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Pub-2016 Public Retirement Plans Mortality Tables Report

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Pub-2016 Public Retirement Plans Mortality Tables Report

AUTHOR Retirement Plans Experience Committee (RPEC)

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Section 1: Executive Summary

1.1 PURPOSE

In January 2019, the Society of Actuaries Research Institute (SOA) and the Retirement Plans Experience Committee (RPEC or "the Committee") published their first-ever mortality study of public pension plans, known as Pub-2010 [SOA 2019]. The primary focus of this study was a comprehensive review of recent mortality experience of public retirement plans in the United States. The objectives of this study were the following:

1. Develop mortality tables based exclusively on public-sector pension plan experience.
2. Provide new insights into the composition of sex-specific pension mortality by factors such as job category (e.g., Teachers, Public Safety, General), salary/benefit amount, health status (i.e., healthy or disabled), geographic region, and duration since event.

At the time of the publication of Pub-2010, the SOA and RPEC indicated that they would publish new studies of the mortality experience of public retirement systems approximately every five years. This study is the first issued since the publication of Pub-2010.

1.2 SUMMARY OF DATA COLLECTED

The final dataset upon which this study has been based includes approximately 58 million life-years of exposure and 774 thousand deaths from public pension systems across the United States. Data were received from a total of 41 different public pension systems that collectively submitted information for 100 plans, and the vast majority of the collected data was included in the study. In an effort to study potential variations in mortality by job category, contributors were asked to identify plan members as teachers, public safety personnel, or general employees.

The mortality experience collected comes from calendar years 2013–2020.[1] To avoid using experience affected by the COVID-19 pandemic, data contributed for calendar year 2020 was excluded from the study. See Subsection 12.2 for RPEC's rationale for this decision. Based on a weighted average of the exposures included in the study, the rates in the tables should be considered to be one-year mortality probabilities as of July 1, 2016.

[1] Contributors were asked to submit data for a seven-year period ending in 2020. Many non-calendar-year plans were included in the study; the final dataset includes partial years of exposure in 2013 and 2020 for these plans. Data collected for calendar year 2020 was excluded from the study so that the results would not be affected by the atypical experience associated with the COVID-19 pandemic.

1.3 MORTALITY TABLES DEVELOPED

The following sex-specific tables were developed on both an amount-weighted and headcount-weighted basis:

- Employee Tables (ages 18 through 80)
  - Teachers
    - Total Teacher dataset
    - Above-Median Income (based on salary)
    - Below-Median Income (based on salary)
  - Public Safety
    - Total Public Safety dataset
    - Above-Median Income (based on salary)
    - Below-Median Income (based on salary)
  - General Employees
    - Total General dataset
    - Above-Median Income (based on salary)
    - Below-Median Income (based on salary)
- Retiree Tables (through age 120, with beginning age differing by job category)[2]
  - Corresponding table types were developed as for Employees, with above- and below-median splits determined by retirement benefit amount rather than salary
- Disabled Retiree Tables (ages 18 through 120)
  - Public Safety
  - Non-Safety (for Teachers and General)
- Contingent Survivor Tables[3] (ages 45 through 120)
  - Total contingent survivor dataset
  - Above-Median Income (based on benefit amount)
  - Below-Median Income (based on benefit amount)

For completeness, the Committee also developed sex-specific Juvenile tables covering ages 0 through 17.[4] These are the same categories of tables that were developed for the Pub-2010 study.

The names for each of the amount-weighted mortality tables presented in this report are PubT-2016, PubS-2016, and PubG-2016, respectively, for the total Teacher, total Public Safety, and total General employee populations. The corresponding names for the headcount-weighted tables are PubT.H-2016, PubS.H-2016 and PubG.H-2016. For Disabled Retirees, the Teachers and General data were combined into a Non-Safety group, and the corresponding Disabled Retiree tables are named PubNS-2016.[5] Wherever applicable, the above-median and below-median versions of a given table are designated by the letter (A) or (B), respectively, immediately following the corresponding total population table name; e.g., PubT-2016(A) for the amount-weighted Above-Median Teachers tables. Collectively, the set of all tables presented in this report is named Pub-2016. The Pub-2016 Mortality Tables can be found on the SOA website at the

[2] Teacher tables cover ages 55 through 120, Public Safety tables cover ages 45 through 120, and General tables cover ages 50 through 120.
[3] The Contingent Survivor tables were based on data from all three job categories combined.
[4] See Section 8.
[5] In the Excel file accompanying this report, the PubNS-2016 rates are not explicitly labeled as such. They can be found in the "Disabled Retiree" columns on the "PubT-2016" and "PubG-2016" tabs. Note that the Disabled Retiree rates are identical between these two tabs.

following link: https://www.soa.org/resources/research-reports/2025/pub2016-retirementplans-morttables-finalreport/.

It should be noted that with the exception of the tables for Contingent Survivors, none of the mortality tables presented in this report reflect the combined experience of members from all three job categories. See Subsection 12.1 for RPEC's rationale for this decision.

1.4 IMPACT ON DEFERRED-TO-62 ANNUITY VALUES

Tables 1.1., 1.2, and 1.3 present comparisons of deferred-to-62 annuity values calculated as of July 1, 2024,[6] for Teachers, Public Safety, and General members, respectively, to those calculated using Pub-2010 mortality tables and the MP-2021 projection scale previously published by the SOA (SOA 2021).[7]

Each of the deferred annuity values shown in the following tables were developed using amount-weighted mortality rates, a pre-retirement discount rate of 7.0%, and a post-retirement discount rate of 5.0%. The 7.0% rate was chosen to be broadly representative of discount rates recently used in the funding valuations of public-sector retirement plans, and the "spread" of 2.0% to be broadly representative of assumed post-retirement cost-of-living adjustments.

Table 1.1
MONTHLY DEFERRED-TO-62 ANNUITY VALUES, PUB-2016 TEACHERS

		Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024		Percentage Change of Moving to PubT-2016 from PubT-2010
	Base Rate → Proj. Scale →	PubT-2010 MP-2021	PubT-2016 MP-2021	
Females	Age 25	1.2385	1.2352	-0.3%
	Age 35	2.4106	2.4037	-0.3%
	Age 45	4.6980	4.6848	-0.3%
	Age 55	9.1793	9.1560	-0.3%
	Age 65	13.9416	13.8771	-0.5%
	Age 75	10.5633	10.4144	-1.4%
	Age 85	6.6318	6.3962	-3.6%
Males	Age 25	1.1842	1.1763	-0.7%
	Age 35	2.2989	2.2838	-0.7%
	Age 45	4.4732	4.4437	-0.7%
	Age 55	8.7447	8.6894	-0.6%
	Age 65	13.2308	13.1319	-0.7%
	Age 75	9.7468	9.6134	-1.4%
	Age 85	5.8915	5.6749	-3.7%

[6] See Subsection 12.5 for a discussion of calculating annuity factors as of July 1, 2024.
[7] Employee mortality rates were assumed for all ages younger than 62, and Retiree rates were assumed for all ages 62 and older.

Table 1.2

MONTHLY DEFERRED-TO-62 ANNUITY VALUES, PUB-2016 SAFETY

	Base Rate → / Proj. Scale →	Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024 PubS-2010 MP-2021	PubS-2016 MP-2021	Percentage Change of Moving to PubS-2016 from PubS-2010
Females	Age 25	1.1850	1.1828	-0.2%
	Age 35	2.3007	2.2945	-0.3%
	Age 45	4.4741	4.4593	-0.3%
	Age 55	8.7160	8.6985	-0.2%
	Age 65	13.1215	13.1120	-0.1%
	Age 75	9.7879	9.6718	-1.2%
	Age 85	6.1657	5.9235	-3.9%
Males	Age 25	1.1336	1.1445	1.0%
	Age 35	2.1982	2.2195	1.0%
	Age 45	4.2713	4.3144	1.0%
	Age 55	8.3255	8.4213	1.2%
	Age 65	12.4787	12.6426	1.3%
	Age 75	8.9967	9.0963	1.1%
	Age 85	5.3647	5.4347	1.3%

Table 1.3

MONTHLY DEFERRED-TO-62 ANNUITY VALUES, PUB-2016 GENERAL

	Base Rate → / Proj. Scale →	Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024 PubG-2010 MP-2021	PubG-2016 MP-2021	Percentage Change of Moving to PubG-2016 from PubG-2010
Females	Age 25	1.2095	1.2045	-0.4%
	Age 35	2.3491	2.3396	-0.4%
	Age 45	4.5699	4.5530	-0.4%
	Age 55	8.9145	8.8904	-0.3%
	Age 65	13.4888	13.4489	-0.3%
	Age 75	10.1255	9.9961	-1.3%
	Age 85	6.2983	6.1292	-2.7%
Males	Age 25	1.1349	1.1322	-0.2%
	Age 35	2.1979	2.1944	-0.2%
	Age 45	4.2720	4.2652	-0.2%
	Age 55	8.3471	8.3419	-0.1%
	Age 65	12.6048	12.6060	0.0%
	Age 75	9.1994	9.1349	-0.7%
	Age 85	5.5589	5.3959	-2.9%

The amount-weighted deferred annuity values for Teachers are consistently larger than those for Public Safety and General. With the exception of factors for male Safety members, the amount-weighted deferred annuity values for all groups are less than those produced by the Pub-2010 tables. The annuity values for male Safety members increased 1.0% to 1.3%.

The corresponding deferred annuity comparisons using headcount-weighted mortality rates are roughly similar to those using amount-weighted rates shown above. Compared to their amount-weighted counterparts, headcount-weighted deferred-to-62 annuities are generally about 0.3% to 1.4% lower for females and about 1.0% to 3.3% lower for males, depending in both cases on job category and age.[8] These relationships are very similar to those produced by the Pub-2010 tables.

During the development of the Pub-2010 tables, multivariate analysis indicated that salary (for Employees) and benefit amount (for nondisabled Annuitants) were the most statistically significant predictors of mortality differences within individual sex/job classifications. The Committee again produced Above-Median and Below-Median versions of the Employee, Retiree, and Contingent Survivor tables. In general, the impact of moving from the total dataset table to either the Above- or Below-Median tables is considerably smaller for Teachers than for Public Safety or General, and the impact for males in each of the three job categories is considerably larger than that for females.[9]

1.5 APPLICATION OF PUB-2016 TABLES

The Committee encourages all stakeholders in the financial viability of U.S. public-sector retirement plans to carefully review the findings presented in this report. The Pub-2016 tables should be considered as part of the "published tables" described in Actuarial Standard of Practice No. 27, *Selection of Assumptions for Measuring Pension Obligations* (ASOP 27),[10] for the measurement of public plan obligations [ASB 2023]. In conjunction with knowledge of the individual characteristics and recent experience of the covered group, actuaries could use the Pub-2016 tables (possibly blended or otherwise adjusted using appropriate credibility techniques) as relevant published tables for a mortality assumption under ASOP 27.

For example, the statistical analyses summarized in this report support the observation that members with higher amounts (salary for Employees and benefit amount for Nondisabled Annuitants) tend to have lower rates of mortality than those with lower amounts. Consistent with the principles of ASOP 27 and subject to other relevant criteria, knowledge that the population being valued falls predominantly in the above (or below) median amount category could indicate that the corresponding Above-Median (or Below-Median) tables developed in this report could be considered as alternative benchmark tables to the corresponding "total population" tables.

The Committee believes that for most pension-related actuarial applications, the Pub-2016 mortality rates (including those for Disabled Retirees) should be projected with an appropriate mortality improvement scale, and that generational projection should be considered as an approach to projecting future mortality rates. In all cases, the selection of a mortality improvement assumption must satisfy the applicable requirements of ASOP 27.

[8] See Subsection 10.1.3 for details.
[9] See Subsection 10.2 for details.
[10] The Committee notes that in 2025, ASOP 35 was consolidated with ASOP 27, which became the operative standard for the selection of both economic and non-economic assumptions in the measurement of pension obligations.

Section 2: Background and Process

2.1 REASON FOR STUDY

The Society of Actuaries Research Institute (SOA) published the Pub-2010 Public Retirement Plans Mortality Tables Report in January 2019. Actuaries began recommending appropriate Pub-2010 mortality table variations in connection with experience studies and assumption reviews occurring in 2019 and later based on each plan's review cycle. This report represents a planned periodic update to the Pub-2010 study to capture any changes in mortality expectations since the collection of data used in the original study.

2.2 RPEC'S PROCESS

The RPEC public sector retirement plan mortality subcommittee commenced oversight of this study in early 2021. The following two subprojects required the services of external resources:

- For data collection, processing, and validation, RPEC relied upon the services of LIMRA and SOA staff; see Section 3 for details.
- For the graduation of raw mortality rates, RPEC enlisted the help of Irina Pogrebivsky, FSA, Assistant Professor and Director of the Actuarial Science Program at Arcadia University. Irina performed all the graduations that formed the basis for the mortality tables summarized in this report; see Section 4 for details.

2.3 NAMING CONVENTIONS

2.3.1 MEMBER STATUS

RPEC has used the following terms throughout this report to describe various subgroups of plan members:

- *Employee:* A nondisabled plan member who is actively employed[11] (including those in plans that no longer have ongoing benefit accruals).
- *Retiree:* A formerly active member in benefit receipt who was not deemed disabled at the date of retirement.
- *Contingent Survivor:* A surviving beneficiary[12] (of a formerly active or retired member) who is older than age 17 and in benefit receipt.
- *Disabled Retiree:* A retired member in benefit receipt who was deemed disabled as of the date of retirement.
- *Juvenile:* A member's surviving beneficiary who is under the age of 18.

The term *Nondisabled Annuitant* is used when it is not necessary to distinguish between a Retiree and a Contingent Survivor, and the term *Annuitant* is used when it is not necessary to distinguish between any member in payment status.

[11] Consistent with the Pub-2010 tables, terminated members (both nonvested and vested but not yet in payment status) were excluded from this study.

[12] Because of the difficulty in obtaining reliable information for beneficiaries while the Retiree is still alive, exposures and deaths for Contingent Survivors were counted starting with the Retiree's death.

2.3.2 TYPE OF PUBLIC-SECTOR EMPLOYMENT

As was the case for the original Pub-2010 mortality study, the data continue to demonstrate that members with certain types of public-sector employment exhibited overall mortality patterns different from those who had other types of jobs. As a result, RPEC analyzes mortality experience separately for each of the following three *job categories:*

- *Teachers:* School teachers and college/university professors, excluding all other school/university staff.
- *Public Safety:* Police officers, firefighters, and correctional officers. The name of this job classification has been shortened to *Safety* throughout most of this report.
- *General:* All other types of public plan members not specifically designated as Teachers or Safety, including members classified as general employees, non-faculty school/university staff, judges, members of the military, officials holding executive offices, and those submitted with miscellaneous or unknown job categories.

The three job categories outlined above are essentially identical to the categories used in the previous Pub-2010 report. RPEC originally considered the development of a set of "combined" public retirement plan mortality tables, which would reflect the aggregated mortality experience of all three job categories. As part of the original Pub-2010 study, the Committee ultimately concluded that it would not be appropriate to develop such tables given (1) the different mortality patterns exhibited by each of the three job categories and (2) the unequal sizes of the job category datasets.[13] See Subsection 12.1 for additional comments regarding this issue.

The previous paragraph notwithstanding, there were two instances when data for different job categories were combined. As explained in Subsection 5.3, data for all three job categories were combined to create the Contingent Survivor tables. The Teachers and General datasets were aggregated for purposes of constructing the Disabled Retiree mortality tables applicable to members in either of those two job categories, as described in Subsection 7.1.

2.3.3 MORTALITY TABLE NAMES

The names of the individual tables presented in this report are intended to clearly identify various important features reflected in those tables, specifically:

- The tables were developed with data provided exclusively by public-sector systems.
- Members in each job category generally exhibited mortality patterns different from those of the other two job categories.
- The central year of the study's observation period began in 2016.[14]
- The research team developed two full sets of mortality tables, one set with amount-weighted rates and the other with headcount-weighted rates.

In an attempt to capture all these features succinctly, RPEC adopted the following naming convention. The amount-weighted mortality tables for the total Teacher, total Safety, and total General populations are denoted *PubT-2016, PubS-2016,* and *PubG-2016,* respectively. The corresponding names for the

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[13] See Appendix B.

[14] The central year of the study, as computed by a weighted average of the calendar year of exposures, is approximately July 1, 2016, through June 30, 2017. See Subsection 11.1 for additional details.

headcount-weighted tables are PubT.H-2016, PubS.H-2016, and PubG.H-2016. For Disabled Retirees, the Teachers and General data were combined into a Non-Safety group, and the corresponding Disabled Retiree tables are named PubNS-2016. Where applicable, the above-median and below-median versions of a given table are designated by the letter (A) or (B), respectively, immediately following the corresponding total population table name, e.g., PubT.H-2016(A) for the headcount-weighted Above-Median Teachers tables.

Section 3: Data Collection and Validation

3.1 OVERVIEW

Below is a list of the phases involved in the development of the final dataset that generated the raw mortality rates for this study:

- Data collection
- Review for reasonableness and completeness
- Data consolidation and validation
- Month-by-month death pattern review
- Actual-to-expected ("A/E") ratio analysis

3.2 DATA COLLECTION

The formal data request package consisted of the following 10 documents (three of which had two separate versions depending on the data submission layout chosen by the contributor):

1. Cover letter outlining the goals of the study, an approximate timetable, and the required file formats
2. Plan-level information questionnaire, which requested details regarding the format of the submission and characteristics of the plan
3. Document containing instructions for completing the plan-level information questionnaire
4. Member-level information worksheet, which showed the information that must be provided for each member and denoted the situations for which each field is required
5. Document containing instructions for completing the member-level information worksheet
6. Excel file showing a sample submission
7. File that summarized the list of acceptable inputs for some categorical data fields
8. Audit checks for contributors to perform on their data prior to submission
9. List of commonly asked data questions
10. Example of how to report deaths that took place during the study period but were not reported until after the study period

The data collection and data processing phases of the project were coordinated by LIMRA staff and completed within LIMRA's secure environment to maintain confidentiality of the submitted data. SOA and LIMRA staff performed validation checks on the data, compiled data statistics, computed experience analytics, and imputed missing information where needed. In many cases, SOA/LIMRA made direct contact with the data contributors (coordinated through and including SOA staff) to address specific issues with data submissions.

The SOA intended to collect experience data for seven complete years. However, many public-sector plans have non-calendar-year valuation cycles. Similar to the Pub-2010 study, systems that track snapshots of member data at a time during the year other than January 1 or December 31 were instructed to provide data for a consecutive seven-year period ending in calendar year 2020. This resulted in the collection of some experience for the 2013 calendar year, which was included in the study. Overall, the SOA received raw data for 100 different[15] public pension plans, which were contributed by 41 different public pension systems from across the country.

3.3 REVIEW FOR REASONABLENESS AND COMPLETENESS

Prior to processing the data, SOA/LIMRA reviewed each data submission to determine whether the format was in accordance with the data request specifications and whether all required information was provided. High-level checks provided at this stage of the process included the following:

- Confirmation that all critical data fields were populated and had valid entries per the format requested for most members
- Review of record identifiers to assess feasibility of linking data across multiple years where necessary
- Review of record pairs with duplicate identifiers to confirm that the correct data could be determined
- Review for consistency with the contributor's indicated method for providing contingent survivor information

In the event that this initial review revealed issues with processing a given submission, the SOA followed up with the contributor to obtain either resubmissions of the data or clarification of how to treat the issues (e.g., a system or rule for handling duplicate records).

3.4 DATA COLLECTION AND VALIDATION

The Committee requested member-level data in accordance with one of the following two layouts:

1. One record per member for the entirety of the study period, including annual updates of member status (i.e., Employee, Terminated, Retiree, Contingent Survivor, Disabled Retiree, or deceased), salary[16] (for Employees) and pension amount (for Annuitants).
2. Eight annual snapshots of census data with a unique identifier for members that would allow information from different years to be linked across the study period.

In the event the second layout was chosen, the provided unique identifiers were used to link together each snapshot of a member's data throughout the study period to make the record of each member's experience as complete as possible. The use of consolidated records facilitated accurate counting of exposures and review of key data fields for internal consistency.

The review of individual records resulted in the identification of various issues for each contributor. Some issues could be resolved by making standardized assumptions, but others required record-specific analysis and often data questions for the contributor. Situations in which missing or invalid data were resolved via an assumption included the following:

[15] Two systems provided data for a very large number of small plans. For purposes of the data processing and the plan count shown here, these were treated as one plan.

[16] RPEC attempted to collect information on the types of compensation included in salary by plan. However, the definitions received were very diverse and did not lend themselves to quantifiable adjustments that could be used to ensure a consistent salary definition throughout the study. RPEC was therefore unable to reflect these varying definitions of salary in its analysis.

Missing Dates (e.g., Date of Termination, Date of Retirement, Date of Death)

The event date was assumed to be on the member's half-birthday during the 12-month period of the change in status. This approach distributes imputed status change dates uniformly throughout the calendar year, rather than clustering them at a particular date (e.g., midyear). The missing date methodology is best illustrated by an example:

- 1/1/2017 Status: Employee
- 1/1/2018 Status: Retiree
- Date of Birth: 6/1/1951
- Date of Retirement: (blank)

In this situation, the assumed Date of Retirement would be 12/1/2017.

Missing Salary or Total Monthly Pension

If the member had a reasonable amount provided for a different year, that year's amount would be used. If no valid amount existed in any year for that member, the plan's average for that member's job category, sex, and status group (Employee, Contingent Survivor, Disabled Retiree, Retiree) would be imputed.

Common situations that required data questions to contributors included the following:

Disappearing Records

In some cases, members would disappear from the data from one snapshot date to the next. Listings of these records were sent to the contributor for clarification. Some instances turned out to be deaths, but others ceased to appear in annual snapshots for other reasons, such as termination of employment, completion of a temporary annuity, or an invalid record.

Unclear Status at Death

There were cases of contributors providing records with a "deceased" status at a particular census date with insufficient information to determine what the member's status was prior to death (prior status codes were blank). These records were investigated to get clarity on the member's history to determine whether the deaths should be included in the study.

Missing Sex or Date of Birth

Records with either a missing Sex or Date of Birth were sent to the contributor in an attempt to obtain the missing information. All records still missing a Sex or Date of Birth after this extra attempt to collect these data were excluded from the study.

Large Monthly Pension Amounts

Unusually large monthly pension values were sent to contributors for confirmation. Many of those values were confirmed to be legitimate, but in some circumstances, it was determined that the contributor had incorrectly provided annual amounts or lump sum distributions, and these records were corrected.

Unclear Disability Status

Per the data request instructions, a status of Disabled Retiree should apply for the entire duration of a member's retirement if and only if they were disabled under the terms of the plan at the time of retirement. Some plans submitted member statuses that transitioned from Disabled Retiree to Retiree and vice versa, which should not have been possible under the requested definition. These records were sent to contributors to determine which of the two statuses should apply.

In some cases, plans tracked Disabled Retirees only prior to a certain age, and attainment of that age would cause a member to transition from Disabled Retiree to Retiree in the data. For these plans, all instances of Retiree were changed to Disabled Retiree if we were provided at least one Disabled Retiree status for the member, unless the contributor directed us otherwise. However, because some members may have attained the age that triggers this change prior to the study's observation period, it is likely that there were some Disabled Retirees classified as healthy Retirees for these plans. The effect of this categorization issue is likely minimal, and the Committee did not observe abnormally high Retiree mortality rates for plans with this issue.

Status Progression Inconsistencies

For situations with a small number of discrepancies between the status progressions provided and the associated non-death event dates, the Committee proceeded by trusting the status progression when the event date occurred more than 15 months prior to the date of the reported status change (with 15 months being used rather than 12 to account for potential reporting lag). See the below examples.

<u>Example 1</u>

- 1/1/2017 Status: Employee
- 1/1/2018 Status: Employee
- 1/1/2019 Status: Retiree
- Date of Retirement: 12/1/2017

In this situation, because the Date of Retirement was within 15 months of the date at which the statuses indicated a movement to Retiree status (i.e., 1/1/2019), the Date of Retirement of 12/1/2017 was treated as the beginning of the member's exposure as a Retiree, and the member was considered to be retired from that date, including as of 1/1/2018 when the member was indicated to be an Employee.

<u>Example 2</u>

- 1/1/2017 Status: Employee
- 1/1/2018 Status: Employee
- 1/1/2019 Status: Retiree
- Date of Retirement: 6/1/2016
- Date of Birth: 5/1/1952

In this situation, the reported Date of Retirement was not within 15 months of the date at which the statuses indicated a movement to Retiree status (i.e., 1/1/2019). The difference is greater than could typically be attributed to a lag in updating the member's status information. Therefore, the Date of Retirement was assumed to be on 11/1/2018, the member's half-birthday during the 12-month period of the change in status (in accordance with the procedure for "Missing Dates," above).

When there were large numbers of such discrepancies, questions were asked to the contributors to help assess the reliability of the information for a given date field or the status progressions. In most cases, the status progressions were confirmed to be more reliable than the dates. In those instances when the contributor did not provide additional assistance in resolving the discrepancies, the Committee's default decision was to rely upon the status progression provided by the contributor.

The only exception to the above rule was in connection with the Committee's handling of the Date of Death field. Any reasonable Date of Death provided by the contributor was always given greater credence than the associated status progression unless specifically instructed otherwise by the contributor.

3.5 MONTH-BY-MONTH DEATH PATTERN REVIEW

Before reviewing aggregate plan statistics, the Committee looked at the distribution of deaths by month and status group for each plan in the study. The original rationale for doing this was to see whether there were plans for which there was a lag in death reporting near the end of the study. In the event that a plan's death count notably dropped in the last month or two of the study period, the Committee wanted to confirm whether the lower counts were due to deaths not yet being reflected in the plan's database by the time of the last snapshot date.

When the Committee analyzed the individual plan reports, a number of other irregularities were discovered. Some plans had entire years of abnormally high or low death counts. Other plans reported an excessive concentration of deaths in a single month, which was typically indicative of the contributor providing Dates of Death that were defaulted to a single date in a given year rather than reflective of the actual Dates of Death. Inquiries on all these issues (including the potential reporting lags) were sent to the contributor for further clarification.

In response to the Committee's questions, most contributors were able to provide an updated register of death records to correct the problem. Others acknowledged that the unusual death patterns in some months or years were inaccurate for a known reason. This resulted in those time periods being excluded from the study for those contributors. In the case of an over-concentration of deaths in a single month, the Committee effectively treated the Date of Death as missing and reallocated it to the member's half-birthday in the same 12-month period as described above.

3.6 ACTUAL-TO-EXPECTED (A/E) RATIO ANALYSIS

Once the final data for each plan were deemed complete, the Committee began reviewing total mortality results for each plan. The "expected" number of deaths for this analysis was calculated on a year-by-year basis using the Pub-2010 mortality rates projected using Scale MP-2021 to the appropriate year in the observation period. The version of Pub-2010 (PubT-2010, PubS-2010, or PubG-2010) used was specific to the member's job category. For each status/job category combination, an exposure-weighted average A/E ratio was developed, which was used to normalize all plan A/E ratios in that subgroup such that the average A/E ratio was 100%. This was done to create a basis for determining outlier A/E ratios.

The Committee then developed approximate 95% confidence intervals for the normalized A/E ratios for each plan/status/job category combination. If the low end of the 95% confidence interval was greater than 110% or if the high end of the interval was less than 90%, the plan was flagged for additional examination.

For example, assume that the Employees in Plan X produced a normalized A/E ratio of 0.63, with a corresponding 95% confidence interval of 0.50 to 0.76. Since 0.76 (the high end of the confidence interval) is less than 0.90, Plan X would have been flagged for additional examination.

Mortality statistics for flagged plan/status/job category combinations were sent to contributors for confirmation. In most cases, contributors were either able to provide confirmation of their statistics or corrected data that resulted in that data subgroup no longer being flagged. Outliers that could not be confirmed by the contributor were dropped from the study. In total, less than 5% of the total dataset was excluded as a result of the Committee's A/E analysis.[17]

3.7 SUMMARY OF THE FINAL DATASET

Table 3.1 presents a summary of the final dataset by status, sex, and job category. This includes only data used in the development of the final Pub-2016 mortality tables.[18] A reconciliation of excluded data can be found in Appendix A.

Table 3.1
SUMMARY OF THE FINAL DATASET

		Teachers		Safety		General		Total All Job Categories	
		Exposures	Deaths	Exposures	Deaths	Exposures	Deaths	Exposures	Deaths
Employee	Female	7,839,298	5,643	245,183	291	10,832,809	12,913	18,917,290	18,847
	Male	2,785,417	3,690	1,817,233	1,708	7,250,421	15,370	11,853,071	20,768
	Total	10,624,715	9,333	2,062,416	1,999	18,083,230	28,283	30,770,361	39,615
Retiree	Female	4,972,224	91,957	252,205	2,694	8,269,955	195,776	13,494,384	290,427
	Male	2,294,149	64,450	1,337,669	24,261	5,998,071	187,710	9,629,889	276,421
	Total	7,266,373	156,407	1,589,874	26,955	14,268,026	383,486	23,124,273	566,848
Disabled Retiree	Female	154,001	4,908	71,809	838	729,919	18,457	955,729	24,203
	Male	52,617	2,382	410,756	9,279	630,016	22,489	1,093,389	34,150
	Total	206,618	7,290	482,565	10,117	1,359,935	40,946	2,049,118	58,353
Contingent Survivor	Female	326,204	14,639	203,794	7,413	1,317,376	64,695	1,847,374	86,747
	Male	117,251	6,268	6,946	277	299,524	16,093	423,721	22,638
	Total	443,455	20,907	210,740	7,690	1,616,900	80,788	2,271,095	109,385
Total	Female	13,291,727	117,147	772,991	11,236	21,150,059	291,841	35,214,777	420,224
	Male	5,249,434	76,790	3,572,604	35,525	14,178,032	241,662	23,000,070	353,977
	Total	18,541,161	193,937	4,345,595	46,761	35,328,091	533,503	58,214,847	774,201

3.8 DETERMINATION OF AMOUNT-BASED QUARTILES AND MEDIANS

To analyze results by benefit amount for Annuitants and annualized salary for Employees, the data were divided into four amount quartiles, with unique breakpoints determined within each status, sex, year, and job category. Data provided with missing amounts were excluded from this process. These splits were

[17] See row (c) of Table A.1 in Appendix A.
[18] A relatively small amount of validated data fell outside of the age ranges used in the graduation phase of the table construction process and therefore was excluded from Table 3.1. See Sections 5–7 for the details of graduation age ranges.

performed on the original seriatim data, meaning that breakpoints were determined to split the number of records evenly between the four quartiles. As some records generated more exposure than others (e.g., a person may have a partial year of exposure due to being hired or terminating during a particular calendar year), this meant that the number of life-years of exposure in each quartile was not exactly equal, though the distribution was reasonably even.

Consistent with the Pub-2010 study, the Committee split the data into above- and below-median groupings for purposes of table construction. Thus, the data for the top two quartiles within each status and job category were combined to create the above-median datasets, and the data for the bottom two quartiles formed the below-median datasets. Records provided without an amount were included in the full dataset (with an imputed amount per Subsection 3.4) but were not part of either the above-median or below-median groups. As a sample, the annualized quartile breakpoints for calendar year 2016 by sex, job category, and status are shown in Table 3.2.

Table 3.2
QUARTILE BREAKPOINTS – CALENDAR YEAR 2016

		Females			Males		
Job Category	**Percentile**	**Active**	**Retiree**	**Contingent Survivor**	**Active**	**Retiree**	**Contingent Survivor**
Teacher	**25th**	42,420	16,995	7,133	45,882	25,080	4,739
	50th	58,846	34,067	15,299	65,454	44,072	10,870
	75th	79,380	55,525	29,724	87,137	65,867	21,777
Safety	**25th**	49,152	14,560	7,133	59,674	26,540	4,739
	50th	65,734	31,025	15,299	83,059	39,472	10,870
	75th	94,316	47,818	29,724	106,974	60,316	21,777
General	**25th**	32,764	7,011	7,133	41,064	11,814	4,739
	50th	45,304	16,157	15,299	55,691	25,744	10,870
	75th	63,026	30,000	29,724	78,582	42,817	21,777

3.9 DATASET OVERLAP WITH PUB-2010 STUDY

This Pub-2016 report presents many comparisons to the Pub-2010 study. The degree of overlap of participating systems between these two studies provides important context for understanding the differences in the results. Table 3.3 below details the number of systems and the percentage of exposure from systems represented in each of the two studies. For all three job categories, a majority of the data from each study comes from systems that participated in both of the two studies.

Table 3.3
OVERLAP BETWEEN PUB-2016 AND PUB-2010 DATASETS

Job Category	Measure	Only in Pub-2010 Dataset	In Pub-2010 and Pub-2016 Datasets	Only in Pub-2016 Dataset
Teacher	Number of Systems	2	13	8
	Percent of Pub-2010 Study Exposures	14%	86%	N/A
	Percent of Pub-2016 Study Exposures	N/A	82%	18%
Safety	Number of Systems	12	14	14
	Percent of Pub-2010 Study Exposures	23%	77%	N/A
	Percent of Pub-2016 Study Exposures	N/A	78%	22%
General	Number of Systems	13	16	18
	Percent of Pub-2010 Study Exposures	34%	66%	N/A
	Percent of Pub-2016 Study Exposures	N/A	73%	27%
Total	Number of Systems	15	19	22
	Percent of Pub-2010 Study Exposures	28%	72%	N/A
	Percent of Pub-2016 Study Exposures	N/A	76%	24%

Section 4: Graduation of Raw Rates

RPEC developed raw mortality rates under two bases: (1) amount-weighted rates, which reflected annualized salary for Employees and annualized retirement plan benefits for Retirees, Contingent Survivors, and Disabled Retirees and (2) headcount-weighted rates. As is typical with empirical datasets, each set of sex-/age-specific raw mortality rates developed by the Committee exhibited a certain degree of random fluctuations around a smooth trend curve.

The objective of any graduation methodology is to smooth observed experience in a way that maintains an appropriate degree of fit with the underlying raw dataset. RPEC developed smoothed mortality rates based on Generalized Additive Model (GAM) methodology.

Central to GAM graduation methodology is the concept of an "objective function" that needs to be minimized. The GAM objective function includes two components: one that measures the overall fit and the other that measures the overall smoothness of the graduated values. For example, given a set of raw mortality rates, q_x, over the age range x_{min} to x_{max}, with weights w_x, the GAM objective function used by RPEC was equivalent to[19]

$$\sum_x w_x\left(\ln q_x - f(x)\right)^2 + \lambda \int_{x_{min}}^{x_{max}} [f''(x)]^2 dx$$

RPEC used the "mgcv" package in R, a widely used language and environment for statistical computing and graphics, to solve for the minimizing function, *f(x)*. Further information on the GAM graduation methodology used by RPEC can be found in Appendix C.

The specific age ranges used in the GAM graduation for each type of table (Employee, Retiree, Contingent Survivor, and Disabled Retiree) and each job classification (Teacher, Safety, and General) are reflected in the dataset summaries presented in Appendix B. The range of ages used to develop the amount-weighted rates and the corresponding headcount-weighted rates are the same.

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[19] Note that for the sake of exposition, some details are omitted. The theory of GAMs is based on maximum likelihood, and the binomial likelihood with log link was used for the RPEC graduations. It can be shown that the likelihoods in the GAM framework are equivalent to optimizing this objective function via Iteratively Reweighted Least Squares (IRLS). Under IRLS, the formula provided here has two adjustments. For each iteration, the weights are updated to reflect the fitted model (to that point), and a special residual, in this case $(q_x - \hat{q}_x)/\sqrt{\hat{q}_x}$, is added to the error $\ln q_x - f(x)$. Each iteration is then a weighted least squares calculation.

Section 5: Construction of Retiree and Contingent Survivor Tables

5.1 OVERVIEW

The following outlines the steps that RPEC took to construct the Retiree and Contingent Survivor mortality tables:

1. The development of mortality rates at ages 100 and above, starting with the graduated sex-specific rates derived from data for the aggregated (i.e., all three job categories combined) Retirees dataset.

2. For each table weighting (amount and headcount), and separately for each job category, graduated sex-specific Retiree mortality rates were developed starting at various job category-specific early retirement ages through age 95.

3. For each table weighting, graduated sex-specific Contingent Survivor mortality rates for all three job categories combined were developed for ages 50 through 95. Contingent Survivor mortality rates for ages 45 through 49 were based on scaled versions of the corresponding aggregated Retiree rates for those ages.

4. For each of the 12 sets of Retiree rates (two sexes, two weightings, and three job categories) and each of the four sets of Contingent Survivor rates (two sexes and two weightings), RPEC used quintic polynomials to interpolate mortality rates smoothly between ages 90 and 100.

5. For each of the 16 separate mortality tables described in step 4, two additional tables were developed, representing subpopulations of the corresponding dataset, bifurcated based on whether the underlying annuity amount was above- or below-median for that population.[20]

As a result, RPEC ended up constructing a total of 36 separate Retiree mortality tables and 12 separate Contingent Survivor tables.

5.2 DEVELOPMENT OF MORTALITY RATES AT AGES 100 AND ABOVE

RPEC decided that the sex-specific mortality rates at ages 100 and above for all annuitants in all three job categories should coincide, as there was insufficient experience to support the contrary. For each of the four combinations of sex and weighting, RPEC developed mortality rates at ages 100 through 119 using projection methodology originally developed by Kannisto [Kannisto 1992]. Each of the Kannisto projections was based on the graduated mortality rates at ages 89 and 90 from the corresponding aggregated (all three job categories combined) Nondisabled Annuitant database. The resulting annual mortality rates were capped at 0.5, and the annual mortality rate at age 120 was set equal to 1.0.

[20] For example, in addition to the amount-weighted Male Retiree Teachers table, an amount-weighted Male Retiree Teachers Above-Median table and an amount-weighted Male Retiree Teachers Below-Median table were produced. The Male Retiree Teachers dataset was split into the Above- and Below-Median subpopulations using the median annual retirement benefit for Male Retiree Teachers of $44,072; see Subsection 3.8.

5.3 GRADUATION OF MORTALITY RATES FOR RETIREES AND CONTINGENT SURVIVORS

Analysis of the final Retiree dataset indicated significant differences in the distribution of exposures and deaths among the three job categories. For example, virtually all Retiree exposures and deaths under age 50 were concentrated within the Safety subpopulation. Because of these differences, the Committee decided to start the graduation processes at different ages for each of the three job category subpopulations: age 55 for Teachers, age 45 for Safety, and age 50 for General. Additional adjustments were required to the Female Retiree rates for the General job category for ages below 55 (56 for amount-weighted tables) to avoid an unexplainable spike in the mortality curve between ages 50 to 55 (56 for amount-weighted tables). The adjustment smoothed the pattern by scaling the expected Female General Retiree mortality rates from ages 50 to 55 (56 for the amount-weighted tables) with the age 55 (56 for amount-weighted tables) ratio of expected Female Retiree mortality rate for all job categories to the expected Female Retiree mortality rate for the General job category.

The graduation processes for all Retiree subgroups ended at age 95.

Although some exposure/death variations by job category were identified within the final Contingent Survivor dataset, those differences were less significant than those within the Retiree dataset. That fact, along with the relatively small size of the Contingent Survivor dataset for males, persuaded RPEC not to construct separate Contingent Survivor tables for each of the three job categories. Hence the graduation processes for the Contingent Survivor rates were based on the total (all three job categories combined) dataset, starting at age 50 and continuing through age 95.

5.4 FURTHER EXTENSIONS OF MORTALITY RATES FOR RETIREES AND CONTINGENT SURVIVORS

At this point, the Committee had developed smoothed mortality rates for all Retiree and Contingent Survivor subpopulations through age 95 using the GAM graduation methodology and for ages 100 and above using Kannisto's methodology. Given the relatively small amount of data at ages greater than 90, RPEC decided to complete each of these tables by fitting a quintic polynomial to rates at the following six ages: 88, 89, and 90 (from the GAM graduation) and 100, 101, and 102 (from the Kannisto projection).

The Committee decided that it would also be useful to develop Contingent Survivor rates down to age 45. The mortality rates for ages 45 through 49 were computed by extending backwards smoothly from the graduated rates at age 50 using a constant multiple of the corresponding aggregated (all three job categories) Retiree rates for ages 45 through 49. Each of these scaling factors was based on the ratio of the age-50 Contingent Survivor mortality rate for the table being extended to the corresponding age-50 aggregate Retiree rate. For example, each of the amount-weighted Contingent Survivor mortality rates for females between ages 45 and 49 was set equal to 1.26355 times the corresponding amount-weighted aggregate Retiree rate, where the scaling factor was calculated as the ratio of the corresponding rates at age 50.[21]

5.5 DEVELOPMENT OF ABOVE-MEDIAN AND BELOW-MEDIAN ANNUITANT TABLES

Based on prior analysis there is clear evidence for variations in mortality experience based on benefit amount for both Retirees and Contingent Survivors. As a result of these findings, the Committee concluded that it would be important to construct separate sets of tables based on datasets bifurcated on "Above-

[21] RPEC constructed aggregate Retiree tables solely for the purpose of extending the Contingent Survivor tables from age 50 down to age 45. See Subsection 13.1 for a discussion of why aggregate Retiree tables were not published as part of this report.

Median" and "Below-Median" subpopulations. For purposes of table development, above- or below-median benefit amount designations were determined separately for each sex and job category.

With the exception of the Female Safety and Female General Retirees discussed below, all the Above-Median and Below-Median tables used the methodology outlined in Section 5.3.

Due to data anomalies, the Above-Median and Below-Median female subpopulations exhibited strange patterns relative to the combined female subpopulation in the General job category. Consequently, the committee decided to scale the Above-Median and Below-Median Female General tables to the Total Female General table. Specifically, the Above-Median and Below-Median tables for female General Retirees were set equal to a constant multiple of the underlying total female General Retiree table, based on the ratio of total actual deaths to total expected deaths for ages 55 through 95. For example, the amount-weighted rates for Above-Median female General Retirees are all 96.05% of the corresponding total female General Retiree amount-weighted rates.

Given the thinness of the total dataset for female Safety Retirees, the Committee decided to scale the Above-Median and Below-Median tables to the Total Safety table by the same factors as it used to scale the Female General Retiree Above-Median and Below-Median Tables. For example, the amount-weighted rates for Above-Median female Safety Retirees are all 96.05% of the corresponding total female Safety Retiree amount-weighted rates.

Section 6: Construction of Employee Tables

6.1 OVERVIEW

The following steps summarize the process that RPEC utilized to construct the Employee mortality tables:

1. The raw sex-specific rates for each job category and weighting combination were graduated using the GAM methodology described in Section 4.

2. Each of these sets of smoothed rates was extended (when necessary) beyond the end of the oldest graduation age to age 80 by determining the constant annual increase factor that would converge exactly to the corresponding Retiree age 100 rate. An exception is for female Safety, which was constructed as a constant multiple of the female General Employee table, per subsection 6.2.

3. Each of these sets of smoothed rates was extended backwards from age 25 (the age at which all of the Employee rate graduations commenced) to age 18 by fitting a cubic polynomial to the following four mortality rates: the Juvenile rates at ages 16 and 17 (see Section 8) and the corresponding graduated Employee rates at ages 25 and 26.

4. For each of the resulting 12 separate mortality tables (two sexes, two weightings, and three job categories), two additional tables were developed. These additional tables reflect subpopulations of the corresponding dataset, bifurcated based on whether the Employee's salary amount was above- or below-median for that population.

Overall, a total of 36 Employee tables were created.

6.2 DEVELOPMENT OF FEMALE PUBLIC SAFETY EMPLOYEE TABLES

Due to the thinness of data, the Committee decided to scale the Female Public Safety table to the Total Female General table. Specifically, the Female Public Safety Employee rates were set equal to a constant multiple of the underlying total Female General Employee table, based on the ratio of total actual deaths to total expected deaths for ages 40 through 65. For example, the amount-weighted rates for Female Safety Employees are all 109.54% of the corresponding total Female General Employee amount-weighted rates.

6.3 EXTENSION TO AGE 80 FOR TEACHERS AND MALE PUBLIC SAFETY

Since there was sufficient reliable data within the General population to graduate Employee rates through age 80, RPEC needed to develop extended Employee rates only for Teachers and male Safety. In each of those cases, rates were extended beyond the oldest graduation age (age 75 for Teachers and age 65 for male Safety) by solving for the constant exponential rate that, if applied to the oldest graduated rate, would equal the corresponding sex-specific age 100 Retiree rate for the total retiree population.

Considering the amount-weighted Safety table for males as an example, the graduated age-65 Employee rate is 0.004725, the corresponding male age-100 Retiree rate is 0.35131, and the resulting exponential factor is 1.131009. Hence the mortality rate for each of the ages 66 through 80 was calculated as 1.131009 times the rate at the preceding age.

6.4 DEVELOPMENT OF ABOVE-MEDIAN AND BELOW-MEDIAN EMPLOYEE TABLES

In the construction of the Pub-2010 tables, the Above-Median and Below-Median Employee rates at ages 25 and older were each set equal to a constant multiple of the corresponding total job category-specific Employee table, based on the ratio of total actual deaths to total expected deaths for ages 25 through 70 (25 through 65 for Safety), with the expected deaths determined using the total job-category-specific reference rates.

The Committee considered doing the same for Pub-2016. However, the data collected for this study had an anomaly that required an adjustment to this methodology. It was observed that the subset of members without a valid salary amount had substantially higher mortality than those with a valid salary amount, which caused the resultant Above-Median and Below-Median mortality curves to appear asymmetrical relative to the total job-category-specific tables. The Committee determined that it was most appropriate to use the ratio of Above- and Below-Median deaths to expected deaths determined using the combined Above- and Below-Median datasets (i.e., the subset of data with a valid salary amount populated). These ratios were then applied to the total job-category-specific tables to create the Above- and Below-Median tables.

Note that depending on the quantity of exposures, the ages at which this methodology commenced varied by sex, job category, and income level. For example, Female Safety Above-Median rates were developed this way starting at age 45 (very little data prior to age 45). Whereas Male General Below-Median rates were developed this way starting at age 25. The rates for ages 18 through each respective methodology commencement age were developed using cubic polynomial interpolation, as described in Subsection 6.1.

Section 7: Construction of Disabled Retiree Tables

7.1 OVERVIEW

Early in the process of constructing tables for Disabled Retirees, RPEC observed that the overall pattern of raw mortality rates for Safety Disabled Retirees was significantly different than that for the Disabled Retirees in both of the other two job categories. This result was not unexpected, because of (1) the nature of the work performed by people in these professions and (2) the fact that Disabled Retirement provisions in plans covering Safety workers are typically quite different from those covering other (Non-Safety) occupations.

Based on that observation, along with the fact that the overall mortality patterns for Disabled Retirees in the Teachers and General job categories were relatively similar at ages 60 and older, the Committee decided to combine these two Disabled Retiree datasets for table construction purposes. Hence, two sets of sex-/weighting-specific Disabled Retiree mortality tables were created: one based on Safety experience and another based on the combined experience of Teachers and General. This latter subgroup is referred to as "Non-Safety" throughout this report.

7.2 PROCESS

The following describes the process that RPEC utilized to construct the Disabled Retiree mortality tables:

1. The raw sex-/weighting-specific rates for the Safety and Non-Safety subgroups were graduated using the GAM methodology described in Section 4. Except for the female Safety subpopulation, graduated rates were used between ages 50 and 95 for all Disabled Retiree subgroups. The graduated rates for female Safety Disabled Retirees covered only ages 50 through 75, because of the limited size of this dataset.

2. Each of these sets of smoothed rates was extended to the corresponding age 100 (nondisabled) Retiree rate using quintic polynomial interpolation. The quintic interpolation process started at ages 83, 84, and 85 and ended at ages 100, 101, and 102 for all subgroups except female Safety, for which the interpolation process started at ages 73, 74, and 75. For ages 100 and older, the Disabled Retiree rates were assumed to equal the corresponding Retiree rates.

3. Each of these sets of smoothed rates was extended backwards starting at age 59 down to age 18 by applying a constant scaling factor to the corresponding Employee rates.[22] Each of these scaling factors was calculated as the ratio of the age-60 rate for a given Disabled Retiree subgroup to the age-60 rate for the corresponding Employee subgroup. Between 50 and 60, the Committee used linear interpolation to connect age-50 to age -60 rates to smooth out blips in the data at those ages. Table 7.1 summarizes those scaling factors.[23]

[22] Note that a combined Teachers and General Employee table was constructed solely for the purpose of extending the Non-Safety Disabled Retiree to ages 18 through 49.
[23] The scaling factors used to develop the headcount-weighted Disabled Retiree rates for a small number of ages (below age 50) were adjusted to ensure those rates were never lower than their amount-weighted counterparts.

Table 7.1
SCALING FACTORS USED TO DEVELOP DISABLED RETIREE RATES BELOW AGE 60

Sex/Job Category	Amount-Weighted	Headcount-Weighted
Female Safety	3.64	3.64
Male Safety	3.41	3.41
Female Non-Safety	8.79	8.79
Male Non-Safety	6.39	6.39

As can be seen in Table 7.1, the factors used to develop the Disabled Retiree rates below age 60 were much smaller for Safety members than those for Non-Safety members. The fact that the Disabled Retiree mortality rates for Safety members are generally lower than the corresponding Disabled Retiree rates for Non-Safety members is not surprising, given that the plan provisions for disability retirement benefits (eligibility and amount) for those in Safety professions are typically considerably less restrictive than those for members in other public-sector jobs. The difference between Safety and Non-Safety Disabled Retiree mortality rates can also be seen by comparing the displays in Subsection 9.5.

Because of the limited predictive value of benefit amount for Disabled Retirees and the thinness of the dataset for female Safety Disabled Retirees, the Committee decided not to develop separate Above- and Below-Median versions of these tables.

Section 8: Construction of Juvenile Tables

For completeness, RPEC has also included a set of sex-specific Juvenile mortality rates for ages zero through 17. The rates of ages zero through 12 were set equal to the average of the top quintile mortality rates for each age in the U.S. population for calendar years 2015-2019 as developed from National Center for Health Statistics (NCHS) data by Magali Barbieri, PhD, for the MIM-2021-v4 Application Tool [SOA 2024]. The top quintile was chosen to represent a subpopulation with more favorable mortality than the general population, and thus a better match for mortality rates for ages above 17 built from the study data.

Both of the sex-specific Juvenile rates for ages 16 and 17 were based on the aforementioned average NCHS top quintile rates for 2015-2019 multiplied by the ratio of (1) the actual number of deaths from all three job categories for Employees between ages 25 and 34 to (2) the total expected number of deaths between ages 25 and 34 based on the average NCHS top quintile for 2015-2019. The Juvenile rates for ages 13, 14, and 15 were calculated using cubic polynomial interpolation.

Note that the sex-specific Juvenile rates are the same for both the amount and headcount weightings.

Section 9: Comparison of Rates

9.1 OVERVIEW

RPEC produced sets of Pub-2016 mortality tables similar to those in the previously published public retirement plans SOA tables, Pub-2010. The Committee viewed the comparison to Pub-2010 as most appropriate, since it believes most practitioners currently use some version of that table, given its widespread application in U.S. public retirement plans' valuations. RPEC produced job category-specific comparisons of amount-weighted[24] mortality rates to those previously published SOA tables.

All the graphs presented in Section 9 compare Pub-2016 mortality rates to Pub-2010 rates projected from July 1, 2010, to July 1, 2016,[25] with Scale MP-2021.

A ratio less than 1.0 means that the Pub-2016 mortality rate is smaller than the corresponding projected Pub-2010 mortality rate.

[24] Corresponding graphs constructed using the headcount-weighted mortality rates exhibit similar ranges of ratios to the amount-weighted versions shown in this section and therefore are not included in this report.
[25] See Subsection 12.5 for a discussion of projecting mortality rates to July 1, 2016.

9.2 COMPARISON OF RETIREE RATES

Figure 9.1 shows that the PubT-2016 rates for males exceed the corresponding rates in the projected Pub-2010 table at all ages. The PubT-2016 rates for females are below the corresponding rates in the projected Pub-2010 table until age 78, after which they exceed the projected Pub-2010 rates.

Figure 9.1

RATIO OF PUBT-2016 RETIREE TO PUBT-2010 RETIREE - MORTALITY RATES PROJECTED TO 2016 WITH SCALE MP-2021

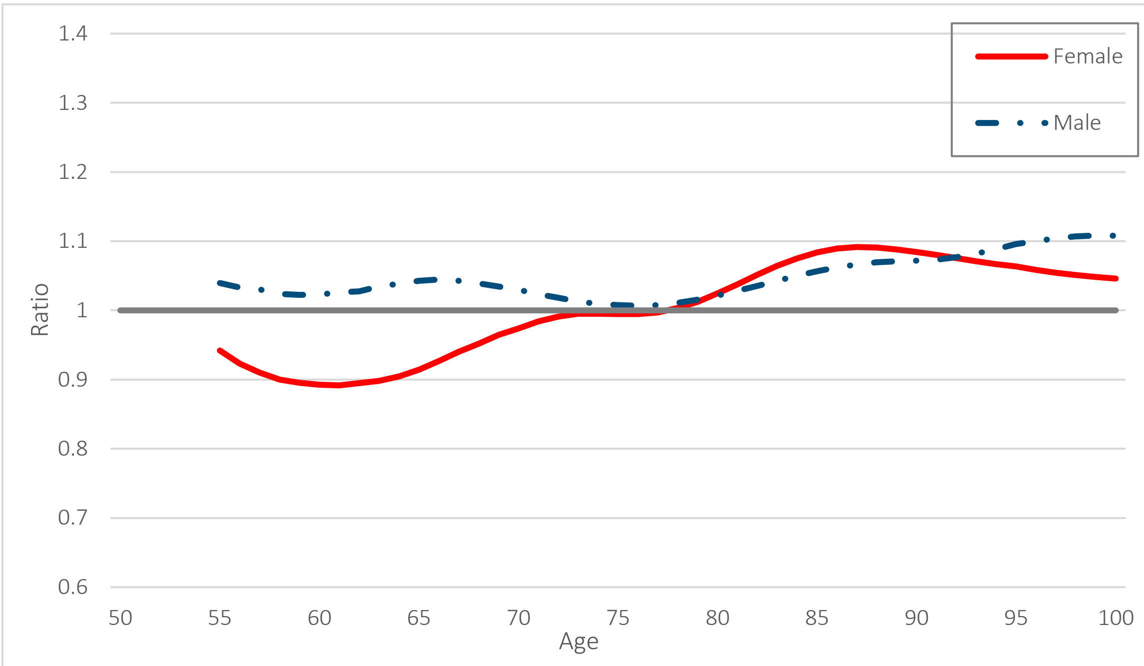


Figure 9.2 shows that the PubS-2016 rates for females are initially above the corresponding projected PubS-2010 rates but drop below them after age 53 and then rise and exceed them at ages 79 and beyond. Similarly, Figure 9.2 shows that male PubS-2016 rates initially exceed the corresponding projected PubS-2010 rates but then drop below them. As in the case of the female rates, the PubS-2016 rates for males eventually exceed the corresponding projected PubS-2010 rates, but only at ages 93 and beyond.

Figure 9.2

RATIO OF PUBS-2016 RETIREE TO PUBS-2010 RETIREE - MORTALITY RATES PROJECTED TO 2016 WITH SCALE MP-2021

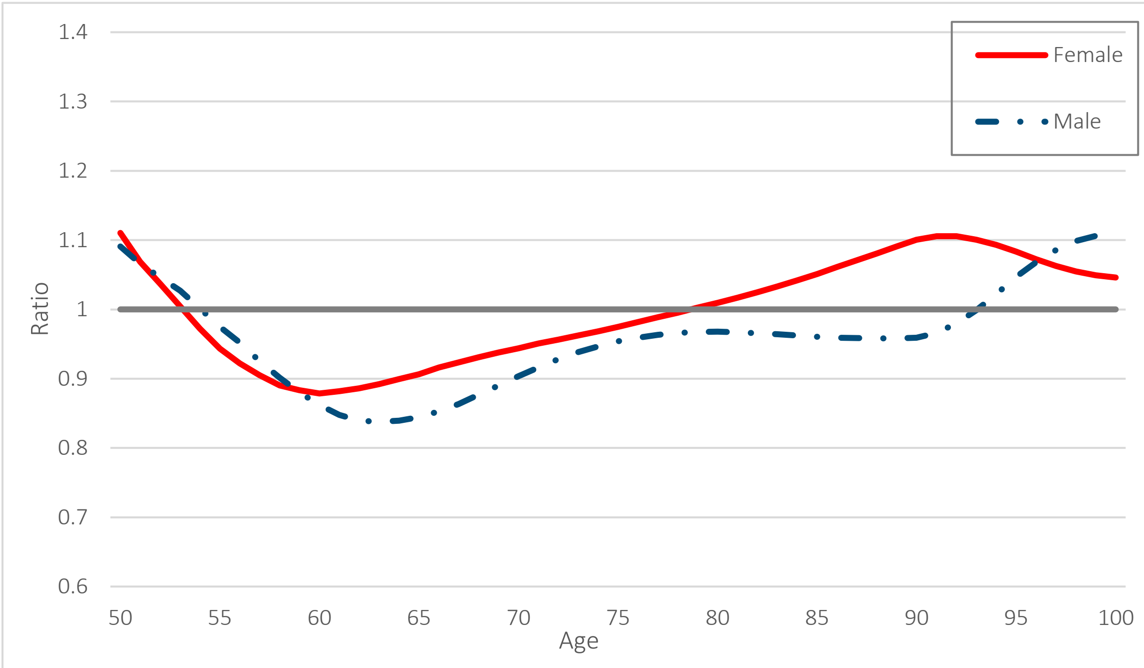
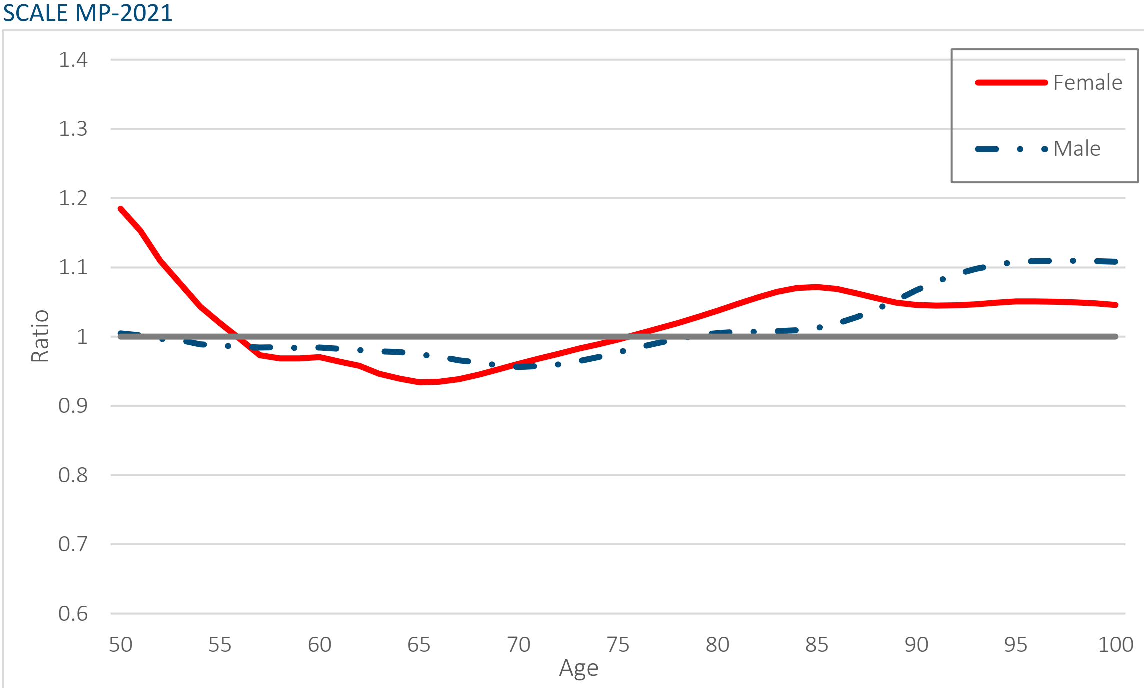


Figure 9.3 shows that the female PubG-2016 rates are lower than the projected PubG-2010 rates between ages 56 and 75 but otherwise slightly higher. Male PubG-2016 rates are very close to or slightly below the projected male PubG-2010 rates for ages below 80 but higher otherwise.

Figure 9.3

RATIO OF PUBG-2016 RETIREE TO PUBG-2010 RETIREE - MORTALITY RATES PROJECTED TO 2016 WITH SCALE MP-2021



9.3 COMPARISON OF EMPLOYEE RATES

Figure 9.4 shows that the PubT-2016 employee rates for females are generally lower than the corresponding projected Pub-2010 rates but equal or exceed them at ages 42 to 51. Figure 9.4 shows a more complicated pattern for the PubT-2016 employee rates for males, which exceed the corresponding projected Pub-2010 rates at ages below 32, are below them at ages between 32 and 39, exceed them between ages 39 and 58, and then fall below them at later ages.

Figure 9.4.

RATIO OF PUBT-2016 EMPLOYEE TO PUBT-2010 EMPLOYEE - MORTALITY RATES PROJECTED TO 2016 WITH SCALE MP-2021

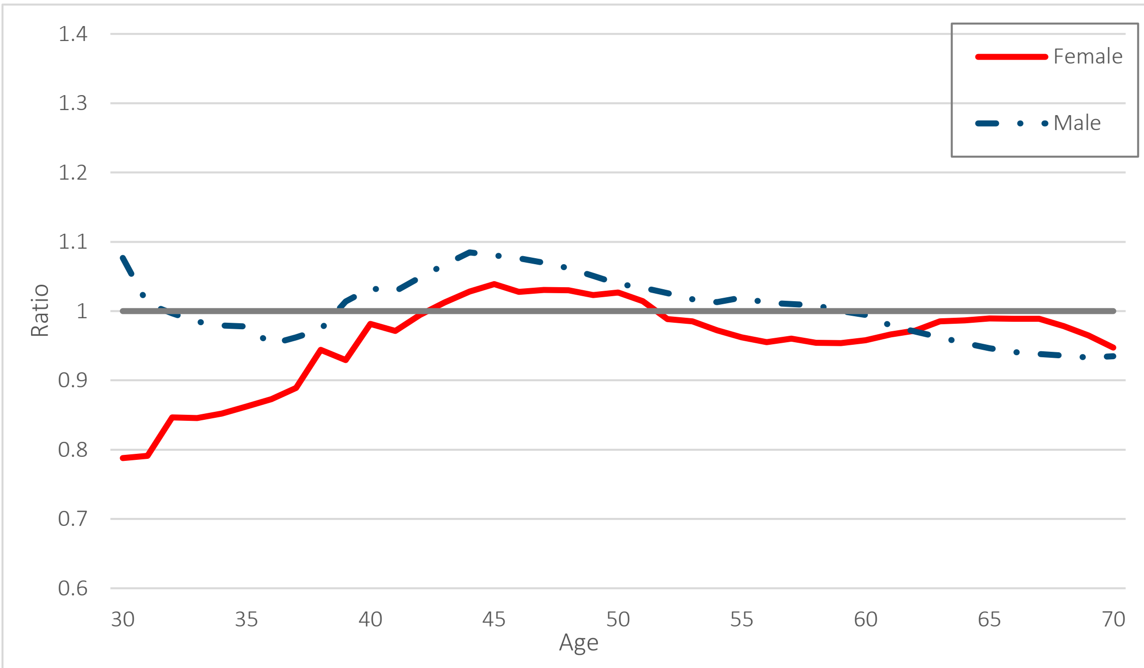


Figure 9.5 shows that both the female and male PubS-2016 rates are lower than the projected PubS-2010 rates for ages under 45 and higher otherwise.

Figure 9.5
RATIO OF PUBS-2016 EMPLOYEE TO PUBS-2010 EMPLOYEE - MORTALITY RATES PROJECTED TO 2016 WITH SCALE MP-2021

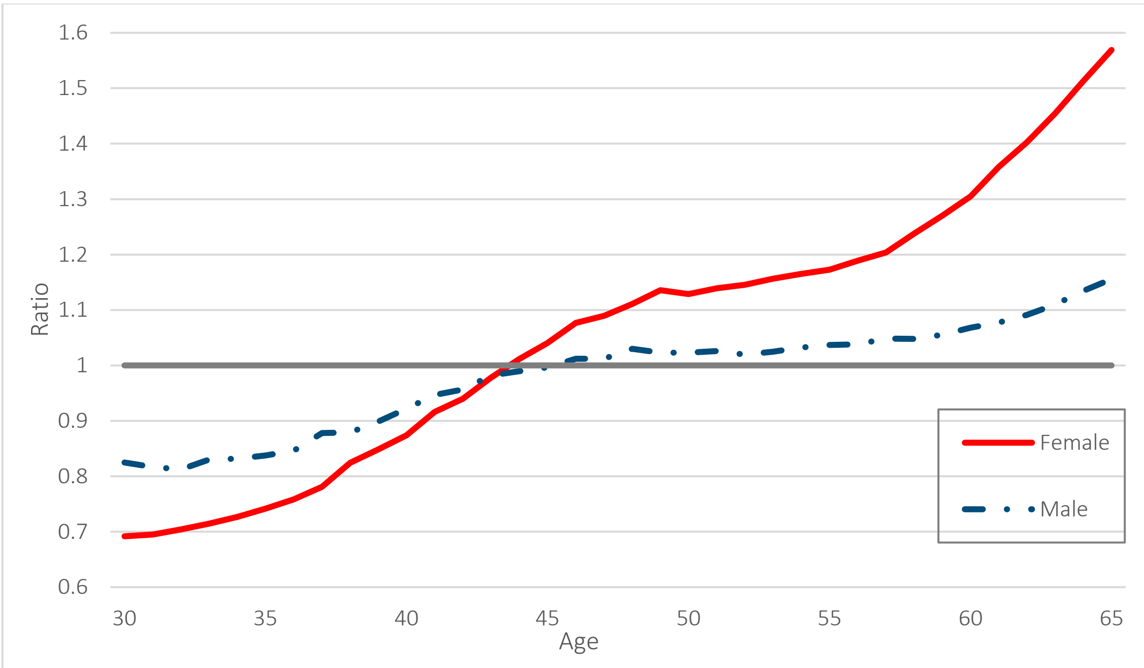
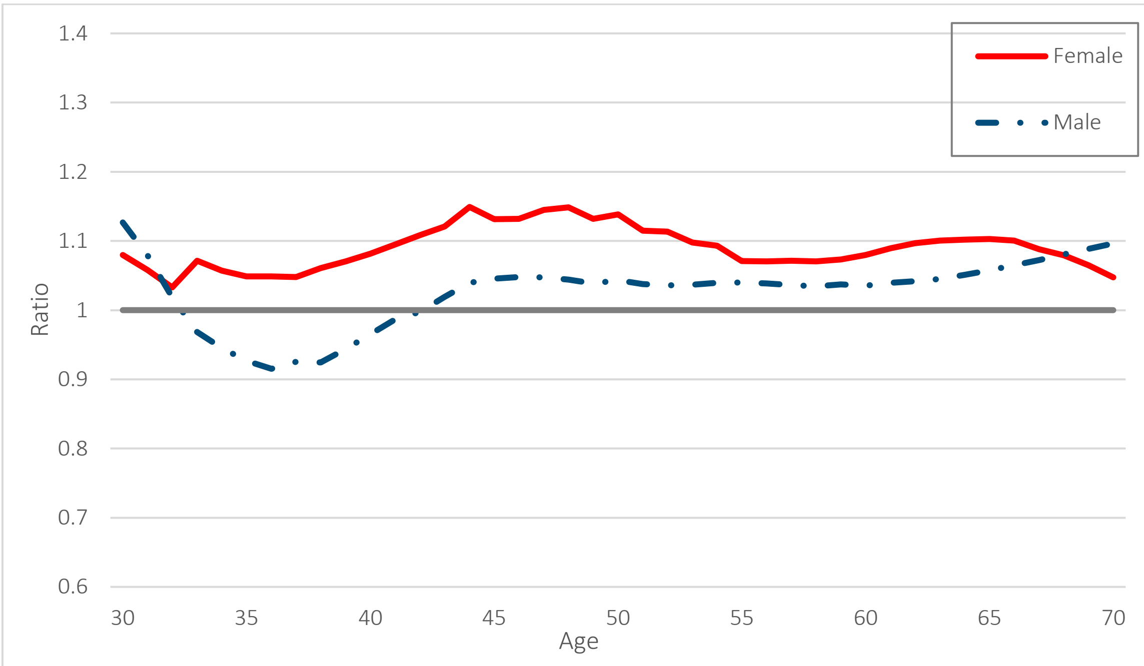


Figure 9.6 shows that the female PubG-2016 rates are higher than the projected PubG-2010 rates across all age groups. A similar pattern is observed for male rates, except for ages between 33 and 42 where PubG-2016 male rates are lower than the projected PubG-2010 rates.

Figure 9.6

RATIO OF PUBG-2016 EMPLOYEE TO PUBG-2010 EMPLOYEE - MORTALITY RATES PROJECTED TO 2016 WITH SCALE MP-2021

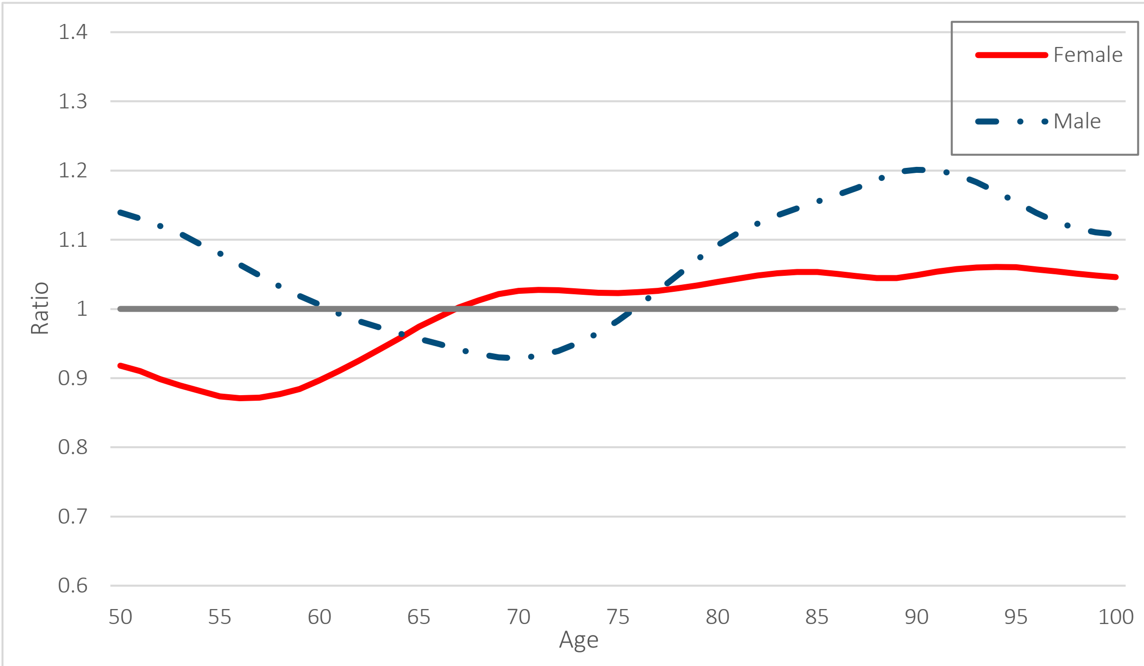


9.4 COMPARISON OF CONTINGENT SURVIVOR RATES

Figure 9.7 shows that the female Pub-2016 Contingent Survivor rates lie below the corresponding projected Pub-2010 rates at ages below 67 and exceed them at later ages. The male Pub-2016 Contingent Survivor rates are higher than the corresponding projected Pub-2010 rates except between ages 61 and 76, at which they are below them.

Figure 9.7

RATIO OF PUB-2016 CONTINGENT SURVIVOR TO PUB-2010 CONTINGENT SURVIVOR - MORTALITY RATES PROJECTED TO 2016 WITH SCALE MP-2021



9.5 COMPARISON OF DISABLED RATES

Figures 9.8 and 9.9 show a comparison between the Pub-2016 Disabled Retiree rates and the corresponding Pub-2010 rates, projected to 2016 using MP-2021.

Figure 9.8 shows that the female PubS-2016 Disabled Retiree rates vary considerably from the projected Pub-2010 rates. They are generally higher, sometimes considerably higher, except for ages between 55 through 65 where they are lower. Male PubS-2016 Disabled Retiree rates are generally higher than the projected Pub-2010 rates, except for ages between 58 through 70.

Figure 9.8

RATIO OF PUBS-2016 DISABLED SAFETY RETIREE TO PUBS-2010 DISABLED SAFETY RETIREE - MORTALITY RATES PROJECTED TO 2016 WITH SCALE MP-2021

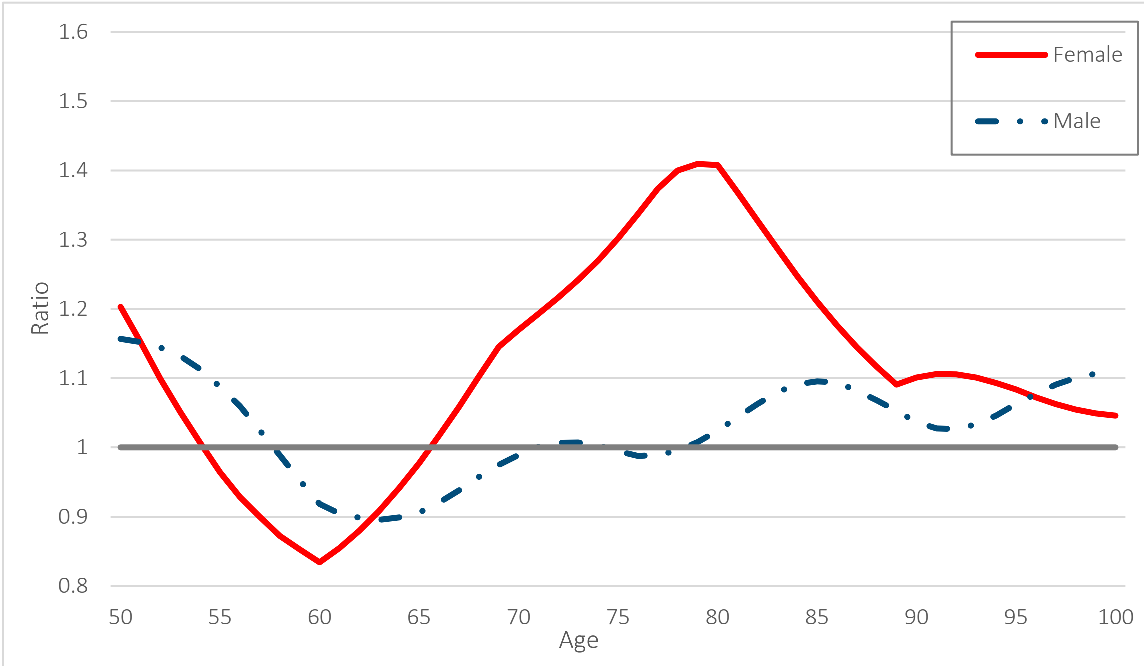
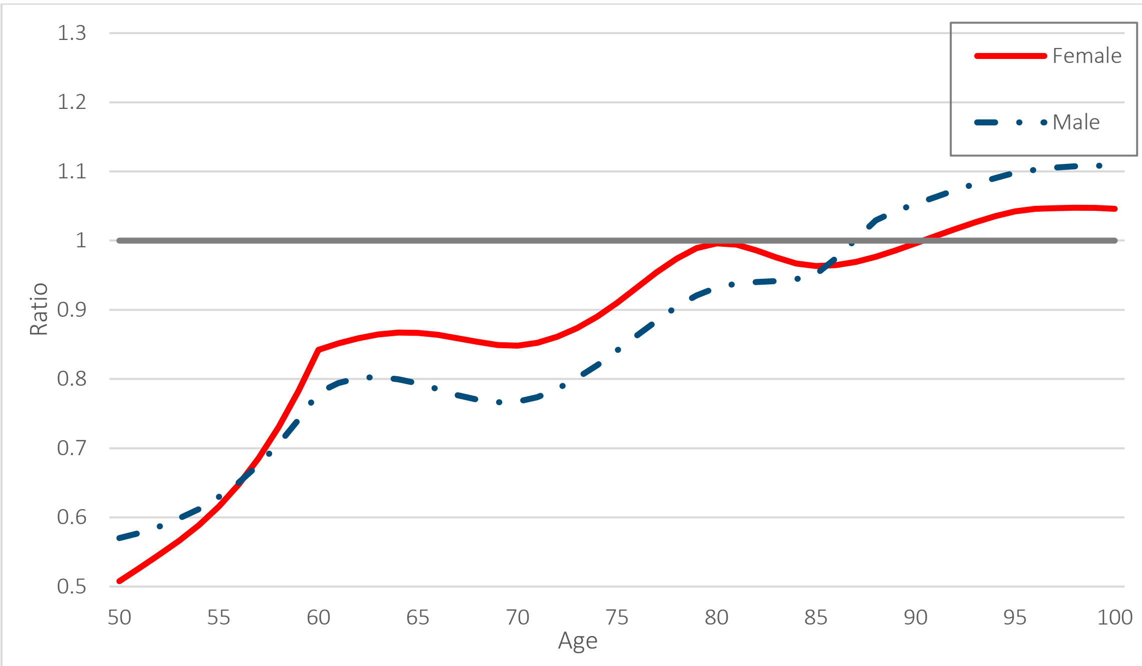


Figure 9.9 shows that the PubNS-2016 Disabled Retiree rates are initially significantly lower than the corresponding projected Pub-2010 but gradually rise in relation to those rates and exceed them at ages above 87 for males and 91 for females.

Figure 9.9

RATIO OF PUBG-2016 DISABLED NON-SAFETY RETIREE TO PUBG-2010 DISABLED NON-SAFETY RETIREE - MORTALITY RATES PROJECTED TO 2016 WITH SCALE MP-2021



Section 10: Annuity Comparisons

10.1 COMPARISON OF ANNUITY VALUES TO OTHER PUBLISHED SOA TABLES

10.1.1 BASIS OF ANNUITY CALCULATIONS

All annuity values in this section were calculated as of July 1, 2024,[26] using a pre-retirement discount rate of 7.0% and a post-retirement discount rate of 5.0%. The 7.0% rate was chosen to be broadly representative of discount rates recently used in the funding valuations of public-sector retirement plans, and the "spread" of 2.0% broadly representative of assumed post-retirement cost-of-living adjustments. Annuity comparisons based on a flat 7.0% discount rate (pre- and post-retirement) are presented in Appendix D.1.

For all deferred-to-age-62 annuity calculations shown in this report, RPEC used Employee rates for ages less than 62 and Retiree rates for ages 62 and older. All monthly annuity values were calculated using the standard approximation to Woolhouse's formula:

$${}_{n|}\ddot{a}^{(12)} \approx {}_{n|}\ddot{a}_x - (11/24)\ {}_{n|}E_x$$

10.1.2 COMPARISONS OF AMOUNT-WEIGHTED DEFERRED ANNUITIES FOR NONDISABLED MEMBERS

The Committee developed deferred-to-age-62 annuity-due values for nondisabled members in each of the three job categories and compared those to deferred annuity values developed using the previously published SOA Pub-2010 tables and MP-2021 mortality improvement scale.

Table 10.1 shows that the amount-weighted deferred annuity values developed using the new tables for Teachers are lower than those developed using the PubT-2010 table. The deferred annuities values produced using the new PubT-2016 range from 0.3% lower for younger females to almost 4% lower for older males and females.

[26] See Subsection 12.5 for a more detailed discussion of the calculation of annuity values as of July 1, 2024.

Table 10.1
AMOUNT-WEIGHTED TEACHERS

	Base Rate → / Proj. Scale →	Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024 PubT-2010 MP-2021	PubT-2016 MP-2021	Percentage Change of Moving to PubT-2016 from PubT-2010
Females	Age 25	1.2385	1.2352	-0.3%
	Age 35	2.4106	2.4037	-0.3%
	Age 45	4.6980	4.6848	-0.3%
	Age 55	9.1793	9.1560	-0.3%
	Age 65	13.9416	13.8771	-0.5%
	Age 75	10.5633	10.4144	-1.4%
	Age 85	6.6318	6.3962	-3.6%
Males	Age 25	1.1842	1.1763	-0.7%
	Age 35	2.2989	2.2838	-0.7%
	Age 45	4.4732	4.4437	-0.7%
	Age 55	8.7447	8.6894	-0.6%
	Age 65	13.2308	13.1319	-0.7%
	Age 75	9.7468	9.6134	-1.4%
	Age 85	5.8915	5.6749	-3.7%

The comparisons for Safety in Table 10.2 differ by sex. The amount-weighted deferred annuity values for PubS-2016 for female Safety members are slightly lower than those developed using the PubS-2010 rates. The PubS-2016 annuity values for male Safety members are 1% to 1.3% higher than PubS-2010 annuity values.

Table 10.2
AMOUNT-WEIGHTED SAFETY

	Base Rate → / Proj. Scale →	Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024 PubS-2010 MP-2021	PubS-2016 MP-2021	Percentage Change of Moving to PubS-2016 from PubS-2010
Females	Age 25	1.1850	1.1828	-0.2%
	Age 35	2.3007	2.2945	-0.3%
	Age 45	4.4741	4.4593	-0.3%
	Age 55	8.7160	8.6985	-0.2%
	Age 65	13.1215	13.1120	-0.1%
	Age 75	9.7879	9.6718	-1.2%
	Age 85	6.1657	5.9235	-3.9%
Males	Age 25	1.1336	1.1445	1.0%
	Age 35	2.1982	2.2195	1.0%
	Age 45	4.2713	4.3144	1.0%
	Age 55	8.3255	8.4213	1.2%
	Age 65	12.4787	12.6426	1.3%
	Age 75	8.9967	9.0963	1.1%
	Age 85	5.3647	5.4347	1.3%

In Table 10.3, the amount-weighted deferred annuity values developed using PubG-2016 for General members are also less than the corresponding values developed using PubG-2010. The annuity values range from nearly equal to the PubG-2010 values to almost 3% less for older General members.

Table 10.3
AMOUNT-WEIGHTED GENERAL

	Base Rate → / Proj. Scale →	Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024 — PubG-2010 MP-2021	PubG-2016 MP-2021	Percentage Change of Moving to PubG-2016 from PubG-2010
Females	Age 25	1.2095	1.2045	-0.4%
	Age 35	2.3491	2.3396	-0.4%
	Age 45	4.5699	4.5530	-0.4%
	Age 55	8.9145	8.8904	-0.3%
	Age 65	13.4888	13.4489	-0.3%
	Age 75	10.1255	9.9961	-1.3%
	Age 85	6.2983	6.1292	-2.7%
Males	Age 25	1.1349	1.1322	-0.2%
	Age 35	2.1979	2.1944	-0.2%
	Age 45	4.2720	4.2652	-0.2%
	Age 55	8.3471	8.3419	-0.1%
	Age 65	12.6048	12.6060	0.0%
	Age 75	9.1994	9.1349	-0.7%
	Age 85	5.5589	5.3959	-2.9%

10.1.3 COMPARISONS OF HEADCOUNT-WEIGHTED DEFERRED ANNUITIES FOR NONDISABLED MEMBERS

The following Tables 10.4, 10.5, and 10.6 compare headcount-weighted annuity values using the Pub-2016 rates with annuity values developed using Pub-2010 rates and with those developed using the amount-weighted Pub-2016 tables.

Table 10.4
HEADCOUNT-WEIGHTED TEACHERS

		Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024		Percentage Change of Moving to PubT.H-2016 from:	
	Base Rate → Proj. Scale →	PubT.H-2010 MP-2021	PubT.H-2016 MP-2021	PubT.H-2010 MP-2021	PubT-2016 MP-2021
Females	Age 25	1.2322	1.2313	-0.1%	-0.3%
	Age 35	2.3978	2.3955	-0.1%	-0.3%
	Age 45	4.6734	4.6681	-0.1%	-0.4%
	Age 55	9.1335	9.1231	-0.1%	-0.4%
	Age 65	13.8749	13.8270	-0.3%	-0.4%
	Age 75	10.4810	10.3736	-1.0%	-0.4%
	Age 85	6.5317	6.3734	-2.4%	-0.4%
Males	Age 25	1.1705	1.1645	-0.5%	-1.0%
	Age 35	2.2717	2.2588	-0.6%	-1.1%
	Age 45	4.4193	4.3924	-0.6%	-1.2%
	Age 55	8.6431	8.5903	-0.6%	-1.1%
	Age 65	13.0807	12.9835	-0.7%	-1.1%
	Age 75	9.5911	9.4783	-1.2%	-1.4%
	Age 85	5.7752	5.6051	-2.9%	-1.2%

Table 10.5
HEADCOUNT-WEIGHTED SAFETY

		Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024		Percentage Change of Moving to PubS.H-2016 from:	
	Base Rate → Proj. Scale →	PubS.H-2010 MP-2021	PubS.H-2016 MP-2021	PubS.H-2010 MP-2021	PubS-2016 MP-2021
Females	Age 25	1.1742	1.1763	0.2%	-0.5%
	Age 35	2.2777	2.2807	0.1%	-0.6%
	Age 45	4.4272	4.4325	0.1%	-0.6%
	Age 55	8.6248	8.6511	0.3%	-0.5%
	Age 65	13.0028	13.0490	0.4%	-0.5%
	Age 75	9.7313	9.6112	-1.2%	-0.6%
	Age 85	6.1510	5.9207	-3.7%	0.0%
Males	Age 25	1.1095	1.1297	1.8%	-1.3%
	Age 35	2.1493	2.1879	1.8%	-1.4%
	Age 45	4.1733	4.2500	1.8%	-1.5%
	Age 55	8.1300	8.2946	2.0%	-1.5%
	Age 65	12.1799	12.4440	2.2%	-1.6%
	Age 75	8.6699	8.9301	3.0%	-1.8%
	Age 85	5.1135	5.3233	4.1%	-2.0%

Table 10.6
HEADCOUNT-WEIGHTED GENERAL

	Base Rate → / Proj. Scale →	Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024 PubG.H-2010 MP-2021	PubG.H-2016 MP-2021	Percentage Change of Moving to PubG.H-2016 from: PubG.H-2010 MP-2021	PubG-2016 MP-2021
Females	Age 25	1.1954	1.1928	-0.2%	-1.0%
	Age 35	2.3206	2.3152	-0.2%	-1.0%
	Age 45	4.5134	4.5029	-0.2%	-1.1%
	Age 55	8.8064	8.7905	-0.2%	-1.1%
	Age 65	13.3301	13.2932	-0.3%	-1.2%
	Age 75	9.9649	9.8605	-1.0%	-1.4%
	Age 85	6.1411	6.0440	-1.6%	-1.4%
Males	Age 25	1.1026	1.1045	0.2%	-2.4%
	Age 35	2.1319	2.1362	0.2%	-2.7%
	Age 45	4.1408	4.1464	0.1%	-2.8%
	Age 55	8.0906	8.1084	0.2%	-2.8%
	Age 65	12.2196	12.2429	0.2%	-2.9%
	Age 75	8.8583	8.8140	-0.5%	-3.5%
	Age 85	5.3317	5.2164	-2.2%	-3.3%

As can be seen in Tables 10.4, 10.5, and 10.6, the overall impact of moving from the headcount-weighted Pub-2010 tables to the headcount-weighted Pub-2016 tables is similar to the patterns observed with the corresponding amount-weighted tables. Most deferred annuity values decreased slightly from those developed using Pub-2010 except for male Safety annuity values which increased from 1.8% to 4.1%.

Broadly speaking, the difference between headcount-weighted and corresponding amount-weighted annuity values represents a measure of the dispersion of individual amounts within the population being studied and the sensitivity of mortality to differences in income. More specifically, the larger the dispersion in underlying amounts, the greater (positive) differential between the amount-weighted annuity values relative to their headcount-weighted counterparts. Therefore, the final columns in the three tables above indicate that

- The salary/benefit amount dispersion within the populations was consistently the lowest for the Teacher population and consistently the highest for the General population and
- The salary/benefit amount dispersion for males is greater than that for females within all three job categories.

10.2 ABOVE- AND BELOW-MEDIAN ANNUITY VALUES

The multivariate analysis performed for the Pub-2010 tables and report on the Employee, Retiree, and Contingent Survivor subpopulations revealed clear evidence for variations in mortality experience based on income quartile. As a result, RPEC again decided to produce additional sets of mortality rates (both amount- and headcount-weighted) based on whether the member fell into one of the two higher income quartiles[27] (above-median) or one of the two lower income quartiles (below-median).

Tables 10.7, 10.8, and 10.9 show comparisons of the amount-weighted deferred annuity values computed using the Above- and Below-Median tables to those computed using the corresponding “total dataset” table for each job category.

Table 10.7
AMOUNT-WEIGHTED TEACHERS: ABOVE- AND BELOW-MEDIAN

		Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024			Percentage Change from PubT-2016 (with MP-2021)	
	Base Rate → Proj. Scale →	PubT-2016 MP-2021	PubT-2016(A) MP-2021	PubT-2016(B) MP-2021	PubT-2016(A) MP-2021	PubT-2016(B) MP-2021
Females	Age 25	1.2352	1.2380	1.2296	0.2%	-0.5%
	Age 35	2.4037	2.4093	2.3926	0.2%	-0.5%
	Age 45	4.6848	4.6958	4.6623	0.2%	-0.5%
	Age 55	9.1560	9.1774	9.1124	0.2%	-0.5%
	Age 65	13.8771	13.9083	13.8242	0.2%	-0.4%
	Age 75	10.4144	10.4516	10.3830	0.4%	-0.3%
	Age 85	6.3962	6.4477	6.3565	0.8%	-0.6%
Males	Age 25	1.1763	1.1855	1.1528	0.8%	-2.0%
	Age 35	2.2838	2.3019	2.2349	0.8%	-2.1%
	Age 45	4.4437	4.4781	4.3450	0.8%	-2.2%
	Age 55	8.6894	8.7534	8.5045	0.7%	-2.1%
	Age 65	13.1319	13.2291	12.8824	0.7%	-1.9%
	Age 75	9.6134	9.7235	9.3920	1.1%	-2.3%
	Age 85	5.6749	5.7624	5.5635	1.5%	-2.0%

[27] See Subsection 3.8 for a description of how income quartiles were calculated.

Table 10.8

AMOUNT-WEIGHTED SAFETY: ABOVE- AND BELOW-MEDIAN

	Base Rate → / Proj. Scale →	Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024			Percentage Change from PubS-2016 (with MP-2021)	
		PubS-2016 MP-2021	PubS-2016(A) MP-2021	PubS-2016(B) MP-2021	PubS-2016(A) MP-2021	PubS-2016(B) MP-2021
Females	Age 25	1.1828	1.1936	1.1596	0.9%	-2.0%
	Age 35	2.2945	2.3159	2.2470	0.9%	-2.1%
	Age 45	4.4593	4.5023	4.3665	1.0%	-2.1%
	Age 55	8.6985	8.7825	8.5251	1.0%	-2.0%
	Age 65	13.1120	13.2328	12.8415	0.9%	-2.1%
	Age 75	9.6718	9.7885	9.3512	1.2%	-3.3%
	Age 85	5.9235	6.0303	5.6306	1.8%	-4.9%
Males	Age 25	1.1445	1.1691	1.1062	2.1%	-3.3%
	Age 35	2.2195	2.2709	2.1378	2.3%	-3.7%
	Age 45	4.3144	4.4188	4.1493	2.4%	-3.8%
	Age 55	8.4213	8.6300	8.1039	2.5%	-3.8%
	Age 65	12.6426	12.9944	12.1655	2.8%	-3.8%
	Age 75	9.0963	9.4446	8.7935	3.8%	-3.3%
	Age 85	5.4347	5.6766	5.2769	4.5%	-2.9%

Table 10.9

AMOUNT-WEIGHTED GENERAL: ABOVE- AND BELOW-MEDIAN

	Base Rate → / Proj. Scale →	Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024			Percentage Change from PubG-2016 (with MP-2021)	
		PubG-2016 MP-2021	PubG-2016(A) MP-2021	PubG-2016(B) MP-2021	PubG-2016(A) MP-2021	PubG-2016(B) MP-2021
Females	Age 25	1.2045	1.2126	1.1828	0.7%	-1.8%
	Age 35	2.3396	2.3557	2.2956	0.7%	-1.9%
	Age 45	4.5530	4.5848	4.4671	0.7%	-1.9%
	Age 55	8.8904	8.9503	8.7298	0.7%	-1.8%
	Age 65	13.4489	13.5395	13.1980	0.7%	-1.9%
	Age 75	9.9961	10.1073	9.6893	1.1%	-3.1%
	Age 85	6.1292	6.2335	5.8421	1.7%	-4.7%
Males	Age 25	1.1322	1.1549	1.0704	2.0%	-5.5%
	Age 35	2.1944	2.2393	2.0653	2.0%	-5.9%
	Age 45	4.2652	4.3541	4.0057	2.1%	-6.1%
	Age 55	8.3419	8.5134	7.8443	2.1%	-6.0%
	Age 65	12.6060	12.8660	11.8603	2.1%	-5.9%
	Age 75	9.1349	9.3913	8.5085	2.8%	-6.9%
	Age 85	5.3959	5.5518	5.0805	2.9%	-5.8%

Consistent with the concept of "amount dispersion" discussed in Subsection 10.1.3, the impact of income (i.e., moving from the total dataset table to either the Above- or Below-Median tables) is considerably smaller for Teachers (especially females) than for Safety or General members. And, once again, the impact for males in each of the three job categories is considerably larger than that for females, particularly for Safety and General members.

10.3 DISABLED RETIREE ANNUITY VALUES

The following tables show comparisons of immediate annuity factors at 5.0% interest developed using Disabled Retiree rates for the Safety (Table 10.10) and Non-Safety (Table 10.11) job categories to those computed using the previously published Pub-2010 mortality tables.

Table 10.10
AMOUNT-WEIGHTED SAFETY DISABLED RETIREES

		Monthly Immediate Annuity Due Values Generational @ July 1, 2024		Percentage Change of Moving to PubS-2016 Disabled (with MP-2021) from:	
	Base Rate → Proj. Scale → Health Status →	PubS-2010 MP-2021 Disabled	PubS-2016 MP-2021 Disabled	PubS-2010 MP-2021 Disabled	PubS-2016 MP-2021 Healthy
Females	Age 55	15.3051	15.0874	-1.4%	-4.0%
	Age 65	12.8971	12.3692	-4.1%	-5.7%
	Age 75	9.7660	9.0165	-7.7%	-6.8%
	Age 85	6.1657	5.7921	-6.1%	-2.2%
Males	Age 55	14.8413	14.8517	0.1%	-3.6%
	Age 65	12.1299	12.1049	-0.2%	-4.3%
	Age 75	8.8006	8.6759	-1.4%	-4.6%
	Age 85	5.3610	5.1605	-3.7%	-5.0%

Table 10.11
AMOUNT-WEIGHTED NON-SAFETY DISABLED RETIREES

		Monthly Immediate Annuity Due Values Generational @ July 1, 2024		Percentage Change of Moving to PubNS-2016 Disabled (with MP-2021) from:		
	Base Rate → Proj. Scale → Health Status →	PubNS-2010 MP-2021 Disabled	PubNS-2016 MP-2021 Disabled	PubNS-2010 MP-2021 Disabled	PubT-2016 MP-2021 Healthy	PubG-2016 MP-2021 Healthy
Females	Age 55	13.3401	13.9081	4.3%	-14.6%	-12.6%
	Age 65	11.4650	11.7592	2.6%	-15.3%	-12.6%
	Age 75	8.6519	8.7427	1.0%	-16.1%	-12.5%
	Age 85	5.6019	5.6285	0.5%	-12.0%	-8.2%
Males	Age 55	12.4225	13.2600	6.7%	-15.8%	-12.9%
	Age 65	10.4378	11.0409	5.8%	-15.9%	-12.4%
	Age 75	7.9777	8.2028	2.8%	-14.7%	-10.2%
	Age 85	5.1550	5.0786	-1.5%	-10.5%	-5.9%

Generally, less restrictive definitions of disability for Safety workers lead to abnormally lower rates of mortality in that job category for Disabled Retirees than what is typically expected in most other lines of work. This explains the much higher annuity factors produced by the Safety Disabled Retiree table compared to those computed with the Non-Safety Disabled Retiree table. As illustrated in Table 10.10, the annuity factors for the PubS-2016 Disabled Retiree table are much closer to (but lower than) those for the PubS-2016 Retiree table than the annuity factors for the PubNS-2016 Disabled Retiree table are to those for either the PubT-2016 Retiree table or the PubG-2016 table.

The annuity factors for the PubS-2016 Disabled Retiree table are generally lower than those for the PubS-2010 Disabled Retiree table. The annuity factors for the PubNS-2016 Disabled Retiree table generally show an increase from the PubNS-2010 Disabled Retiree table.

10.4 CONTINGENT SURVIVOR ANNUITY VALUES

Table 10.12 shows a comparison at a 5.0% (post-retirement) interest rate of immediate annuity factors using the Contingent Survivor mortality rates (denoted PubCS-2016) to those generated by the prior PubCS-2010 tables. A discussion of the application of the Contingent Survivor tables can be found in Subsection 11.4.

Table 10.12
AMOUNT-WEIGHTED CONTINGENT SURVIVORS

		Monthly Immediate Annuity Due Values Generational @ July 1, 2024		Percentage Change of Moving to PubCS-2016 from PubCS-2010
	Base Rate → **Proj. Scale →**	**PubCS-2010** **MP-2021**	**PubCS-2016** **MP-2021**	
Females	Age 55	15.5372	15.5531	0.1%
	Age 65	13.1998	13.1160	-0.6%
	Age 75	10.0106	9.8772	-1.3%
	Age 85	6.3096	6.1501	-2.5%
Males	Age 55	14.5081	14.4339	-0.5%
	Age 65	12.0421	11.9542	-0.7%
	Age 75	8.9258	8.5982	-3.7%
	Age 85	5.5754	5.0777	-8.9%

Section 11: Application of Tables

11.1 "AS-OF DATE" OF THE PUB-2016 TABLES

After accounting for data exclusions, RPEC determined that the central year of the study's observation period was approximately the 12-month period from July 1, 2016, through June 30, 2017. Therefore, the mortality rates for each age, *x*, in the Pub-2016 tables should be interpreted as one-year probabilities of death for a person exactly age *x* on July 1, 2016. For applications that use integral ages, rounding ages to the nearest birthday (rather than truncating to the last birthday) as of the measurement date would represent appropriate usage of these rates consistent with their development. The study's "as-of date" of July 1, 2016, notwithstanding, RPEC believes that the Pub-2016 tables could represent reasonable benchmarks for mortality rates for any date within calendar year 2016.

11.2 SELECTING APPROPRIATE BENCHMARK MORTALITY TABLES

The potential uses of the Pub-2016 tables as published depend to a certain extent on the size and credibility of the underlying population to which the tables would be applied. For example, very large public retirement systems that have performed recent mortality experience studies might compare those results to one or more of the Pub-2016 tables, or blends/adjustments thereof, taking job categories and pay/benefit amount into consideration. Covered populations that are not large enough to support fully credible mortality results might use suitably selected Pub-2016 tables as "benchmark" starting points; i.e., tables that in conjunction with a recent mortality experience study could be used with appropriate adjustments, or as reference tables for credibility-weighted blended mortality rates.

Consistent with the principles of ASOP 27, actuaries are encouraged to take characteristics such as job category and income level of the covered population into consideration when selecting appropriate benchmark mortality tables. Given the high statistical significance of income as a predictor of mortality the Above-Median or Below-Median tables developed in this report should be considered as an alternative to the corresponding "total population" table, whenever appropriate.

In those situations where the covered population includes more than one job category and/or income level,[28] to the extent practical, the actuary could consider using a number of separate tables for subgroups stratified into appropriate job/income subpopulations or develop custom tables using appropriately weighted combinations of those tables.[29]

11.3 COMMENTS ON DISABLED RETIREE TABLES

Developing reliable mortality rates for Disabled Retirees has always presented special challenges to those tasked with the construction of mortality tables for retirement plans. These challenges include the following:

- Issues with the accurate tracking of those who initially retire under a disability retirement provision but are automatically reclassified as a Retiree upon attainment of some fixed age. See the discussion of "Unclear Disability Status" in Subsection 3.4, for example.

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[28] It should also be noted that even in public-sector retirement plans that cover members in a single job category, different member subgroups can often have disparate income profiles and possibly be covered by a separate set of plan provisions. It would not be unusual, for example, for a plan covering General members to include both judges and low-paid administrative staff.

[29] See Subsection 12.1 for RPEC's rationale for not developing "combined" public plan tables.

- The more subjective nature of disability retirement eligibility criteria compared to other (nondisabled) retirement provisions. This issue was particularly significant in this study due to the disparity between Safety and Non-Safety members.

In accordance with ASOP 27, actuaries should use professional judgment when applying any of the Disabled Retiree mortality tables developed in this report, especially when the plan's disability retirement provisions—particularly the eligibility criteria—are known to be particularly strict or broad.

11.4 COMMENTS ON CONTINGENT SURVIVOR TABLES

11.4.1 CONTINGENT SURVIVOR MORTALITY RATES

Similar to the approach taken in the Pub-2010 report, the Contingent Survivor database for this study only contains life-years of exposure for Contingent Survivors after the death of the primary member. Because the Pub-2016 Contingent Survivor tables were constructed using experience specifically from designated beneficiaries who had survived deceased plan members, these rates could be appropriate for application to current Contingent Survivors within plan populations. Above- and Below-Median versions can help practitioners tailor their mortality assumption to the applicable populations.

11.4.2 JOINT-AND-SURVIVOR ANNUITIES

The availability of distinct tables for Retirees and Contingent Survivors raises the question of which set of mortality rates might be used for designated beneficiaries in the calculation of joint-and-survivor annuities. There are several possibilities including, but not limited to, the three discussed below:

1. One approach ("Approach 1") would be to assume the same mortality basis as the Retiree, except using the rates applicable to the beneficiary's sex. It should be noted that Pub-2016 Retiree experience includes many members with joint-and-survivor annuities, and presumably additional members with spouses/partners not designated under joint-and-survivor options. Over the years, a percentage of these Retirees will lose a spouse/partner, and any grieving widow(er) effect would be reflected in the Retiree experience. On average, the Retiree rates may contain a reasonable provision for this impact. In addition, the socioeconomic status correlated to job category, and above- or below-median designation within job category, could well be relevant in predicting beneficiary mortality.

2. Another approach ("Approach 2") would use the Retiree basis (with beneficiary sex, as in Approach 1 above) while the Retiree is alive, but utilize Contingent Survivor mortality rates after the death of the Retiree. The rationale would be that portions of the present value calculation that specifically address the beneficiary's mortality while a Contingent Survivor of the deceased member might be appropriately modeled by the Contingent Survivor rates. This approach, in which the applicable beneficiary mortality rates (Retiree or Contingent Survivor) depend on whether or not the primary retiree is alive, may not be easy to implement in the typical valuation software in use today.

3. A third approach ("Approach 3") would be to assume Contingent Survivor mortality rates for the beneficiary both before and after the death of the original member. It is possible that the Contingent Survivor mortality experience in Pub-2016 shows higher mortality due to a number of factors correlated with beneficiary status, apart from a grieving widow(er) effect. In that case,

Contingent Survivor mortality might be appropriate both before and after the death of the original member.

Comparisons of joint-and-100%-survivor annuity values calculated using Approach 2[30] to those developed using previously published SOA tables can be found in Appendix D.2. Comparisons of the Approach 2 joint-and-100%-survivor annuity values to those calculated using Approaches 1 and 3 are shown in Appendix D.3. Although the Approach 2 values generally fall between the corresponding Approach 1 and Approach 3 values, the magnitude and direction of the differences among the three approaches will vary by job category and the ages of the joint annuitants.

Per ASOP 27, the selection or development of beneficiary mortality rates should reflect the actuary's judgement, consider the intended purpose, and incorporate actual plan experience to the extent it is deemed credible (per Actuarial Standard of Practice No. 25, *Credibility Procedures* [ASB 2013]) and predictive.

11.5 AMOUNT-WEIGHTED AND HEADCOUNT-WEIGHTED TABLES

The reason for using a weighted version of a mortality table—either amount-weighted or headcount-weighted—is to obtain the most appropriate result for the particular application at hand. For the measurement of most pension obligations, tables weighted by amount (salary for active employees and benefit amount for those in payment status) generally produce the most appropriate results. On the other hand, headcount-weighted tables might be more appropriate for applications such as the measurement of obligations for retirement programs with benefit structures uncorrelated with income, such as many retiree medical or retiree life insurance programs.

This report includes both amount-weighted and headcount-weighted versions of each of the public plan mortality tables. Per ASOP 27, the actuary should select a mortality assumption that is appropriate for the purpose of the measurement. Therefore, it would not necessarily be inappropriate—or inconsistent—to use amount-weighted tables to measure pension obligations and the corresponding headcount-weighted tables to measure most postretirement medical obligations, even when the two covered populations are identical.

11.6 PROJECTION OF MORTALITY RATES BEYOND 2016

The Committee believes that for most pension-related actuarial applications, the Pub-2016 mortality rates (including those for Disabled Retirees) should be projected with an appropriate mortality improvement scale, and that generational projection should be considered as an approach to projecting future mortality rates. In all cases, the selection of a mortality improvement assumption must satisfy the applicable requirements of ASOP 27.

[30] The Committee would like to make it clear that using Approach 2 as the basis for these comparisons does not represent a recommendation or preference.

Section 12: Observations and Other Considerations

12.1 RATIONALE FOR NO "COMBINED" PUBLIC TABLE

In the original Pub-2010 study, the Committee did consider publishing a "combined" public plans table that included all the data received for the study from each of the three job categories. Ultimately, it was decided that this would not be done and the rationale for that decision persists with this updated 2016 study. In addition to the statistically significant differences in mortality by job category discussed in Section 4 of the Pub-2010 study, it was determined that "combined" rates at various ages were often more reflective of the relative concentrations of the component subpopulations (Teachers, Safety, General) than of underlying mortality characteristics. The covered populations in many public retirement plans have demographic characteristics (including job category) that are quite different than that of the population that would have been used to develop any combined Pub-2016 table. Therefore, it would be better for the actuary with knowledge of the specific member demographics either to segregate the populations and use appropriate tables for each, or to construct a custom combined table using appropriate weighted averages of the job category and Above- or Below-Median rates from this study.

Lastly, many public-sector retirement programs specifically cover Teachers, Safety, or General employee populations. Even those that cover multiple populations often provide different benefit features and track census data separately by job categories.

12.2 TREATMENT OF DATA FOR CALENDAR YEAR 2020

The COVID-19 pandemic significantly affected U.S. population mortality rates in calendar year 2020. The Committee elected to collect data for 2020 because it was the most recent year for which data were likely to be available at the time of the data request. The Committee's review noted that mortality for calendar year 2020 did not appear to be much different than the preceding years for most splits of the data, although there was significant variation by contributing system. Possible reasons for this include:

- Many plans had a mid-year valuation date, which meant that data were only provided through June 30, 2020. This meant that effectively half of the 2020 data for such plans represented pre-pandemic experience.
- The Committee reviewed death patterns by calendar month and status category for each submitted plan, searching for outliers. It is possible that a lag in reporting of deaths for 2020 was masked by excess mortality from the pandemic and related causes, which meant data with understated mortality could have been retained in the dataset without adjustment.

The Committee did not believe that reasonable conclusions could be drawn from a review of the 2020 experience and did not feel comfortable including data from a pandemic year in base mortality tables. Therefore, it was decided to exclude data for calendar year 2020 from the study.

12.3 RATIONALE FOR ABOVE- AND BELOW-MEDIAN TABLES

The multivariate analysis completed as part of the Pub-2010 study indicated a significant difference between below-median (quartiles Q1 and Q2) and above-median (Q3 and Q4) mortality, which the Committee believes persists in the underlying data collected for this Pub-2016 study. Differences between each of the bottom two quartiles (Q1 and Q2) were less stable in models that contained more explanatory variables, but differences between above- and below-median remained strong. Given these observations and the potentially greater ease of application, Above-Median and Below-Median tables were constructed for this study rather than top-quartile and bottom-quartile tables that have been produced in some previous pension studies.

12.4 TABULATION OF EXPOSURES AND DEATHS

Exposures and deaths were tabulated into integral ages based on an exact-age methodology, in which the age increments on the participant's birthday. For example, exposures and deaths for Retirees aged 70 consist of experience for individuals between the exact ages of 70.00 and 70.99. It should be noted that this methodology is different than, but analogous to, the methodology utilized for the Pub-2010 study. This methodology is more precise than that used for the Pub-2010 study because ages are not rounded prior to allocating experience to integral ages.

These tabulation rules, in conjunction with the study's central year, produced raw one-year mortality probabilities as of July 1, 2016.

12.5 APPLICATION OF MORTALITY IMPROVEMENT RATES

A central study year consisting of portions of two consecutive calendar years raises the question of how a mortality projection scale with improvement factors described in terms of age and calendar year (such as MP-2021) might be applied to the Pub-2016 base rates. The annuity factors displayed in this report are shown as of July 1, 2024. To compute the mortality rates underpinning these amounts, RPEC applied full years of mortality improvement prospectively from 2016 rather than a fractional blend of calendar-year improvement rates. For example, the age-65 male Teachers rate applicable in calendar year 2024 was calculated by applying the cumulative 2017–2024 age-65 male mortality improvement rates from Scale MP-2021 to the base mortality rate for an age-65 male Teacher from the PubT-2016 table. The Committee believes that this is the most common approach among pension practitioners, but that other approaches might also be reasonable.

12.6 AGE-65 LIFE EXPECTANCY COMPARISON

Table 12.1 presents a comparison of 2024 complete cohort life expectancy values at age 65. These values are based on the headcount-weighted Pub-2016 tables and the headcount-weighted Pub-2010 tables.

Table 12.1
AGE-65 COMPLETE COHORT LIFE EXPECTANCIES

		Age-65 Cohort Life Expectancies (Complete) Generational at July 1, 2024			Percentage Change of Moving from Pub.H-2010 (with MP-2021) to:		
	Base Rate → **Proj. Scale →**	**PubT.H-2016** **MP-2021**	**PubS.H-2016** **MP-2021**	**PubG.H-2016** **MP-2021**	**PubT.H-2016** **MP-2021**	**PubS.H-2016** **MP-2021**	**PubG.H-2016** **MP-2021**
Females	Age 65	24.75	22.67	23.31	-0.8%	-0.2%	-0.7%
Males	Age 65	22.34	20.96	20.50	-1.4%	3.3%	-0.1%

Table 12.1 indicates that of the three job categories, Teachers have the longest age-65 life expectancy by a substantial margin, followed by General and then Public Safety. Appendix D.4 contains additional life expectancy comparisons for ages other than 65.

Section 13: Reliance and Limitations

The Pub-2016 Public Retirement Plans Mortality Tables released in conjunction with this report have been developed from public pension mortality experience in the United States and are intended for use in connection with actuarial applications related to public-sector retirement programs. No assessment has been made concerning the applicability of these tables to other purposes.

Section 14: Acknowledgements

The SOA and LIMRA are grateful for the assistance of the National Association of State Retirement Administrators (NASRA) and the National Conference on Public Employee Retirement Systems (NCPERS) for their work in promoting the study and distributing the data request package.

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Appendixes

APPENDIX A: RECONCILIATION OF EXCLUDED DATA

Table A.1 summarizes the amount of data received for the study and the amount of data that was excluded from the final dataset. A little over 90% of all the data submitted was included in the development of Pub-2016 Mortality Tables, with the largest component of excluded data attributable to exposures for data subgroups with outlier A/E ratios that could not be confirmed or remedied by the contributor. Note that data for calendar year 2020 has been excluded from this reconciliation.

Table A.1
RECONCILIATION OF EXCLUDED DATA

		Life Years of Exposure (Thousands)				
		Employees	**Retirees**	**Contingent Survivors**	**Disabled Retirees**	**Total**
(a)	**Total Beginning Exposures**	**34,186**	**25,038**	**2,539**	**2,340**	**64,103**
(b)	Estimated exposures for months with anomalous death counts that could not be confirmed or remedied by the contributor	200	136	15	4	355
(c)	Exposures for data subgroups with outlier A/E ratios that could not be confirmed or remedied by the contributor	1,970	1,533	58	111	3,672
(d)	Exposures with ages outside of age ranges used in final graduation	1,246	245	195	176	1,861
(e)	**Exposures in Final Dataset**	**30,770**	**23,124**	**2,271**	**2,049**	**58,215**

Below is a more detailed description of the intermediate line items in Table A.1:

(b) Estimated exposures for months with anomalous death counts that could not be confirmed by the contributor

These counts represent the estimated amount of data excluded for time periods for which a plan had an unusual pattern of month-by-month death counts that was not confirmed or remedied by the contributor, as detailed in Subsection 3.5. As these exclusions took place before exposure was calculated, these were estimated based on a given plan's total included exposure and the fraction of the study period that was excluded for that plan.

(c) Exposures for data subgroups with outlier A/E ratios that could not be confirmed by the contributor

As discussed in Subsection 3.6, some subgroups within certain plans exhibited abnormal mortality experience that could not be confirmed or remedied by the contributor.

(d) Exposures with ages outside of age ranges used in final graduation

As described in Sections 5 through 7, graduations of the raw data were performed for specific age ranges within each status/job category/sex subset of the total database. Those ranges were determined based on the ages for which a sufficiently robust amount of data was provided. This effectively excluded life-years of data for relatively very old or young members within each subset, which are reflected in this row of the table.

APPENDIX B: SUMMARY OF FINAL DATASETS

The tables in this appendix summarize the exposures, deaths, and resulting raw death rates upon which the Pub-2016 Mortality Tables were constructed. The data in these tables (and in Table 3.1) reflect the data ultimately used in the graduations described in Sections 5–7; additional life-years of data were processed that fell outside of the graduation age ranges. The data reconciliation in Appendix A shows the small amount of data that was processed but not included in the graduations due to age.

Sex-specific tables are shown separately for each member subgroup: Employee, Healthy Retiree, Disabled Retiree, and Contingent Survivor. The exposure sums (by age band, job category, or income grouping) might not match the total because of rounding.

Table B.1
SUMMARY OF FEMALE EMPLOYEE TEACHERS DATASET

	Number		Number With Amount		Annual Salary Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
25-29	755,531	77	708,267	63	36,193,480	3,667	0.00010	0.00009	0.00010
30-34	973,565	179	927,726	161	54,554,779	9,631	0.00018	0.00017	0.00018
35-39	1,110,629	261	1,078,172	242	70,672,997	16,304	0.00024	0.00022	0.00023
40-44	1,140,738	464	1,110,779	427	77,617,100	30,295	0.00041	0.00038	0.00039
45-49	1,148,945	683	1,116,702	632	79,528,639	43,148	0.00059	0.00057	0.00054
50-54	1,029,761	965	1,000,473	903	71,492,541	66,165	0.00094	0.00090	0.00093
55-59	897,444	1,114	871,865	1,058	61,858,994	73,830	0.00124	0.00121	0.00119
60-64	564,012	1,103	543,370	1,026	38,525,247	71,803	0.00196	0.00189	0.00186
65-69	174,077	556	161,071	496	11,428,251	34,536	0.00319	0.00308	0.00302
70-75	44,596	241	38,367	198	2,630,468	13,622	0.00540	0.00516	0.00518
Total	**7,839,298**	**5,643**	**7,556,792**	**5,206**	**504,502,495**	**363,002**	**0.00072**	**0.00069**	**0.00072**

Table B.2
SUMMARY OF MALE EMPLOYEE TEACHERS DATASET

	Number		Number With Amount		Annual Salary Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
25-29	222,241	62	203,500	42	10,656,686	3,253	0.00028	0.00021	0.00031
30-34	323,021	110	305,234	85	18,790,393	6,055	0.00034	0.00028	0.00032
35-39	392,569	155	380,543	136	27,009,183	9,691	0.00039	0.00036	0.00036
40-44	417,370	233	407,185	222	31,926,745	16,227	0.00056	0.00055	0.00051
45-49	419,023	404	408,592	368	33,563,143	30,075	0.00096	0.00090	0.00090
50-54	365,311	529	355,931	500	29,641,784	38,303	0.00145	0.00140	0.00129
55-59	307,766	711	298,733	659	24,602,207	51,540	0.00231	0.00221	0.00209
60-64	211,589	721	202,566	657	16,413,910	51,355	0.00341	0.00324	0.00313
65-69	91,807	475	84,223	407	6,830,752	32,442	0.00517	0.00483	0.00475
70-75	34,721	290	30,358	234	2,518,849	18,832	0.00835	0.00771	0.00748
Total	**2,785,417**	**3,690**	**2,676,866**	**3,310**	**201,953,651**	**257,773**	**0.00132**	**0.00124**	**0.00128**

Table B.3

SUMMARY OF FEMALE EMPLOYEE SAFETY DATASET

	Number		Number With Amount		Annual Salary Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
40-44	70,126	45	69,041	39	5,758,477	2,903	0.00064	0.00056	0.00050
45-49	70,589	57	69,742	55	6,045,715	4,026	0.00081	0.00079	0.00067
50-54	54,181	79	53,260	70	4,596,793	6,633	0.00146	0.00131	0.00144
55-59	32,926	55	32,230	46	2,663,473	4,391	0.00167	0.00143	0.00165
60-65	17,361	55	16,984	51	1,388,458	3,685	0.00317	0.00300	0.00265
Total	**245,183**	**291**	**241,258**	**261**	**20,452,916**	**21,639**	**0.00119**	**0.00108**	**0.00106**

Table B.4

SUMMARY OF MALE EMPLOYEE SAFETY DATASET

	Number		Number With Amount		Annual Salary Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
25-29	206,030	81	199,555	66	13,486,644	5,421	0.00039	0.00033	0.00040
30-34	285,053	126	279,254	111	22,486,418	9,857	0.00044	0.00040	0.00044
35-39	297,846	155	293,867	142	26,255,041	12,954	0.00052	0.00048	0.00049
40-44	310,115	225	307,172	218	29,093,495	18,739	0.00073	0.00071	0.00064
45-49	324,400	325	321,615	299	32,055,978	29,004	0.00100	0.00093	0.00090
50-54	232,211	355	229,739	338	23,638,031	33,354	0.00153	0.00147	0.00141
55-59	114,356	256	112,696	233	11,205,484	23,077	0.00224	0.00207	0.00206
60-64	47,222	185	46,067	160	4,327,118	15,483	0.00392	0.00347	0.00358
Total	**1,817,233**	**1,708**	**1,789,964**	**1,567**	**162,548,210**	**147,890**	**0.00094**	**0.00088**	**0.00091**

Table B.5

SUMMARY OF FEMALE EMPLOYEE GENERAL DATASET

	Number		Number With Amount		Annual Salary Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
25-29	783,599	132	711,078	93	33,587,168	5,317	0.00017	0.00013	0.00016
30-34	1,020,723	242	966,129	183	50,810,110	11,076	0.00024	0.00019	0.00022
35-39	1,156,547	445	1,104,746	361	62,030,654	22,067	0.00038	0.00033	0.00036
40-44	1,261,008	652	1,210,264	555	68,882,266	32,729	0.00052	0.00046	0.00048
45-49	1,503,588	1,176	1,449,793	1,046	81,644,825	57,868	0.00078	0.00072	0.00071
50-54	1,743,634	2,116	1,689,305	1,859	94,119,607	105,818	0.00121	0.00110	0.00112
55-59	1,713,034	2,967	1,661,748	2,639	91,579,682	143,824	0.00173	0.00159	0.00157
60-64	1,134,660	2,843	1,092,482	2,562	59,886,072	141,522	0.00251	0.00235	0.00236
65-69	377,683	1,491	348,372	1,315	19,289,444	73,418	0.00395	0.00377	0.00381
70-74	104,212	554	87,138	459	4,823,077	24,752	0.00532	0.00527	0.00513
75-80	34,120	295	25,214	227	1,450,180	12,770	0.00865	0.00900	0.00881
Total	**10,832,809**	**12,913**	**10,346,269**	**11,299**	**568,103,082**	**631,161**	**0.00119**	**0.00109**	**0.00111**

Table B.6

SUMMARY OF MALE EMPLOYEE GENERAL DATASET

	Number		Number With Amount		Annual Salary Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
25-29	534,041	299	479,011	184	24,931,056	14,817	0.00056	0.00038	0.00059
30-34	708,559	356	669,915	274	39,873,452	18,262	0.00050	0.00041	0.00046
35-39	783,961	509	752,863	419	49,580,575	29,196	0.00065	0.00056	0.00059
40-44	832,333	752	803,909	664	56,240,373	44,047	0.00090	0.00083	0.00078
45-49	982,280	1,359	952,614	1,207	68,421,515	80,802	0.00138	0.00127	0.00118
50-54	1,127,302	2,280	1,096,226	2,054	79,033,150	137,479	0.00202	0.00187	0.00174
55-59	1,091,638	3,370	1,059,928	3,012	75,353,049	204,360	0.00309	0.00284	0.00271
60-64	763,414	3,332	732,768	3,016	51,303,422	200,243	0.00436	0.00412	0.00390
65-69	295,744	1,742	269,527	1,480	19,257,127	105,941	0.00589	0.00549	0.00550
70-74	95,311	858	78,363	662	5,577,134	48,193	0.00900	0.00845	0.00864
75-80	35,837	513	25,958	335	1,873,058	25,690	0.01431	0.01291	0.01372
Total	**7,250,421**	**15,370**	**6,921,082**	**13,307**	**471,443,911**	**909,030**	**0.00212**	**0.00192**	**0.00193**

Table B.7

SUMMARY OF FEMALE RETIREE TEACHERS DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
55-59	206,300	515	206,072	500	9,388,903	21,970	0.00250	0.00243	0.00234
60-64	766,412	2,560	765,852	2,527	34,025,022	108,110	0.00334	0.00330	0.00318
65-69	1,355,072	7,035	1,354,722	6,973	58,452,275	285,935	0.00519	0.00515	0.00489
70-74	1,086,652	10,271	1,086,433	10,195	44,471,609	403,414	0.00945	0.00938	0.00907
75-79	675,803	12,364	675,531	12,237	24,878,785	440,498	0.01830	0.01811	0.01771
80-84	435,332	16,378	434,933	16,188	14,247,518	523,880	0.03762	0.03722	0.03677
85-89	286,880	20,773	286,322	20,489	8,409,196	604,105	0.07241	0.07156	0.07184
90-95	159,773	22,061	159,192	21,762	4,031,682	548,453	0.13808	0.13670	0.13604
Total	**4,972,224**	**91,957**	**4,969,056**	**90,871**	**197,904,992**	**2,936,364**	**0.01849**	**0.01829**	**0.01484**

Table B.8

SUMMARY OF MALE RETIREE TEACHERS DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
55-59	74,644	296	74,580	288	3,958,054	11,796	0.00397	0.00386	0.00298
60-64	263,929	1,466	263,754	1,447	13,934,691	69,112	0.00555	0.00549	0.00496
65-69	546,065	4,629	545,902	4,599	28,646,321	222,974	0.00848	0.00842	0.00778
70-74	541,918	7,762	541,786	7,719	27,800,446	363,563	0.01432	0.01425	0.01308
75-79	375,983	9,901	375,813	9,821	18,202,421	446,136	0.02633	0.02613	0.02451
80-84	263,923	13,533	263,711	13,424	11,851,260	571,966	0.05128	0.05090	0.04826
85-89	159,559	15,176	159,323	15,058	6,681,727	619,765	0.09511	0.09451	0.09276
90-95	68,130	11,687	67,960	11,591	2,549,079	424,048	0.17154	0.17056	0.16635
Total	2,294,149	64,450	2,292,830	63,947	113,623,998	2,729,360	0.02809	0.02789	0.02402

Table B.9

SUMMARY OF FEMALE RETIREE SAFETY DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
45-49	7,225	8	6,875	8	318,071	309	0.00111	0.00116	0.00097
50-54	31,904	89	29,861	83	1,456,530	3,810	0.00279	0.00278	0.00262
55-59	52,239	174	43,165	152	2,104,430	6,324	0.00333	0.00352	0.00300
60-64	56,784	303	36,843	204	2,084,441	10,495	0.00534	0.00554	0.00503
65-69	48,218	388	24,841	232	1,686,213	13,175	0.00805	0.00934	0.00781
70-74	29,324	430	11,747	204	1,019,563	14,285	0.01466	0.01737	0.01401
75-79	14,617	425	5,144	188	496,679	13,847	0.02908	0.03655	0.02788
80-84	6,542	303	2,635	154	212,532	9,244	0.04632	0.05844	0.04349
85-89	3,415	299	1,572	121	103,238	9,434	0.08756	0.07697	0.09138
90-95	1,939	275	1,042	122	55,419	8,932	0.14185	0.11707	0.16117
Total	252,205	2,694	163,726	1,468	9,537,117	89,852	0.01068	0.00897	0.00942

Table B.10

SUMMARY OF MALE RETIREE SAFETY DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
45-49	29,137	54	28,982	51	1,445,934	2,231	0.00185	0.00176	0.00154
50-54	137,184	416	133,538	388	7,183,527	18,085	0.00303	0.00291	0.00252
55-59	225,095	893	191,729	775	11,724,037	41,858	0.00397	0.00404	0.00357
60-64	253,814	1,592	188,171	1,212	13,003,866	70,060	0.00627	0.00644	0.00539
65-69	253,726	2,681	175,642	1,921	12,656,835	117,741	0.01057	0.01094	0.00930
70-74	198,335	3,759	132,855	2,562	9,690,261	168,062	0.01895	0.01928	0.01734
75-79	122,790	4,173	83,163	2,885	5,685,971	179,563	0.03398	0.03469	0.03158
80-84	66,909	4,085	45,786	2,818	2,952,003	171,034	0.06105	0.06155	0.05794
85-89	35,801	3,849	25,018	2,763	1,528,253	157,027	0.10751	0.11044	0.10275
90-95	14,878	2,759	10,931	2,003	637,430	114,543	0.18544	0.18324	0.17970
Total	**1,337,669**	**24,261**	**1,015,814**	**17,378**	**66,508,116**	**1,040,204**	**0.01814**	**0.01711**	**0.01564**

Table B.11

SUMMARY OF FEMALE RETIREE GENERAL DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
50-54	82,921	306	79,866	284	2,147,079	7,883	0.00369	0.00356	0.00367
55-59	517,403	2,112	485,799	1,974	14,204,033	46,991	0.00408	0.00406	0.00331
60-64	1,354,116	7,024	1,209,163	6,204	35,799,029	159,868	0.00519	0.00513	0.00447
65-69	2,025,365	15,509	1,737,682	13,281	49,193,288	334,368	0.00766	0.00764	0.00680
70-74	1,629,931	21,776	1,321,053	17,850	36,201,213	437,885	0.01336	0.01351	0.01210
75-79	1,103,200	26,776	877,799	21,580	21,761,911	489,907	0.02427	0.02458	0.02251
80-84	749,552	33,961	599,002	27,480	13,206,859	567,494	0.04531	0.04588	0.04297
85-89	504,737	42,365	404,983	34,379	8,235,791	671,239	0.08393	0.08489	0.08150
90-95	302,731	45,947	236,543	36,167	4,601,751	677,524	0.15178	0.15290	0.14723
Total	**8,269,955**	**195,776**	**6,951,890**	**159,199**	**185,350,954**	**3,393,161**	**0.02367**	**0.02290**	**0.01831**

Table B.12

SUMMARY OF MALE RETIREE GENERAL DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
50-54	102,131	483	99,849	453	3,545,612	12,842	0.00473	0.00454	0.00362
55-59	409,383	2,663	384,898	2,490	14,262,733	72,067	0.00650	0.00647	0.00505
60-64	941,250	8,650	847,880	7,734	32,194,703	239,880	0.00919	0.00912	0.00745
65-69	1,444,772	18,249	1,258,951	15,956	47,193,924	494,697	0.01263	0.01267	0.01048
70-74	1,217,302	24,607	1,020,324	20,950	38,698,879	662,311	0.02021	0.02053	0.01711
75-79	830,437	29,874	687,077	25,130	24,781,411	770,069	0.03597	0.03658	0.03107
80-84	560,746	35,686	462,907	29,806	15,720,604	895,274	0.06364	0.06439	0.05695
85-89	337,229	37,516	275,891	30,964	9,059,749	935,625	0.11125	0.11223	0.10327
90-95	154,820	29,982	124,973	24,307	3,959,508	734,996	0.19366	0.19450	0.18563
Total	**5,998,071**	**187,710**	**5,162,752**	**157,790**	**189,417,122**	**4,817,760**	**0.03130**	**0.03056**	**0.02543**

Table B.13

SUMMARY OF FEMALE DISABLED RETIREE NON-SAFETY DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
50-54	66,001	923	55,902	829	1,397,733	18,295	0.01398	0.01483	0.01309
55-59	121,132	1,951	99,240	1,721	2,376,054	38,393	0.01611	0.01734	0.01616
60-64	176,559	3,051	147,988	2,685	3,270,715	57,044	0.01728	0.01814	0.01744
65-69	207,995	3,992	178,959	3,419	3,517,299	70,704	0.01919	0.01910	0.02010
70-74	157,702	3,877	135,458	3,271	2,459,051	62,279	0.02458	0.02415	0.02533
75-79	88,314	3,561	73,171	2,912	1,304,363	55,011	0.04032	0.03980	0.04217
80-84	39,220	2,593	31,090	2,077	575,081	38,121	0.06611	0.06681	0.06629
85-89	18,472	1,917	14,178	1,487	264,619	27,352	0.10378	0.10488	0.10336
90-95	8,525	1,500	6,174	1,087	118,382	20,355	0.17596	0.17606	0.17194
Total	**883,920**	**23,365**	**742,160**	**19,488**	**15,283,297**	**387,553**	**0.02643**	**0.02626**	**0.02536**

Table B.14

SUMMARY OF MALE DISABLED RETIREE NON-SAFETY DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
50-54	61,434	859	53,945	795	1,877,601	18,516	0.01398	0.01474	0.00986
55-59	97,152	1,915	82,154	1,705	2,423,890	40,961	0.01971	0.02075	0.01690
60-64	128,258	3,128	106,779	2,763	2,818,445	62,069	0.02439	0.02588	0.02202
65-69	149,710	4,201	125,802	3,617	3,225,354	81,557	0.02806	0.02875	0.02529
70-74	117,762	4,259	100,140	3,625	2,568,443	82,068	0.03617	0.03620	0.03195
75-79	68,327	3,807	56,592	3,080	1,446,227	69,766	0.05572	0.05442	0.04824
80-84	35,107	2,980	28,488	2,358	756,792	57,136	0.08488	0.08277	0.07550
85-89	18,212	2,366	14,739	1,863	423,883	49,149	0.12992	0.12640	0.11595
90-95	6,670	1,356	5,222	1,056	159,209	30,693	0.20330	0.20222	0.19278
Total	682,633	24,871	573,861	20,862	15,699,844	491,915	0.03643	0.03635	0.03133

Table B.15

SUMMARY OF FEMALE DISABLED RETIREE SAFETY DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
50-54	15,578	78	8,956	50	633,324	2,436	0.00501	0.00558	0.00385
55-59	17,924	92	8,398	52	734,778	2,844	0.00513	0.00619	0.00387
60-64	15,826	122	6,456	49	628,373	4,371	0.00771	0.00759	0.00696
65-69	11,443	169	3,939	74	452,886	5,740	0.01477	0.01879	0.01268
70-74	6,194	147	1,905	56	246,105	5,652	0.02373	0.02939	0.02297
75-79	2,906	102	865	26	113,114	3,926	0.03510	0.03007	0.03471
80-84	1,413	68	405	28	54,910	2,756	0.04812	0.06906	0.05020
85-89	409	41	114	14	15,411	1,526	0.10034	0.12274	0.09904
90-95	115	19	37	6	3,809	626	0.16452	0.16046	0.16436
Total	71,809	838	31,076	355	2,882,712	29,880	0.01167	0.01142	0.01037

Table B.16

SUMMARY OF MALE DISABLED RETIREE SAFETY DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
50-54	52,531	302	39,030	224	2,941,051	12,040	0.00575	0.00574	0.00409
55-59	69,121	448	45,966	275	4,113,203	22,285	0.00648	0.00598	0.00542
60-64	76,001	767	44,819	432	4,411,323	36,398	0.01009	0.00964	0.00825
65-69	74,843	1,135	38,899	576	4,037,463	53,740	0.01517	0.01481	0.01331
70-74	61,596	1,488	30,828	689	3,331,944	71,346	0.02416	0.02235	0.02141
75-79	40,793	1,656	21,173	798	2,193,455	81,846	0.04060	0.03769	0.03731
80-84	22,368	1,567	12,321	814	1,174,827	77,223	0.07006	0.06607	0.06573
85-89	9,952	1,215	5,659	636	521,216	61,005	0.12209	0.11238	0.11704
90-95	3,552	701	2,189	431	183,426	33,930	0.19738	0.19688	0.18498
Total	**410,756**	**9,279**	**240,884**	**4,875**	**22,907,907**	**449,813**	**0.02259**	**0.02024**	**0.01964**

Table B.17

SUMMARY OF FEMALE CONTINGENT SURVIVOR DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
50-54	46,193	211	41,063	201	964,783	3,247	0.00457	0.00489	0.00337
55-59	85,268	483	75,401	421	1,878,069	9,374	0.00566	0.00558	0.00499
60-64	144,960	1,175	128,087	1,034	3,362,219	23,094	0.00811	0.00807	0.00687
65-69	219,211	2,617	192,793	2,241	5,382,172	54,820	0.01194	0.01162	0.01019
70-74	268,593	4,804	235,791	4,177	6,644,669	104,591	0.01789	0.01771	0.01574
75-79	297,677	8,491	259,894	7,378	6,994,073	179,260	0.02852	0.02839	0.02563
80-84	308,374	15,016	267,259	12,828	6,934,432	314,048	0.04869	0.04800	0.04529
85-89	282,780	24,363	242,101	20,646	6,081,851	497,242	0.08616	0.08528	0.08176
90-95	194,316	29,587	161,745	24,340	3,853,029	565,068	0.15226	0.15048	0.14666
Total	**1,847,374**	**86,747**	**1,604,134**	**73,266**	**42,095,298**	**1,750,743**	**0.04696**	**0.04567**	**0.04159**

Table B.18

SUMMARY OF MALE CONTINGENT SURVIVOR DATASET

	Number		Number With Amount		Annual Benefit Amount ($ thousands)		Raw Death Rates Based on		
Age Band	Exposed Life Years	Deaths	Exposed Life Years	Deaths	Exposed $ Years	$-weighted Deaths	Number	Number With Amount	Amount
50-54	16,774	162	14,478	138	230,492	2,178	0.00966	0.00953	0.00945
55-59	26,046	271	22,930	239	383,390	3,326	0.01040	0.01042	0.00868
60-64	42,169	580	37,434	485	714,819	8,924	0.01375	0.01296	0.01248
65-69	63,621	1,076	56,450	924	1,186,681	17,210	0.01691	0.01637	0.01450
70-74	70,685	1,817	61,909	1,596	1,315,592	30,169	0.02571	0.02578	0.02293
75-79	64,699	2,669	55,305	2,218	1,097,017	42,201	0.04125	0.04011	0.03847
80-84	59,732	4,212	50,216	3,506	910,440	63,641	0.07051	0.06982	0.06990
85-89	49,175	5,650	40,805	4,690	680,913	80,591	0.11489	0.11494	0.11836
90-95	30,818	6,201	24,654	4,889	400,238	83,727	0.20121	0.19831	0.20919
Total	423,721	22,638	364,180	18,685	6,919,582	331,966	0.05343	0.05131	0.04797

APPENDIX C: DISCUSSION OF GAM GRADUATION

The splines that underlie the GAM models have a long history. Before the advent of computers, engineers and drafting technicians used “splines” to draw curves. Such splines were thin flexible strips of wood or metal. The technician would place wooden or metal dowels vertically on the drawing surface and position the spline strip such that the strip passed through the dowels and then was flexed to the desired curve. By both arranging the positions and orientations of the dowels and setting the length of the strip between each dowel, a technician could obtain a wide range of smooth curves.

With the advent of computer-aided drafting and design, mathematical representations of splines were developed by practitioners with the desired features that were needed to solve problems specific to their fields. The Renault engineer Pierre Bézier is remembered for his introduction of Bézier splines, which can be thought of as a weighted average of *n* control points, with the weighting determined by the binomial formula. Since then, computer representations of splines have found uses throughout engineering, statistics, and visual effects.

There is a large and growing diversity of spline types of one and higher dimensions. The GAM framework is agnostic with respect to spline type, but the most natural and easiest to understand type for the purposes of one-dimensional mortality modeling is the class of cubic regression splines. A cubic spline is a type of spline constructed using piecewise cubic polynomials that pass through a certain set of points called knots. The cubic splines used in the GAM models are set up in a way similar to traditional drafting. In R’s mgcv package, 10 knots are placed evenly by default over the attained age range of the data, with one knot reserved for each end. For example, if the attained ages run from 50 to 95, then knots are placed at ages 50 and 95, and eight other knots are placed evenly, in this case at quinquennial ages. Then a model matrix is set up in R. The model matrix is configured such that, when combined with the model coefficients, (a) the function is a cubic polynomial between knots, expressed relative to some basis, and (b) each of the zeroth, first, and second derivatives of the cubic polynomials agree at the knots. Model coefficients are then determined using optimization routines. If the GAM model equation is specified as

$$\ln q_x = f(x) + \varepsilon_x$$

where $f(x)$ is the function of cubic splines and ε_x is the error term (as is encountered for the RPEC graduations using a binomial likelihood with log link), then subject to appropriate weighting w_x, and other considerations related to the fitting algorithm, the goal of the optimization is to find the function *f*(*x*) such that the following is minimized:

$$\sum_x w_x\big(\ln q_x - f(x)\big)^2 + \lambda \int_{x_{min}}^{x_{max}} [f''(x)]^2 dx$$

The formula represents a trade-off between rewarding a tight fit of the data (the summation on the left) and rewarding a curve with low curvature (the integral on the right). The parameter λ is the smoothness penalty, with higher values increasing the penalty for curvature.

Technical Discussion

A generalized additive model (GAM) extends the generalized linear model (GLM) by including specifications for a smooth function of one or more predictors (e.g., a smooth function of age) and a penalty term to penalize the “wigglyness” of that function. The main advantage to this approach is that the modeler is freed of the chore of hunting for an appropriate polynomial or other smooth function that both fits the data and permits stable predictions from the model. Since GAMs extend GLMs, many of the intuitions from fitting GLMs carry over to GAMs.

In turn, GLMs extend linear models to broader types of data. In linear models, a response is regressed linearly onto a collection of predictor variables using least squares minimization, and it is assumed that the response data are independent normally distributed random variables with mean equal to a linear combination of the predictors. Least-squares minimization is equivalent to maximizing the likelihood of the independent normally distributed data. Replacing the likelihood function with exponential families (e.g., binomial, Poisson etc.) leads to GLMs.

The remainder of Appendix C is meant to provide a high-level overview of statistical techniques underpinning GAMs. Readers interested in learning more about GAM’s mathematical underpinnings are advised to consult *Generalized Additive Models: An Introduction in R,* 2nd edition, by Simon Wood [Wood 2017] from which much of Appendix C is adapted.

The methodology for fitting GAMs tracks these extensions. First, convert the GAM problem to a penalized GLM problem by setting up model and penalty matrices that reflect the specified spline structure. Second, convert the GLM problem into an iteratively reweighted least squares problem, and finally iterate the fit by alternating between optimizing the regression parameters for fixed smoothing parameter, and optimizing the smoothing penalty for fixed regression parameters. In addition, the R package mgcv automates this procedure in the function “gam.”

The algorithm in gam does the following:

1. Sets up the matrices and other parameters for the problem, along with any computational optimizations.
2. Minimizes generalized cross-validation (GCV) with respect to λ using a version of Newton’s method for a fixed vector of regression parameters (the so-called “outer loop”).
    a. For fixed λ, fits GLM using penalized iteratively reweighted least squares (the so-called “inner loop”).
    b. Computes derivative information to enable the minimization in the outer loop.
3. Generates statistics for final model.

When the algorithm is done, the modeler receives a model that both fits the data optimally (up to the limitations of its specifications) *and* has the optimal smoothness, all without the need for hand-tuning the smoothness parameter. This is an improvement on the process that is commonly carried out in Whittaker-Henderson graduation, in which the modeler uses trial-and-error and visual inspection to get to an acceptable smoothing parameter.

APPENDIX D: ADDITIONAL ANNUITY COMPARISONS

D.1: ANNUITY COMPARISONS AT 7% INTEREST

Tables D.1, D.2, and D.3 show annuity factor comparisons for Teachers, Safety, and General, respectively, at a flat 7.0% interest rate, in contrast to the 7.0% pre-retirement/5.0% post-retirement interest rate structure shown in Tables 1.1–1.3 and Tables 10.1–10.3.

Table D.1
AMOUNT-WEIGHTED TEACHERS AT FLAT 7.0% INTEREST

	Base Rate → Proj. Scale →	Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024 PubT-2010 MP-2021	PubT-2016 MP-2021	Percentage Change of Moving to PubT-2016 from PubT-2010
Females	Age 25	1.0069	1.0057	-0.1%
	Age 35	1.9641	1.9614	-0.1%
	Age 45	3.8367	3.8315	-0.1%
	Age 55	7.5146	7.5066	-0.1%
	Age 65	11.5807	11.5469	-0.3%
	Age 75	9.1967	9.0899	-1.2%
	Age 85	6.0587	5.8595	-3.3%
Males	Age 25	0.9702	0.9654	-0.5%
	Age 35	1.8882	1.8790	-0.5%
	Age 45	3.6840	3.6657	-0.5%
	Age 55	7.2221	7.1882	-0.5%
	Age 65	11.0944	11.0310	-0.6%
	Age 75	8.5693	8.4727	-1.1%
	Age 85	5.4295	5.2468	-3.4%

Table D.2
AMOUNT-WEIGHTED SAFETY AT FLAT 7.0% INTEREST

	Base Rate → Proj. Scale →	Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024 PubS-2010 MP-2021	PubS-2016 MP-2021	Percentage Change of Moving to PubS-2016 from PubS-2010
Females	Age 25	0.9701	0.9695	-0.1%
	Age 35	1.8884	1.8856	-0.1%
	Age 45	3.6828	3.6748	-0.2%
	Age 55	7.1962	7.1895	-0.1%
	Age 65	10.9961	11.0028	0.1%
	Age 75	8.5836	8.5029	-0.9%
	Age 85	5.6554	5.4515	-3.6%
Males	Age 25	0.9353	0.9434	0.9%
	Age 35	1.8190	1.8346	0.9%
	Age 45	3.5457	3.5769	0.9%
	Age 55	6.9339	7.0038	1.0%
	Age 65	10.5561	10.6804	1.2%
	Age 75	7.9730	8.0542	1.0%
	Age 85	4.9699	5.0351	1.3%

Table D.3

AMOUNT-WEIGHTED GENERAL AT FLAT 7.0% INTEREST

	Base Rate → Proj. Scale →	Monthly Deferred-to-62 Annuity Due Values Generational @ July 1, 2024 PubG-2010 MP-2021	PubG-2016 MP-2021	Percentage Change of Moving to PubG-2016 from PubG-2010
Females	Age 25	0.9872	0.9843	-0.3%
	Age 35	1.9221	1.9165	-0.3%
	Age 45	3.7490	3.7394	-0.3%
	Age 55	7.3333	7.3217	-0.2%
	Age 65	11.2614	11.2432	-0.2%
	Age 75	8.8552	8.7599	-1.1%
	Age 85	5.7719	5.6284	-2.5%
Males	Age 25	0.9347	0.9333	-0.1%
	Age 35	1.8155	1.8141	-0.1%
	Age 45	3.5395	3.5367	-0.1%
	Age 55	6.9383	6.9388	0.0%
	Age 65	10.6390	10.6487	0.1%
	Age 75	8.1314	8.0887	-0.5%
	Age 85	5.1377	5.0028	-2.6%

D.2: JOINT-AND-100%-SURVIVOR ANNUITIES

Tables D.4, D.5, and D.6 show comparisons of Pub-2016 joint-and-100%-survivor annuity values at 5.0% interest to those produced by the SOA Pub-2010 tables. As described in Subsection 11.4, the annuity factors for the Pub-2016 tables were developed using Approach 2, in which Retiree mortality tables are used for the beneficiary prior to the death of the primary member, and Contingent Survivor mortality tables are used for the beneficiary after the death of the primary member.

All joint-and-survivor annuity calculations in this Appendix D.2 and the following Appendix D.3 assume that beneficiaries are of the opposite sex of the primary Retiree, and that females are three years younger than males.

Table D.4

AMOUNT-WEIGHTED TEACHERS JOINT-AND-100%-SURVIVOR ANNUITIES

	Base Rate → Proj. Scale →	Monthly Immediate Annuity Due Values Generational @ July 1, 2024 PubT-2010 MP-2021	PubT-2016 MP-2021	Percentage Change of Moving to PubT-2016 from PubT-2010
Females	Age 55	17.1123	17.0400	-0.4%
	Age 65	14.9519	14.8190	-0.9%
	Age 75	11.7116	11.4799	-2.0%
	Age 85	7.6709	7.3545	-4.1%
Males	Age 55	17.5696	17.5212	-0.3%
	Age 65	15.6538	15.5710	-0.5%
	Age 75	12.7258	12.5836	-1.1%
	Age 85	8.8133	8.5779	-2.7%

Table D.5

AMOUNT-WEIGHTED SAFETY JOINT-AND-100%-SURVIVOR ANNUITIES

	Base Rate → Proj. Scale →	Monthly Immediate Annuity Due Values Generational @ July 1, 2024 PubS-2010 MP-2021	Monthly Immediate Annuity Due Values Generational @ July 1, 2024 PubS-2016 MP-2021	Percentage Change of Moving to PubS-2016 from PubS-2010
Females	Age 55	16.7735	16.7402	-0.2%
	Age 65	14.4468	14.3614	-0.6%
	Age 75	11.1413	10.9554	-1.7%
	Age 85	7.2619	6.9848	-3.8%
Males	Age 55	17.3309	17.3413	0.1%
	Age 65	15.2851	15.2878	0.0%
	Age 75	12.2741	12.2333	-0.3%
	Age 85	8.4298	8.3180	-1.3%

Table D.6

AMOUNT-WEIGHTED GENERAL JOINT-AND-100%-SURVIVOR ANNUITIES

	Base Rate → Proj. Scale →	Monthly Immediate Annuity Due Values Generational @ July 1, 2024 PubG-2010 MP-2021	Monthly Immediate Annuity Due Values Generational @ July 1, 2024 PubG-2016 MP-2021	Percentage Change of Moving to PubG-2016 from PubG-2010
Females	Age 55	16.8911	16.8317	-0.4%
	Age 65	14.6434	14.5351	-0.7%
	Age 75	11.3617	11.1554	-1.8%
	Age 85	7.3889	7.1184	-3.7%
Males	Age 55	17.3894	17.3552	-0.2%
	Age 65	15.4146	15.3557	-0.4%
	Age 75	12.4489	12.3287	-1.0%
	Age 85	8.5843	8.3712	-2.5%

D.3: APPROACHES FOR COMPUTING JOINT-AND-SURVIVOR ANNUITIES

As discussed in Subsection 11.4, several possible approaches can be taken to compute a joint-and-survivor annuity value. Approach 2 was used to compute the Pub-2016 joint-and-survivor annuities in Subsection D.2 above. Other possibilities include Approach 1, which uses Retiree mortality for the beneficiary for the entire duration of the annuity, and Approach 3, which uses Contingent Survivor mortality for the beneficiary for the duration of the annuity. Tables D.7, D.8, and D.9 compare the joint-and-100%-survivor annuity values at 5.0% interest for each job category using each of the three methods, using the above Approach 2 values as the baseline.

Table D.7

AMOUNT-WEIGHTED TEACHERS JOINT-AND-100%-SURVIVOR ANNUITIES BY METHOD

	Base Rate → / Type →	Monthly Immediate Annuity Due Values MP-2021 Generational @ July 1, 2024			Percentage Change of Moving from PubT-2016 Approach 2 to:	
		PubT-2016 Approach 1	PubT-2016 Approach 2	PubT-2016 Approach 3	PubT-2016 Approach 1	PubT-2016 Approach 3
Females	Age 55	17.1075	17.0400	16.9340	0.4%	-0.6%
	Age 65	14.9103	14.8190	14.6888	0.6%	-0.9%
	Age 75	11.5827	11.4799	11.3361	0.9%	-1.3%
	Age 85	7.4180	7.3545	7.2520	0.9%	-1.4%
Males	Age 55	17.5936	17.5212	17.3953	0.4%	-0.7%
	Age 65	15.6768	15.5710	15.4003	0.7%	-1.1%
	Age 75	12.7061	12.5836	12.4150	1.0%	-1.3%
	Age 85	8.6740	8.5779	8.4726	1.1%	-1.2%

Table D.8

AMOUNT-WEIGHTED SAFETY JOINT-AND-100%-SURVIVOR ANNUITIES BY METHOD

	Base Rate → / Type →	Monthly Immediate Annuity Due Values MP-2021 Generational @ July 1, 2024			Percentage Change of Moving from PubS-2016 Approach 2 to:	
		PubS-2016 Approach 1	PubS-2016 Approach 2	PubS-2016 Approach 3	PubS-2016 Approach 1	PubS-2016 Approach 3
Females	Age 55	16.7931	16.7402	16.6513	0.3%	-0.5%
	Age 65	14.4287	14.3614	14.2772	0.5%	-0.6%
	Age 75	11.0301	10.9554	10.8717	0.7%	-0.8%
	Age 85	7.0352	6.9848	6.9110	0.7%	-1.1%
Males	Age 55	17.3204	17.3413	17.3112	-0.1%	-0.2%
	Age 65	15.2439	15.2878	15.2730	-0.3%	-0.1%
	Age 75	12.1534	12.2333	12.2682	-0.7%	0.3%
	Age 85	8.2226	8.3180	8.3871	-1.1%	0.8%

Table D.9

AMOUNT-WEIGHTED GENERAL JOINT-AND-100%-SURVIVOR ANNUITIES BY METHOD

	Base Rate → / Type →	Monthly Immediate Annuity Due Values MP-2021 Generational @ July 1, 2024			Percentage Change of Moving from PubG-2016 Approach 2 to:	
		PubG-2016 Approach 1	PubG-2016 Approach 2	PubG-2016 Approach 3	PubG-2016 Approach 1	PubG-2016 Approach 3
Females	Age 55	16.8767	16.8317	16.7623	0.3%	-0.4%
	Age 65	14.5923	14.5351	14.4561	0.4%	-0.5%
	Age 75	11.2162	11.1554	11.0724	0.5%	-0.7%
	Age 85	7.1530	7.1184	7.0618	0.5%	-0.8%
Males	Age 55	17.3829	17.3552	17.2915	0.2%	-0.4%
	Age 65	15.3851	15.3557	15.2687	0.2%	-0.6%
	Age 75	12.3426	12.3287	12.2710	0.1%	-0.5%
	Age 85	8.3627	8.3712	8.3668	-0.1%	-0.1%

D.4: COMPLETE COHORT LIFE EXPECTANCIES

Tables D.10, D.11, and D.12 display comparisons of complete cohort life expectancies as of July 1, 2024, at a variety of ages for Teachers, Safety, and General members, respectively. For purposes of determining mortality rates for these life expectancies, retirement is assumed to occur at age 62.

Table D.10

TEACHERS COMPLETE COHORT LIFE EXPECTANCIES

		Cohort Life Expectancies (Complete) Generational @ July 1, 2024		Percentage Change of Moving to PubT.H -2016 from PubT.H -2010
	Base Rate → Proj. Scale →	PubT.H -2010 MP-2021	PubT.H -2016 MP-2021	
Females	Age 25	66.34	66.20	-0.2%
	Age 35	55.80	55.65	-0.3%
	Age 45	45.35	45.19	-0.4%
	Age 55	34.97	34.81	-0.5%
	Age 65	24.96	24.75	-0.8%
	Age 75	15.83	15.57	-1.6%
	Age 85	8.40	8.15	-3.0%
Males	Age 25	63.77	63.47	-0.5%
	Age 35	53.22	52.90	-0.6%
	Age 45	42.78	42.45	-0.8%
	Age 55	32.47	32.15	-1.0%
	Age 65	22.65	22.34	-1.4%
	Age 75	13.99	13.73	-1.9%
	Age 85	7.23	6.96	-3.7%

Table D.11

SAFETY COMPLETE COHORT LIFE EXPECTANCIES

		Cohort Life Expectancies (Complete) Generational @ July 1, 2024		Percentage Change of Moving to PubS.H -2016 from PubS.H -2010
	Base Rate → Proj. Scale →	PubS.H -2010 MP-2021	PubS.H -2016 MP-2021	
Females	Age 25	64.17	64.10	-0.1%
	Age 35	53.59	53.48	-0.2%
	Age 45	43.10	42.98	-0.3%
	Age 55	32.64	32.59	-0.2%
	Age 65	22.72	22.67	-0.2%
	Age 75	14.41	14.11	-2.1%
	Age 85	7.84	7.48	-4.6%
Males	Age 25	61.39	62.14	1.2%
	Age 35	50.88	51.57	1.4%
	Age 45	40.45	41.12	1.7%
	Age 55	30.06	30.78	2.4%
	Age 65	20.30	20.96	3.3%
	Age 75	12.25	12.73	3.9%
	Age 85	6.28	6.56	4.4%

Table D.12

GENERAL COMPLETE COHORT LIFE EXPECTANCIES

	Base Rate → / Proj. Scale →	Cohort Life Expectancies (Complete) Generational @ July 1, 2024: PubG.H-2010 MP-2021	Cohort Life Expectancies (Complete) Generational @ July 1, 2024: PubG.H -2016 MP-2021	Percentage Change of Moving to PubG.H -2016 from PubG.H -2010
Females	Age 25	64.89	64.74	-0.2%
	Age 35	54.30	54.13	-0.3%
	Age 45	43.81	43.64	-0.4%
	Age 55	33.39	33.25	-0.4%
	Age 65	23.48	23.31	-0.7%
	Age 75	14.79	14.57	-1.5%
	Age 85	7.81	7.66	-1.9%
Males	Age 25	61.34	61.31	0.0%
	Age 35	50.76	50.75	0.0%
	Age 45	40.36	40.32	-0.1%
	Age 55	30.09	30.07	-0.1%
	Age 65	20.52	20.50	-0.1%
	Age 75	12.63	12.50	-1.0%
	Age 85	6.59	6.40	-2.9%

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