Q. **Reference: Volume II, Wood Pole Line Management Program - Various, Tab 11, Appendix A, page A-1**

Please provide all data and assumptions underlying the Current (Projection) shown in Figure A-1.

A. The Current (Projection) curve shown in Figure A-1 was created using all transmission pole inspection and replacement data collected by Newfoundland and Labrador Hydro ("Hydro") dating back prior to the inception of the formal Wood Pole Line Management Program in 2003. To provide this data in a response to a Request for Information is not practical given the size of the database from which this the analysis is extracted; however, NP-NLH-049, Attachment 1 provides the guide currently used by Hydro to develop Iowa Curve projections.

Iowa Curves for the Wood Pole Line Management Program

Transmission and Distribution Group

Newfoundland and Labrador Hydro

June 2013

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1. Introduction

The Iowa Curve is a form of Survival Curve which is used to predict the useful life and retirement age of assets. The Wood Pole Line Management Program uses Iowa Curves to predict the number of wood poles to be replaced each year based on previous inspection data.

At the time of this report, there are presently graphs available for the Avalon region, Central region and Northern region. These graphs include all relevant inspection data for the lines included within these regions. Additionally, there is a Province wide graph which combines all of the data from these regions as well as a transmission line from Labrador. Within each Iowa graph, there are three separate curves which are obtained from the original data. First, the "Original Iowa (50 year)" curve is plot as a reference, then a "Current" curve is predicted from the trajectory of the actual data points and finally an "Extended Life" projection is created based on the current data to represent potential benefits from intervention.

These curves should be updated regularly with new inspection data to accurately reflect the life cycles of these assets. This report will serve as a reference for how these curves were developed to aid in maintaining and updating them so that they can be interpreted for future predictions. The procedure will be described with the aid of the Avalon region curves as an example.

This report would be most effective if the procedure is read while following along in an Iowa spreadsheet file.

2. Procedure

For each region, a separate spreadsheet is developed on the common drive.
In particular, each regional file is within that region's Analysis folder.
Each of these files has four tabs:

- Original Data
- Data

- Graph
- Life Extension Graph

2.1 Original Data

The Original Data tab is used to present and organize the raw data. Data is copied from the WPLM Inspection results for the appropriate transmission lines. The total number of poles should be added from all lines that have been inspected to be used in the Data tab. From this WPLM data, an additional table is created with the pertinent information, including:

- TL Number
- Year Installed
- Year Inspected
- Age at Inspection (Year Installed-Year Inspected)
- Number of Poles Inspected
- Number of Poles Rejected

Each inspection has a separate row in the table, as seen in Table 1 below. Certain transmission lines may have multiple rows depending on where they are in the inspection cycle, such as TL 203 which has had two inspections. The rejected poles include those rated 4 and 5 at the time of inspection. Inspections which took place prior to the WPLM program use data from Dr. Asim Haldar's 2004 report.

Line Number	Year Installed	Year Inspected	Age an Inspection	Number of Poles Inspected	Number of Poles Rejected
TL 201	1966	1985	19	766	0
TL 201	1966	1998	32	766	45
TL 201	1966	2004	38	766	38
TL 203	1965	1985	20	418	0
TL 203	1965	1998	33	418	24
TL 203	1965	2003	38	418	27

Table 1 - Avalon Region Original Data

Replacement numbers are not used for the Iowa graphs as these poles are not an accurate representation of which poles are rejected. Poles may be replaced for reasons other than being rejected, such as changes in the line, making these numbers provide a pessimistic result in the Iowa curves. It should also be noted that the rejection and survival may be recorded for some regions in the Original Data tab but these values are just for one year and do represent actual survival. The actual incremental survival and rejection are found in the Data tab, as described in Section 2.1 below.

2.2 Data

The Data tab is used to tabulate the data that will be directly used for the Iowa graph. First, the table with relevant information from the Original Data tab (Table 1 above) is copy and pasted to the top of the sheet. This data is then sorted based on increasing age at inspection, as seen in Table 2 below.

Line Number	Year Installed	Year Inspected	Age an Inspection	Number of Poles Inspected	Number of Poles Rejected
TL 201	1966	1985	19	766	0
TL 203	1965	1985	20	418	0
TL 201	1966	1998	32	766	45
TL 203	1965	1998	33	418	24
TL 201	1966	2004	38	766	38
TL 203	1965	2003	38	418	27

Table 2 - Avalon Region Sorted Original Data

Below this table, a new table is created with the following columns:

- Age
- Number of Poles Rejected
- Total Poles
- Percent Rejection
- Percent Survival

For each duplicate age in the first table, all poles rejected should be added together to get the total number of poles rejected at that age. The total poles at each age will be the same for each region and is found from the Original Data Tab by adding all poles for the regions transmission lines as described in Section 2.1 above. This Data table can be seen in Table 3 below.

Age	Rejected	Total Poles	% Rejection	% Survival
19	0	1184	0	100
20	0	1184	0	100
32	45	1184	0.038006757	96.1993243
33	24	1184	0.058277027	94.1722973
38	65	1184	0.113175676	88.6824324

Table 3 - Avalon Region Data Table

According to Roberts(1962), "In obtaining an estimate of the per cent p_t of poles decayed at age *t*, it is not adequate to select for inspection a set of *N* poles of age t at random from the field. The difficulty is that those poles of age *t* that had been previously removed because of decay would be missing from the sample. For example, suppose 50 per cent of poles at age 40 years have been removed for failure due to decay, and suppose we select at random 100 of the remaining poles for inspection and find ten of them decayed-the proper estimate of per cent decayed at age 40 years is not 10/100=10 per cent, but rather 110/200=55 per cent." It is therefore essential to consider the history of the line and the accumulated rejections from the total initial number of poles.

The Percent Rejection for each age is then found using the following formula:

$$\%\ Rejection = \frac{\sum_{i=0}^{n}(Number\ of\ Poles\ Rejected)}{(Total\ Poles)}$$

Where n is the particular age being evaluated. Similarly, the Percent Survival is found by:

$$\%\ Survival = 100 * (1 - \%\ Rejection)$$

To the right of these two tables, an additional table should be set up to be directly used to create the graph, as seen in the Avalon table in Appendix A. This table will include values for the Original Iowa curve, Current Actual data points, Current Projection values and Life Extension values. The Original Iowa curve values can be copy and pasted within each Iowa file, as they are a reference. For the Original and Current values, the following columns are used:

- Age
- Ln(Age)
- Original Iowa (Copy and Paste values)
- Actual % Survival
- Current Actual Calculations to find alpha and beta
  - Actual Survival S(t)
  - –Ln(S(t))
  - Ln(-Ln(S(t)))
- Current Projection Calculations using alpha and beta
  - Ln(-Ln(S(t)))
  - Current Projection Survival - S(t)*100

As seen in the Avalon table, the first section presents the data points to be used directly for the curves for Original Iowa and Actual Current. The next sections then calculate the Current Projection and Life Extension Projection based on the procedures described below.

Alpha and beta for the Current Projection curve are determined in the Graph tab, as described in Section 2.2.1. These values are then used in the following formulas to determine the Current Projection values.

- $Ln(-Ln(S(t)) = (\alpha * Ln(Age)) + Ln(^1/_{\beta^\alpha})$
- $S(t) * 100 = \exp\left(-\exp\left(Ln\left(-Ln(S(t))\right)\right)\right) * 100$

The following columns are used to determine the life extension values:

- Ln(Age*)
- Ln(-Ln(S(t)))
- Current Projection Survival - S(t)*100

For these columns, Age* is the actual age for the Survival plus the extended life. However, Ln(-Ln(S(t))) and S(t) are equal to the Current Projection values at the actual age. As seen in Appendix A, below is an example for an actual age of 33 years and a life extension of 10 years for the Avalon region.

Age	LN(Age)	LN(-LN(s(t)))	S(t)*100	Age*	LN(Age*)	LN(-LN(s(t)))	S(t)*100
33	3.49651	-2.951241069	94.9068	43	3.7612	-2.951241069	94.9068

It can be observed that the Age* value Is 10 greater than the actual age but both values have the same value for Ln(-Ln(S(t))) and Survival Percent. All values are calculated in the same manner from the Current Projection and the results are plot in the Graph tab. Alpha and beta for this curve can be found in the Life Extension tab.

In addition to these tables, one small table should be created to link required information for the above calculations, as seen in Table 4. In particular, this table should include α and β as determined from the Graph tab. It should also include the Life Extension, which is the amount that will be added to the Age in order to find Age*. These values can then easily be used in the tables previously described for the Data tab.

α	β	Life Extension*
6.0677	53.67208	**10**

Table 4 - Avalon Region Data Table (Required Information)

2.2.1 Alpha and Beta

Alpha and beta for the Current Survival are found from the Graph tabs by plotting the Ln(-Ln(S(t)) vs. Ln(Age) for the actual data points along with the linear trendline for these points. This graph for the Avalon region can be seen in Figure 1 below.

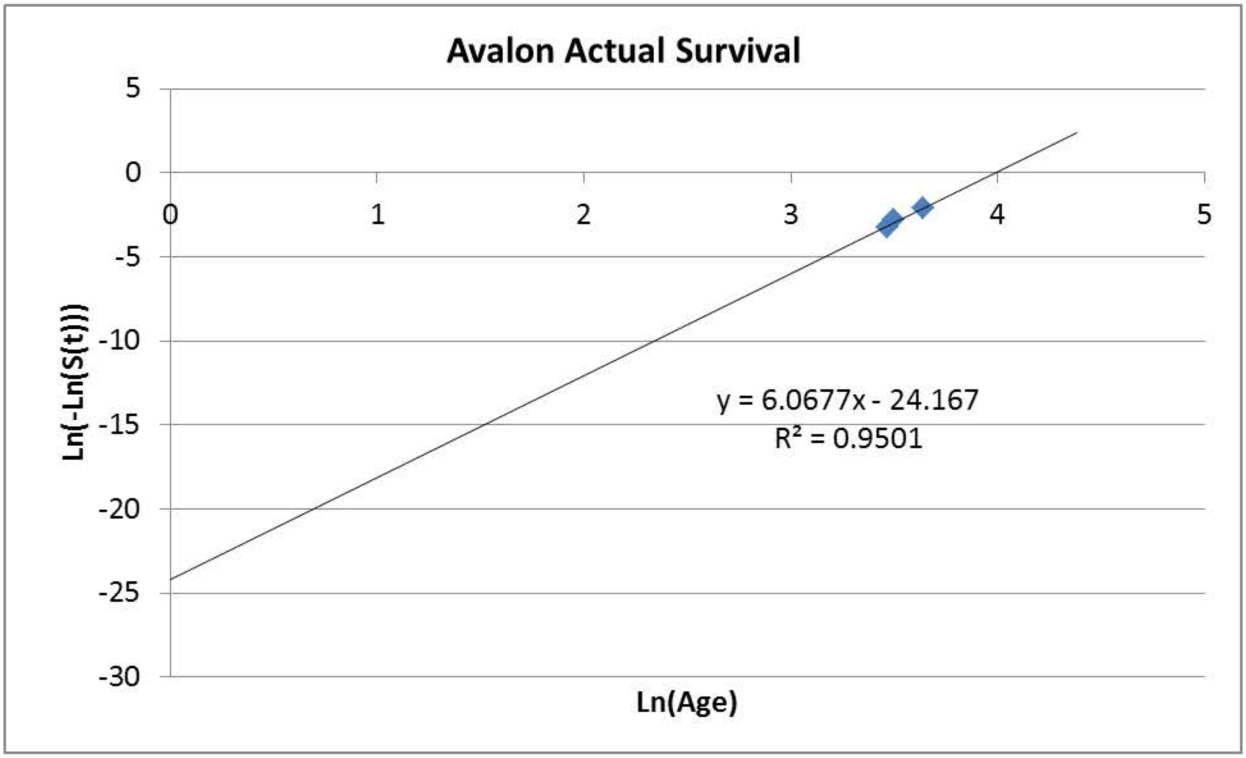

Figure 1 - Avalon Region Actual Survival Graph

The following relationships are then used:

- Trendline: $y = mx + b$
- $\alpha = m$
- $\lambda = \exp(b)$
- $\beta = (\frac{1}{\lambda})^{1/\alpha}$

2.3 Graph

The Graph tab is used to plot the graph with the three Iowa curves as well as a graph to determine the alpha and beta values for the Current Projection values. All three Survival curves are plot in one graph of Percent Survival vs. Age, as seen in Figure 2 below.

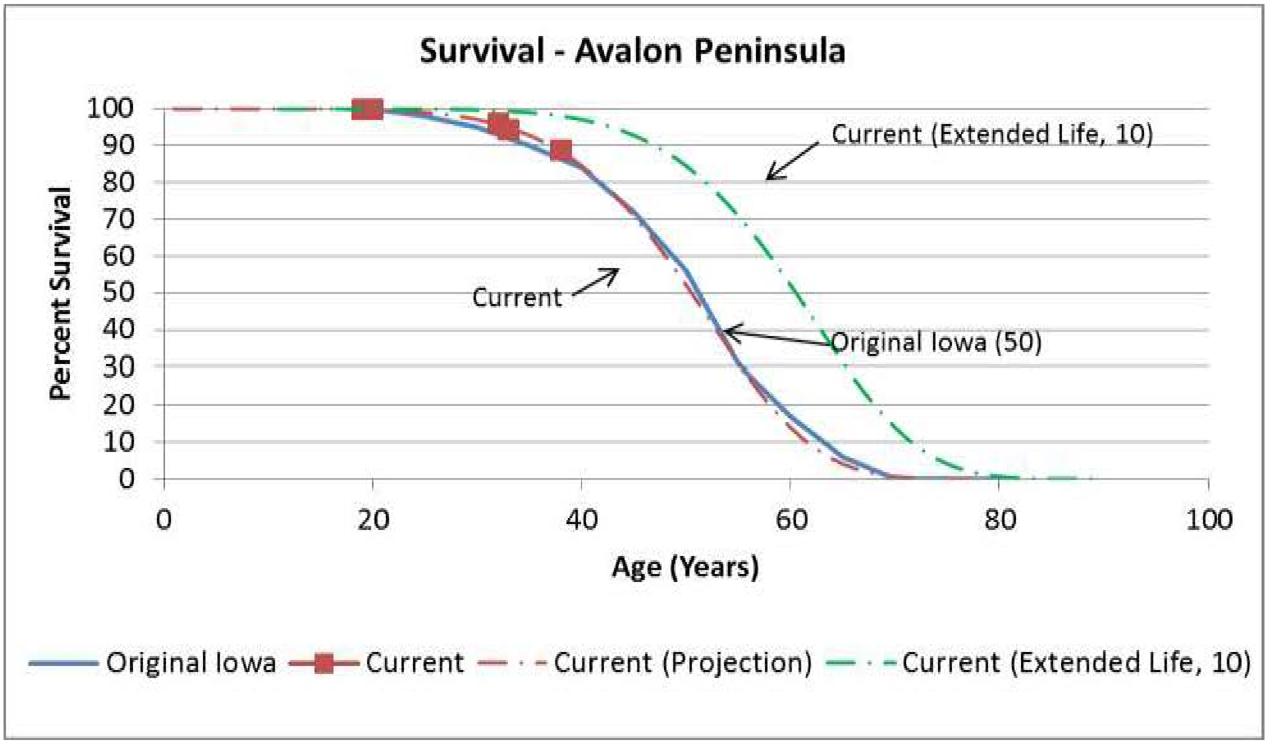

Figure 2 - Avalon Region Iowa Graph

Next to this graph, an additional graph is set up to determine alpha and beta for the Current (Actual) data as described in Section 2.2.1 above. This is a plot of Ln(-Ln(S(t)) vs. Ln(Age) for the actual data points along with the linear trendline for these points. In addition to finding alpha and beta, the following values are calculated on this sheet from the trendline:

- $Mean\ Life = \beta * \Gamma(x)$
- $Variance = (\beta^2) * (\Gamma(x_2) - (\Gamma(x))^2)$
- $Standard\ Deviation = \sqrt{Variance}$
- $Coefficient\ of\ Variation = \frac{Standard\ Deviation}{Mean\ Life}$

Where:

- $x = 1 + \frac{1}{\alpha}$ and $\Gamma(x) = \exp(gammaLn(x))$
- $x_2 = 1 + \frac{2}{\alpha}$ and $\Gamma(x_2) = \exp(gammaLn(x_2))$

This information for the Avalon region can be found in Tables 5 and 6 below.

	m	b
y = 6.0677x - 24.167	6.068	-24.17

Table 5 - Avalon Current Trendline Data

α	λ	β	x1	Γ(x)	Mean Life	x2	Γ(x2)	Var	SD	COV
6.068	3E-11	53.67208445	1.16481	0.928	49.8235	1.33	0.89342	91.3	9.555	0.192

Table 6 - Avalon Current Trendline Calculations

2.4 Life Extension Graph

The Life Extension Graph tab is used to plot the Life extension curves and determine the α and β values for 5, 10, and 15 year life extensions. Once the life extension values are tabulated based on the input life extension in the Data tab, these values are plot by Ln(-Ln(S(t)) vs. Ln(Age*). Similar to the Current Survival graph, the trendline is plot in order to obtain the alpha and beta values and compare the Mean Life and associated results. This graph can be seen in Figure 3 below.

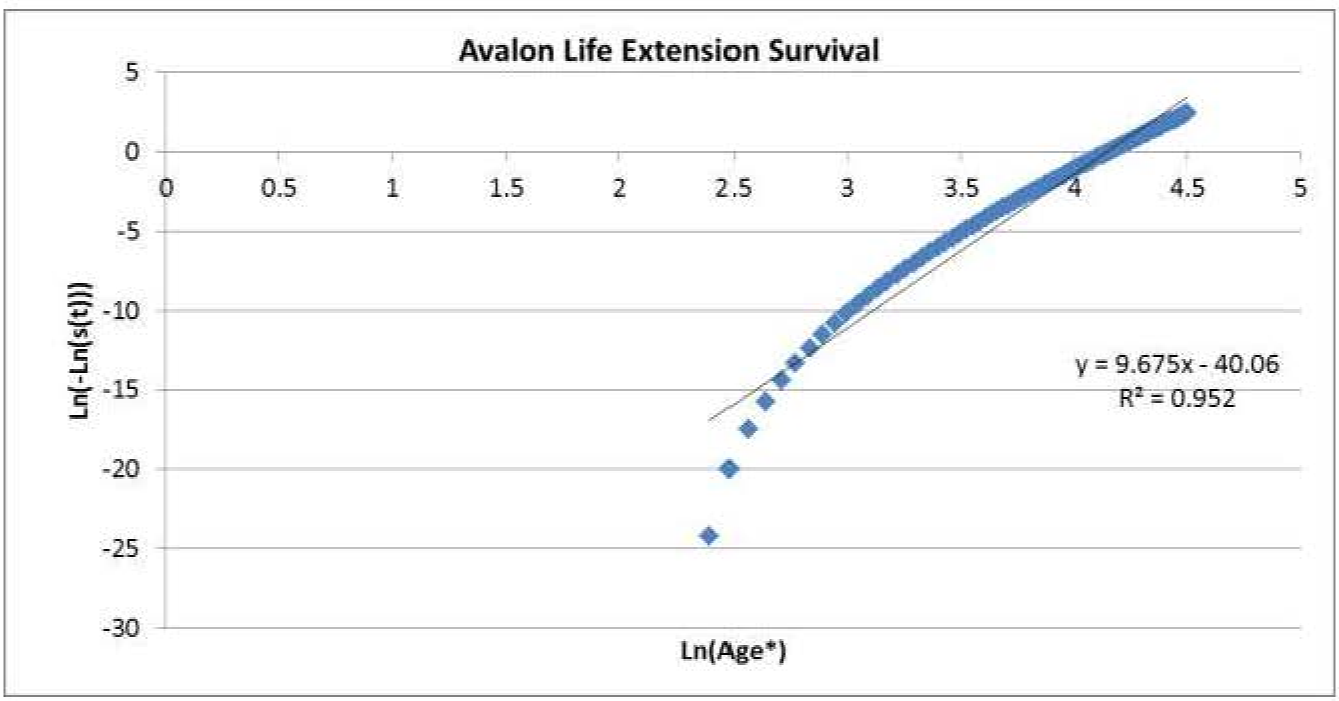

Figure 3 - Avalon Life Extension Survival Graph (10 years)

When updating or creating an Iowa spreadsheet, the life extension should be plot for 5, 10 and 15 years by changing the life extension number in the Data tab. The trendline should be taken for each option and used in the table below the graph. Once all three options are completed, the results from the trendlines can be used in the Life Extension tab for comparison purposes. The results can be seen in Tables 7 and 8 below.

Life Extension	Trendline	m	b
15	y = 11.031x - 46.557	11.03	-46.56
10	y = 9.675x - 40.064	9.675	-40.06
5	y = 8.1653x - 33.109	8.165	-33.11

Table 7 – Avalon Life Extension Trendline Data

	α	λ	β	x1	Γ(x)	Mean Life	x2	Γ(x2)	Var	SD	COV
5	11.03	6.03326E-21	68.07161	1.090654	0.95519	65.02106105	1.18131	0.923	50.82	7.129	0.11
10	9.675	3.98498E-18	62.86451859	1.103359	0.95001	59.72161885	1.20672	0.916	54.95	7.413	0.124
15	8.165	4.17776E-15	57.67603969	1.122469	0.94267	54.36965504	1.24494	0.907	62.63	7.914	0.146

Table 8 – Avalon Life Extension Trendline Calculations

The graph in Figure 3 above represents the 10 year life extension, as observed from the trendline in Table 7. This graph changes when you input the life extension into Table 4, found in the Data tab, which is how the trendlines are found for each alternative. However, the final life extension used should be 10 years as this is what will be displayed on the Avalon Iowa graph, as seen in Figure 2.

3. Exceptions

3.1 TL 218

Transmission Line 218 in the Avalon region was modified significantly over its history. The number of poles on this line has therefore changed significantly and the installation date of these poles varies. As described in Section 2.2, the history of the line is essential in accurately determining the survival rate of the poles. Due to this inconsistent history with TL 218, the present Iowa curves neglect the data available for these poles. Unless there becomes an efficient and reliable way to track the installation dates and cause for removal of these poles, it is recommended to omit future inspections of TL 218 from the curves as well.

4. Conclusion

The Iowa curves can evidently be a useful tool in the Wood Pole Line Management program in estimating future costs and determining benefits of intervention, and it would be worthwhile to effectively maintaining these files. Significant consideration has been put into the current procedure and values used within these files. The above procedure should provide a reliable estimate of the survival rate and mean life of poles for particular regions as well as province wide.

References

Haldar, A. (2004). *Wood Pole Line Management Using RCM Principles*. Newfoundland Labrador Hydro.

Roberts, S. W. (1962). Scheduling of Pole Line Inspections. The Bell System Technical Journal, November 1962, 1737-1758.

Appendix A

Avalon Region Data Table (Graphical Data)

Iowa Avalon												
Graph Values				Current Projection Calculations					Life Extension			
Original Iowa and Actual Avalon							Using α and β					
Age	LN(Age)	Iowa-50	Avalon	s(t)	-Ln(s(t))	.N(-LN(s(t))	LN(-LN(s(t)))	S(t)*100	Age*	LN(Age*)	LN(-LN(s(t)))	S(t)*100
1	0			0			-24.167	100	11	2.397895273	-24.167	100
2	0.6931			0			-19.96119085	99.99999979	12	2.48490665	-19.96119085	99.99999979
3	1.0986			0			-17.50095022	99.99999749	13	2.564949357	-17.50095022	99.99999749
4	1.3863			0			-15.75538171	99.99998563	14	2.63905733	-15.75538171	99.99998563
5	1.6094			0			-14.40141358	99.99994434	15	2.708050201	-14.40141358	99.99994434
6	1.7918			0			-13.29514107	99.99983174	16	2.772588722	-13.29514107	99.99983174
7	1.9459			0			-12.35980099	99.99957125	17	2.833213344	-12.35980099	99.99957125
8	2.0794			0			-11.54957256	99.99903599	18	2.890371758	-11.54957256	99.99903599
9	2.1972			0			-10.83490043	99.99803004	19	2.944438979	-10.83490043	99.99803004
10	2.3026			0			-10.19560443	99.99626666	20	2.995732274	-10.19560443	99.99626666
11	2.3979			0			-9.617290853	99.99334345	21	3.044522438	-9.617290853	99.99334345
12	2.4849			0			-9.089331921	99.98871429	22	3.091042453	-9.089331921	99.98871429
13	2.5649			0			-8.603656784	99.9816583	23	3.135494216	-8.603656784	99.9816583
14	2.6391			0			-8.153991841	99.97124563	24	3.17805383	-8.153991841	99.97124563
15	2.7081			0			-7.735363795	99.95630022	25	3.218875825	-7.735363795	99.95630022
16	2.7726			0			-7.34376341	99.93535965	26	3.258096538	-7.34376341	99.93535965
17	2.8332			0			-6.975911392	99.90663215	27	3.295836866	-6.975911392	99.90663215
18	2.8904			0			-6.629091285	99.86795093	28	3.33220451	-6.629091285	99.86795093
19	2.9444		100	1	0		-6.301027606	99.81672628	29	3.36729583	-6.301027606	99.81672628
20	2.9957	100	100	1	0		-5.989795284	99.74989562	30	3.401197382	-5.989795284	99.74989562
21	3.0445	99.6		0			-5.693751205	99.66387226	31	3.433987204	-5.693751205	99.66387226
22	3.091	99.2		0			-5.411481706	99.55449339	32	3.465735903	-5.411481706	99.55449339
23	3.1355	98.8		0			-5.141761746	99.41696836	33	3.496507561	-5.141761746	99.41696836
24	3.1781	98.4		0			-4.883522774	99.2458284	34	3.526360525	-4.883522774	99.2458284
25	3.2189	98		0			-4.635827157	99.03487929	35	3.555348061	-4.635827157	99.03487929
26	3.2581	97.4		0			-4.397847636	98.77715885	36	3.583518938	-4.397847636	98.77715885
27	3.2958	96.8		0			-4.168850648	98.46490158	37	3.610917913	-4.168850648	98.46490158
28	3.3322	96.2		0			-3.948182694	98.0895131	38	3.63758616	-3.948182694	98.0895131
29	3.3673	95.6		0			-3.735259092	97.64155776	39	3.663561646	-3.735259092	97.64155776
30	3.4012	95		0			-3.529554647	97.11076325	40	3.688879454	-3.529554647	97.11076325
31	3.434	94		0			-3.330595839	96.48604645	41	3.713572067	-3.330595839	96.48604645
32	3.4657	93	96.19932	0.961993	0.038748	-3.25068	-3.137954263	95.75556555	42	3.737669618	-3.137954263	95.75556555
33	3.4965	92	94.1723	0.941723	0.060044	-2.81268	-2.951241069	94.90680375	43	3.761200116	-2.951241069	94.90680375
34	3.5264	91		0			-2.770102245	93.92669032	44	3.784189634	-2.770102245	93.92669032
35	3.5553	90		0			-2.594214567	92.80176487	45	3.80666249	-2.594214567	92.80176487
36	3.5835	88.8		0			-2.423282137	91.51839067	46	3.828641396	-2.423282137	91.51839067
37	3.6109	87.6		0			-2.257033381	90.06302234	47	3.850147602	-2.257033381	90.06302234
38	3.6376	86.4	88.68243	0.886824	0.120108	-2.11936	-2.095218459	88.4225321	48	3.871201011	-2.095218459	88.4225321
39	3.6636	85.2		0			-1.937607	86.58459742	49	3.891820298	-1.937607	86.58459742
40	3.6889	84		0			-1.783986136	84.5381503	50	3.912023005	-1.783986136	84.5381503
41	3.7136	81.6		0			-1.634158771	82.27388528	51	3.931825633	-1.634158771	82.27388528
42	3.7377	79.2		0			-1.487942057	79.78481905	52	3.951243719	-1.487942057	79.78481905
43	3.7612	76.8		0			-1.345166058	77.06688948	53	3.970291914	-1.345166058	77.06688948
44	3.7842	74.4		0			-1.205672558	74.11957586	54	3.988984047	-1.205672558	74.11957586
45	3.8067	72		0			-1.069314011	70.94651531	55	4.007333185	-1.069314011	70.94651531
46	3.8286	68.8		0			-0.935952599	67.55608347	56	4.025351691	-0.935952599	67.55608347
47	3.8501	65.6		0			-0.805459397	63.96190061	57	4.043051268	-0.805459397	63.96190061
48	3.8712	62.4		0			-0.677713626	60.1832186	58	4.060443011	-0.677713626	60.1832186
49	3.8918	59.2		0			-0.552601977	56.24513984	59	4.077537444	-0.552601977	56.24513984
50	3.912	56		0			-0.43001801	52.17861866	60	4.094344562	-0.43001801	52.17861866
51	3.9318	51		0			-0.309861608	48.02019827	61	4.110873864	-0.309861608	48.02019827
52	3.9512	46		0			-0.192038489	43.81144488	62	4.127134385	-0.192038489	43.81144488
53	3.9703	41		0			-0.076459756	39.59805461	63	4.143134726	-0.076459756	39.59805461
54	3.989	36		0			0.036958499	35.42862925	64	4.158883083	0.036958499	35.42862925
55	4.0073	31		0			0.148295568	31.35314321	65	4.17438727	0.148295568	31.35314321
56	4.0254	28.2		0			0.257626454	27.42115436	66	4.189654742	0.257626454	27.42115436
57	4.0431	25.4		0			0.365022178	23.67984419	67	4.204692619	0.365022178	23.67984419
58	4.0604	22.6		0			0.470550055	20.17200326	68	4.219507705	0.470550055	20.17200326
59	4.0775	19.8		0			0.574273948	16.93410235	69	4.234106505	0.574273948	16.93410235
60	4.0943	17		0			0.6762545	13.9946034	70	4.248495242	0.6762545	13.9946034
61	4.1109	14.8		0			0.776549346	11.37266256	71	4.262679877	0.776549346	11.37266256
62	4.1271	12.6		0			0.875213308	9.077357607	72	4.276666119	0.875213308	9.077357607
63	4.1431	10.4		0			0.972298579	7.107533145	73	4.290459441	0.972298579	7.107533145
64	4.1589	8.2		0			1.067854885	5.452301471	74	4.304065093	1.067854885	5.452301471
65	4.1744	6		0			1.161929638	4.092170657	75	4.317488114	1.161929638	4.092170657
66	4.1897	4.8		0			1.254568078	3.000703005	76	4.33073334	1.254568078	3.000703005
67	4.2047	3.6		0			1.345813407	2.146546708	77	4.343805422	1.345813407	2.146546708
68	4.2195	2.4		0			1.435706903	1.495641762	78	4.356708827	1.435706903	1.495641762
69	4.2341	1.2		0			1.524288038	1.013385819	79	4.369447852	1.524288038	1.013385819
70	4.2485	0		0			1.61159458	0.666560221	80	4.382026635	1.61159458	0.666560221
71	4.2627	0		0			1.69766269	0.424859041	81	4.394449155	1.69766269	0.424859041
72	4.2767	0		0			1.78252701	0.261926856	82	4.406719247	1.78252701	0.261926856
73	4.2905	0		0			1.866220751	0.15588268	83	4.418840608	1.866220751	0.15588268
74	4.3041	0		0			1.948775766	0.089374676	84	4.430816799	1.948775766	0.089374676
75	4.3175	0		0			2.030222627	0.049261548	85	4.442651256	2.030222627	0.049261548
76	4.3307	0		0			2.110590689	0.026044604	86	4.454347296	2.110590689	0.026044604
77	4.3438	0		0			2.189908158	0.013177791	87	4.465908119	2.189908158	0.013177791
78	4.3567	0		0			2.268202148	0.006365617	88	4.477336814	2.268202148	0.006365617
79	4.3694	0		0			2.345498734	0.002928376	89	4.48863637	2.345498734	0.002928376
80	4.382	0		0			2.421823011	0.001279598	90	4.49980967	2.421823011	0.001279598