Updated Rainfall Coefficients for Texas – The EBDLKUP-NEW.XLS Tool

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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; the tool differs from discrete-duration IDF in that it facilitates estimation for real-value durations (not discrete durations). This real-value duration capability is a great utility tool for many hydrologic methods such as the rational method. The rainfall coefficients (*E*, *B*, and *D*) for the spreadsheet were created by interpreting the rainfall depth contours by duration and frequencies from research by the National Weather Service completed in the early 1960s and augmented in the 1970s. (TP-40 Hershfield, 1961; NWS Hydro-35, 1977)

Recent research projects sponsored by TxDOT have produced newer knowledge related to rainfall depths from longer rainfall records, newer statistical methods, and improved presentation methods. The results of these studies are incorporated into a new tool *EBDLKUP-NEW.xls*. The new tool was designed to maintain a similar interface and data structure to ensure that the revised coefficients can be inserted into existing design software (GeoPack-Drainage, WinStorm, and other drainage design tools that directly use the *E*, *B*, and *D* values). Added features include embedded depth-duration-frequency (DDF) estimates for use with a companion tool to parameterize empirical Texas hyetographs, embedded documentation, and embedded video training. This paper presents the new tool, the underlying database analysis, and the embedded training concept.

INTRODUCTION

Rainfall-runoff estimation is pertinent to designing adequate drainage systems in urbanized watersheds. Growth in impervious areas result in lower infiltration rates and increases the risk of flooding within the watershed. Engineers frequently use several hydrological methods to estimate peak discharge of rainfall at specific return periods. Rainfall intensity (*i*) is one of the important variables used in the rational method for the determination of runoff. Intensity (*i*) is defined as a measure of the depth of the water covering an area in a period of time (in/hr). Rainfall frequency analyses are useful to estimate the rainfall intensity at a given location for a specified duration and annual recurrence interval (ARI).

Depth-duration frequency (DDF) relationships are used to estimate the accumulated depth of precipitation (in) for a specified duration and recurrence interval. Intensity-duration frequency (IDF) relationships are used to estimate the average rate of precipitation (in/hr) for a given period of time in a recurrence interval for a specified geographical region. Both DDF and IDF estimates were utilized for revising E, B, and D values.

IDF values are often expressed as simple algebraic equations to avoid graphical or tabular lookup for design rainfall intensities. While DDF analyses of rainfall are often restricted to only a few durations (Asquith, 1998; Asquith and Roussel, 2004), equations for IDF curves provide a mechanism to estimate rainfall intensity for arbitrary durations. Collectively these reasons make IDF curves especially attractive to practitioners. Many algebraic forms have been used to represent IDF curves fit to discrete depth or intensity values and thus produce a smooth model of rainfall IDF. Some examples include:

Chow and others (1988)

$$IDF_F(T_c; c, e, f) = K \times \frac{c}{T_c^e + f} \quad (1)$$

Hann and others (1994)

$$IDF_F(T_c, F; x, n, b) = K \times \frac{F^x}{(T_c + b)^n} \quad (2)$$

McCuen and others (2002)

$$IDF_F(T_c; a, b, c, d) = K \times \begin{cases} \frac{a}{T_c + b} & for\ T_c \leq 2\ hrs \\ c{T_c}^d & for\ T_c > 2\ hrs \end{cases} \quad (3)$$

Texas Department of Transportation (2014)

$$IDF_F^{county}(T_c; E, B, D) = K \times \frac{B}{(T_c+D)^E} \quad (4)$$

where T_c is a characteristic response time (critical storm duration), K is a unit conversion constant and is treated as unity herein, F is a frequency that is related to annual exceedance probability (AEP), and $a, b, c, d, e, f, x, n, E, B, D$ are various coefficients that result from regression analysis (fitting the functions to prescribed discrete intensities). The coefficients E, B, D are separately acknowledged because they are known colloquially as the "EBD coefficients" for Texas. The subscripted IDF implies that the function and corresponding coefficients are a function of frequency, and in the case of the Texas functions are also a function of location (by county).

The end fraction in equation (4) represents the expression incorporated into various spreadsheets that are currently used by the Texas Department of Transportation (TxDOT, 2014, p. 10-45) and multiple Texas engineering practitioners and academics to aid in water resource design. The spreadsheet is known by various names, the more common variants include *TXDOT IDF Coeffs.xls*, and *ebdlkup.xls,* which was named based on the naming convention found in TxDOT's hydraulic design manual (TxDOT 2014). The *ebdlkup.xls* spreadsheet is a user-friendly tool used to estimate the rainfall intensity for Texas counties based on *E*, *B*, and *D* coefficients, where *E* is an exponent, *B* is a scaling value, and *D* is an offset. The coefficients were developed from interpreting rainfall depth contours developed by the National Weather Service in the early 1960s and augmented in the 1970s. (TP-40 Hershfield, 1961; NWS Hydro-35, 1977). Recent TxDOT research has resulted in up-to-date DDF estimates that enable the revision of the existing *E*, *B*, and *D* values based on a greater range and addition of data, and newer knowledge of statistical methods.

The current version of the tool uses coefficients last examined in 1985, and the purpose of the study is to update the coefficients to incorporate rainfall data analyzed since that time using newer statistical modeling techniques. In particular the updated tables (and tool) incorporate techniques applied in Asquith, 1998, Asquith and Roussel, 2004, and Cleveland and others, 2011.

The IDF functional expression, equation (4), was not changed in part due to the fact that the "E, B, D coefficients" are directly embedded in design software currently in use in Texas (GeoPack Drainage; WinStorm; HouStorm). Overwriting the coefficients appear to be a straightforward exercise in these software tools, but changing equation structure would possibly require substantial re-programming.

EBDLKUP-NEW.xls is the proposed spreadsheet that incorporates the updated *E*, *B*, and *D* values from TxDOT research. The updated spreadsheet maintains a similar interface and includes the revised coefficients based on the existing tables of 24,384 values of DDF sorted by recurrence interval, duration, and county. The spreadsheet will also include features such as: DDF curves, a companion tool used to parameterize empirical Texas hyetographs, and embedded documentation including embedded video training. This paper presents the improved *EBDLKUP-NEW.xls* spreadsheet along with the principal database analysis, and the embedded training concept.

METHODOLOGY AND DEVELOPMENT

The analysis and updating of the coefficients employed results from Asquith (1998) and Asquith and Roussel (2004) for 2, 5, 10, 25, 50, and 100-year recurrence intervals for 15-minute to 24 hour durations.

Initial estimates were created using a computer program by a two-step process that performed linear regression using ordinary least squares (OLS) with assumed values for *D*. With *D* specified and letting $\eta = T_c + D$, elementary algebra can linearize equation (4) to $IDF_F^{county}(\eta; E, B) \rightarrow log_{10}\left(IDF_F^{county}\right) = B + Elog_{10}(\eta)$. Once linearity was formed, the solution for *E* and *B* was trivial for a computer script using OLS.

The remaining challenge for parameter estimation was the single coefficient *D* that was refined using one-dimensional line search (root finding); a single function call in statistical programming languages such as R (R Core Team, 2014). The process uses the OLS results as an intermediate computational step in the one-dimensional line search essentially employing a sequential unconstrained minimization technique (Fiacco and McCormick, 1964). The results of this program are provisional IDF curves for each county, such as Figure 1.

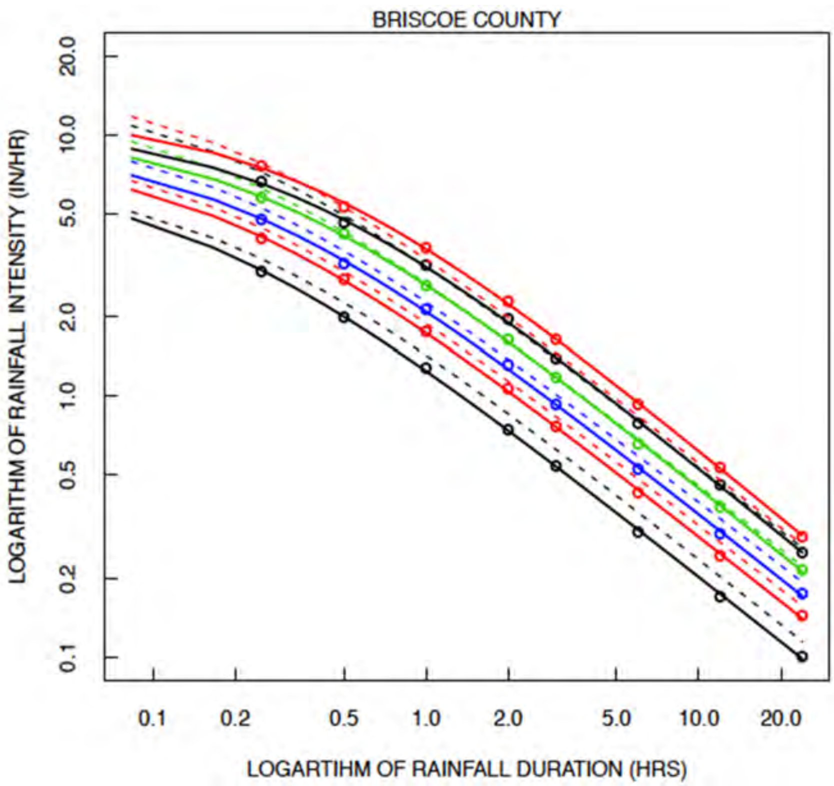


Figure 1. Provisional county-mean values of intensity-duration frequency (IDF) of rainfall for Briscoe County, Texas derived from Asquith (1998) and Asquith and Roussel (2004) for 2, 5, 10, 25, 50, and 100-year recurrence intervals and in addition IDF curves (dashed lines) following (4) using existing TxDOT EBD coefficients (TxDOT, 2014, p. 10-45) and provisional IDF fits to the values (solid lines) to county-mean values.

In Figure 1, the markers (dots) are the fitted IDF values based on the discrete values from Asquith (1998) and Asquith and Roussel (2004). The solid lines are drawn using Equation 4 with the recently estimated *E*, *B*, and *D* values. The dashed lines are drawn using Equation 4 with the older *E*, *B*, and *D* values from the TxDOT hydraulic design manual. Figure 1 is representative of the changes to be anticipated with the revised values.

The 25-yr ARI line (green) with both the provisional revised values and the current values is nearly the same (no change), except for the shortest duration (15 minutes) where the provisional revised value is a smaller intensity. The 2-yr, 5-yr, and 10-yr ARI lines with provisional revised values lie below the lines based on the current values – thus the revisions for these ARI would produce lower intensities over the entire duration range. The 100-yr ARI line with provisional revised values lie above the line based on current values – hence the revision will produce higher intensities for the entire duration range for this ARI. The behavior in Figure 5 is typical for most of the counties examined.

After initial processing, a second program, R, provides an editing capability of the recently estimated E, B, and D values. Figure 2 is a screen capture of the editing program that illustrates the program as well as the reason for the editing step.

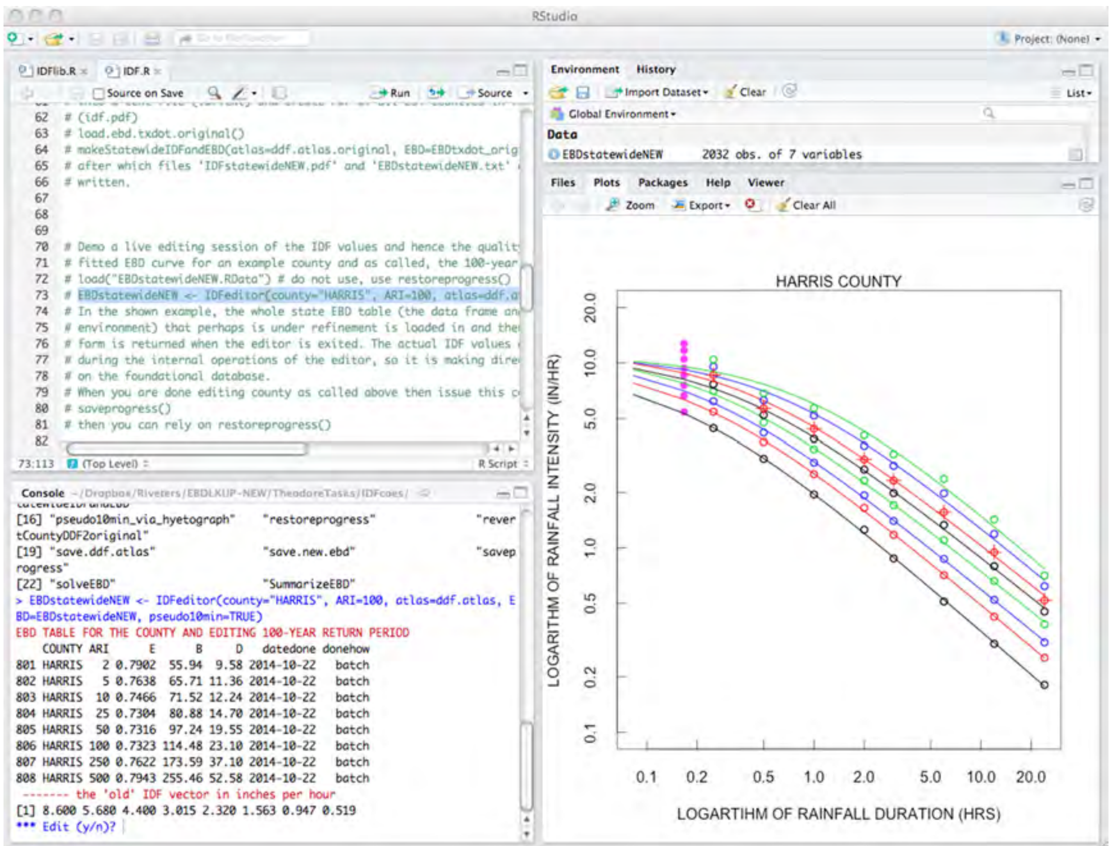


Figure 2. Screen capture of the R Software utilized for graphically displaying, editing, and estimating IDF curves. IDF curves displayed for Harris County, Texas is derived from Asquith (1998) and Asquith and Roussel (2004) for 2, 5, 10, 25, 50, and 100-year recurrence intervals.

Figure 2 shows the initial estimates for Harris County, Texas. The current values are suppressed (no dashed lines). Many (not all) counties exhibit the behavior shown in Figure 2 where the IDF curves contract at smaller durations – some counties displayed a large overlapping of curves. Other counties displayed curves that changed from concave to convex at different ARI. These un-anticipated results required each county to be examined by at least two members of the research team, and required minor adjustments to the IDF curves that included: monotonically decreasing IDF curves with increasing duration for a fixed ARI, and ensuring greater ARI curves lay above lower ARI curves at all durations (the family of curves is quasi-parallel). Figure 2 also shows a set of markers (pink dots) at the 10-minute duration. These values are estimated from the 15-minute values using the tabulation in Williams-Sether (2004). These markers are useful to the researchers to guide the adjustments to the *E*, *B*, and *D* values but are otherwise superfluous. Additionally the researchers determined that the *D* values should not vary largely for a county (for example the values in Figure 2 range from about 10 to 50 depending on ARI).

Figure 3 is the result of editing the initial estimates to produce a family of IDF curves that meet the monotonic decreasing behavior with duration and the quasi-parallel behavior. The *D* values have reduced range (from about 10 to 20 depending on ARI – this range is substantially larger that *D* values in prior work, but comparable in absolute magnitude) as anticipated.

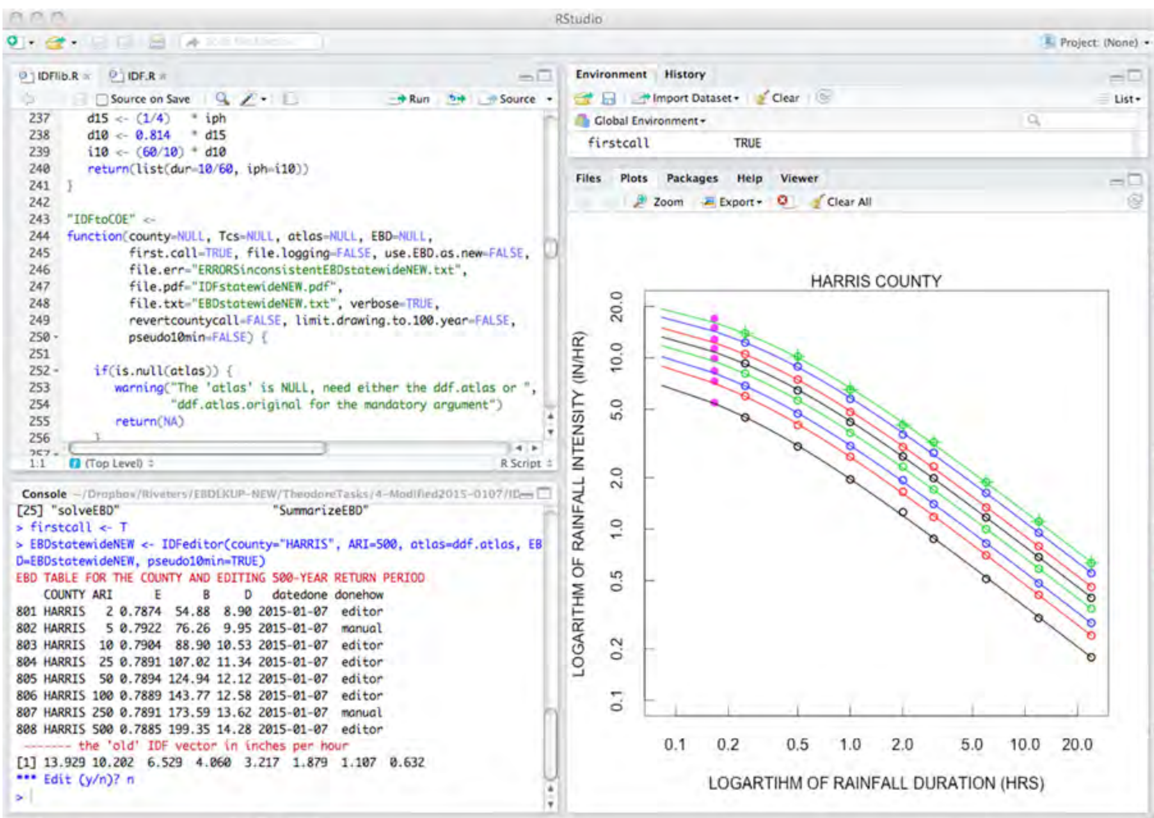
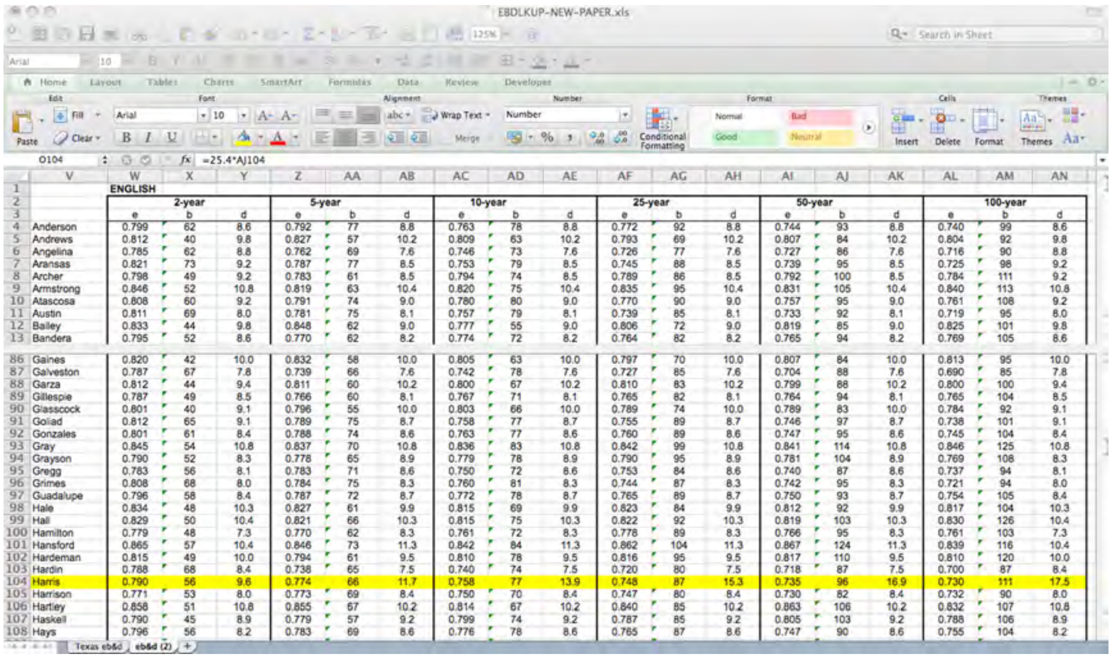


Figure 3. Screen capture of the R Software utilized for graphically displaying, editing, and estimating IDF curves. IDF curves displayed for Harris County, Texas is the result of minor adjustments from team member to construct quasi-parallel curves. Original DDF estimates are derived from Asquith (1998) and Asquith and Roussel (2004) for 2, 5, 10, 25, 50, and 100-year recurrence intervals.

Upon completion of a county using this analyst-directed adjustment, a second analyst examined the work as a QA/QC step, and made manual adjustments as indicated in Figure 3 for the 100-yr ARI. The table produced by the software is exported and saved then inserted into the *EBDLKUP-NEW.xls* worksheet.



		2-year e	2-year b	2-year d	5-year e	5-year b	5-year d	10-year e	10-year b	10-year d	25-year e	25-year b	25-year d	50-year e	50-year b	50-year d	100-year e	100-year b	100-year d
4	Anderson	0.799	62	8.6	0.792	77	8.8	0.763	78	8.8	0.772	92	8.8	0.744	93	8.8	0.740	99	8.6
5	Andrews	0.812	40	9.8	0.827	57	10.2	0.809	63	10.2	0.793	69	10.2	0.807	84	10.2	0.804	92	9.8
6	Angelina	0.785	62	8.8	0.762	69	7.6	0.746	73	7.6	0.726	77	7.6	0.727	86	7.6	0.716	90	8.8
7	Aransas	0.821	73	9.2	0.787	77	8.5	0.753	79	8.5	0.745	88	8.5	0.739	95	8.5	0.725	98	9.2
8	Archer	0.798	49	9.2	0.783	61	8.5	0.794	74	8.5	0.789	86	8.5	0.792	100	8.5	0.784	111	9.2
9	Armstrong	0.846	52	10.8	0.819	63	10.4	0.820	75	10.4	0.835	95	10.4	0.831	105	10.4	0.840	113	10.8
10	Atascosa	0.808	60	9.2	0.791	74	9.0	0.780	80	9.0	0.770	90	9.0	0.757	95	9.0	0.761	108	9.2
11	Austin	0.811	69	8.0	0.781	75	8.1	0.757	79	8.1	0.739	85	8.1	0.733	92	8.1	0.719	95	8.0
12	Bailey	0.833	44	9.8	0.848	62	9.0	0.777	55	9.0	0.806	72	9.0	0.819	85	9.0	0.825	101	9.8
13	Bandera	0.795	52	8.6	0.770	62	8.2	0.774	72	8.2	0.764	82	8.2	0.765	94	8.2	0.769	105	8.6
86	Gaines	0.820	42	10.0	0.832	58	10.0	0.805	63	10.0	0.797	70	10.0	0.807	84	10.0	0.813	95	10.0
87	Galveston	0.787	67	7.8	0.739	66	7.6	0.742	78	7.6	0.727	85	7.6	0.704	88	7.6	0.690	85	7.8
88	Garza	0.812	44	9.4	0.811	60	10.2	0.800	67	10.2	0.810	83	10.2	0.799	88	10.2	0.800	100	9.4
89	Gillespie	0.787	49	8.5	0.766	60	8.1	0.767	71	8.1	0.765	82	8.1	0.764	94	8.1	0.765	104	8.5
90	Glasscock	0.801	40	9.1	0.796	55	10.0	0.803	66	10.0	0.789	74	10.0	0.789	83	10.0	0.784	92	9.1
91	Goliad	0.812	65	9.1	0.789	75	8.7	0.758	77	8.7	0.755	89	8.7	0.746	97	8.7	0.738	101	9.1
92	Gonzales	0.801	61	8.4	0.788	74	8.6	0.763	77	8.6	0.760	89	8.6	0.747	95	8.6	0.745	104	8.4
93	Gray	0.845	54	10.8	0.837	70	10.8	0.836	83	10.8	0.842	99	10.8	0.841	114	10.8	0.846	125	10.8
94	Grayson	0.790	52	8.3	0.778	65	8.9	0.779	78	8.9	0.790	95	8.9	0.781	104	8.9	0.769	108	8.3
95	Gregg	0.783	56	8.1	0.783	71	8.6	0.750	72	8.6	0.753	84	8.6	0.740	87	8.6	0.737	94	8.1
96	Grimes	0.808	68	8.0	0.784	75	8.3	0.760	81	8.3	0.744	87	8.3	0.742	95	8.3	0.721	94	8.0
97	Guadalupe	0.796	58	8.4	0.787	72	8.7	0.772	78	8.7	0.765	89	8.7	0.750	93	8.7	0.754	105	8.4
98	Hale	0.834	48	10.3	0.827	61	9.9	0.815	69	9.9	0.823	84	9.9	0.812	92	9.9	0.817	104	10.3
99	Hall	0.829	50	10.4	0.821	66	10.3	0.815	75	10.3	0.822	92	10.3	0.819	103	10.3	0.830	126	10.4
100	Hamilton	0.779	48	7.3	0.770	62	8.3	0.761	72	8.3	0.778	89	8.3	0.766	95	8.3	0.761	103	7.3
101	Hansford	0.865	57	10.4	0.846	73	11.3	0.842	84	11.3	0.862	104	11.3	0.867	124	11.3	0.839	116	10.4
102	Hardeman	0.815	49	10.0	0.794	61	9.5	0.810	78	9.5	0.816	95	9.5	0.817	110	9.5	0.810	120	10.0
103	Hardin	0.788	68	8.4	0.738	65	7.5	0.740	74	7.5	0.720	80	7.5	0.718	87	7.5	0.700	87	8.4
104	Harris	0.790	56	9.6	0.774	66	11.7	0.758	77	13.9	0.748	87	15.3	0.735	96	16.9	0.730	111	17.5
105	Harrison	0.771	53	8.0	0.773	69	8.4	0.750	70	8.4	0.747	80	8.4	0.730	82	8.4	0.732	90	8.0
106	Hartley	0.858	51	10.8	0.855	67	10.2	0.814	67	10.2	0.840	85	10.2	0.863	106	10.2	0.832	107	10.8
107	Haskell	0.790	45	8.9	0.779	57	9.2	0.799	74	9.2	0.787	85	9.2	0.805	103	9.2	0.788	106	8.9
108	Hays	0.796	56	8.2	0.783	69	8.6	0.776	78	8.6	0.765	87	8.6	0.747	90	8.6	0.755	104	8.2

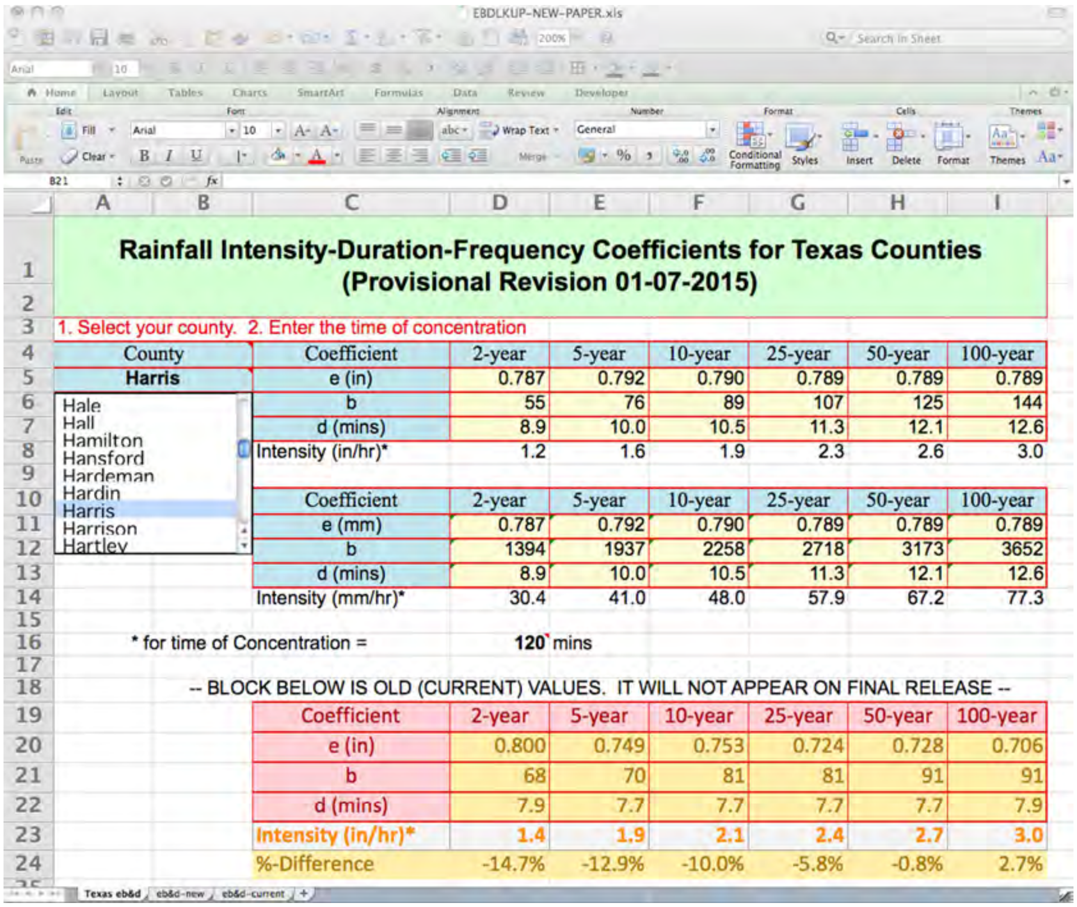
Figure 4. *EBDLKUP-NEW.xls* data sheet containing updated *E, B, D* values retrieved from edited IDF curves for each Texas county at specified recurrence intervals. Data sheet is pertinent and separate from the *EBDLKUP* tool to maintain a clean interface.

After minor manual edits from the team, the *E, B, D* values for each county at each specified duration and recurrence interval were entered and dated into a spreadsheet. When all counties were edited and verified by at least two team members, the data was gathered and placed into the *EBDLKUP-NEW.xls* spreadsheet. The spreadsheet offers a user-friendly interface and provides a quick search for rainfall intensities for Texas counties for specified ARI based on a given duration.

RESULTS

The adjusted IDF curves based on the revised *E*, *B*, and *D* values affected the intensities for almost all Texas counties. Figures 2 and 3 are representative of the magnitudes of change to be anticipated with the revised values.

Figure 5 is representative of the revised tool for Harris County (using the values from Figure 3). When compared to the current (older tool) the intensities estimated using the revised coefficients are smaller except at the 100-yr ARI, where the intensity is the same[1]. There is a noticeable decrease in intensities at each ARI for Harris County, Texas. The rest of the counties have similar changes in intensities when compared to the current (old) *ebdlkup.xls* spreadsheet.



Rainfall Intensity-Duration-Frequency Coefficients for Texas Counties (Provisional Revision 01-07-2015)

1. Select your county. 2. Enter the time of concentration

County	Coefficient	2-year	5-year	10-year	25-year	50-year	100-year
Harris	e (in)	0.787	0.792	0.790	0.789	0.789	0.789
Hale	b	55	76	89	107	125	144
Hall	d (mins)	8.9	10.0	10.5	11.3	12.1	12.6
Hamilton	Intensity (in/hr)*	1.2	1.6	1.9	2.3	2.6	3.0
Hansford							
Hardeman							
Hardin	Coefficient	2-year	5-year	10-year	25-year	50-year	100-year
Harris	e (mm)	0.787	0.792	0.790	0.789	0.789	0.789
Harrison	b	1394	1937	2258	2718	3173	3652
Hartley	d (mins)	8.9	10.0	10.5	11.3	12.1	12.6
	Intensity (mm/hr)*	30.4	41.0	48.0	57.9	67.2	77.3

* for time of Concentration = 120 mins

-- BLOCK BELOW IS OLD (CURRENT) VALUES. IT WILL NOT APPEAR ON FINAL RELEASE --

Coefficient	2-year	5-year	10-year	25-year	50-year	100-year
e (in)	0.800	0.749	0.753	0.724	0.728	0.706
b	68	70	81	81	91	91
d (mins)	7.9	7.7	7.7	7.7	7.7	7.9
Intensity (in/hr)*	1.4	1.9	2.1	2.4	2.7	3.0
%-Difference	-14.7%	-12.9%	-10.0%	-5.8%	-0.8%	2.7%

Figure 5. *EBDLKUP-NEW* Provisional Tool. The interface is similar to current tool, but parts are modified to identify the two different tools. The new spreadsheet will include instructional video training embedded documentation and embedded depth-duration-frequency (DDF) estimates for use with a companion tool to parameterize empirical Texas hyetographs.

[1] The current (old) tool produces the following estimates of intensity: 1.4, 1.9, 2.1, 2.4, 2.7, and 3.0 in/hr for 2-yr to 100-yr ARI. These estimates are also shown on the provisional tool described herein, but will not appear on the final release.

SUMMARY

A user-friendly spreadsheet used for calculating rainfall intensities for Texas counties at given durations for a specified recurrence interval, *EBDLKUP-NEW.xls*, was redeveloped based on the current *ebdlkup.xls* due to an increase in research and updated DDF data from TxDOT that directly affected the *E, B, D* values and rainfall intensities throughout Texas. Utilizing computer programming that executed linear regression using ordinary least squares (OLS) with assumed values for *D*, preliminary *E*, and *B* values were determined. Once the *D* value was refined using one-dimensional line search, IDF curves could be plotted for each county. The new IDF curves were plotted in R for editing purposes to adjust the new IDF curves based on a quasi-parallel structure. For QA/QC purposes, at least two members of the project were in charge of the analyst-directed adjustment for every Texas county. The newly adjusted IDF curves were validated using the previous curves graphically displayed in R. All updated quantified values were added to the *EBDLKUP-NEW.xls* spreadsheet to provide TxDOT and other design engineers a tool for estimating IDF of design rainfall by county. Almost all counties resulted in a decrease in rainfall intensities at any given duration or specified ARI. The new spreadsheet includes embedded depth-duration-frequency (DDF) estimates for use with a companion tool to parameterize empirical Texas hyetographs, and embedded documentation, including embedded video training.

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