

TXHYETO.XLS a tool to facilitate use of Texas-Specific Hyetographs for design storm modeling.

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ABSTRACT

EBDLKUP.xls is a spreadsheet tool in current use by the Texas Department of Transportation (TxDOT) engineers and other design engineers for estimating intensity-duration-frequency (IDF) of design rainfall by county in Texas; the tool differs from discrete-duration IDF in that it facilitates estimation for real-value durations (not discrete durations). Research projects sponsored by TxDOT produced newer knowledge related to rainfall depths and the results of these studies are incorporated into a new tool EBDLKUP-NEW.xls projected for deployment in 4th Quarter of 2015. Added features are imbedded depth-duration-frequency (DDF) estimates for use with a companion tool TXHYETO.XLS to parameterize empirical Texas hyetographs, and imbedded documentation, including imbedded video training.

The paper presents the companion tool, TXHYETO.XLS that simplifies the task of using the Texas dimensionless hyetographs; An example of tool use is presented – combined the two tools enhance hydrologic design capability for instances where either a single intensity is needed (EBDLKUP-NEW.XLS), or where an entire design hyetograph is needed (TXHYETO.XLS).

INTRODUCTION

The Texas Department of Transportation sponsored research to develop Texas-specific storm hyetographs. The results were reported in Williams-Sether and others (2004), but use of the hyetographs has been limited by difficulty in using either the graphical or tabulated hyetographs for arbitrary durations and depths (dimensional mapping), and in producing uniform time step estimates for inclusion into hydrologic software such as HEC-HMS or SWMM.

Williams-Sether and others (2004) analyzed data from 1,659 runoff-producing storms near 91 U.S. Geological Survey streamflow-gauging stations in north and south central Texas. These streamflow-gauging stations were used to develop empirical, dimensionless, cumulative-rainfall hyetographs. Storm-quartile classifications were determined from the cumulative-rainfall values, which were divided into data groups on the basis of storm-quartile classifications, storm duration, and rainfall amount (as per Huff 1967 and 1990). Two storm groups, untrimmed and trimmed, were used for analysis.

The 90th-percentile curve for first-quartile storms indicated about 90 percent of cumulative rainfall occurs during the first 20 percent of the storm duration. The 10th-percentile curve for first quartile storms indicated about 30 percent of the cumulative rainfall occurs during the first 20 percent of the storm duration. The 90th-percentile curve for fourth-quartile storms indicated about 33 percent of the cumulative rainfall occurs during the first 20 percent of the storm duration. The 10th-percentile curve for fourth-quartile storms indicated less than 5 percent of cumulative rainfall occurs during the first 20 percent of the storm duration.

Williams-Sether and others (2004) present statistics for the empirical, dimensionless, cumulative-rainfall hyetographs in the report along with hyetograph curves and tables. The hyetograph curves and tables presented can be used to estimate distributions of rainfall with time for small drainage areas of less than about 160 square miles in urban and small rural watersheds in Texas.

Figure 1 is the fundamental result from Williams-Sether and others (2004). The annotations highlight the 90th percentile hyetograph (90 percent of observed hyetographs plot at or below this curve) and the 50th percentile (median) hyetograph. The dashed line represents an “average intensity” that would result from the ratio of total storm depth and total storm duration.

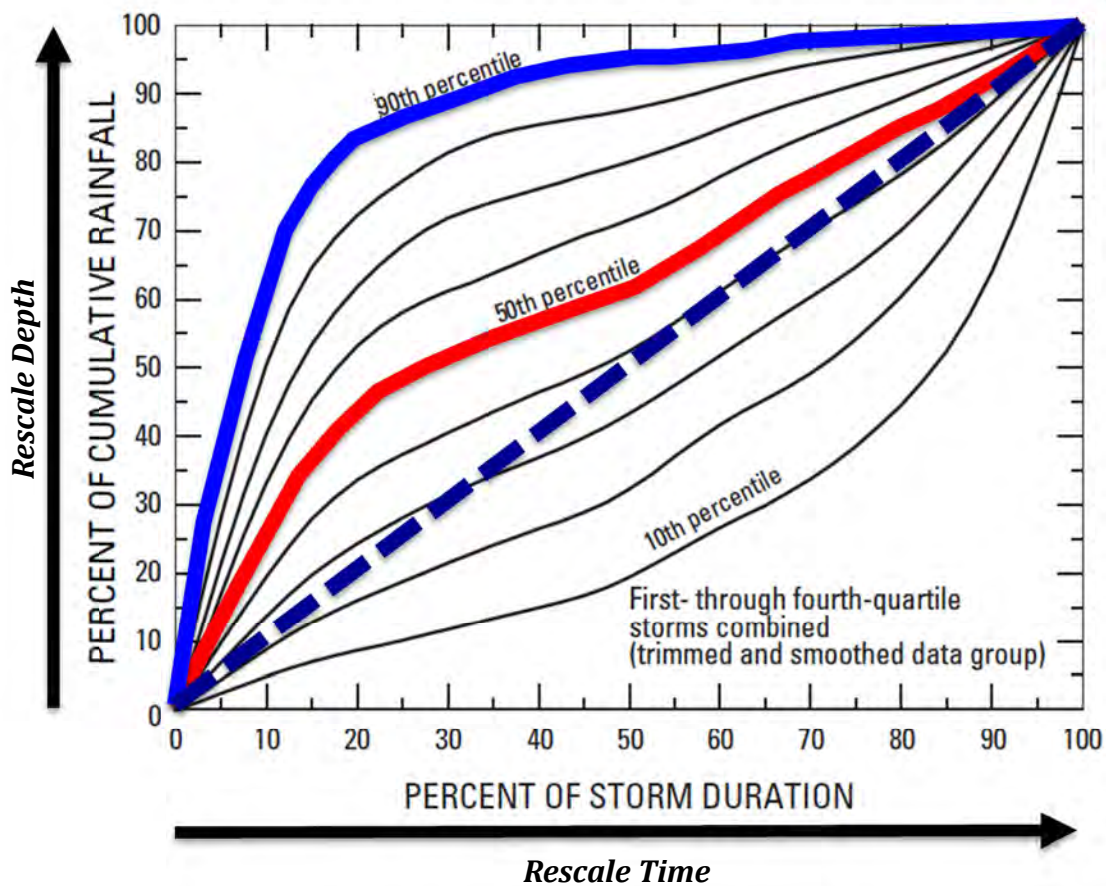


Figure 1. Dimensionless Hyetograph (from Williams-Sether (2004)) with annotations.

The two rescaling arrows indicate the dimensional mapping. For practical application an engineer would determine the depth for a particular duration, in Texas such tools include Asquith and Roussel (2004), Asquith (1998), Frederick and others (1977), and Hershfield (1961). The tools authored by Asquith are cited in the Texas Department of Transportation Hydraulic Design Manual (2014). In other states NOAA Atlas 14 would be logical tool for the rescaling step¹.

For example, if the 25-yr, 6-hr storm for a Texas location had a depth of 10 inches, then the horizontal axis would range from 0 to 6 hours, and the vertical axis would range from 0 to 10 inches. Further assuming the engineer is interested in the median hyetograph, then the cumulative depths at different portions of the storm could be recovered from Figure 2.

¹ The approach herein would be usable in other states, however the generation of a dimensionless hyetograph would require an analysis similar to that of Williams-Sether (2004).

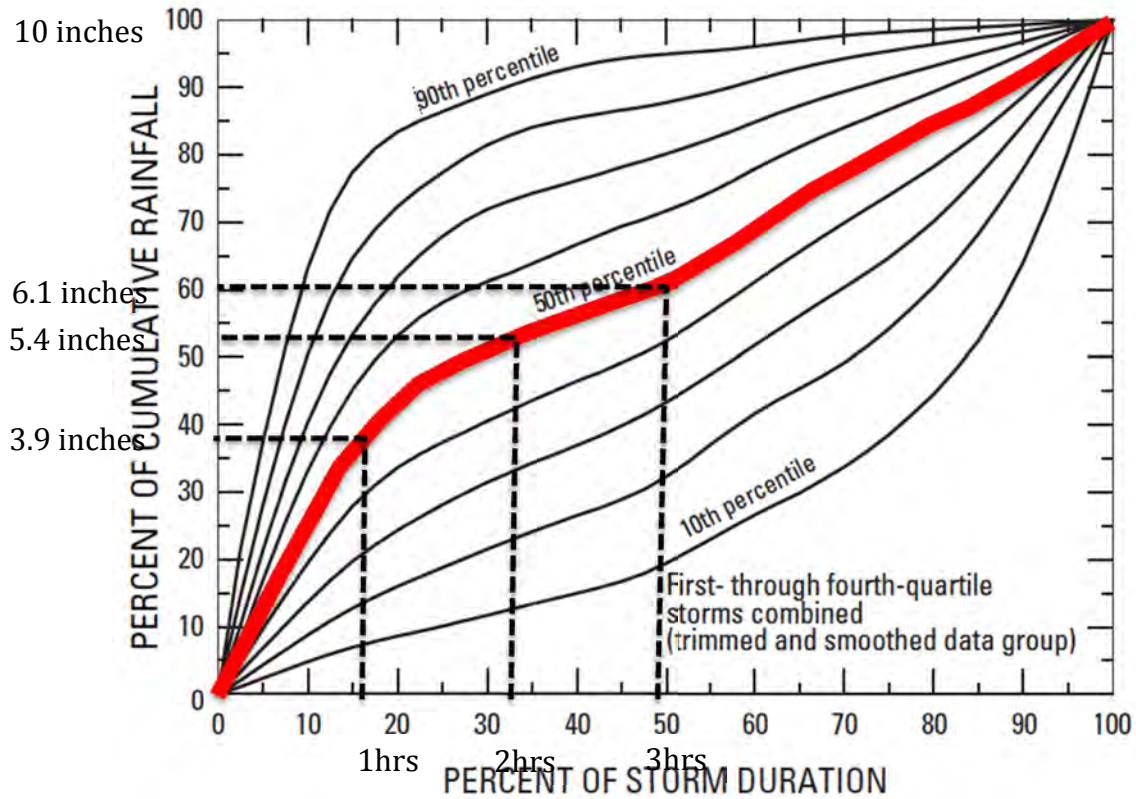


Figure 2. Dimensional Mapping

Continuing the example, the rescaled figure would then return values of 3.9 inches, 5.4 inches, and 6.1 inches of accumulated depth for the design storm for elapsed times of 1 hours, 2 hours, and 3 hours. If smaller uniform timesteps would be required, using the figure directly would quickly become cumbersome.

The figures were created using tabulated values as displayed in Figure 3. These values would be the logical choice for dimensional mapping for small uniform time intervals (say every 15 minutes). The impediment to using the tabulation (which is illustrated in the methodology section) is a need to be able to map time and depth (which is relatively straightforward – multiply by the total storm duration and total storm depth) and then a need to interpolate between the dimensional pairs of time and depth which may not fall onto the time intervals needed.

Supplement 5. Trimmed and smoothed percentiles for empirical hyetograph analysis, 1959–86.—Continued

[The interval is the center of the percent-of-storm-duration interval; —, no data]

Interval	Percentile										
	10th	20th	25th	30th	40th	50th	60th	70th	75th	80th	90th
First- through fourth-quartile storms combined; storm duration 0 to 72 hours											
2.5	1.08	2.04	2.58	3.34	4.69	6.37	7.81	10.30	12.16	14.66	21.60
5.0	2.35	4.32	5.47	6.84	9.74	13.58	16.97	21.38	24.48	28.12	37.57
7.5	3.59	6.56	8.32	10.27	14.68	20.49	25.56	31.57	35.63	40.20	51.55
10.0	4.82	8.78	11.16	13.68	19.47	26.83	33.19	40.38	45.16	50.47	63.04
12.5	5.92	10.85	13.80	16.85	23.94	32.42	39.68	47.57	52.72	58.62	71.66
15.0	6.92	12.77	16.23	19.72	27.91	37.21	45.23	53.41	58.54	64.61	77.38
17.5	7.80	14.43	18.29	22.14	31.01	41.00	49.56	57.96	62.97	68.83	80.89
20.0	8.60	15.99	20.23	24.32	33.59	44.11	53.16	61.80	66.74	72.25	83.32
22.5	9.31	17.38	21.89	26.21	35.63	46.55	55.92	65.02	69.84	74.94	85.01
25.0	10.06	18.75	23.51	28.07	37.35	48.54	58.09	67.80	72.62	77.28	86.35
27.5	10.87	20.11	25.00	29.79	38.88	50.23	59.80	70.07	75.06	79.47	87.66
30.0	11.70	21.51	26.51	31.41	40.52	51.68	61.22	71.87	76.92	81.38	88.96
32.5	12.51	22.77	27.81	32.85	42.01	52.90	62.34	73.12	78.10	82.81	90.18
35.0	13.35	24.09	29.22	34.30	43.56	54.27	63.76	74.21	79.02	84.02	91.29
37.5	14.16	25.27	30.47	35.54	44.99	55.49	65.16	75.15	79.64	84.83	92.25
40.0	14.96	26.51	31.85	36.89	46.42	56.80	66.62	76.11	80.22	85.47	93.05
42.5	15.78	27.58	33.21	38.24	47.68	58.03	67.98	77.06	80.86	86.03	93.72
45.0	16.71	28.90	34.80	39.80	49.13	59.31	69.33	78.12	81.72	86.61	94.24
47.5	17.89	30.35	36.44	41.44	50.66	60.49	70.35	79.07	82.56	87.09	94.64
50.0	19.41	32.28	38.33	43.33	52.45	61.97	71.60	80.06	83.51	87.72	94.92
52.5	21.16	34.45	40.32	45.28	54.39	63.51	72.89	81.15	84.53	88.42	95.18
55.0	22.94	36.99	42.49	47.39	56.57	65.39	74.37	82.30	85.61	89.20	95.40
57.5	24.82	39.38	44.67	49.56	58.80	67.56	76.05	83.52	86.75	90.06	95.70
60.0	26.62	41.64	46.83	51.75	61.09	69.85	77.89	84.82	88.01	91.04	96.06
62.5	28.29	43.62	49.00	53.94	63.38	72.11	79.55	86.10	89.22	91.97	96.47
65.0	29.86	45.38	50.95	56.07	65.59	74.32	81.14	87.25	90.31	92.83	96.90
67.5	31.76	47.16	52.88	58.23	67.77	76.38	82.65	88.36	91.31	93.60	97.32
70.0	33.75	49.16	54.81	60.32	69.87	78.21	84.02	89.37	92.17	94.27	97.68
72.5	36.00	51.52	56.94	62.47	71.97	80.00	85.35	90.35	92.90	94.84	97.97
75.0	38.51	54.15	59.24	64.72	73.98	81.61	86.69	91.30	93.55	95.38	98.19
77.5	41.45	57.17	62.09	67.30	76.10	83.25	88.02	92.25	94.20	95.89	98.38
80.0	44.54	60.42	65.22	70.08	78.24	84.84	89.34	93.15	94.86	96.39	98.56
82.5	48.24	64.13	68.85	73.31	80.60	86.54	90.72	94.08	95.54	96.87	98.72
85.0	52.41	68.26	72.78	76.77	83.07	88.30	92.09	94.98	96.22	97.34	98.90
87.5	57.68	72.90	77.10	80.53	85.81	90.21	93.49	95.87	96.93	97.81	99.09
90.0	64.02	77.90	81.55	84.43	88.65	92.18	94.92	96.75	97.61	98.28	99.29
92.5	71.71	83.28	86.22	88.48	91.66	94.22	96.37	97.65	98.29	98.75	99.49
95.0	80.43	88.80	90.85	92.47	94.62	96.21	97.81	98.54	98.96	99.22	99.70
97.5	90.01	94.42	95.53	96.53	97.64	98.21	99.26	99.44	99.65	99.70	99.92

Figure 3. Tabulation used to generate Dimensionless Hyetograph figures. (from Williams-Sether (2004)).

An alternative to interpolation is to “fit” smooth functions to the tabulation and directly estimate time-depth pairs from this smooth function. Once the smooth function is created, dimensional mapping is relatively straightforward and is the subject of the remainder of this paper.

METHODOLOGY

An initial attempt at a general tool was explored using the tabulation in Figure 3 and the straightforward rescaling as illustrated in Figure 4. The values of duration and depth are the same as the example in the introduction. Once the tabulation is rescaled, the challenge is to obtain estimates at arbitrary time increments – for example every 15 minutes.

Figure 5 is an interpolation spreadsheet using built-in functions in Excel – the engineer needs to enter the desired time increments in minutes in column A. The sheet draws the now dimensional values from columns D and E of Figure 4 and places them into columns I and J of Figure 5.

Then linear interpolation for each time value is implemented by the formulas in columns E through H of Figure 5.

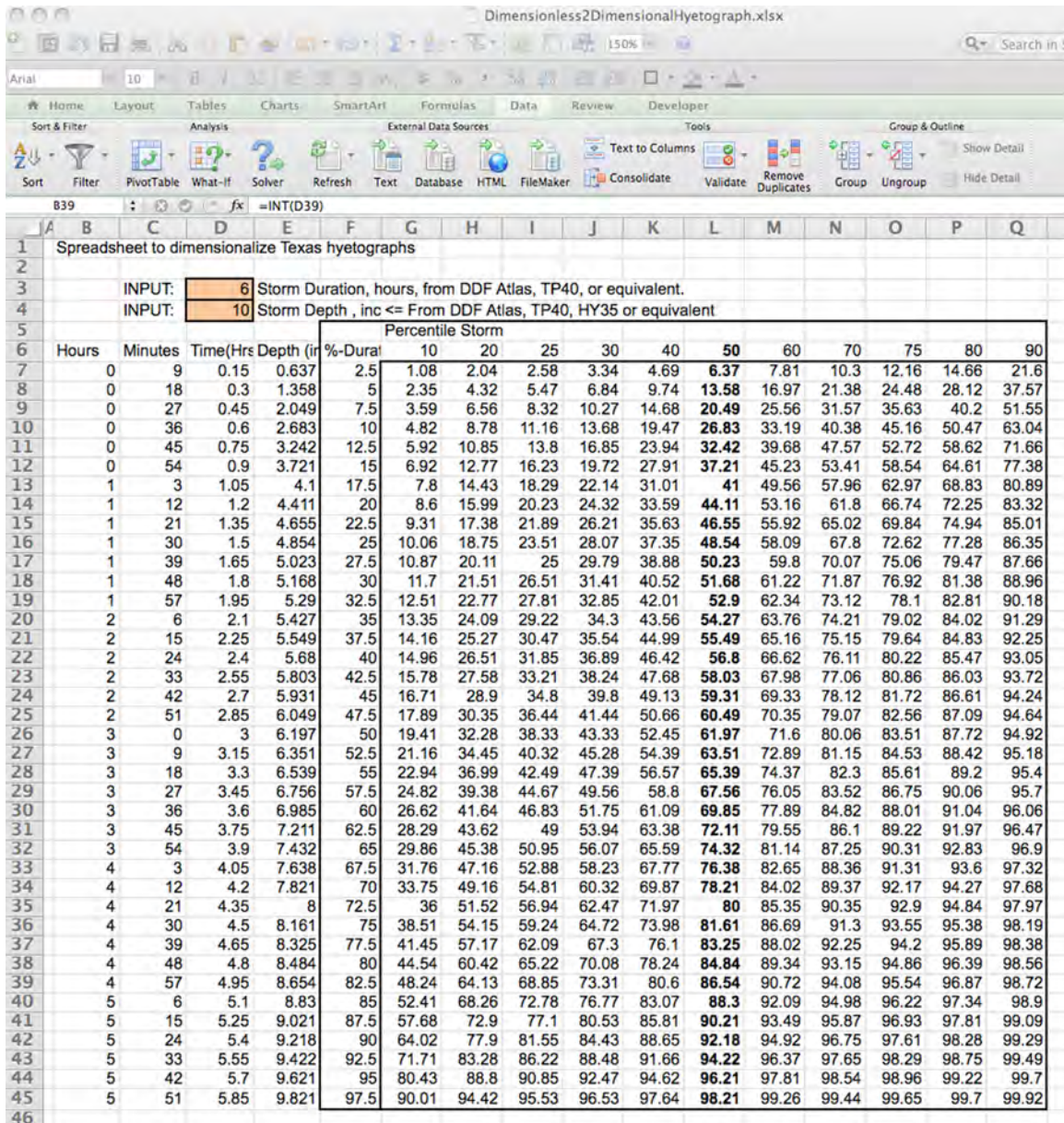


Figure 4. Rescaling Spreadsheet.

This interpolation process does require the engineer to “reprogram” the interpolation for different storms. For instance, if one minute time steps were desired, the engineer would have to know to enter the values 0,1,...360 in column A and then remember to copy the interpolation formulas to

the corresponding rows. This last step is a principal impediment and there was desire for a slightly more automated way to accomplish the hyetograph construction.

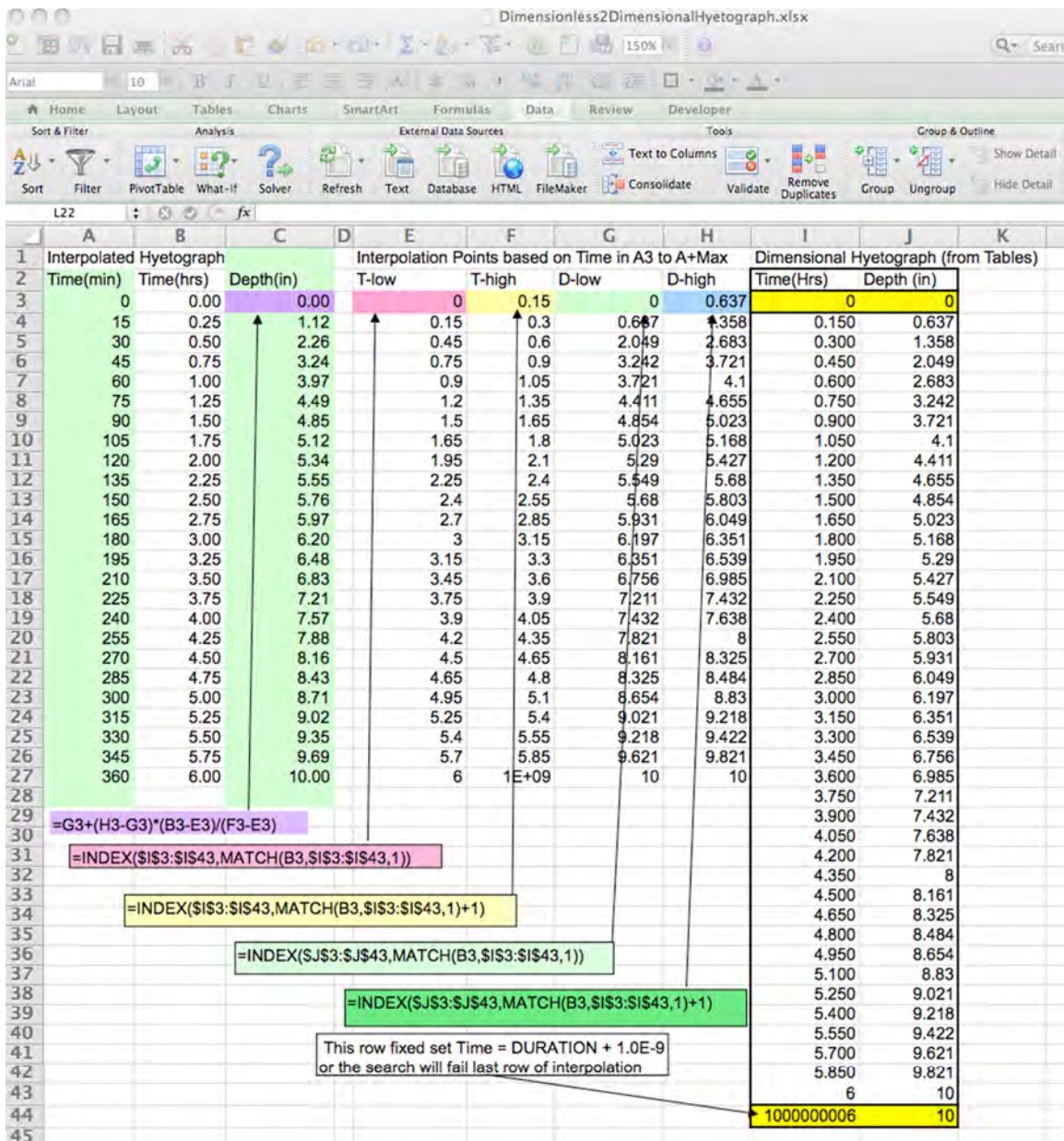


Figure 5. Interpolation Portion of Dimensional Mapping Spreadsheet.

Rather than attempt to program the spreadsheet to automatically build the interpolation formulas (in part to allow for non-uniform time steps) we instead fit a functional form to the dimensionless hyetographs. Once these functions are established, then the “interpolation” is simply a function call, which is decidedly easier for the engineer to remember.

Several functional forms were investigated to fit the shape of the tabulated Texas hyetographs in dimensionless space into continuous functions for subsequent dimensional mapping into arbitrary durations and depths (and arbitrary time steps). Considerable exploratory analysis (graphing functions and the tabulations) was conducted using many postulated functional forms.

The two most visually satisfying were a function based on the inverse tangent function, and a second based on a mixture of a cumulative beta function and a normal density function. The authors note herein, that the use of cumulative beta and normal density nomenclature is to identify the functions. The functional forms are entirely to preserve shape, and for all practical purposes these structures are treated as ordinary continuous functions (like a logarithm) without regard to any statistical meaning of the functions or the parameters.

The trigonometric function-based model is

$$D^*(t^*) = w_1(\tan^{-1}(t^*))^\alpha \quad [1]$$

where

$D^*()$ is the dimensionless depth of precipitation as a function of dimensionless time.

t^* is the dimensionless time.

w_1 is a weighting parameter.

α is an exponent on the inverse tangent function (helps adjust curvature)

The distribution mixture-based model is

$$D^*(t^*) = w_1(I_{t^*}(\alpha, \beta)) - w_2\left(\frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{(t^*-\mu)^2}{2\sigma^2}\right)\right) \quad [2]$$

where

$D^*()$ is the dimensionless depth of precipitation as a function of dimensionless time.

t^* is the dimensionless time.

w_1 is a weighting parameter.

α is a shape parameter for the Beta distribution.

β is a shape parameter for the Beta distribution.

w_2 is a weighting parameter.

μ is the mean (used to locate the mode of the function in this work).

σ is the standard deviation (used to control the width of the function in this work).

The parameters were estimated using the GRG Algorithm in MS Excel. Initial estimates were determined by trial-and-error.

RESULTS

The functional forms were fit using a non-linear least-squares approach where the difference between the model value and the tabulated value were minimized by changing the values of the parameters.

Table 1. Inverse Tangent model

Parameter	50th % MODEL	90th % MODEL
w_1	1.322947116	1.359494588
α	1.258701623	1.304471405

Table 2. Distribution-mixture model

Parameter	50th % MODEL	90th % MODEL
w_1	1.038977414	0.990892603
α	0.795462882	0.989635985
β	3.485892325	10.26915766
w_2	0.248832841	0.032686418
μ	0.471873548	0.325310683
σ	0.283390998	0.189525712

The distribution-mixture model was ultimately selected because it was able to reproduce the shape of the dimensionless distributions better than the inverse-tangent model.

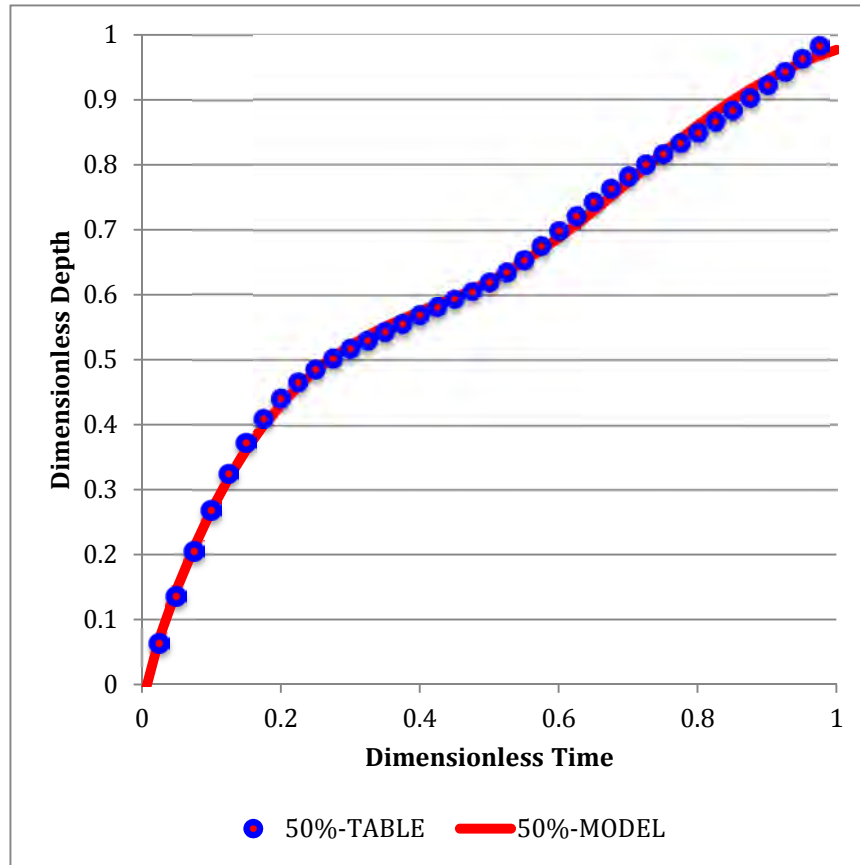


Figure 6. Distribution mixture-model for 50th percentile dimensionless hyetograph. Markers are tabulation values, solid line is the fitted function.

Figures 6 and 7 are plots of the tabular values from Williams-Sether (2004) and the fitted functions for the 50th percentile and the 90th percentile hyetographs. These figures are still in dimensionless form, but the tabulation is now replaced with a continuous function. The authors took some liberty with 0 and 1 in dimensionless time, and built the functions to force 0 and 1 dimensionless depth at these two particular time values. The remaining values are as computed with the functions.

Figure 8 is a screen capture of the TXHYETO provisional tool that implements the smooth functions rather than the tabulation of Williams-Sether (2004). The engineering inputs are unchanged (a storm length and a storm depth – determined using other tools as indicated on the worksheet). However once these values are supplied, the engineer only needs to supply the desired time values and then copy the single function to recover the dimensional hyetograph. The authors believe this step is easier to remember than copying the interpolation functions and

as the time series change length, the spreadsheet will generate obvious errors (which the interpolation sheet does not).

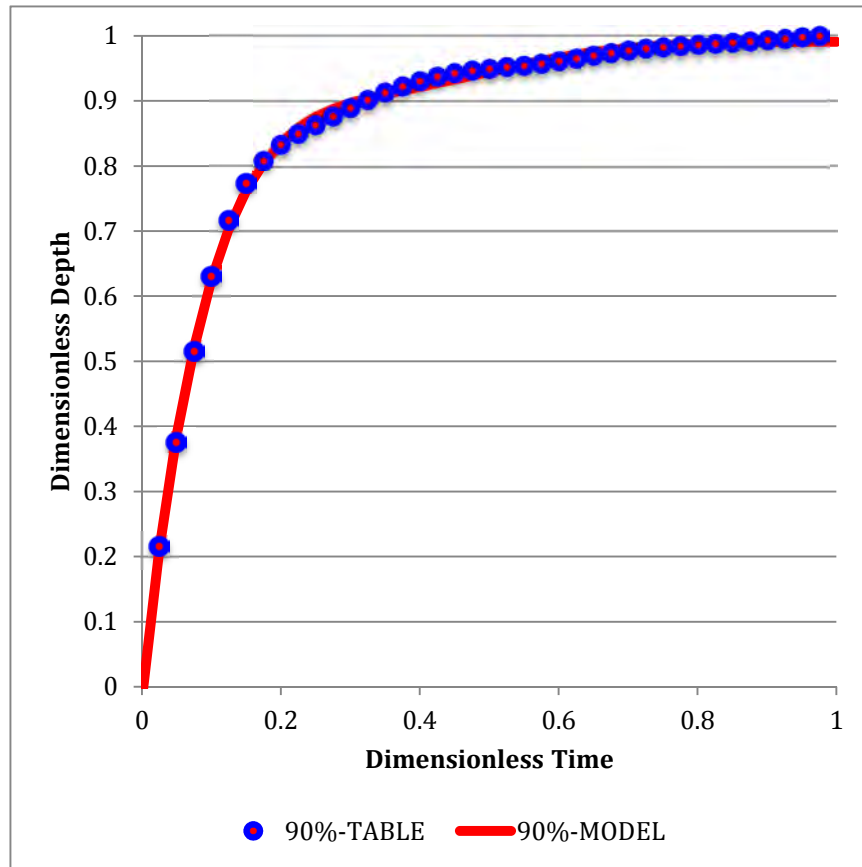


Figure 7. Distribution mixture-model for 90th percentile dimensionless hyetograph. Markers are tabulation values, solid line is the fitted function.

Using the example from the introduction the functional representation of the dimensionless hyetograph, when mapped into dimensional space produces a maximum relative error of less than 5 percent. Figure 9 is a screen capture of a worksheet showing the hyetograph estimated using the approximation function, the tabulation, and the relative error. Also on Figure 9 is a plot of the dimensional tabular values superimposed on the approximation function. The plot illustrates the fidelity of the approximation function. Similar behavior was observed for the 90th percentile hyetograph but is omitted here for brevity.

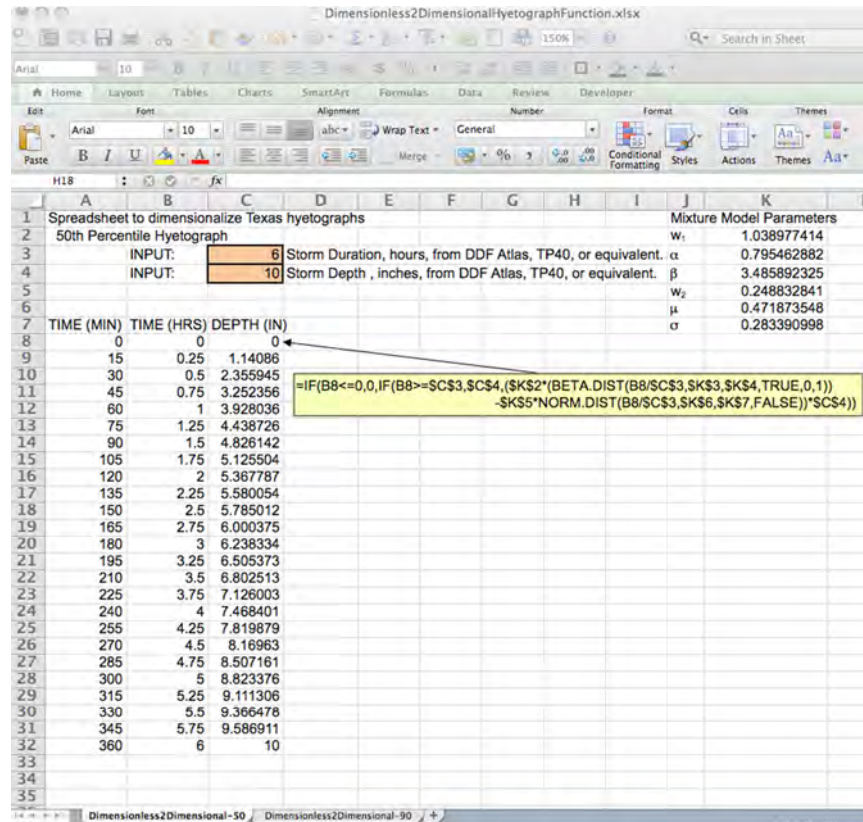


Figure 8. Dimensionless to dimensional hyetograph using Distribution Mixture-Model for 50th Percentile Hyetograph.

SUMMARY

A provisional tool, TXHYETO.XLS, that simplifies the task of using the Texas dimensionless hyetographs was presented. The tool uses an approximation function that is comprised of a mixture of distribution functions to approximate the shape of the dimensionless hyetographs reported in Williams-Sether (2004). An example is presented in the introduction and used to demonstrate that the approximation replicates estimates that would be made using linear interpolation with relative error less than 5 percent – certainly acceptable for a design storm. Future versions of the tool, anticipated by 4th quarter of 2015 are to enable the engineer to directly input calendar and clock time as typically expected by HEC-HMS or SWMM and embedded examples, training materials, and documentation.

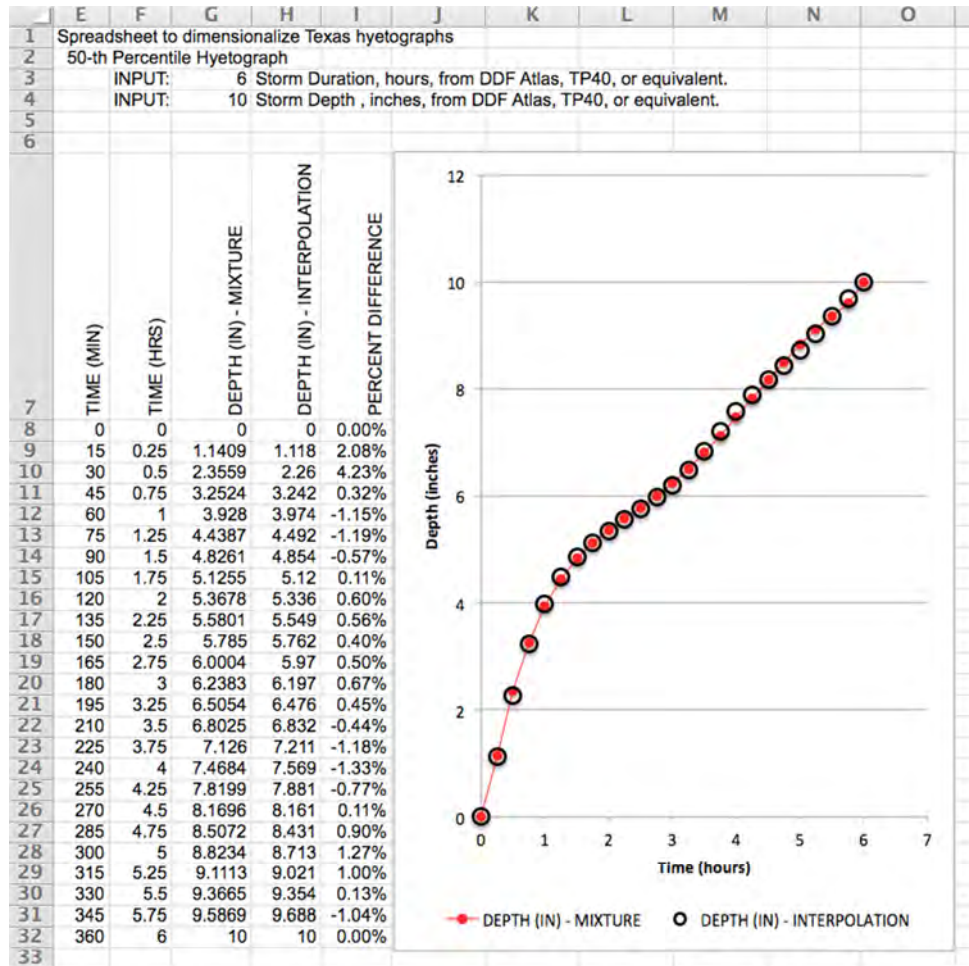


Figure 9. Comparison of example hyetograph using the approximation function versus the tabulation.

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