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OFFICE OF POPULATION CENSUSES AND SURVEYS

1970-1972

Life tables

decennial supplement

England and Wales

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OFFICE OF POPULATION CENSUSES AND SURVEYS

Life tables

The Registrar General's decennial supplement for England and Wales 1970-72

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Contents

These English Life Tables (thirteenth in the series) together with associated additional tables and commentary were prepared by Edward Johnston, CB, the Government Actuary, at the invitation of the Registrar General for England and Wales.

The tables are based on the mortality experience in England and Wales during the years 1970, 1971 and 1972 and the present volume forms part of the Decennial Supplement 1971. It is generally similar to its predecessor, *Decennial Supplement 1961, Life Tables No 12,* apart from the adoption of graduation by cubic splines.

The Registrar General wishes to place on record his appreciation of all the work which has been done to provide the accompanying valuable commentary and tables.

The series of English Life Tables has continued for well over a century. The idea was conceived by Dr William Farr, the first Medical Statistician at the General Register Office, who himself produced Numbers 1,2 and 3 which were published between 1843 and 1864. The next three tables were also produced at the General Register Office. Number 4 was compiled by Dr William Ogle and published in 1885 and Dr John Tatham was responsible for Numbers 5 and 6 which appeared in 1895 and 1907 respectively. After the 1911 Census the Registrar General invited Mr George King, a former Vice-President of the Institute of Actuaries, to prepare Tables 7 and 8 and these incorporated important advances in principles and methods. Subsequently the English Life Tables were prepared by the Government Actuary of the time at the invitation of the Registrar General. Thus Sir Alfred Watson, KCB, undertook the preparation of Tables 9 and 10 after the 1921 and 1931 Censuses, and Table No 11, which was based on the 1951 Census and formed part of the Decennial Supplement 1951, was the work of Sir George Maddex, KBE. Sir Herbert Tetley, KBE, CB prepared the English Life Tables No 12 which were based on the 1961 Census.

Report on Life Tables by the Government Actuary

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Sir,

In compliance with your request, Life Tables for males and females have been constructed, based on the mortality experience of the population of England and Wales during the three years 1970, 1971 and 1972. The calculations have been based on the deaths registered in those years and on the population enumerated at the 1971 Census. I have also examined the variations in mortality according to marital condition during the same three years.

2. The present tables form English Life Tables No. 13 and, like the previous ones, English Life Tables Nos. 8 to 12, have been based on a period of three calendar years centred on the year in which a full census has been carried out. Study of the data disclosed no grounds for thinking that the mortality of the years 1970-72 differed materially from the general trend of mortality over the years 1966 to 1976[1]. There was therefore no reason to depart from the customary three-year period.

The construction of English Life Tables No.13

3. **Calculation of crude death rates.** In my predecessor's report on the English Life Tables for 1960 to 1962[2] he explained how the 'exposed to risk' was estimated as accurately as possible from the enumerated census population and the tabulations of registered deaths. A very similar process was used on this occasion; it is described in detail in Appendix I. Crude central rates of mortality (m_x) were obtained by dividing the 1970-72 deaths at each age by the corresponding exposed to risk; these figures are given in Appendix II.

4. **Calculation of graduated rates of mortality.** The crude rates of mortality given in Appendix II do not run smoothly from age to age. In part, these irregularities may be due to misstatements of age, both in the census and when deaths are registered, though such misstatements are thought to be less important nowadays than they used to be. In part, too, they are due to the impossibility of calculating exactly the 'exposed to risk' at each age. Another cause of the irregularities is, however, random variations. So far as possible these random variations ought to be removed in the published Life Tables, and this is the purpose of graduation. The intention is to replace the crude rates by a series of graduated rates which, while forming a smooth progression over the whole range of ages covered, still preserves the general shape of the mortality curve.

5. For English Life Tables Nos. 11 and 12, graduated rates of mortality were obtained by a mathematical formula which combined a logistic curve with a 'Normal' curve. Not unnaturally, the first attempt at graduating the 1970-72 rates was to see if such a formula could be used again. The particular mathematical formula used for the 1950-52 and 1960-62 tables had been derived, not from any philosophical considerations, but empirically after study of the run of pivotal values of m_x and, in particular, of the ratios m_{x+5}/m_x. These pivotal values and ratios are given in Appendix III; the picture shown by the ratios was rather different from that in 1950-52 and 1960-62, and this indicated that it would be difficult to obtain a satisfactory fit with the same mathematical formula as before. Indeed, the male ratios in particular ran in such an irregular fashion as to suggest that it would be extremely difficult to fit any mathematical formula not involving more parameters than the seven required for the 1950-52 and 1960-62 formula.

6. Experiments with that formula and alternative methods were carried out in the Department and also by Dr (now Professor) McCutcheon FFA and Dr Eilbeck of Heriot-Watt University who had been supplied with a copy of the data in order to undertake experiments in graduation[3]. The results of the work carried out in both locations was to confirm that a satisfactory fit could not be obtained with the formula as previously used, although it could be improved by adding to the number of parameters. Since there is no theoretical basis for a formula, and as there appeared now to be no particular advantage in its use, it was decided to discard it. Another method which was examined was to fit a polynomial to log m_x over long ranges of ages by the method of orthogonal polynomials. This produced very satisfactory results over each range, but there was difficulty in obtaining a smooth join at the point where

[1] See *The Recent Trend of Mortality in Great Britain* C D Daykin (Journal of the Institute of Actuaries Vol. 104 p. 93)

[2] *The Registrar General's Decennial Supplement, England and Wales, 1961 Life Tables.*

[3] The results of their work were published as Experiments in the Graduation of the English Life Tables (No. 13) Data, *Transactions of the Faculty of Actuaries* Vol 35, p.281.

the ranges of ages overlap. The method finally adopted was graduation by cubic splines, suggested by McCutcheon and Eilbeck[4].

7. The method of cubic splines is in essence a refinement of the method of osculatory interpolation devised by George King and used for English Life Tables from the beginning of the century until 1930-32. Details of graduation by cubic splines are given in the reference already cited. It involves the fitting of third-degree polynomials to sections of the data, the polynomials being chosen so that they and their first two differential coefficients are continuous at the boundaries of each section. The method differs from King's method in three respects: first, the data at individual ages are used, and not just the pivotal values; secondly, the length of each section can be chosen to give the best results, whereas King's method used a fixed length of five years; thirdly, second, as well as the first, differences are continuous at the junctions.

8. The spline graduations cover the age range two to 95 for each sex. Appendix III shows comparisons between deaths actually recorded in 1970-72 and those 'expected' on the basis of the 'exposed to risk' and the graduated rates both at individual ages and in five-year groups. It will be seen that, though the deviations are fairly large at some individual ages, the actual and expected deaths in each age-group are very close to one another and the accumulated deviation is always small.

9. It was then necessary to complete the graduation by obtaining rates at ages below two and over 95. Rates at ages nought and one were obtained from the records of births and deaths in the years 1968 to 1973 rather than from the census data. At ages over 95 the graduations were completed by extrapolation, assuming that the limiting age for both males and females was 110; at these ages the census data and death registrations are probably unreliable[5].

Comparison with earlier English Life Tables

10. A picture of changes in mortality over a period of 60 years can be obtained by comparing English Life Tables No. 13 with the five previous sets, Nos. 8 to 12. Table A shows the rates of mortality (q_x) for each tenth age for males and females given by each of these six sets of Tables, and in Table B the changes in the rates since 1911 are shown by expressing the rates from the five later tables as percentages of those from English Life Table No.8. At ages up to 70, the ratios in Table B are shown graphically in Figure A.

11. The percentages in Table B and Figure A give a broad picture of the secular trend of mortality from 1911 to 1971. The figures for ages 80 and 90 should, however, be treated with some reserve. Mortality at these older ages is much more affected than at younger ages by the incidence of epidemics or severe winter weather, so that even the experience of a three-year period may differ considerably from the general trend. For age 90, the uncertainty is even greater than at age 80. First, the data are relatively scanty; further, examination of the data suggests that there may be some misstatement of age in extreme old age and, finally, changes in the graduation method from one table to another may tend to distort the results at these very old ages.

12. The tables show that there has been great improvement in mortality over the period since 1911 and that, at every age and for both sexes, the 1970-72 death rates, as shown by the English Life Tables No. 13, are lower than the 1910-12 rates. The percentage improvement has, however, varied considerably. Over the 60-year period the infant mortality rate has been reduced to one sixth of its former level for both sexes; in

Table A Rates of mortality (q_x)

Age x	ELT 8 (1910-12)	ELT 9 (1920-22)	ELT 10 (1930-32)	ELT 11 (1950-52)	ELT 12 (1960-62)	ELT 13 (1970-72)
Males						
0	.12044	.08996	.07186	.03266	.02449	.01980
10	.00193	.00181	.00146	.00052	.00039	.00034
20	.00348	.00349	.00316	.00129	.00119	.00106
30	.00478	.00434	.00340	.00157	.00115	.00097
40	.00811	.00688	.00562	.00290	.00235	.00226
50	.01482	.01179	.01128	.00850	.00728	.00739
60	.03042	.02561	.02415	.02369	.02287	.02075
70	.06470	.05997	.06035	.05651	.05566	.05546
80	.14299	.14002	.14500	.13629	.12747	.12019
90	.27395	.26752	.28614	.29255	.25593	.24077
Females						
0	.09767	.06942	.05455	.02510	.01896	.01523
10	.00196	.00180	.00134	.00035	.00024	.00023
20	.00295	.00306	.00268	.00083	.00044	.00045
30	.00411	.00392	.00319	.00127	.00075	.00060
40	.00660	.00532	.00440	.00227	.00180	.00160
50	.01140	.00915	.00816	.00524	.00439	.00449
60	.02310	.01897	.01770	.01271	.01088	.01025
70	.05259	.04646	.04451	.03532	.03104	.02784
80	.12419	.11766	.11858	.10466	.09108	.08014
90	.23826	.23852	.25061	.24146	.22128	.19805

[4] I am indebted to McCutcheon and Eilbeck for letting me have details of their computer output.

[5] See 'Mortality at the oldest ages' (G T Humphrey) *Journal of the Institute of Actuaries,* Vol. 96, p.105.

Figure A Rates of mortality expressed as percentages of 1911 rates (logarithmic scale)

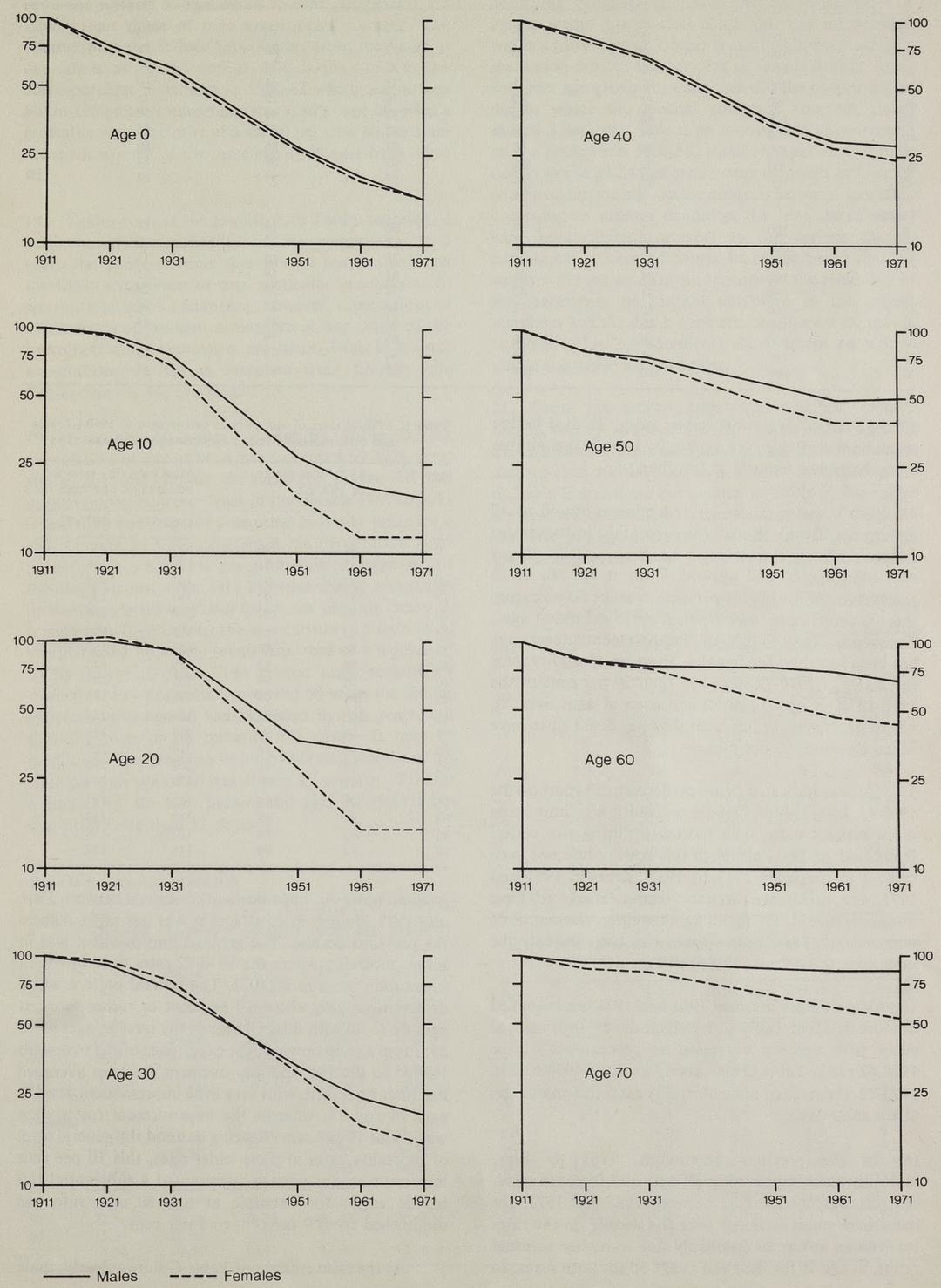

Table B Rates of mortality expressed as percentages of English Life Table No. 8 rates

Age	ELT 8 (1910-12)	ELT 9 (1920-22)	ELT 10 (1930-32)	ELT 11 (1950-52)	ELT 12 (1960-62)	ELT 13 (1970-72)
Males						
0	100	75	60	27	20	16
10	100	94	76	27	20	18
20	100	100	91	37	34	30
30	100	91	71	33	24	20
40	100	85	69	36	29	28
50	100	80	76	57	49	50
60	100	84	79	78	75	68
70	100	93	93	87	86	86
80	100	98	101	95	89	84
90	100	98	104	107	93	88
Females						
0	100	71	56	26	19	16
10	100	92	68	18	12	12
20	100	104	91	28	15	15
30	100	95	78	31	18	15
40	100	81	67	34	27	24
50	100	80	72	46	39	39
60	100	82	77	55	47	44
70	100	88	85	67	59	53
80	100	95	95	84	73	65
90	100	100	105	101	93	83

1910-12 out of every 100 babies born, 11 died before reaching their first birthday, but by 1970-72 the number dying had been reduced to less than two.

13. For females, a similar reduction is found at all ages up to 30 and, though the percentage improvement lessens with age thereafter, it has been at least 50 per cent until age 60 and beyond. Even at age 80, death rates have declined by 35 per cent over the 60 years and there is evidence of improvement up to the oldest ages. For males, except in infancy, improvement at every age has been less than for females. Even so, mortality rates for males in 1970-72 were less than 50 per cent of the 1910-12 rates up to age 50 and even at ages over 70, where improvement has been slowest, death rates have fallen by about 15 per cent.

14. As was indicated in my predecessor's report on the 1960-62 Life Tables, female mortality was improving more rapidly than male mortality during the period from 1931 to 1961, although this feature had not been evident in the years 1911 to 1931. Between 1961 and 1971, the difference in pace seems largely to have disappeared and, taking all ages together, the degree of improvement for the two sexes has been broadly the same over the decade, except at ages over 70.

15. The changes between 1961 and 1971 are examined in more detail in Table C, in which the 1970-72 rates at every fifth age are expressed as percentages of the 1960-62 rates. Table C also gives, for both 1960-62 and 1970-72, the ratio of male mortality rates to female rates at the same age.

16. In the previous decennium, 1951 to 1961, mortality rates improved at all ages and for both sexes, but this was not the case between 1961 and 1971, for there were small increases over the decade in the rates for women at age 20 (probably due to higher accident rates), at age 45 for men and at age 50 for both sexes. In

Table C 1970-72 rates of mortality as percentages of 1960-62 rates and male mortality rates as percentages of female rates

Age	1970-72 as percentage of 1960-62		Male mortality rates as percentages of female rates	
	Males	Females	1960-62	1970-72
0	81	80	129	130
5	82	81	136	138
10	87	96	162	148
15	95	97	197	193
20	89	102	270	236
25	89	83	183	196
30	84	80	153	162
35	86	82	136	144
40	96	89	131	141
45	104	99	140	148
50	102	102	166	165
55	94	99	195	185
60	91	94	210	202
65	95	91	202	210
70	100	90	179	199
75	98	89	157	173
80	94	88	140	150
85	93	88	127	134
90	94	90	116	122

general, however, improvement continued between 1961 and 1971, though at most ages it was less rapid than in the previous decade. The greatest improvement was in infant mortality where the 1970-72 rates were one fifth lower than those in 1960-62. The general pattern was a decline averaging about 10 per cent or rather more at ages up to 40 with little change in the rates at ages 45 to 55. From age 60 onward, the experience of the two sexes tended to diverge; the improvement for men averaged less than 5 per cent, with very little improvement at all at ages 70 and 75, whereas the improvement for women was about 10 per cent. Bearing in mind the general level of mortality rates at these older ages, this 10 per cent improvement for women represented a substantial fall in the rates; for example at age 80, the rate has diminished from 9 per cent to 8 per cent.

17. As the final column of Table C shows clearly, male

mortality was heavier than female mortality in 1970-72 at all ages. The excess male mortality ranged from 30 per cent in infancy to 110 per cent at age 65, with an isolated peak of 136 per cent at age 20. The mortality rates for women at ages 60 to 75 were, in general, no higher than those of men seven years younger. The maximum male: female ratio (apart from the value at age 20) is at age 65 and at 2.10 is the same as the corresponding maximum in 1960-62 which was at age 60; in 1950-52 the maximum was 1.86 at age 60. Men's mortality rates are now at least 50 per cent higher than those for women of the same age at all ages from 50 to 80.

18. Tables such as the English Life Tables represent a snapshot of the mortality of the community at a particular point of time; they do not purport to show the likely experience of any particular generation. In spite of relating to a snapshot, however, expectations of life form as convenient a measure as any other of the overall effects of changes in mortality. Table D sets out expectations of life as compiled from English Life Tables Nos. 8, 10, 11, 12 and 13.

19. Over the 60 years covered by Table D, the expectation of life at birth has increased by 17½ years for a boy and almost 20 years for a girl. Of this improvement, however, that in the decade 1961 to 1971 is less than one year for a boy and only 1¼ years for a girl. On the 1970-72 experience the expectation is 69 years for a boy and 75¼ years for a girl. A large part of the improvement since 1911 has been due to reductions in mortality in infancy, but this is not the only cause, as is shown by the fact that the expectation of a man of 20 has increased by nearly seven years and of a woman of 20 by nearly 10 years. The greater improvement for women is very noticeable; over the 60 years the female expectation at age 60 has increased by 4½ years, but that for men of 60 by only 1⅔ years. It may be mentioned that the expectation of life of a woman at the state pension age of 60 was almost 20 years in 1971; for a man of 65, the male pensionable age, the expectation was little more than 12 years.

Table D Expectations of life ($\mathring{e}_x$)

Age x	ELT 8 (1910-12)	ELT 10 (1930-32)	ELT 11 (1950-52)	ELT 12 (1960-62)	ELT 13 (1970-72)
Males					
0	51.50	58.74	66.42	68.09	69.00
10	53.08	55.79	59.24	60.21	60.74
20	44.21	46.81	49.64	50.57	51.08
30	35.81	38.21	40.27	41.06	41.51
40	27.74	29.62	30.98	31.62	32.01
50	20.29	21.60	22.23	22.68	23.11
60	13.78	14.43	14.79	15.06	15.41
70	8.53	8.62	9.00	9.29	9.50
Females					
0	55.35	62.88	71.54	74.00	75.25
10	55.91	58.87	63.87	65.77	66.71
20	47.10	49.88	54.17	55.95	56.89
30	38.54	41.22	44.68	46.23	47.13
40	30.30	32.55	35.32	36.69	37.52
50	22.51	24.18	26.34	27.57	28.41
60	15.48	16.50	18.07	19.11	19.98
70	9.58	10.02	10.97	11.78	12.56

Mortality rates according to marital condition

20. Both the 1971 Census population and the deaths registered in 1970, 1971 and 1972 have been tabulated according to marital condition. Not all registrations of deaths record the marital condition; this information was not available for 1.1 per cent of male deaths during the period nor for 0.3 per cent of female deaths. In no five-year age-group for either sex did the proportion of deaths where the marital condition was not stated exceed 3 per cent. This is an appreciable improvement on the position in 1960-62, when 16.4 per cent of male deaths in the 20-24 age-group were recorded as 'marital condition not stated'. In the analysis below of mortality according to marital condition the 'not stated' cases have been allotted rateably to the various marital conditions. It must of course be remembered that the validity of such an analysis depends on the reliability of the statements of marital condition in the census schedules and the death registers, but there is no reason to believe that misstatements are frequent enough to vitiate the tables shown below.

21. From the census population and the 1970-72 deaths, pivotal values of the mortality rates at ages 22, 27, 32 and so on were calculated for all men, for women and for each marital condition. Rates for men are given in Table E and those for women in Table F. No values are inserted in the tables where the number of deaths in the three years was less than 100; in some other groups the numbers are so small that the rates given are subject

Table E 1970-72 rates of mortality per thousand ($10^3 q_x$) for men according to marital condition

Age x	All men	Single men	Married men	Widowers	Divorced men
22	1.0	1.2	0.6		
27	0.9	1.6	0.7		
32	1.1	2.2	0.9		2.2
37	1.6	3.3	1.4		3.6
42	2.9	5.0	2.6	5.1	5.6
47	5.3	8.4	4.8	9.5	9.8
52	9.1	13.7	8.4	14.3	15.6
57	15.2	20.2	14.3	22.6	24.3
62	25.5	32.0	24.0	36.7	37.2
67	42.2	47.6	39.9	56.2	55.3
72	66.1	70.3	62.4	79.8	82.6
77	97.3	102	90.8	112	113
82	139	140	128	154	146
87	203	192	185	216	

Table F 1970-72 rates of mortality per thousand ($10^3 q_x$) for women according to marital condition

Age x	All women	Single women	Married women	Widows	Divorced women
22	0.4	0.6	0.3		
27	0.5	1.1	0.4		
32	0.7	1.5	0.6		1.1
37	1.2	2.0	1.0		2.0
42	2.0	3.3	1.8		2.7
47	3.5	4.8	3.2	4.8	5.0
52	5.3	6.9	5.0	6.4	6.4
57	7.9	9.4	7.4	9.2	9.2
62	12.3	13.6	11.5	13.9	14.3
67	20.3	20.6	19.0	22.1	22.8
72	34.6	34.9	32.4	36.4	37.7
77	59.6	57.9	54.4	62.1	70.9
82	97.6	95.2	88.3	100	115
87	157	153	134	160	192

to considerable margins of statistical error. It should be noted that the values given for all men and all women do not agree exactly with the pivotal values given in Appendix III; the differences are due to the use of the unadjusted census population as a denominator in this section of the report, whereas in Appendix III the population used was the 'exposed to risk' (see Appendix I).

22. In the corresponding section of the report on the Life Tables for 1960-62, widowers and divorced men were treated as one category. The characteristics of the two groups are, however, likely to differ and they have been treated separately on this occasion. Similarly separate figures are now given for widows and divorced women.

23. At all ages and for both sexes, the mortality rates for married persons are lighter than those for other members of the same sex, often by a large margin. For men, mortality rates for widowers and the divorced are heavier than for bachelors. Similarly, for women, spinsters appear to have lighter rates than do widows and divorced women, though the differences are, on the whole, smaller than for men. These differences between death rates for the various marital conditions are brought out in Table G which shows the rates for the single, widowed and divorced as percentages of those for married persons.

Table G 1970-72 mortality rates for single, widowed and divorced as percentages of those for married

Age	Men			Women		
	Rates as a percentage of those for married men			Rates as a percentage of those for married women		
	Single men	Widowers	Divorced men	Single women	Widows	Divorced women
22	197			176		
27	242			268		
32	259		255	245		184
37	247		268	196		193
42	197	201	218	176		146
47	175	197	203	150	149	153
52	162	170	186	138	128	129
57	141	158	170	127	123	123
62	133	153	155	118	121	124
67	119	141	139	108	117	120
72	113	128	132	108	112	116
77	112	123	124	106	114	130
82	109	120	115	108	113	131

24. Looking first at men, the mortality rates for bachelors are double or more the rates for married men at ages up to 45. Though the excess decreases thereafter, it is still substantial, being one third at age 62 and more than 10 per cent up to age 80. The excess mortality of spinsters is, at almost all ages, less than the excess mortality of bachelors, but again at ages 27 and 32 the single women's rate is well over double that for married women; the excess has fallen to 18 per cent at age 62 and is less than 10 per cent after age 65. These differences, particularly at the younger ages, must be in large measure due to the selective effect of marriage. There is likely to be a higher proportion with impairment of health amongst those remaining unmarried.

25. Widowers and divorced men experience even heavier mortality rates than bachelors; again, some part of the excess may be due to selection, since those who are healthy are more likely to remarry. At all ages widowers experience mortality rates at least 20 per cent higher than those for married men and the excess is considerably greater at the younger ages. There appears to be little overall difference between the mortality of widowers and divorced men.

26. The differences are again less in the case of women and the excess of widows' mortality over that of married women is less than 20 per cent at age 67 and less than 15 per cent at higher ages. At almost all ages the excess mortality of divorced women is greater than that of widows.

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October 1978

Appendix I Calculation of the 'exposed to risk' for the years 1970-72

1. The census was taken on the night of 25/26 April 1971, or 0.315 years after the beginning of 1971. If one considers the enumerated population at age x last birthday, say P_x, then on the assumption of an even spread of birthdays over the year, $0.315P_x$ were aged between $x-1.315$ and $x-1$ on 1 January 1970 and $0.685P_x$ were aged between $x-1$ and $x-0.315$ on that date. Ignoring mortality and migration, each person in the first group would on average have been exposed to risk in the period 1970-72 for the following periods:

At age $x-2$ last birthday:	0.1575 years (ie ½ of 0.315)
At age $x-1$ last birthday:	1 year
At age x last birthday:	1 year
At age $x+1$ last birthday:	0.8425 years (ie the average of durations ranging from 0.685 to 1)

This is a total of three years, as it clearly should be.

Similarly, the second group would on average have been exposed for the following periods:

At age $x-1$ last birthday:	0.6575 years (ie the average of durations ranging from 1 to 0.315)
At age x last birthday:	1 year
At age $x+1$ last birthday:	1 year
At age $x+2$ last birthday:	0.3425 years (ie ½ of 0.685)

2. Thus the enumerated population P_x were exposed to risk for the following periods in years:

At age $x-2$ last birthday:	$0.04961P_x$ (0.315×0.1575)
At age $x-1$ last birthday:	$0.76539P_x$ $(0.315 + 0.685_{1\times 8}\, 0.6575)$
At age x last birthday:	$1.00000P_x$ $(0.315 + 0.685)$
At age $x+1$ last birthday:	$0.95039P_x$ $(0.315 \times 0.8425 + 0.685)$
At age $x+2$ last birthday:	$0.23461P_x$ (0.685×0.3425)
	$3.00000P_x$

It follows from this that the 'exposed to risk' for 1970-72 at age x last birthday, ignoring deaths and migration, is:

$$0.04961P_{x+2} + 0.76539P_{x+1} + P_x + 0.95039P_{x-1} + 0.23461P_{x-2} = A_x \text{ say}$$

3. A_x is not the true 'exposed to risk', because it assumes that all those enumerated in the census formed part of the population for the whole of the three years 1970-72 and that no other persons contributed to the 'exposed to risk'. An addition has to be made for those who died between 1 January 1970 and the census date, since they were exposed to risk up to the date of death, but are not part of the census population; on the other hand, a deduction has to be made for those enumerated at the census but who died before the end of 1972 and therefore did not contribute to the 'exposed to risk' for the full three years.

4. The method of adjusting for the deaths in the period 1970-72 may be illustrated by reference to the deaths in 1970. Of the deaths in that year at age x last birthday, some were aged $x-1$ and some were aged x last birthday on 1 January 1970. Of deaths at time t years after the beginning of the year (when t is less than 1), the proportion aged x last birthday on 1 January may be taken as $1-t$ and for each such death the addition to the 'exposed to risk' is t years, all at age x last birthday. Similarly, the proportion aged $x-1$ on 1 January would be t, the ages at that date ranging from $x-t$ to x; thus, of the additional t years of exposure for such deaths, $\frac{1}{2}t$, on average, relates to age $x-1$ and $\frac{1}{2}t$ to age x. The additional exposure per death at age x last birthday in 1970 is therefore:

At age $x-1$: $\int_0^1 \frac{1}{2}t^2 dt = \frac{1}{6}$ years

At age x: $\int_0^1 t(1-t)dt + \int_{\frac{1}{2}}^1 t^2 dt = \frac{1}{3}$ years

Thus if the deaths in 1970 at age x are θ^{70}_x, the adjustment to the 'exposed to risk' at age x for deaths in 1970 is $\frac{1}{6}\theta^{70}_{x+1} + \frac{1}{3}\theta^{70}_x$

5. Similar methods applied to the deaths in other years, led to the following formula for the adjustment to A_x to obtain the 'exposed to risk':

$$\tfrac{1}{6}\theta^{70}_{x+1} + \tfrac{1}{3}\theta^{70}_x + .0170\theta^{71a}_{x+2} + .6410\theta^{71a}_{x+1} + \tfrac{1}{2}\theta^{71a}_x - \tfrac{1}{2}\theta^{71b}_x - .7640\theta^{71b}_{x-1} - .0780\theta^{71b}_{x-2} - \tfrac{1}{3}\theta^{72}_x - \tfrac{1}{6}\theta^{72}_{x-1}$$

In this formula θ^{71a}_x and θ^{71b}_x are respectively the deaths at age x in 1971 before and after the census date. In dividing the 1971 deaths between those included in θ^{71a}_x and θ^{71b}_x, recourse was had to the quarterly tabulations of deaths: on the basis of the monthly totals of deaths at all ages which are also available it was assumed that between 25 and 28 per cent, depending on age, of deaths in the second quarter of 1971 occurred before the census date.

6. In theory, there should be a further adjustment for migration, but statistics of migration were not available in enough detail for this to be done. It is believed, however, that the resulting error is relatively small.

Appendix II

Table II.1 Crude central rates of mortality (m_x), 1970-72 England and Wales
Note: The method of Appendix I did not give the 'exposed to risk' at ages 0 and 1; at these ages mortality rates were calculated from records of births and deaths.

Age x	Males			Females		
	Exposed to risk (1)	Deaths 1970-72 (2)	m_x = (2) ÷ (1) (3)	Exposed to risk (1)	Deaths 1970-72 (2)	m_x = (2) ÷ (1) (3)
2	1191743	957	.00080	1132886	761	.00067
3	1211605	759	.00063	1150786	599	.00052
4	1232567	634	.00051	1169813	482	.00041
5	1254028	579	.00046	1189876	413	.00035
6	1261948	589	.00047	1198630	362	.00030
7	1255220	519	.00041	1192521	319	.00027
8	1236213	456	.00037	1173991	303	.00026
9	1211189	436	.00036	1147993	288	.00025
10	1180077	396	.00034	1116294	266	.00024
11	1149807	384	.00033	1086925	217	.00020
12	1122522	368	.00033	1061235	240	.00023
13	1099146	411	.00037	1038203	225	.00022
14	1073505	473	.00044	1012107	239	.00024
15	1046519	536	.00051	985408	281	.00029
16	1031388	837	.00081	972530	351	.00036
17	1021084	1058	.00104	969511	406	.00042
18	1014114	1049	.00103	973756	386	.00040
19	1010447	1091	.00108	982299	435	.00044
20	1023106	1093	.00107	1004524	478	.00048
21	1053824	1119	.00106	1040348	447	.00043
22	1107406	1096	.00099	1097042	498	.00045
23	1167428	1113	.00095	1156110	511	.00044
24	1152600	943	.00082	1140548	485	.00043
25	1098575	956	.00087	1083853	492	.00045
26	1023420	935	.00091	1006104	477	.00047
27	996718	913	.00092	975650	464	.00048
28	953636	828	.00087	930862	472	.00051
29	901666	808	.00090	877499	510	.00058
30	872172	864	.00099	846834	520	.00061
31	873149	927	.00106	845802	517	.00061
32	885631	961	.00109	856468	615	.00072
33	884387	989	.00112	854016	678	.00079
34	875516	1057	.00121	845984	697	.00082
35	862662	1207	.00140	835646	742	.00089
36	846631	1296	.00153	823693	853	.00104
37	838613	1336	.00159	818561	970	.00119
38	842115	1437	.00171	824567	1053	.00128
39	859650	1693	.00197	846323	1199	.00142
40	872204	1961	.00225	865798	1422	.00164
41	876636	2223	.00254	876944	1572	.00179
42	873230	2573	.00295	875402	1738	.00199
43	879039	2915	.00332	880245	2007	.00228
44	891111	3270	.00367	891520	2199	.00247
45	903355	3829	.00424	907287	2535	.00279
46	910739	4287	.00471	920946	2817	.00306
47	917556	4765	.00519	936324	3305	.00353
48	941926	5513	.00585	968595	3682	.00380
49	977703	6583	.00673	1011647	4194	.00415

Table II.1 *continued*

Age x	Males			Females		
	Exposed to risk (1)	Deaths 1970-72 (2)	m_x = (2) ÷ (1) (3)	Exposed to risk (1)	Deaths 1970-72 (2)	m'_x = (2) ÷ (1) (3)
50	998894	7552	.00756	1038147	4693	.00452
51	931794	7585	.00814	975493	4806	.00493
52	823841	7492	.00909	867867	4756	.00548
53	751477	7618	.01014	796402	4498	.00565
54	763587	8821	.01155	809995	4966	.00613
55	822503	10480	.01274	876186	5877	.00671
56	858503	11840	.01379	919781	6606	.00718
57	874768	13338	.01525	942453	7649	.00812
58	864908	14641	.01693	934924	8192	.00876
59	848975	16211	.01909	927439	8740	.00942
60	834709	17508	.02097	922363	9697	.01051
61	822865	19079	.02319	921792	10181	.01104
62	804962	20813	.02586	911167	11301	.01240
63	780114	22031	.02824	895554	12293	.01373
64	747831	24059	.03217	874284	13131	.01502
65	714359	25415	.03558	854817	14116	.01651
66	679426	26173	.03852	833950	14867	.01783
67	644123	27485	.04267	810035	16726	.02065
68	604672	28336	.04686	779349	17697	.02271
69	563082	29479	.05235	754709	19135	.02535
70	516090	29672	.05749	727181	20600	.02833
71	465134	28815	.06195	695145	21537	.03098
72	413421	28110	.06799	651727	23213	.03562
73	369234	27167	.07358	612459	24167	.03946
74	332709	26516	.07970	577970	25393	.04393
75	302104	26168	.08662	544906	26713	.04902
76	272462	25563	.09382	506871	27864	.05497
77	246644	24858	.10078	468081	28281	.06042
78	221226	24223	.10949	430226	29101	.06764
79	196772	23357	.11870	395125	29968	.07584
80	172956	22117	.12788	360980	30396	.08420
81	151378	20380	.13463	330701	29980	.09066
82	130567	19538	.14964	297591	30437	.10228
83	110226	17569	.15939	262874	29742	.11314
84	91688	16323	.17803	226578	28373	.12522
85	75619	14582	.19284	194300	27003	.13898
86	61705	12698	.20579	164403	25703	.15634
87	49533	11097	.22403	136853	22779	.16645
88	38927	9263	.23796	111988	20657	.18446
89	30542	7833	.25647	91129	18234	.20009
90	23318	6275	.26911	72412	15684	.21659
91	17175	4982	.29007	54986	12945	.23542
92	11966	3868	.32325	39973	10795	.27006
93	8328	2764	.33189	28842	8498	.29464
94	5734	2166	.37775	20919	6462	.30891
95	3857	1467	.38035	14926	4965	.33264
96	2541	996	.39197	10166	3558	.34999
97	1638	625	.38156	6816	2331	.34199
98	1116	424	.37993	4687	1652	.35246
99	771	243	.31518	3283	1017	.30978
100 and over	1487	283	.19032	6019	1597	.26533

Appendix III

Table III.1 Pivotal values of m_x

Age x	1960-62		1970-72		Ratio of m_x (1970-72) to 1960-62 rate	Age x	1960-62		1970-72		Ratio of m_x (1970-72) to 1960-62 rate
	Pivotal value of m_x	$\frac{m_{x+5}}{m_x}$	Pivotal value of m_x	$\frac{m_{x+5}}{m_x}$			Pivotal value of m_x	$\frac{m_{x+5}}{m_x}$	Pivotal value of m_x	$\frac{m_{x+5}}{m_x}$	
Males						**Females**					
27	.00099	1.21	.00088	1.22	0.89	27	.00060	1.45	.00049	1.44	0.82
32	.00120	1.54	.00108	1.49	0.90	32	.00087	1.55	.00070	1.62	0.80
37	.00185	1.59	.00161	1.80	0.87	37	.00135	1.59	.00114	1.76	0.84
42	.00295	1.76	.00290	1.84	0.98	42	.00214	1.60	.00201	1.73	0.94
47	.00520	1.76	.00532	1.70	1.02	47	.00344	1.55	.00347	1.51	1.01
52	.00914	1.84	.00906	1.71	0.99	52	.00530	1.53	.00525	1.52	0.99
57	.01679	1.69	.01545	1.67	0.92	57	.00812	1.67	.00799	1.55	0.98
62	.02833	1.56	.02584	1.66	0.91	62	.01356	1.66	.01241	1.64	0.92
67	.04406	1.54	.04290	1.58	0.97	67	.02253	1.75	.02035	1.73	0.90
72	.06804	1.55	.06760	1.50	0.99	72	.03932	1.75	.03520	1.73	0.90
77	.10516	1.52	.10149	1.46	0.97	77	.06896	1.71	.06092	1.68	0.88
82	.15963	1.51	.14844	1.50	0.93	82	.11767	1.62	.102 8	1.65	0.87
87	.24091	1.45	.22295	1.41	0.93	87	.19103	1.55	.16803	1.56	0.88

Table III.2 Comparison of actual and expected deaths

Age x	Males			Females		
	Actual deaths 1970-72 (A)	Expected deaths using graduated m_x (E)	A-E	Actual deaths 1970-72 (A)	Expected deaths using graduated m_x (E)	A-E
2	957	963	− 6	761	759	2
3	759	754	5	599	600	− 1
4	634	640	− 6	482	485	− 3
5	579	587	− 8	413	408	5
6	589	555	34	362	360	2
7	519	519	0	319	329	− 10
8	456	478	− 22	303	305	− 2
9	436	439	− 3	288	280	8
10	396	402	− 6	266	255	11
11	384	375	9	217	236	− 19
12	368	371	− 3	240	226	14
13	411	399	12	225	229	− 4
14	473	466	7	239	249	− 10
15	536	585	− 49	281	287	− 6
16	837	777	60	351	336	15
17	1058	1058	0	406	383	23
18	1049	1096	− 47	386	418	− 32
19	1091	1097	− 6	435	440	− 5
20	1093	1088	5	478	455	23
21	1119	1080	39	447	468	− 21
22	1096	1085	11	498	485	13
23	1113	1096	17	511	504	7
24	943	1043	− 100	485	500	− 15
25	956	967	− 11	492	486	6
26	935	889	46	477	469	8
27	913	869	44	464	478	− 14
28	828	850	− 22	472	485	− 13
29	808	835	− 27	510	489	21
30	864	847	17	520	507	13
31	927	897	30	517	547	− 30
32	961	964	− 3	615	601	14
33	989	1025	− 36	678	654	24
34	1057	1086	− 29	697	712	− 15

Table III.2 *continued*

Age x	Males			Females		
	Actual deaths 1970-72 (A)	Expected deaths using graduated m_x (E)	A-E	Actual deaths 1970-72 (A)	Expected deaths using graduated m'_x (E)	A-E
35	1207	1156	51	742	776	− 34
36	1296	1238	58	853	848	5
37	1336	1351	− 15	970	937	33
38	1437	1509	− 72	1053	1054	− 1
39	1693	1726	− 33	1199	1210	− 11
40	1961	1971	− 10	1422	1388	34
41	2223	2237	− 14	1572	1578	− 6
42	2573	2520	53	1738	1768	− 30
43	2915	2871	44	2007	1992	15
44	3270	3291	− 21	2199	2254	− 55
45	3829	3767	62	2535	2553	− 18
46	4287	4280	7	2817	2871	− 54
47	4765	4850	− 85	3305	3219	86
48	5513	5586	− 73	3682	3655	27
49	6583	6491	92	4194	4175	19
50	7552	7408	144	4693	4672	21
51	7585	7703	− 118	4806	4778	28
52	7492	7575	− 83	4756	4618	138
53	7618	7674	− 56	4498	4598	− 100
54	8821	8651	170	4966	5069	− 103
55	10480	10331	149	5877	5943	− 66
56	11840	11948	− 108	6606	6766	− 160
57	13338	13483	− 145	7649	7526	123
58	14641	14764	− 123	8192	8116	76
59	16211	16056	155	8740	8765	− 25
60	17508	17499	9	9697	9504	193
61	19079	19130	− 51	10181	10381	− 200
62	20813	20759	54	11301	11247	54
63	22031	22314	− 283	12293	12154	139
64	24059	23716	343	13131	13084	47
65	25415	25098	317	14116	14146	− 30
66	26173	26419	− 246	14867	15296	− 429
67	27485	27679	− 194	16726	16505	221
68	28336	28646	− 310	17697	17676	21
69	29479	29320	159	19135	19084	51
70	29672	29436	236	20600	20525	75
71	28815	28955	− 140	21537	21916	− 379
72	28110	27998	112	23213	22956	257
73	27167	27142	25	24167	24099	68
74	26516	26507	9	25393	25397	− 4
75	26168	26061	107	26713	26720	− 7
76	25563	25434	129	27864	27711	153
77	24858	24908	− 50	28281	28497	− 216
78	24223	24170	53	29101	29129	− 28
79	23357	23261	96	29968	29719	249
80	22117	22127	− 10	30396	30131	265
81	20380	20964	− 584	29980	30605	− 625
82	19538	19573	− 35	30437	30506	− 69
83	17569	17882	− 313	29742	29818	− 76
84	16323	16088	235	28373	28406	− 33
85	14582	14340	242	27003	26885	118
86	12698	12635	63	25703	25064	639
87	11097	10940	157	22779	22945	− 166
88	9263	9262	1	20657	20608	49
89	7833	7819	14	18234	18368	− 134
90	6275	6414	− 139	15684	15955	− 271
91	4982	5069	− 87	12945	13226	− 281
92	3868	3784	84	10795	10487	308
93	2764	2817	− 53	8498	8248	250
94	2166	2072	94	6462	6519	− 57
95	1467	1486	− 19	4965	5067	− 102

Table III.3 Comparison of 'actual' and 'expected' deaths in five-year age-groups

Age-group	Actual deaths 1970-72 (A)	Expected deaths on basis of graduated rates (E)	Deviation A-E		Accumulated deviation ∑(A-E)	
			+	−	+	−
Males						
5-9	2579	2578	1		1	
10-14	2032	2013	19		20	
15-19	4571	4613		42		22
20-24	5364	5392		28		50
25-29	4440	4410	30			20
30-34	4798	4819		21		41
35-39	6969	6980		11		52
40-44	12942	12890	52		0	
45-49	24977	24974	3		3	
50-54	39068	39011	57		60	
55-59	66510	66582		72		12
60-64	103490	103418	72		60	
65-69	136888	137162		274		214
70-74	140280	140038	242		28	
75-79	124169	123834	335		363	
80-84	95927	96634		707		344
85-89	55473	54996	477		133	
90-94	20055	20156		101	32	
Total	850532	850500	32			
Females						
5-9	1685	1682	3		3	
10-14	1187	1195		8		5
15-19	1859	1864		5		10
20-24	2419	2412	7			3
25-29	2415	2407	8		5	
30-34	3027	3021	6		11	
35-39	4817	4825		8	3	
40-44	8938	8980		42		39
45-49	16533	16473	60		21	
50-54	23719	23735		16	5	
55-59	37064	37116		52		47
60-64	56603	56370	233		186	
65-69	82541	82707		166	20	
70-74	114910	114893	17		37	
75-79	141927	141776	151		188	
80-84	148928	149466		538		350
85-89	114376	113870	506		156	
90-94	54384	54435		51	105	
Total	817332	817227	105			

Appendix IV

Table IV.1 English Life Tables No.13 1970-72

Age x	l_x	d_x	q_x	$\mathring{e}_x$
Males				
0	100000	1980	.01980	69.00
1	98020	117	.00119	69.39
2	97903	79	.00081	68.47
3	97824	61	.00062	67.53
4	97763	51	.00052	66.57
5	97712	46	.00047	65.60
6	97666	43	.00044	64.64
7	97623	40	.00041	63.66
8	97583	38	.00039	62.69
9	97545	35	.00036	61.71
10	97510	33	.00034	60.74
11	97477	32	.00033	59.76
12	97445	32	.00033	58.78
13	97413	35	.00036	57.80
14	97378	42	.00043	56.82
15	97336	55	.00056	55.84
16	97281	73	.00075	54.87
17	97208	101	.00104	53.91
18	97107	105	.00108	52.97
19	97002	106	.00109	52.02
20	96896	103	.00106	51.08
21	96793	99	.00102	50.13
22	96694	95	.00098	49.19
23	96599	91	.00094	48.23
24	96508	87	.00090	47.28
25	96421	85	.00088	46.32
26	96336	84	.00087	45.36
27	96252	84	.00087	44.40
28	96168	86	.00089	43.44
29	96082	89	.00093	42.48
30	95993	93	.00097	41.51
31	95900	99	.00103	40.55
32	95801	104	.00109	39.60
33	95697	111	.00116	38.64
34	95586	119	.00124	37.68
35	95467	128	.00134	36.73
36	95339	139	.00146	35.78
37	95200	153	.00161	34.83
38	95047	170	.00179	33.88
39	94877	191	.00201	32.94
40	94686	214	.00226	32.01
41	94472	241	.00255	31.08
42	94231	271	.00288	30.16
43	93960	306	.00326	29.24
44	93654	346	.00369	28.34
45	93308	388	.00416	27.44
46	92920	436	.00469	26.55
47	92484	487	.00527	25.68
48	91997	544	.00591	24.81
49	91453	605	.00662	23.95
50	90848	671	.00739	23.11
51	90177	742	.00823	22.28
52	89435	818	.00915	21.46
53	88617	900	.01016	20.65
54	87717	989	.01127	19.86
55	86728	1082	.01248	19.08
56	85646	1184	.01382	18.32
57	84462	1292	.01530	17.56
58	83170	1408	.01693	16.83
59	81762	1532	.01874	16.11
60	80230	1665	.02075	15.41
61	78565	1805	.02298	14.72
62	76760	1954	.02546	14.06
63	74806	2110	.02821	13.41
64	72696	2270	.03122	12.79
65	70426	2432	.03453	12.18
66	67994	2594	.03815	11.60
67	65400	2752	.04208	11.04
68	62648	2900	.04629	10.50
69	59748	3033	.05076	9.99
70	56715	3145	.05546	9.50
71	53570	3235	.06038	9.02
72	50335	3297	.06551	8.57
73	47038	3335	.07091	8.14
74	43703	3349	.07662	7.72
75	40354	3337	.08269	7.32
76	37017	3301	.08918	6.93
77	33716	3241	.09612	6.56
78	30475	3156	.10357	6.21
79	27319	3048	.11158	5.87
80	24271	2917	.12019	5.54
81	21354	2764	.12944	5.23
82	18590	2591	.13935	4.94
83	15999	2398	.14990	4.66
84	13601	2191	.16110	4.39
85	11410	1973	.17293	4.14
86	9437	1749	.18538	3.90
87	7688	1525	.19842	3.68
88	6163	1307	.21202	3.47
89	4856	1098	.22615	3.28
90	3758	905	.24077	3.09
91	2853	730	.25586	2.92
92	2123	576	.27137	2.76
93	1547	444	.28726	2.61
94	1103	335	.30348	2.47
95	768	246	.31999	2.34
96	522	176	.33675	2.22
97	346	122	.35371	2.10
98	224	83	.37083	2.00
99	141	55	.38804	1.91
100	86	35	.40535	1.84
101	51	22	.42277	
102	29	13	.44028	
103	16	7	.45790	
104	9	4	.47562	
105	5	2	.49344	
106	3	2	.51136	
107	1	1	.52938	

Table IV.1 *Continued*

Age x	l_x	d_x	q_x	$\mathring{e}_x$
Females				
0	100000	1523	.01523	75.25
1	98477	104	.00106	75.41
2	98373	66	.00067	74.49
3	98307	51	.00052	73.54
4	98256	40	.00041	72.58
5	98216	33	.00034	71.61
6	98183	29	.00030	70.63
7	98154	27	.00028	69.65
8	98127	26	.00026	68.67
9	98101	24	.00024	67.69
10	98077	23	.00023	66.71
11	98056	22	.00022	65.72
12	98032	21	.00021	64.74
13	98011	22	.00022	63.75
14	97989	24	.00025	62.76
15	97965	28	.00029	61.78
16	97937	34	.00035	60.80
17	97903	38	.00039	59.82
18	97865	42	.00043	58.84
19	97823	44	.00045	57.86
20	97779	44	.00045	56.89
21	97735	44	.00045	55.92
22	97691	43	.00044	54.94
23	97648	43	.00044	53.96
24	97605	43	.00044	52.99
25	97562	44	.00045	52.01
26	97518	46	.00047	51.03
27	97472	48	.00049	50.06
28	97424	51	.00052	49.08
29	97373	55	.00056	48.11
30	97318	58	.00060	47.13
31	97260	63	.00065	46.16
32	97197	68	.00070	45.19
33	97129	75	.00077	44.22
34	97054	82	.00084	43.26
35	96972	90	.00093	42.29
36	96882	100	.00103	41.33
37	96782	110	.00114	40.37
38	96672	124	.00128	39.42
39	96548	138	.00143	38.47
40	96410	154	.00160	37.52
41	96256	173	.00180	36.58
42	96083	194	.00202	35.65
43	95889	217	.00226	34.72
44	95672	242	.00253	33.80
45	95430	268	.00281	32.88
46	95162	296	.00311	31.97
47	94866	325	.00343	31.07
48	94541	356	.00377	30.18
49	94185	388	.00412	29.29
50	93797	421	.00449	28.41
51	93376	457	.00489	27.53
52	92919	493	.00531	26.66
53	92426	532	.00576	25.80
54	91894	573	.00624	24.95
55	91321	617	.00676	24.10
56	90704	665	.00733	23.26
57	90039	716	.00795	22.43
58	89323	772	.00864	21.61
59	88551	833	.00941	20.79
60	87718	899	.01025	19.98
61	86819	972	.01120	19.19
62	85847	1053	.01227	18.40
63	84794	1143	.01348	17.62
64	83651	1243	.01486	16.86
65	82408	1352	.01641	16.10
66	81056	1474	.01818	15.36
67	79582	1605	.02017	14.64
68	77977	1749	.02243	13.93
69	76228	1904	.02498	13.24
70	74324	2069	.02784	12.56
71	72255	2243	.03104	11.91
72	70012	2424	.03462	11.27
73	67588	2609	.03860	10.66
74	64979	2795	.04301	10.06
75	62184	2977	.04787	9.50
76	59207	3152	.05323	8.95
77	56055	3313	.05910	8.42
78	52742	3455	.06550	7.92
79	49287	3573	.07250	7.44
80	45714	3664	.08014	6.98
81	42050	3720	.08846	6.54
82	38330	3738	.09752	6.13
83	34592	3713	.10734	5.74
84	30879	3642	.11795	5.37
85	27237	3524	.12937	5.02
86	23713	3357	.14157	4.69
87	20356	3146	.15456	4.39
88	17210	2897	.16831	4.10
89	14313	2617	.18281	3.83
90	11696	2316	.19805	3.57
91	9380	2009	.21413	3.34
92	7371	1704	.23113	3.11
93	5667	1412	.24912	2.90
94	4255	1141	.26817	2.70
95	3114	898	.28831	2.52
96	2216	686	.30954	2.35
97	1530	508	.33186	2.19
98	1022	363	.35523	2.04
99	659	250	.37957	1.91
100	409	166	.40489	1.79
101	243	105	.43118	
102	138	63	.45844	
103	75	37	.48668	
104	38	20	.51590	
105	18	10	.54609	
106	8	5	.57726	
107	3	2	.60940	
108	1	1	.64251	

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