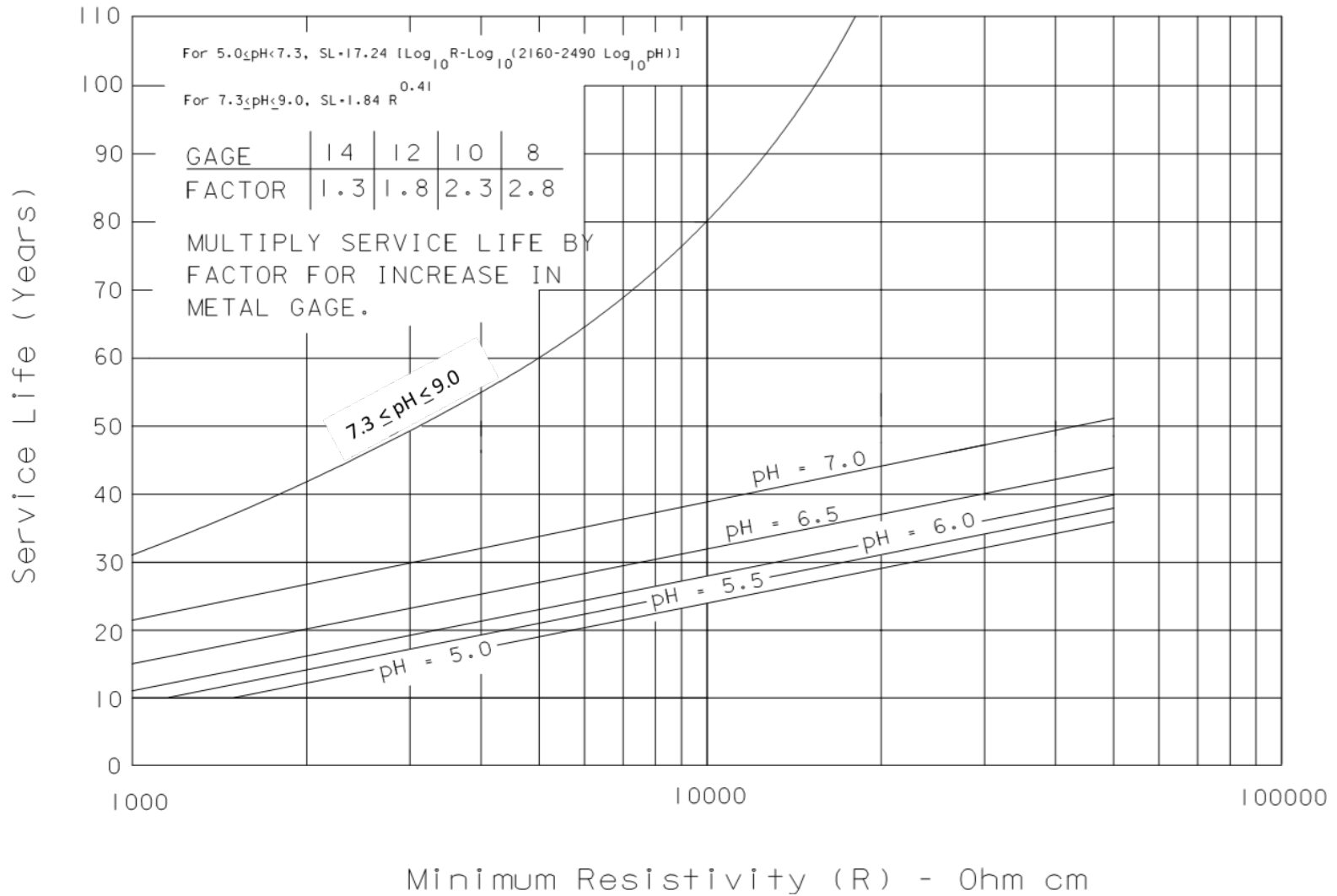


## **APPENDIX**

### **M. PIPE CORROSION TABLES AND CHARTS**

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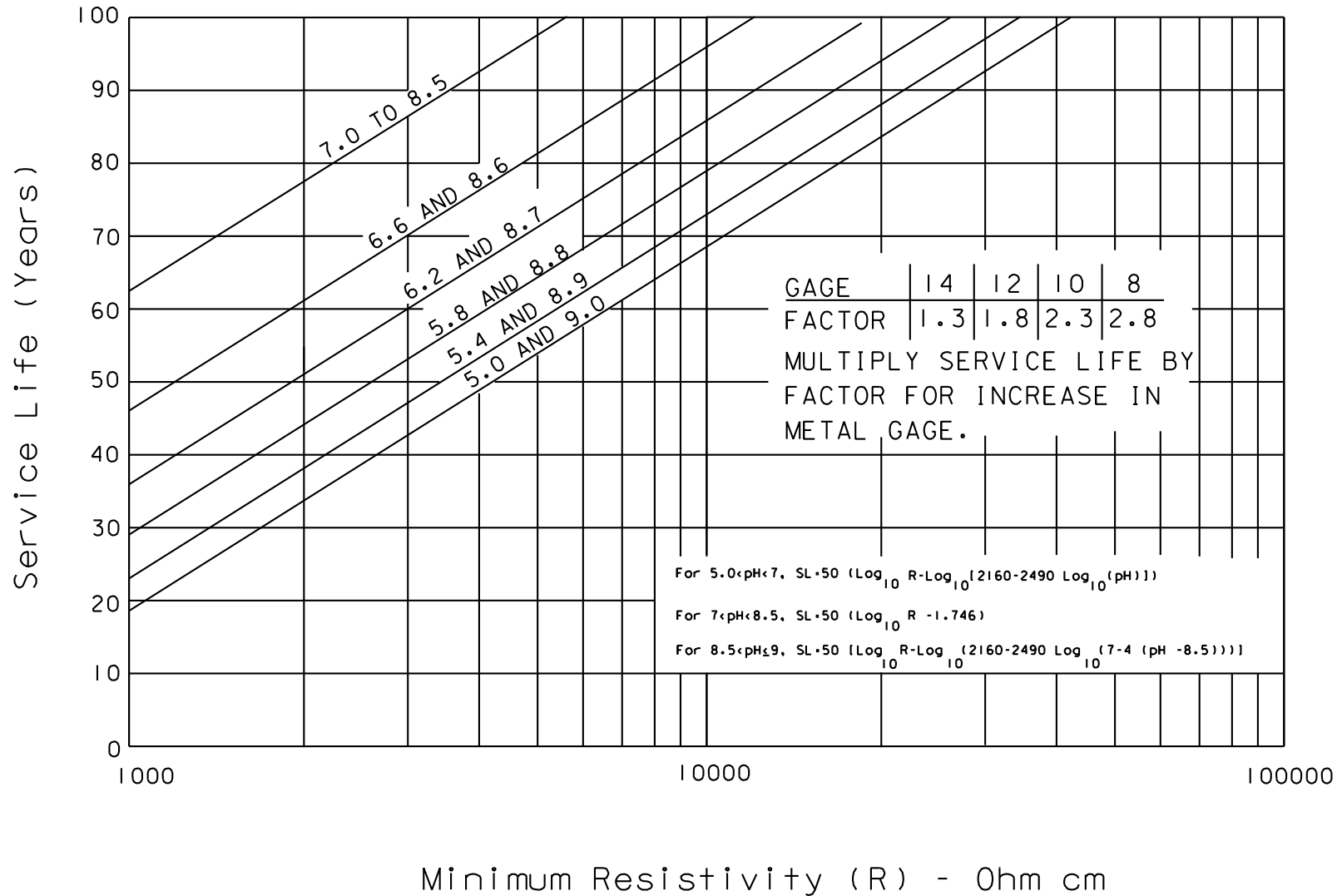


**Figure M-1: Estimated Service Life – 16 ga. Galvanized Steel Pipe**

**Table M-1: Estimated Service Life – 16 ga. Galvanized Steel Pipe**

| pH        | Resistivity |      |      |      |      |      |      |       |       |       |       |       |        |
|-----------|-------------|------|------|------|------|------|------|-------|-------|-------|-------|-------|--------|
|           | 1000        | 1500 | 2000 | 3000 | 4000 | 5000 | 7000 | 10000 | 15000 | 20000 | 30000 | 40000 | ≤50000 |
| 5.0       | 7           | 10   | 12   | 15   | 17   | 19   | 21   | 24    | 27    | 29    | 32    | 34    | 36     |
| 5.1       | 7           | 10   | 12   | 15   | 17   | 19   | 21   | 24    | 27    | 29    | 32    | 34    | 36     |
| 5.2       | 8           | 10   | 13   | 16   | 18   | 19   | 22   | 25    | 28    | 30    | 33    | 35    | 37     |
| 5.3       | 8           | 11   | 13   | 16   | 18   | 20   | 22   | 25    | 28    | 30    | 33    | 35    | 37     |
| 5.4       | 8           | 11   | 13   | 16   | 19   | 20   | 23   | 25    | 28    | 31    | 34    | 36    | 37     |
| 5.5       | 9           | 12   | 14   | 17   | 19   | 21   | 23   | 26    | 29    | 31    | 34    | 36    | 38     |
| 5.6       | 9           | 12   | 14   | 17   | 19   | 21   | 24   | 26    | 29    | 32    | 35    | 37    | 38     |
| 5.7       | 10          | 13   | 15   | 18   | 20   | 22   | 24   | 27    | 30    | 32    | 35    | 37    | 39     |
| 5.8       | 10          | 13   | 15   | 18   | 21   | 22   | 25   | 27    | 30    | 32    | 36    | 38    | 39     |
| 5.9       | 11          | 14   | 16   | 19   | 21   | 23   | 25   | 28    | 31    | 33    | 36    | 38    | 40     |
| 6.0       | 11          | 14   | 16   | 20   | 22   | 23   | 26   | 28    | 32    | 34    | 37    | 39    | 41     |
| 6.1       | 12          | 15   | 17   | 20   | 22   | 24   | 26   | 29    | 32    | 34    | 37    | 40    | 41     |
| 6.2       | 13          | 16   | 18   | 21   | 23   | 25   | 27   | 30    | 33    | 35    | 38    | 40    | 42     |
| 6.3       | 13          | 16   | 19   | 22   | 24   | 25   | 28   | 31    | 34    | 36    | 39    | 41    | 43     |
| 6.4       | 14          | 17   | 19   | 22   | 24   | 26   | 29   | 31    | 34    | 36    | 40    | 42    | 43     |
| 6.5       | 15          | 18   | 20   | 23   | 25   | 27   | 30   | 32    | 35    | 37    | 40    | 43    | 44     |
| 6.6       | 16          | 19   | 21   | 24   | 26   | 28   | 31   | 33    | 36    | 38    | 41    | 44    | 45     |
| 6.7       | 17          | 20   | 22   | 25   | 27   | 29   | 32   | 34    | 37    | 39    | 42    | 45    | 46     |
| 6.8       | 18          | 21   | 23   | 26   | 29   | 30   | 33   | 36    | 39    | 41    | 44    | 46    | 48     |
| 6.9       | 20          | 23   | 25   | 28   | 30   | 32   | 34   | 37    | 40    | 42    | 45    | 47    | 49     |
| 7.0       | 22          | 25   | 27   | 30   | 32   | 34   | 36   | 39    | 42    | 44    | 47    | 49    | 51     |
| 7.1       | 24          | 27   | 29   | 32   | 34   | 36   | 39   | 41    | 44    | 46    | 50    | 52    | 53     |
| 7.2       | 28          | 31   | 33   | 36   | 38   | 40   | 42   | 45    | 48    | 50    | 53    | 55    | 57     |
| 7.3       | 34          | 37   | 39   | 42   | 45   | 46   | 49   | 52    | 54    | 57    | 60    | 61    | 64     |
| 7.4 - 9.0 | 34          | 37   | 42   | 49   | 55   | 60   | 69   | 80    | 95    | 107   | 126   | 142   | 155    |

Estimated Service Life: (SL) = 17.24{Log<sub>10</sub>R - Log<sub>10</sub>[2160-2490(Log<sub>10</sub>pH)]} for 5 ≤ pH ≤ 7.3  
(SL) = 1.84 R<sup>0.41</sup> for 7.3 ≤ pH ≤ 9

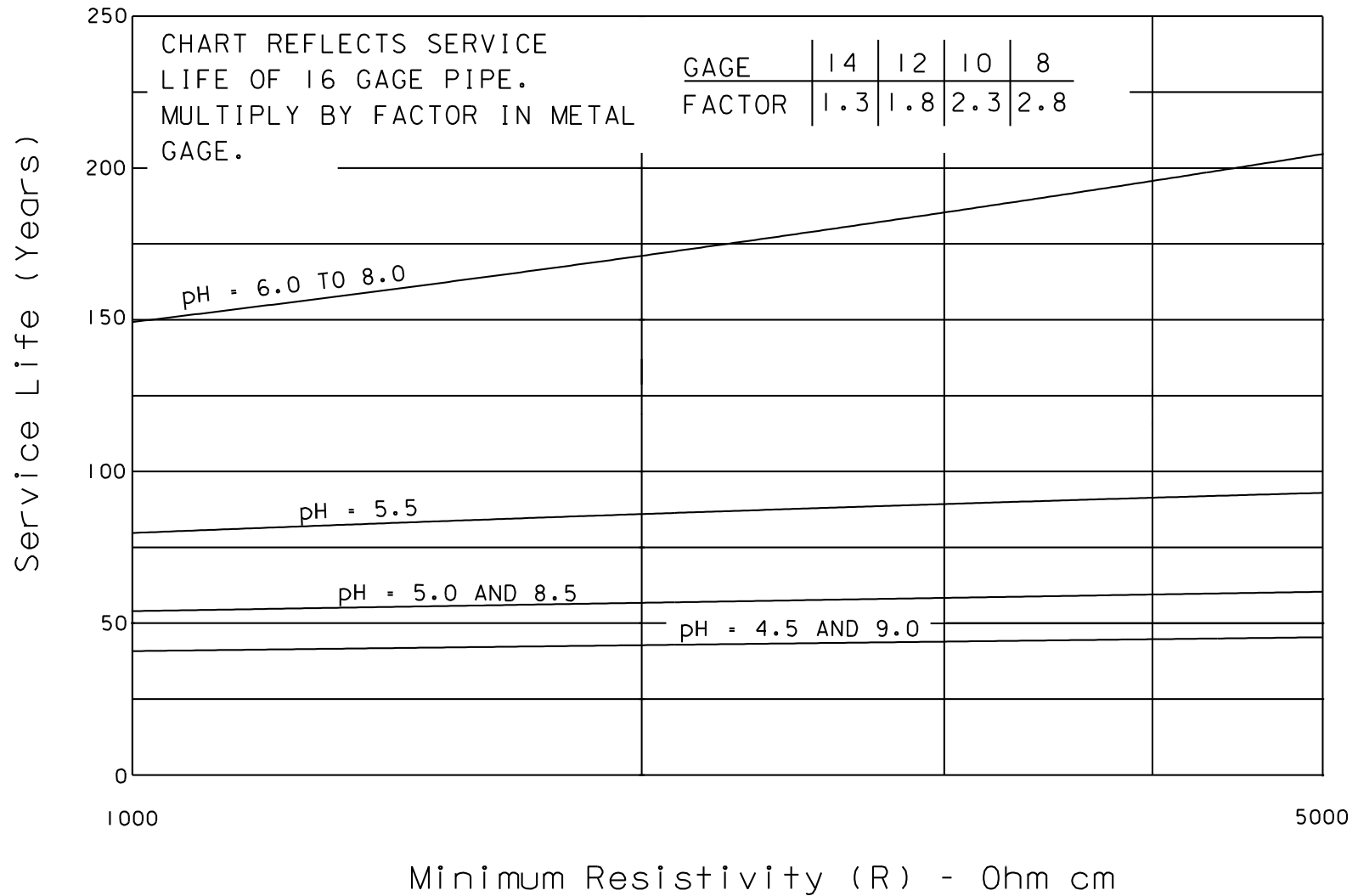


**Figure M-2: Estimated Service Life – 16 ga. Aluminized Steel Pipe**

**Table M-2: Estimated Service Life – 16 ga. Aluminized Steel Pipe**

| pH         | Resistivity |      |      |      |      |      |      |       |       |       |       |       |        |
|------------|-------------|------|------|------|------|------|------|-------|-------|-------|-------|-------|--------|
|            | 1000        | 1500 | 2000 | 3000 | 4000 | 5000 | 7000 | 10000 | 15000 | 20000 | 30000 | 40000 | ≤50000 |
| 5.0        | 19          | 28   | 34   | 43   | 49   | 54   | 61   | 69    | 78    | 84    | 93    | 99    | 104    |
| 5.1        | 20          | 29   | 35   | 44   | 50   | 55   | 62   | 70    | 79    | 85    | 94    | 100   | 105    |
| 5.2        | 21          | 30   | 36   | 45   | 51   | 56   | 63   | 71    | 80    | 86    | 95    | 101   | 106    |
| 5.3        | 22          | 31   | 37   | 46   | 52   | 57   | 65   | 72    | 81    | 87    | 96    | 102   | 107    |
| 5.4        | 24          | 32   | 39   | 48   | 54   | 59   | 66   | 74    | 82    | 89    | 98    | 104   | 109    |
| 5.5        | 25          | 34   | 40   | 49   | 55   | 60   | 67   | 75    | 84    | 90    | 99    | 105   | 110    |
| 5.6        | 26          | 35   | 41   | 50   | 56   | 61   | 69   | 76    | 85    | 91    | 100   | 106   | 111    |
| 5.7        | 28          | 37   | 43   | 52   | 58   | 63   | 70   | 78    | 87    | 93    | 102   | 108   | 113    |
| 5.8        | 29          | 38   | 44   | 53   | 59   | 64   | 72   | 79    | 88    | 94    | 103   | 109   | 114    |
| 5.9        | 31          | 40   | 46   | 55   | 61   | 66   | 73   | 81    | 90    | 96    | 105   | 111   | 116    |
| 6.0        | 33          | 41   | 48   | 56   | 63   | 68   | 75   | 83    | 91    | 98    | 106   | 113   | 118    |
| 6.1        | 34          | 43   | 50   | 58   | 65   | 69   | 77   | 84    | 93    | 100   | 108   | 115   | 119    |
| 6.2        | 36          | 45   | 51   | 60   | 67   | 71   | 79   | 86    | 95    | 101   | 110   | 116   | 121    |
| 6.3        | 38          | 47   | 54   | 62   | 69   | 73   | 81   | 88    | 97    | 104   | 112   | 119   | 123    |
| 6.4        | 41          | 50   | 56   | 65   | 71   | 76   | 83   | 91    | 100   | 106   | 115   | 121   | 126    |
| 6.5        | 43          | 52   | 58   | 67   | 73   | 78   | 86   | 93    | 102   | 108   | 117   | 123   | 128    |
| 6.6        | 46          | 55   | 61   | 70   | 76   | 81   | 88   | 96    | 105   | 111   | 120   | 126   | 131    |
| 6.7        | 49          | 58   | 64   | 73   | 79   | 84   | 92   | 99    | 108   | 114   | 123   | 129   | 134    |
| 6.8        | 53          | 62   | 68   | 77   | 83   | 88   | 95   | 103   | 112   | 118   | 127   | 133   | 138    |
| 6.9        | 57          | 66   | 72   | 81   | 87   | 92   | 100  | 107   | 116   | 122   | 131   | 137   | 142    |
| 7.0 to 8.5 | 63          | 72   | 78   | 87   | 93   | 98   | 105  | 113   | 122   | 128   | 137   | 143   | 148    |
| 8.6        | 46          | 55   | 61   | 70   | 76   | 81   | 88   | 96    | 105   | 111   | 120   | 126   | 131    |
| 8.7        | 36          | 45   | 51   | 60   | 67   | 71   | 79   | 86    | 95    | 101   | 110   | 116   | 121    |
| 8.8        | 29          | 38   | 44   | 53   | 59   | 64   | 72   | 79    | 88    | 94    | 103   | 109   | 114    |
| 8.9        | 24          | 32   | 39   | 48   | 54   | 59   | 66   | 74    | 82    | 89    | 98    | 104   | 109    |
| 9.0        | 19          | 28   | 34   | 43   | 49   | 54   | 61   | 69    | 78    | 84    | 93    | 99    | 104    |

Estimated Service Life (SL) = 50{Log<sub>10</sub>R - Log<sub>10</sub>[2160 - 2490(Log<sub>10</sub>pH)]} for 5.0 ≤pH<7.0  
 (SL) = 50(Log<sub>10</sub>R - 1.746) for 7.0 ≤pH ≤8.5  
 (SL) = 50{Log<sub>10</sub>R - Log<sub>10</sub>{2160 - 2490 Log<sub>10</sub>[7 - 4(pH - 8.5)]}} for 8.5<pH ≤9.0



**Figure M-3: Estimated Service Life – 16 ga. Aluminum Pipe**

**Table M-3: Estimated Service Life – 16 ga. Aluminum Pipe**

| pH          | Resistivity |     |     |     |      |      |      |      |      |      |      |      |      |      |      |       |
|-------------|-------------|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|-------|
|             | ≥200        | 400 | 600 | 800 | 1000 | 1200 | 1400 | 1600 | 1800 | 2000 | 2300 | 2700 | 3200 | 3800 | 4500 | ≤5000 |
| 4.5 & 9.0   | 36          | 39  | 40  | 41  | 41   | 42   | 42   | 42   | 43   | 43   | 43   | 43   | 44   | 44   | 44   | 45    |
| 4.6 & 8.9   | 38          | 41  | 42  | 43  | 43   | 44   | 44   | 45   | 45   | 45   | 45   | 46   | 46   | 47   | 47   | 48    |
| 4.7 & 8.8   | 40          | 43  | 44  | 45  | 46   | 46   | 47   | 47   | 47   | 48   | 48   | 48   | 49   | 49   | 50   | 51    |
| 4.8 & 8.7   | 42          | 45  | 46  | 48  | 48   | 49   | 49   | 50   | 50   | 50   | 51   | 51   | 52   | 52   | 53   | 54    |
| 4.9 & 8.6   | 44          | 48  | 49  | 50  | 51   | 52   | 52   | 53   | 53   | 54   | 54   | 55   | 55   | 56   | 56   | 57    |
| 5.0 & 8.5   | 46          | 50  | 52  | 53  | 54   | 55   | 56   | 56   | 57   | 57   | 58   | 58   | 59   | 59   | 60   | 61    |
| 5.1         | 49          | 53  | 56  | 57  | 58   | 59   | 60   | 60   | 61   | 61   | 62   | 62   | 63   | 64   | 65   | 66    |
| 5.2 & 8.4   | 52          | 57  | 59  | 61  | 62   | 63   | 64   | 65   | 65   | 66   | 67   | 67   | 68   | 69   | 70   | 71    |
| 5.3         | 55          | 61  | 64  | 66  | 67   | 68   | 69   | 70   | 71   | 71   | 72   | 73   | 74   | 75   | 76   | 77    |
| 5.4 & 8.3   | 59          | 66  | 69  | 71  | 73   | 74   | 75   | 76   | 77   | 78   | 79   | 80   | 81   | 82   | 83   | 84    |
| 5.5         | 63          | 71  | 75  | 78  | 80   | 81   | 83   | 84   | 85   | 86   | 87   | 88   | 90   | 91   | 92   | 93    |
| 5.6 & 8.2   | 68          | 78  | 82  | 85  | 88   | 90   | 91   | 93   | 94   | 95   | 97   | 98   | 100  | 102  | 104  | 105   |
| 5.7         | 74          | 85  | 91  | 95  | 98   | 100  | 102  | 104  | 106  | 107  | 109  | 111  | 113  | 116  | 118  | 119   |
| 5.8 & 8.1   | 81          | 95  | 102 | 107 | 110  | 114  | 116  | 119  | 121  | 122  | 125  | 128  | 131  | 134  | 137  | 138   |
| 5.9         | 89          | 107 | 115 | 122 | 127  | 131  | 134  | 138  | 140  | 143  | 146  | 150  | 154  | 158  | 163  | 165   |
| ≥6.0 & ≤8.0 | 100         | 122 | 133 | 142 | 149  | 154  | 159  | 164  | 168  | 171  | 176  | 182  | 188  | 194  | 200  | 204   |

Where:

SL = Years to first perforation

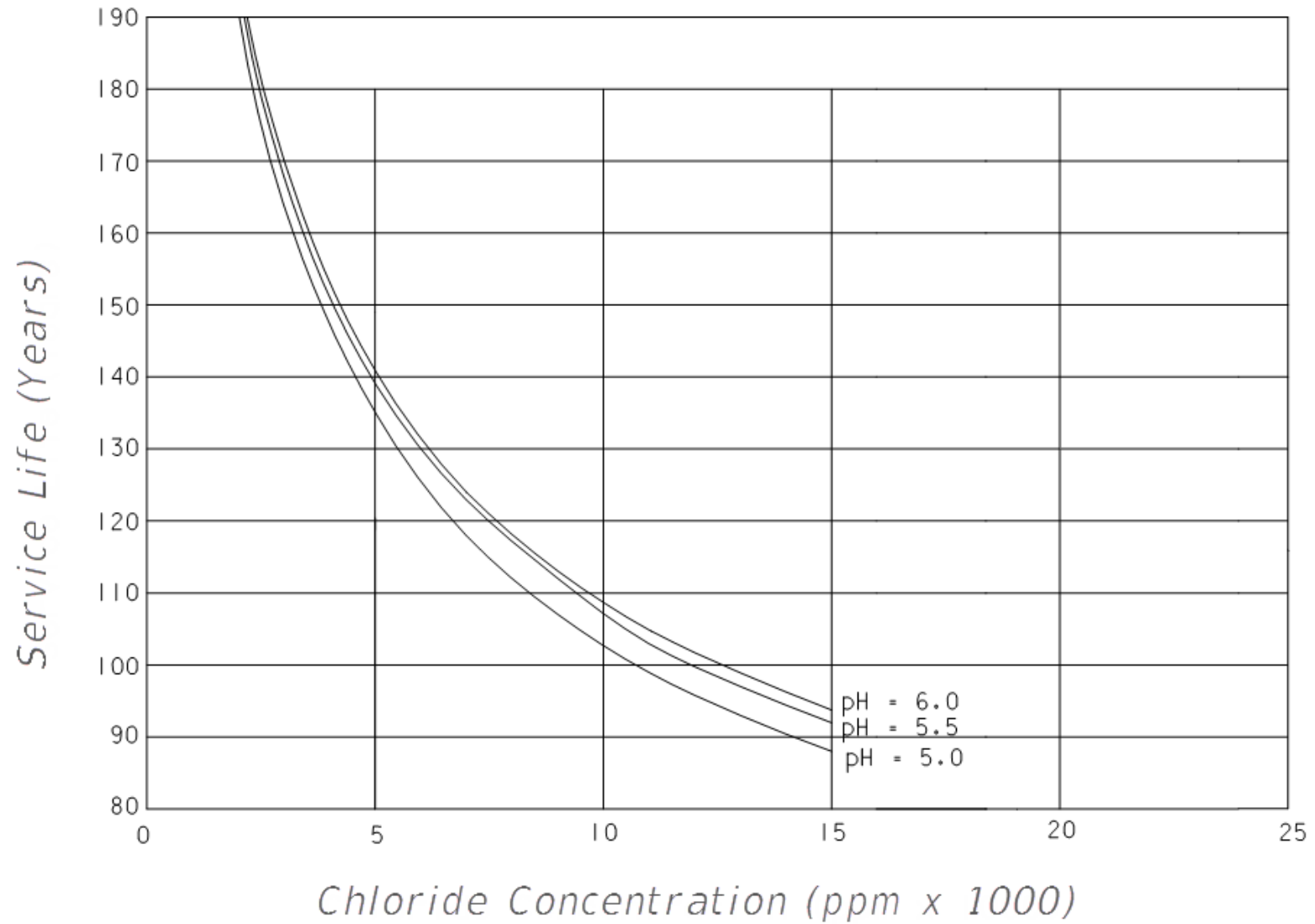
T<sub>p</sub> = Thickness of pipe (inches)

R<sub>pH</sub> = Corrosion rate for pH (inches/year)

R<sub>r</sub> = Corrosion rate for resistivity (inches/year)

$$\text{Service Life (SL)} = T_p / (R_{pH} + R_r)$$





**Figure M-4: Estimated Service Life – 60” Dia. Reinforced Concrete Pipe, S = 1500**

**Table M-4: Estimated Service Life – 60" Dia. Reinforced Concrete Pipe, S = 1500**

| pH   | Chlorides |       |       |      |      |      |      |      |      |     |     |     |
|------|-----------|-------|-------|------|------|------|------|------|------|-----|-----|-----|
|      | 15000     | 13000 | 11000 | 9000 | 7000 | 5000 | 3000 | 2000 | 1000 | 750 | 500 | 250 |
| 5.0  | 88        | 93    | 99    | 107  | 118  | 135  | 164  | 192  | 250  | 278 | 324 | 360 |
| 5.1  | 89        | 94    | 101   | 109  | 119  | 136  | 165  | 193  | 251  | 279 | 325 | 360 |
| 5.2  | 90        | 95    | 102   | 110  | 121  | 137  | 167  | 194  | 252  | 281 | 327 | 360 |
| 5.3  | 91        | 96    | 102   | 111  | 122  | 138  | 167  | 195  | 253  | 282 | 327 | 360 |
| 5.4  | 92        | 97    | 103   | 111  | 122  | 139  | 168  | 196  | 253  | 282 | 328 | 360 |
| 5.5  | 92        | 97    | 103   | 112  | 123  | 139  | 168  | 196  | 254  | 282 | 328 | 360 |
| 5.6  | 93        | 98    | 104   | 112  | 123  | 140  | 169  | 196  | 254  | 283 | 329 | 360 |
| 5.7  | 93        | 98    | 104   | 112  | 123  | 140  | 169  | 197  | 254  | 283 | 329 | 360 |
| 5.8  | 93        | 98    | 104   | 113  | 124  | 140  | 169  | 197  | 255  | 283 | 329 | 360 |
| 5.9  | 93        | 98    | 105   | 113  | 124  | 140  | 170  | 197  | 255  | 284 | 330 | 360 |
| ≥6.0 | 94        | 99    | 105   | 113  | 124  | 141  | 170  | 197  | 255  | 284 | 330 | 360 |

| Conversion Factors for Different Size Culverts |          |           |          |
|--|----------|-----------|----------|
| Pipe Dia.                                      | Mult. By | Pipe Dia. | Mult. By |
| 12"  | 0.36     | 48"       | 0.76     |
| 18"  | 0.36     | 60"       | 1.00     |
| 24"  | 0.41     | 72"       | 1.25     |
| 30"  | 0.48     | 84"       | 1.51     |
| 36"  | 0.54     | 96"       | 1.77     |
| 42"  | 0.65     | 108"      | 2.04     |

| SL Reduction Factors for Sulfates |                  |
|-----------------------------------|------------------|
| Sulfate Content                   | Subtract from SL |
| 1500                              | 0                |
| 3200                              | 5                |
| 4900                              | 10               |
| 6600                              | 15               |
| 8300                              | 20               |
| 10000                             | 25               |

Note: Sulfate derating not applicable when Type V cement is used.

$$\text{Service Life (SL)} = 1000(1.107^C C^{0.717} D^{1.22} K^{-0.37} W^{-0.631}) - 4.22 \times 10^{10} (\text{pH}^{-14.1}) - 2.94 \times 10^{-3} (S) + 4.41$$

Where: C = Sacks of cement per cubic yard      D = Steel depth in concrete      K = Environmental chloride concentration in ppm  
 W = Total percentage of water in the mix      S = Environmental sulfate content in ppm