***

For all the Lee-Carter projections we have used an ARIMA(1,1,0) model to project the $k(t)$ parameters.

The following age ranges were used:

| | |
|---|---|
| Permanent Assurances lives, males | 20-90 |
| ONS, males | 20-89 |
| ONS, females | 20-89 |

For the projections using ONS datasets, the classification of deaths is as shown in Appendix B for P-spline projections.