Application of BDF to Determine Clark Unit Hydrograph Parameters

Presented by

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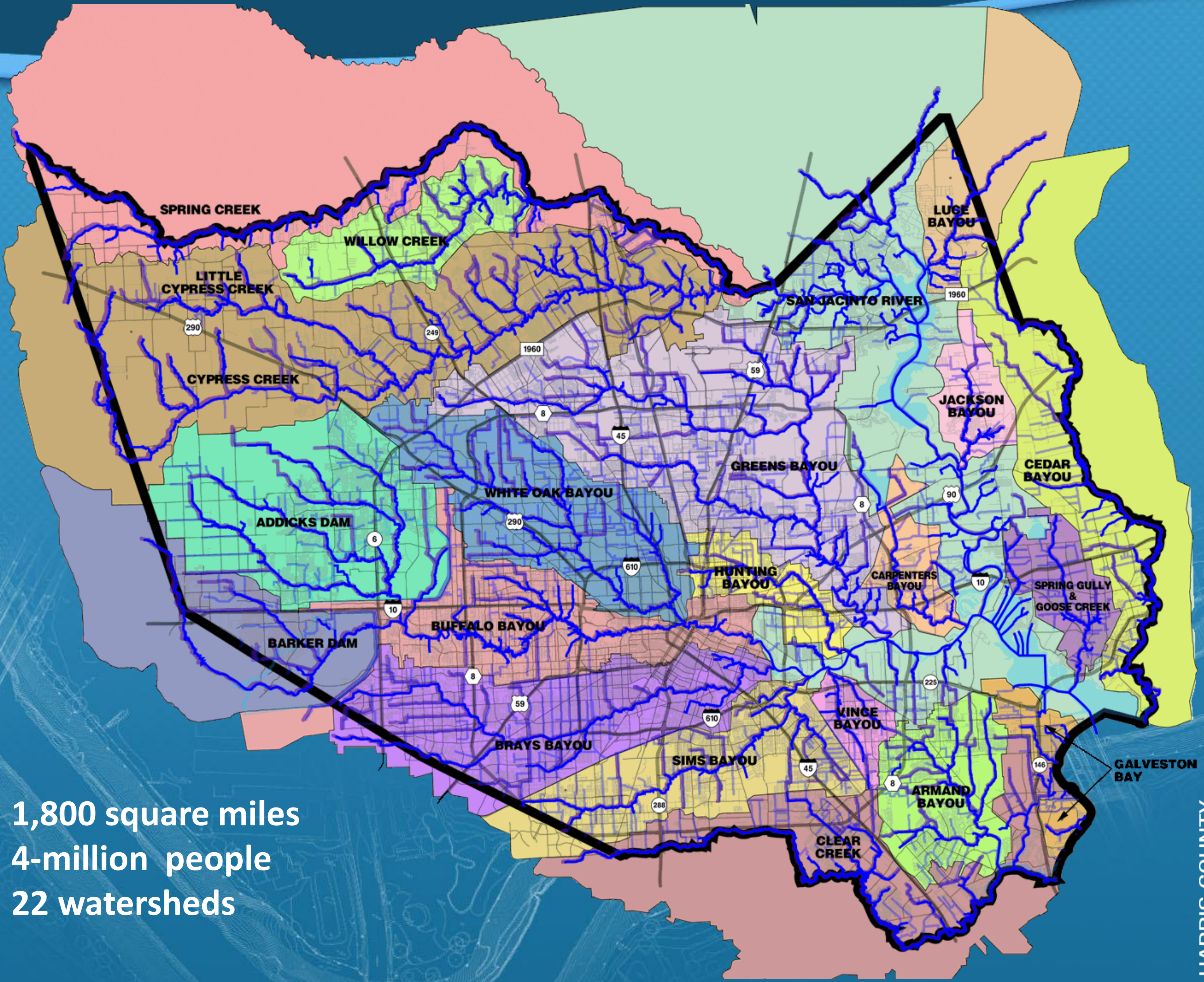
Harris County



- -- 1,800 square miles
- -- 4-million people
- -- 22 watersheds

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Stormwater Management Issues for Harris County

(1) Extreme flooding from rare storms (recurrence >= 100-yr)

(2) Floodplain delineation to aid in protecting structures

(3) Adequacy of drainage network, including channels and detention

(4) Localized flooding from more frequent storms (recurrence <= 10-yr)

(5) Method(s) to determine response to rainfall events

(6) Understanding rainfall-runoff from ungaged area.

(7) Understanding relation between rainfall and runoff as watershed changes from natural (undeveloped) to urban (developed)

(8) Impact of changes to drainage network – e.g., redevelopment, or undeveloped to developed

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Addressing Stormwater Management Issues

Previous Major Efforts --

(1) Develop Standard Hydrologic Methodology, Harris County Flood Hazard Study (1984)

(2) Establish FEMA accepted floodplain delineations for county after Tropical Storm Allison (June 2001), effective June 2007

Current Effort --

(1) County-wide Study -- Urban Stormwater Management Study, aka, FloodWise

(2) FloodWise, organized into 6-Study Blocks, has 2-major Technical Objectives:

  a) Improve understanding of rainfall-runoff relationship for natural and changed conditions

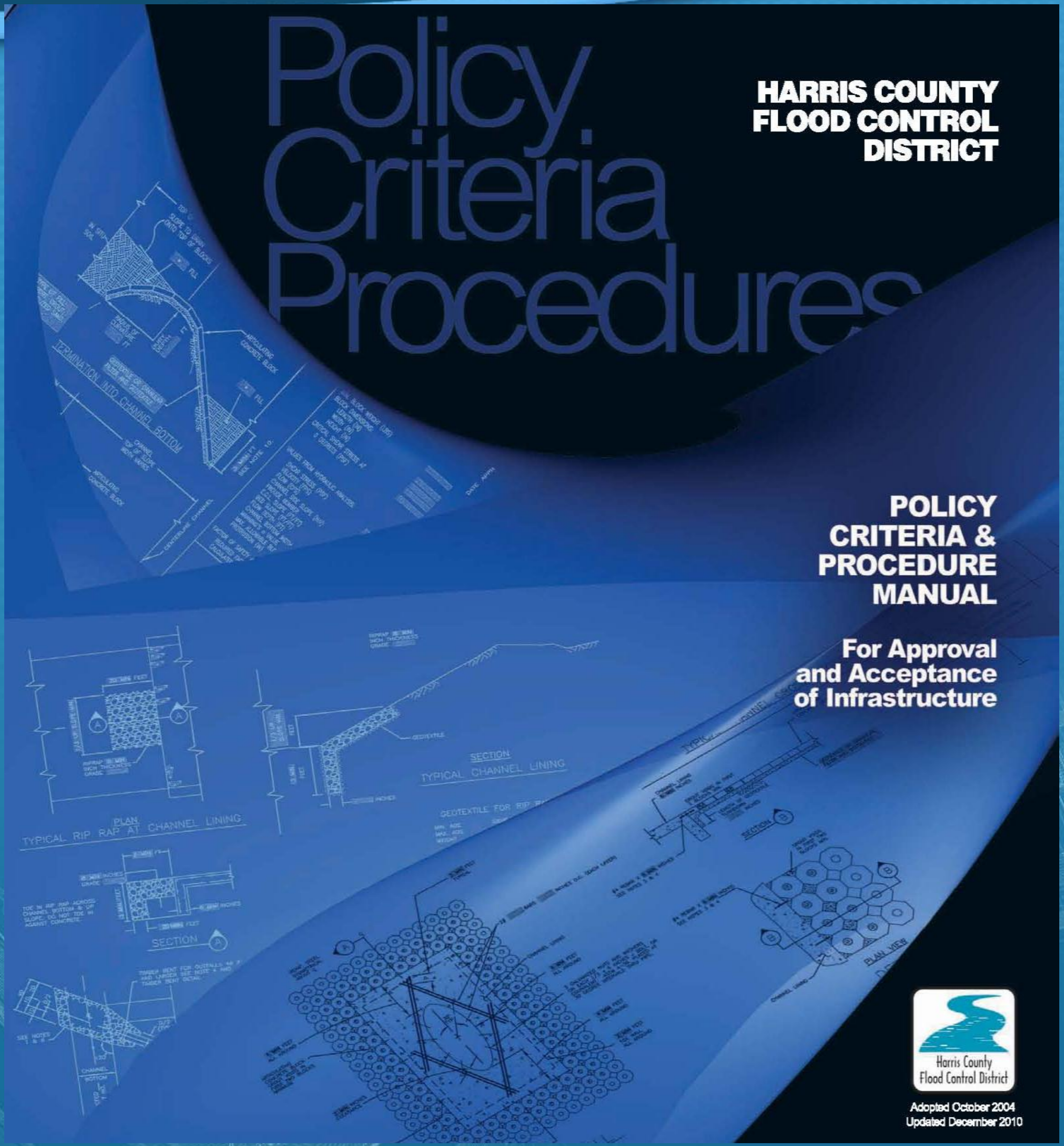
  b) Improve understanding of interaction of various components of drainage system

(3) Block B, specifically, addressed development of procedures to “evaluate the effects of changing from natural to urban conditions” (i.e., 10 to 640 acres).

(4) Block B, Preliminary Analysis, Result – Most statistical significant variable related to Urban Development is BDF, Basin Development Factor

(5) Block B, Final Analysis, Result – Method to determine Hydrology for Small Watersheds as functions of BDF and A (drainage area).

HCFCD Standard Hydrologic Methodology



Policy
Criteria
Procedures

HARRIS COUNTY
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POLICY
CRITERIA &
PROCEDURE
MANUAL

For Approval
and Acceptance
of Infrastructure

Harris County
Flood Control District

Adopted October 2004
Updated December 2010

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HCFCD Standard Hydrologic Methodology
--- Overview Summary ---

When Analysis required –

"Estimating peak discharges and routing flow hydrographs for existing and future conditions is necessary for the planning, analysis, and design of both new development and redevelopment and associated flood damage reduction facilities."

Computer Models –

"Current effective models use the HEC-HMS and HEC-RAS computer programs. Guidance for applying these programs is in the HCFCD Hydrology and Hydraulics Guidance Manual. "

Discharge Methodology –

Primarily depends on drainage area of project. HCFCD allows:

For Small areas Less than 640-acres – Site Runoff Curves

For Large areas Greater than 640-acres – Watershed Modeling

Limitations for use of Watershed Modeling –

- ○ Method only for areas with an open channel or major enclosed channel.
- ○ Results may not be valid for drainage areas less than 640 acres.
- ○ May be used where complexity of a project justifies a detailed analysis for a project drainage area greater than 300 acres and less than 640 acres.

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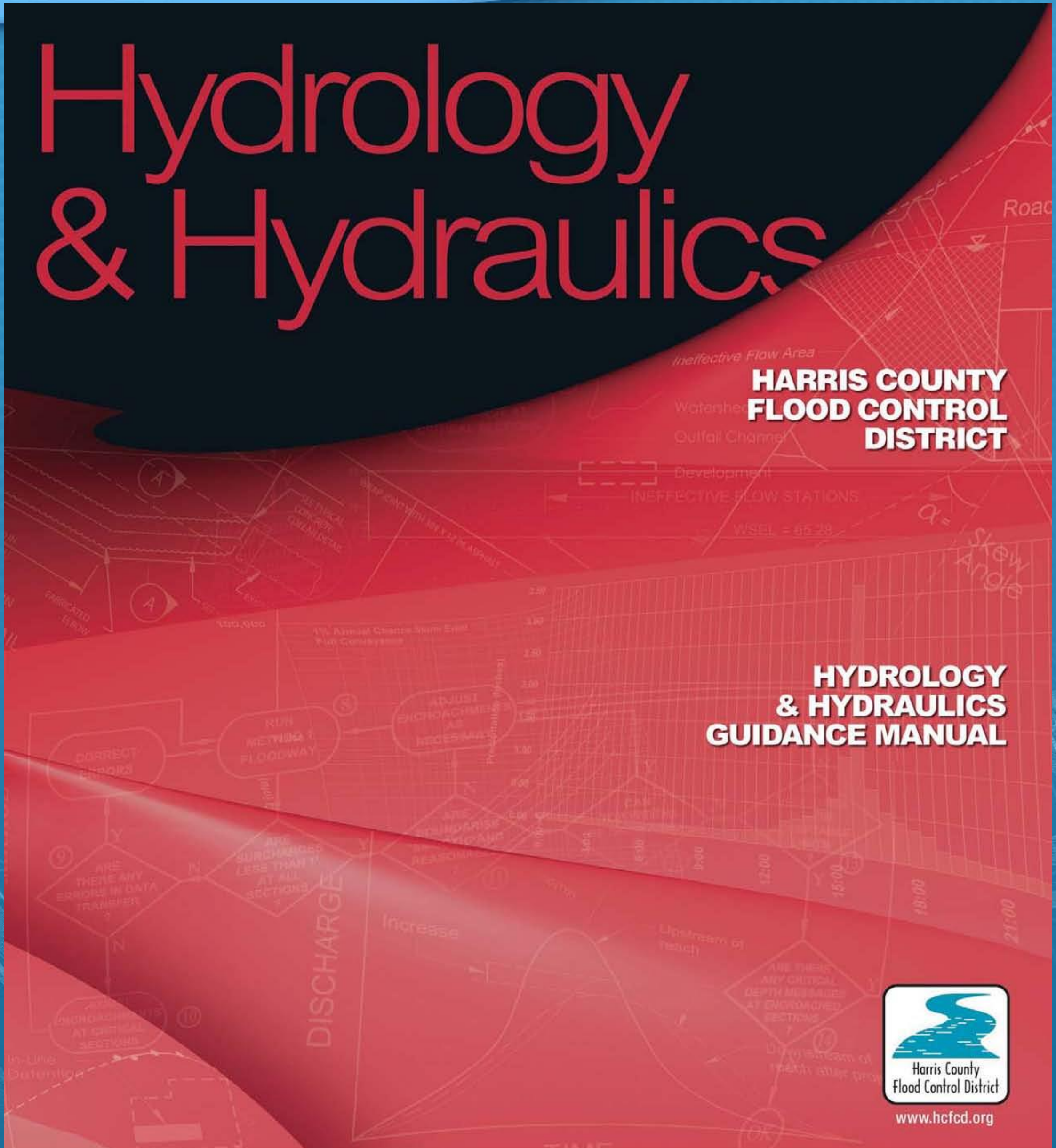
HCFCD Standard Hydrologic Methodology
--- Clark UH Application Summary ---



Hydrology & Hydraulics

HARRIS COUNTY
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HYDROLOGY
& HYDRAULICS
GUIDANCE MANUAL

Harris County
Flood Control District

www.hcfcd.org

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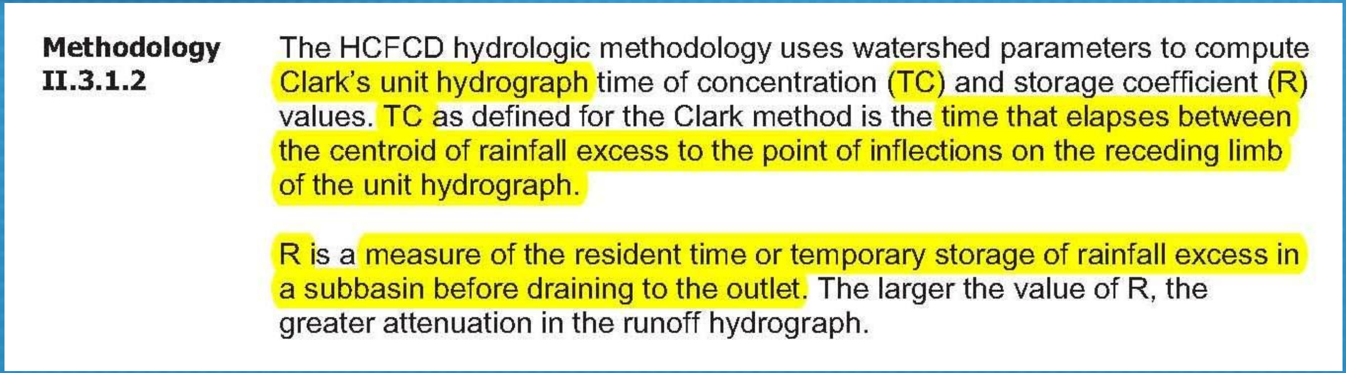
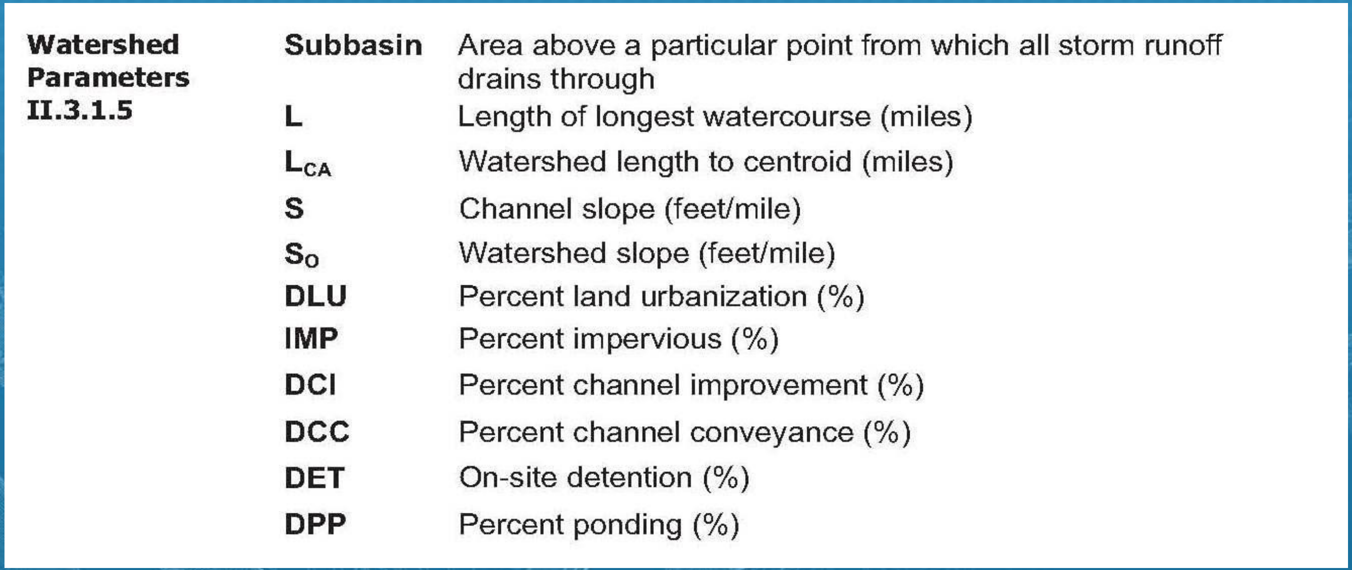


Methodology II.3.1.2

The HCFCD hydrologic methodology uses watershed parameters to compute Clark's unit hydrograph time of concentration (TC) and storage coefficient (R) values. TC as defined for the Clark method is the time that elapses between the centroid of rainfall excess to the point of inflections on the receding limb of the unit hydrograph.

R is a measure of the resident time or temporary storage of rainfall excess in a subbasin before draining to the outlet. The larger the value of R, the greater attenuation in the runoff hydrograph.



Watershed Parameters II.3.1.5

Subbasin	Area above a particular point from which all storm runoff drains through
L	Length of longest watercourse (miles)
L_{CA}	Watershed length to centroid (miles)
S	Channel slope (feet/mile)
S_O	Watershed slope (feet/mile)
DLU	Percent land urbanization (%)
IMP	Percent impervious (%)
DCI	Percent channel improvement (%)
DCC	Percent channel conveyance (%)
DET	On-site detention (%)
DPP	Percent ponding (%)

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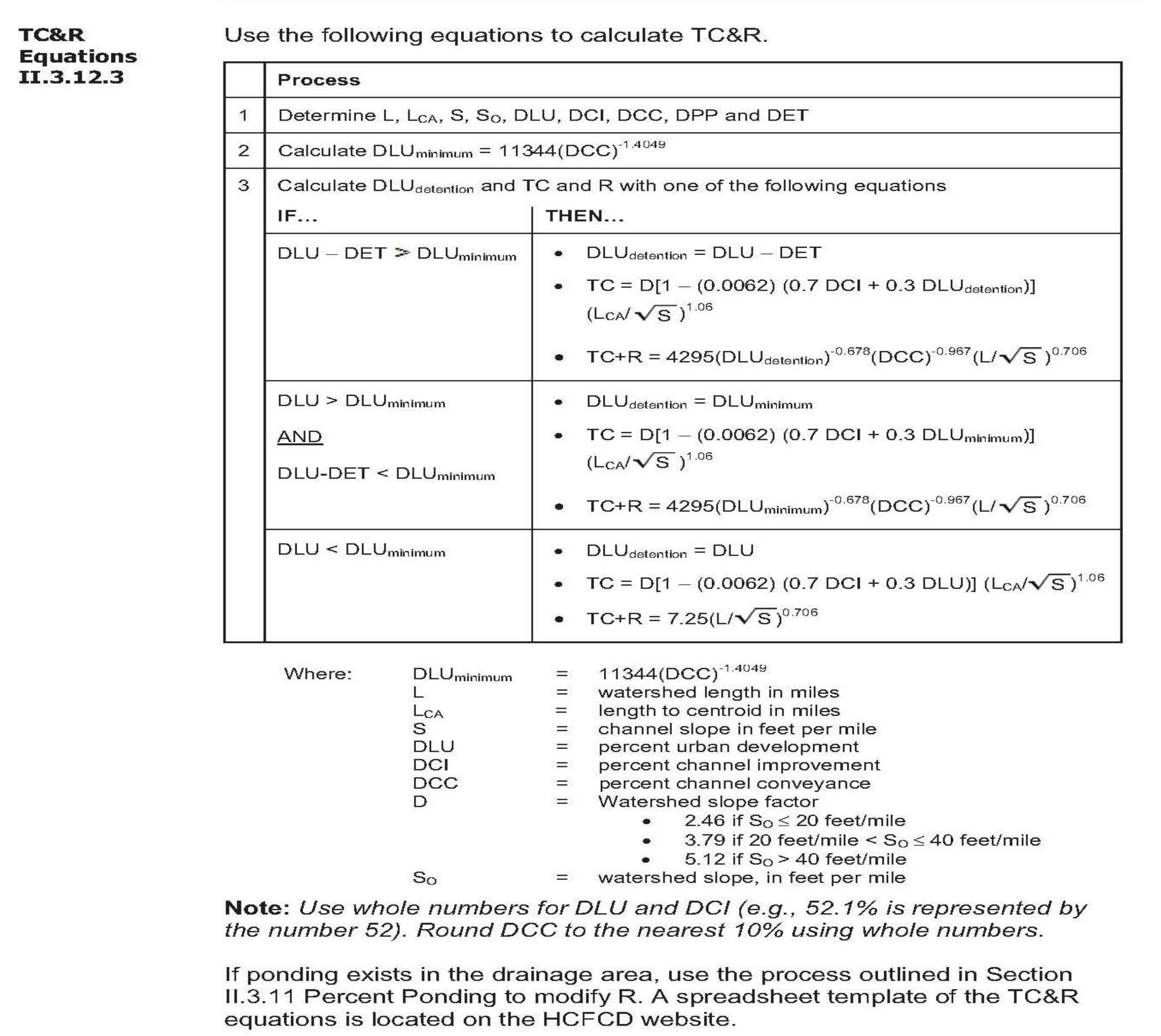

TC&R Equations II.3.12.3

Use the following equations to calculate TC&R.

	Process	
1	Determine L, L_{CA}, S, S_O, DLU, DCI, DCC, DPP and DET	
2	Calculate $DLU_{minimum} = 11344(DCC)^{-1.4049}$	
3	Calculate $DLU_{detention}$ and TC and R with one of the following equations	
	IF…	THEN…
	$DLU - DET \geq DLU_{minimum}$	• $DLU_{detention} = DLU - DET$ • $TC = D[1 - (0.0062)\ (0.7\ DCI + 0.3\ DLU_{detention})]\ (L_{CA}/\sqrt{S})^{1.06}$ • $TC+R = 4295(DLU_{detention})^{-0.678}(DCC)^{-0.967}(L/\sqrt{S})^{0.706}$
	$DLU > DLU_{minimum}$ AND $DLU\text{-}DET < DLU_{minimum}$	• $DLU_{detention} = DLU_{minimum}$ • $TC = D[1 - (0.0062)\ (0.7\ DCI + 0.3\ DLU_{minimum})]\ (L_{CA}/\sqrt{S})^{1.06}$ • $TC+R = 4295(DLU_{minimum})^{-0.678}(DCC)^{-0.967}(L/\sqrt{S})^{0.706}$
	$DLU < DLU_{minimum}$	• $DLU_{detention} = DLU$ • $TC = D[1 - (0.0062)\ (0.7\ DCI + 0.3\ DLU)]\ (L_{CA}/\sqrt{S})^{1.06}$ • $TC+R = 7.25(L/\sqrt{S})^{0.706}$

Where:
$DLU_{minimum}$ = $11344(DCC)^{-1.4049}$
L = watershed length in miles
L_{CA} = length to centroid in miles
S = channel slope in feet per mile
DLU = percent urban development
DCI = percent channel improvement
DCC = percent channel conveyance
D = Watershed slope factor
- 2.46 if $S_O \leq 20$ feet/mile
- 3.79 if 20 feet/mile $< S_O \leq 40$ feet/mile
- 5.12 if $S_O > 40$ feet/mile

S_O = watershed slope, in feet per mile

Note: *Use whole numbers for DLU and DCI (e.g., 52.1% is represented by the number 52). Round DCC to the nearest 10% using whole numbers.*

If ponding exists in the drainage area, use the process outlined in Section II.3.11 Percent Ponding to modify R. A spreadsheet template of the TC&R equations is located on the HCFCD website.

BDF, Basin Development Factor

Introduction –

Original--Sauer, V.B., Thomas, W.O., Stricker, V.A., and Wilson, K.V., 1983, Flood characteristics of urban watersheds in the United States: U.S. Geological Survey Water-Supply Paper 2207, 63p.

Based on 239-sites nationwide; 21 in Houston.

1st Houston study-- Liscum, Fred, 2001, Effects of urban development on stormwater runoff characteristics for the Houston, Texas, Metropolitan Area: U.S. Geological Survey Water Resources Investigations Report 01-4071, 35p.

Based on 42-sites in and around Harris County and a total of 1,089 storms.

Definition –

The Basin Development Factor is a simple measure of the extent to which a given watershed has been urbanized, especially in the context of drainage improvements that accompany urbanization.

- BDF -- "a measure of the extent of development of the drainage system in the basin."
- Increases in BDF reflect improvements in drainage systems that accompany urbanization.

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BDF, Basin Development Factor -- continued

Basics –

- **BDF Range: 0 → 12**
- **Watershed divided into thirds.**
- **Four (4) indices of Urbanization for each third**
    - ***Channel Improvements***
    - ***Channel linings***
    - ***Storm Sewers***
    - ***Curb & Gutter Streets***
- **Each Index = 0 or 1**
- **Maximum Value for a Third = 4**
- **Minimum Value for a Third = 0**
- **Total for All Thirds = BDF**

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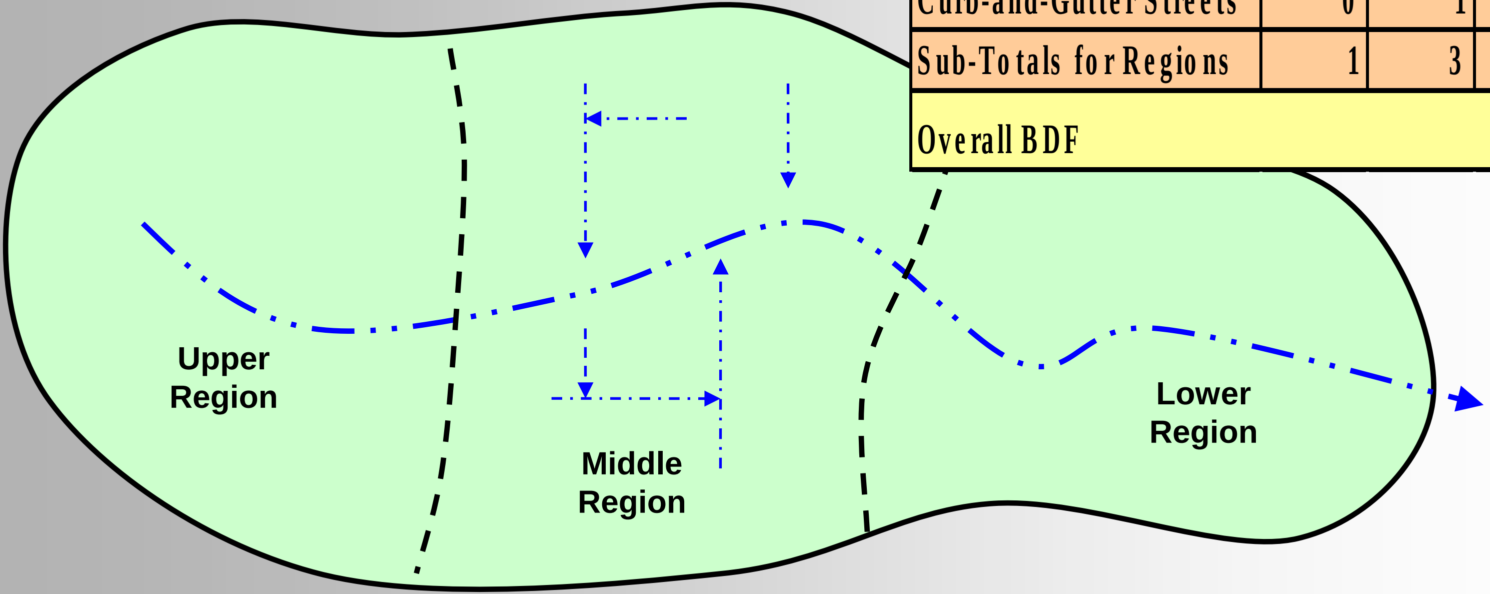
Example Determination of BDF



Index	Upper	Middle	Lower
Channel Improvements	1	1	0
Channel Linings	0	0	0
Storm Sewers	0	1	0
Curb-and-Gutter Streets	0	1	0
Sub-Totals for Regions	1	3	0
Overall BDF			4

Application of BDF within Harris County

Why ?

- ○ Straightforward Method
- ○ Reproducible Results
- ○ Statistically Significant
- ○ Well-Researched & Documented

Modifications --

- ○ Minimum Step size for index-value set to 0.5
- ○ Adjust index for old infrastructure & tailwater
- ○ Vary index with storm frequency
- ○ Dial method developed if want more sensitivity

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Quantifying BDF with Harris County modifications, 1 of 2

1) Channel Improvements.

Original --If channel improvements such as straightening, enlarging, deepening, and clearing are prevalent for the main drainage channels and principal tributaries, then a code of 1 is assigned. Otherwise, a code of 0 is assigned.

Modified -- *For small watersheds not served by a drainage channel, this factor is applied to arterial storm sewers or to the most significant collector ditches within roadside ditch systems. For areas with roadside ditch drainage in which this condition is satisfied, a code of 0.5 is used in lieu of the normal value of 1.*

2) Channel Linings.

Original -- If more than 50 percent of the length of the main drainage channel and principal tributaries has been lined with an impervious material such as concrete, a code of 1 is assigned. Otherwise, a code of 0 is assigned.

Modified -- *For small watersheds not served by a drainage channel, this factor is applied to trunk storm sewers or principal collector ditches within roadside ditch systems. For areas with roadside ditch drainage in which this condition is satisfied, a code of 0.5 is used in lieu of the normal value of 1.*

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Quantifying BDF with Harris County modifications, 2 of 2

3) Storm Sewers.

Original -- If more than 50 percent of the main channel and secondary tributaries are enclosed as storm sewers, a code of 1 is assigned. Otherwise, a code of 0 is assigned.

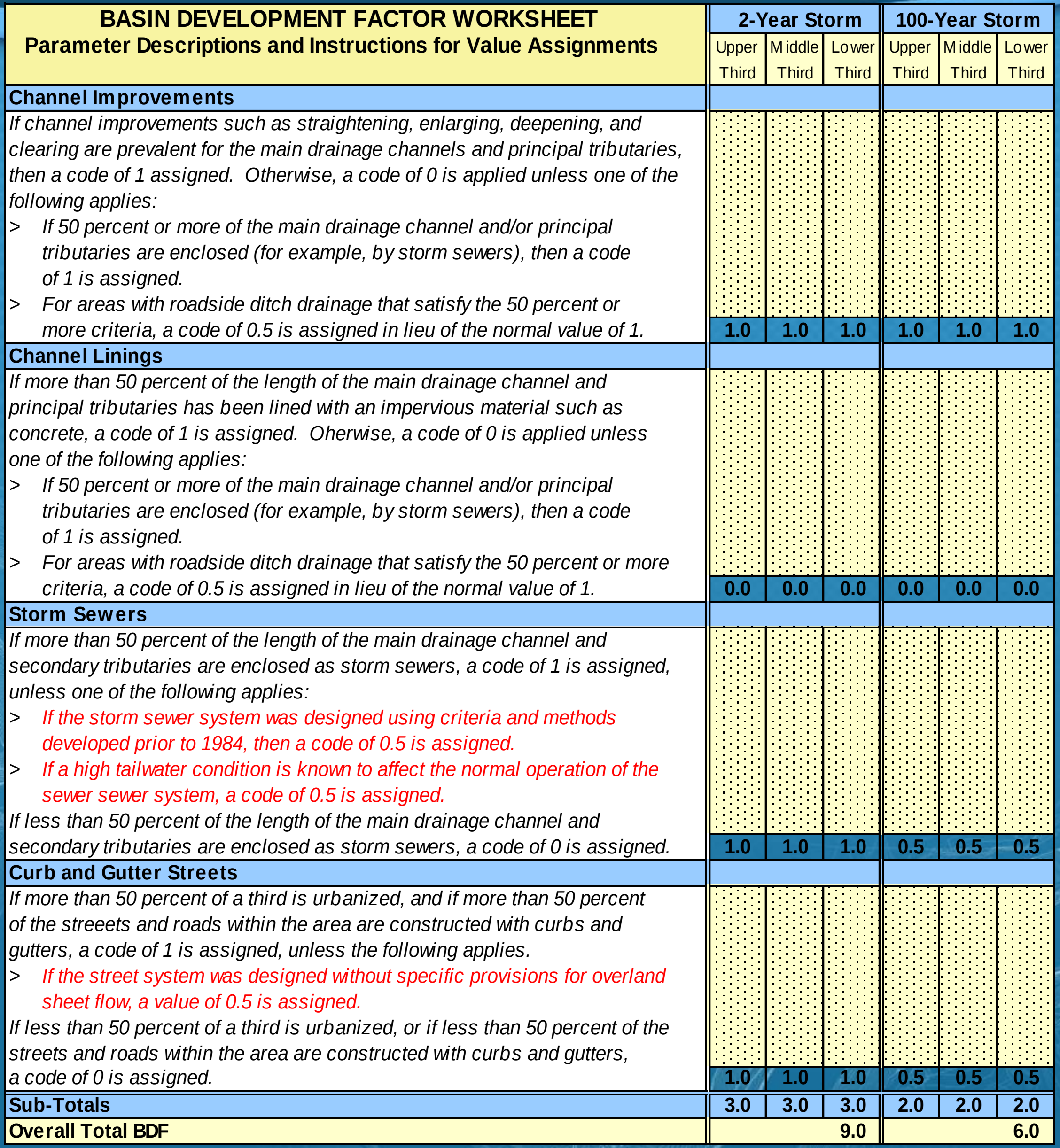
Modified -- *For small watersheds not served by a drainage channel, this factor is applied only to tributary drainage systems. For 10-year to 100-year storm events, if storm sewers were designed before 1984, or if high tailwater conditions are known to exist, a value of 0.5 is applied.*

4) Curb-and-Gutter Streets.

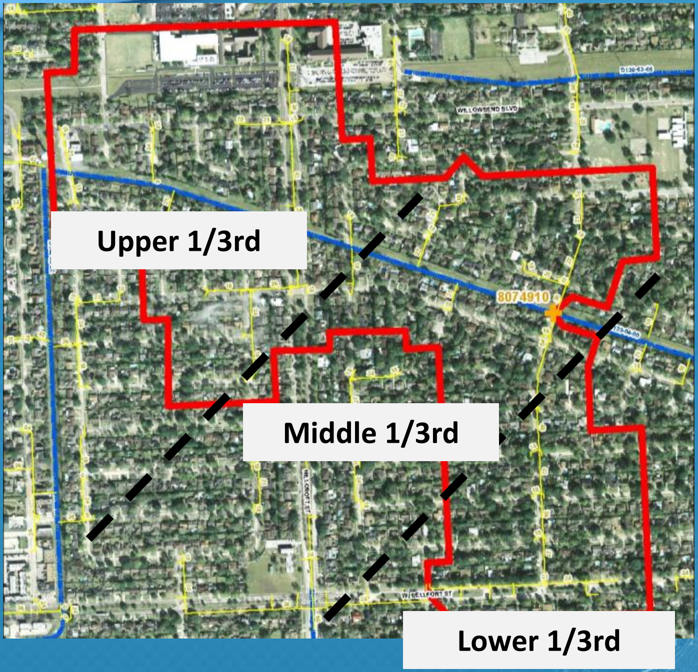
Original -- If more than 50 percent of a region is urbanized, and if more than 50 percent of the streets and roads within the area are constructed with curbs and gutters, a code of 1 is assigned to this index. Otherwise, a code of 0 is assigned.

Modified -- *If more than 50 percent of the streets and roads are constructed with curbs and gutters, but the streets were not designed with a positive slope to convey sheet flow, a value of 0.5 is assigned to this factor for 10-year to 100-year storm events.*

Example Determination of BDF using Modified Worksheet



BASIN DEVELOPMENT FACTOR WORKSHEET **Parameter Descriptions and Instructions for Value Assignments**	**2-Year Storm**			**100-Year Storm**		
	Upper Third	Middle Third	Lower Third	Upper Third	Middle Third	Lower Third
Channel Improvements						
If channel improvements such as straightening, enlarging, deepening, and clearing are prevalent for the main drainage channels and principal tributaries, then a code of 1 assigned. Otherwise, a code of 0 is applied unless one of the following applies: *> If 50 percent or more of the main drainage channel and/or principal tributaries are enclosed (for example, by storm sewers), then a code of 1 is assigned.* *> For areas with roadside ditch drainage that satisfy the 50 percent or more criteria, a code of 0.5 is assigned in lieu of the normal value of 1.*	1.0	1.0	1.0	1.0	1.0	1.0
Channel Linings						
If more than 50 percent of the length of the main drainage channel and principal tributaries has been lined with an impervious material such as concrete, a code of 1 is assigned. Oherwise, a code of 0 is applied unless one of the following applies: *> If 50 percent or more of the main drainage channel and/or principal tributaries are enclosed (for example, by storm sewers), then a code of 1 is assigned.* *> For areas with roadside ditch drainage that satisfy the 50 percent or more criteria, a code of 0.5 is assigned in lieu of the normal value of 1.*	0.0	0.0	0.0	0.0	0.0	0.0
Storm Sewers						
If more than 50 percent of the length of the main drainage channel and secondary tributaries are enclosed as storm sewers, a code of 1 is assigned, unless one of the following applies: *> If the storm sewer system was designed using criteria and methods developed prior to 1984, then a code of 0.5 is assigned.* *> If a high tailwater condition is known to affect the normal operation of the sewer sewer system, a code of 0.5 is assigned.* *If less than 50 percent of the length of the main drainage channel and secondary tributaries are enclosed as storm sewers, a code of 0 is assigned.*	1.0	1.0	1.0	0.5	0.5	0.5
Curb and Gutter Streets						
If more than 50 percent of a third is urbanized, and if more than 50 percent of the streeets and roads within the area are constructed with curbs and gutters, a code of 1 is assigned, unless the following applies. *> If the street system was designed without specific provisions for overland sheet flow, a value of 0.5 is assigned.* *If less than 50 percent of a third is urbanized, or if less than 50 percent of the streets and roads within the area are constructed with curbs and gutters, a code of 0 is assigned.*	1.0	1.0	1.0	0.5	0.5	0.5
Sub-Totals	3.0	3.0	3.0	2.0	2.0	2.0
Overall Total BDF			9.0			6.0



This worksheet was developed for determining BDF values for 2-year and 100-year storm events. The red type indicates conditions considered only for a 100-year event.

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Applying BDF to Determine Clark UH Parameters

Results from FloodWise –

Final report as reference:

Asquith, W.H., Cleveland, T.G., and Roussel, M.C., 2011, A method for estimating peak and time of peak streamflow from excess rainfall for 10- to 640-acre watersheds in the Houston, Texas, metropolitan area: U.S. Geological Survey Scientific Investigations Report 2011-5104, 38 p.

Based on 24-sites in and around Harris County and a total of 317 storms.

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USGS
science for a changing world

Prepared in cooperation with the Harris County Flood Control District and the Texas Department of Transportation

A Method for Estimating Peak and Time of Peak Streamflow from Excess Rainfall for 10- to 640-Acre Watersheds in the Houston, Texas, Metropolitan Area

Scientific Investigations Report 2011–5104

U.S. Department of the Interior
U.S. Geological Survey

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Significant Findings from Asquith:

Defined a Gamma Function Unit Hydrograph to compute flow rates.

Where Unit Hydrograph Volume : $V = q_p T_p \Gamma(K)(e^{(l)}/K)^{K}$

Unit Hydrograph Peak : $q_p = 10^{-0.02682BDF - 0.5789\log_{10}A - 0.6575}$

Time to UHG Peak : $T_p = 10^{-0.03421BDF + 0.3936\log_{10}A + 0.1745}$

Also, defined Lag Time : $T_r = 10^{-0.05288BDF + 0.4028\log_{10}A + 0.3926}$

Time of Concentration : $T_c = T_r + (A^{0.5}/2)$

Analysis of Data within FloodWise:

Clark Storage Coefficient : $R = 8.27\, e^{-0.1167*BDF}\, A^{0.3856}$

Applying BDF to Determine Clark UH Parameters

Steps to Determine and Test Clark's TC & R using BDF –

(1) Select Watersheds to Test

(2) Select Methods to determine BDF for each Subarea

(3) Compute Clark's TC and R for each BDF-method using

$TC = f(T_r , A)$ and derived equation for R

(4) Run HMS and view Results versus Effective HMS run

(5) What did we learn ----

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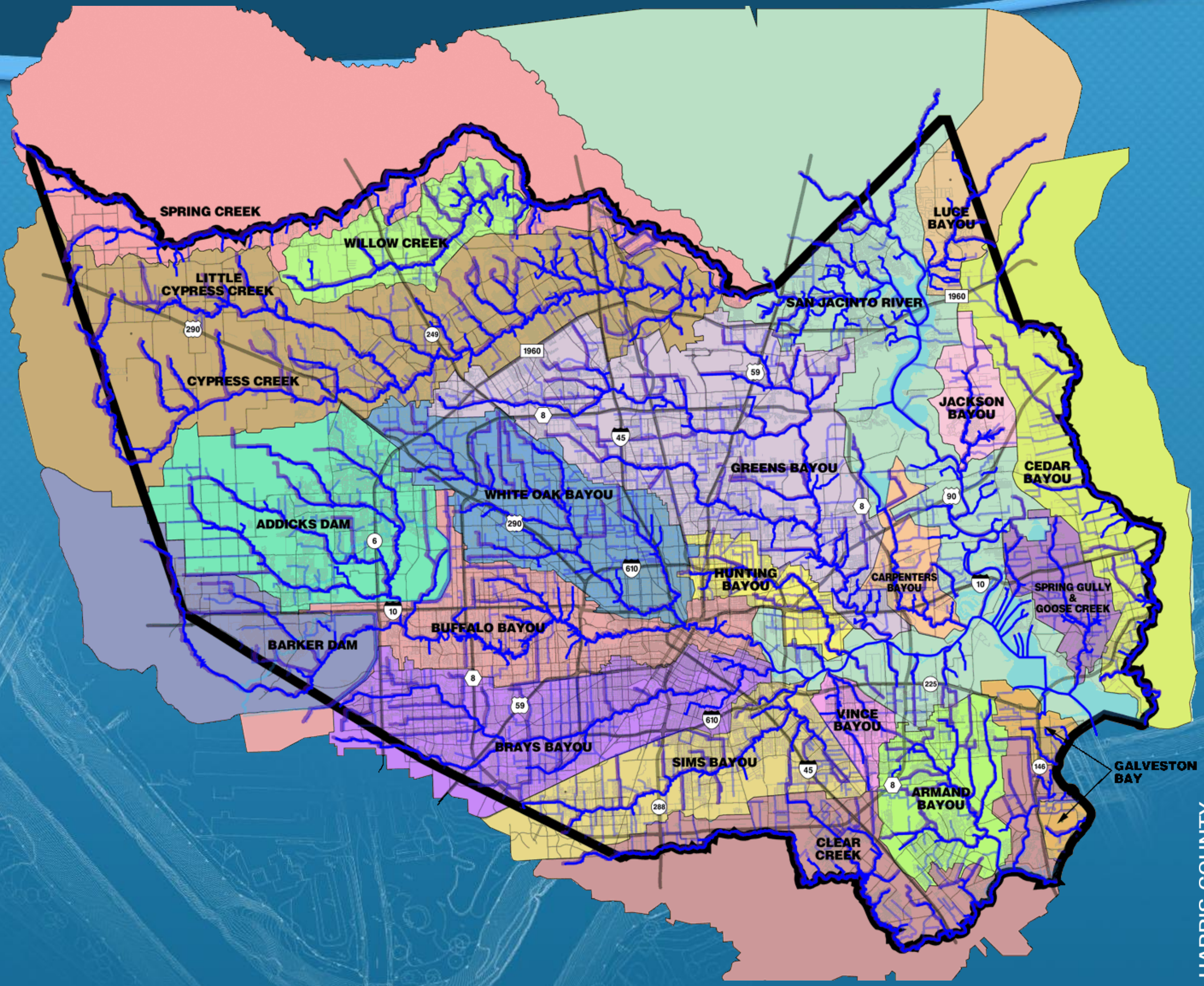
Applying BDF to Determine Clark UH Parameters

Steps to Determine and Test Clark's TC & R using BDF –

(1) Select Watersheds to Test

- Greens Bayou
- White Oak Bayou

Harris County Watersheds



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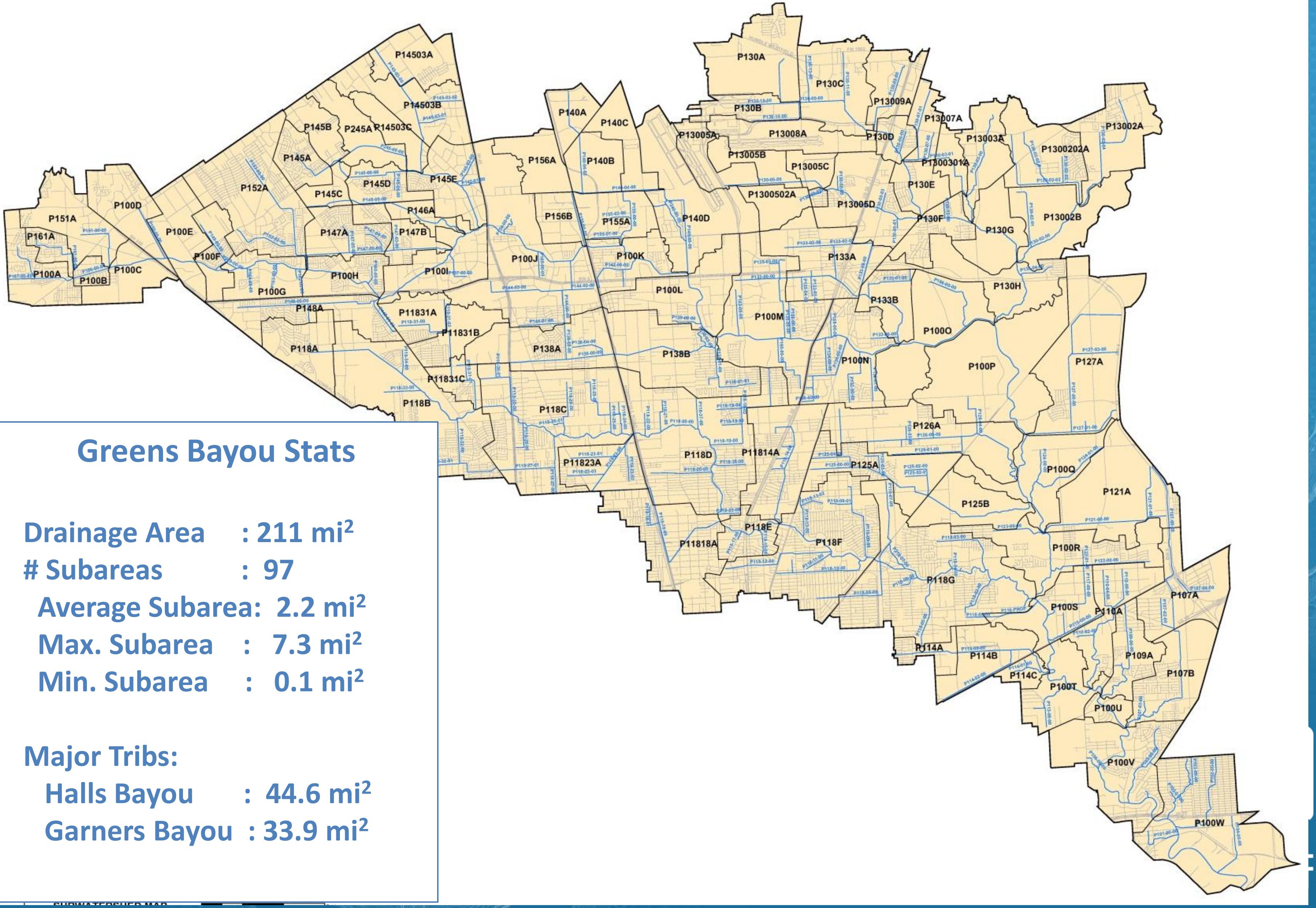
Greens Bayou Watershed



Greens Bayou Stats

Drainage Area : 211 mi^2

Subareas : 97

Average Subarea: 2.2 mi^2

Max. Subarea : 7.3 mi^2

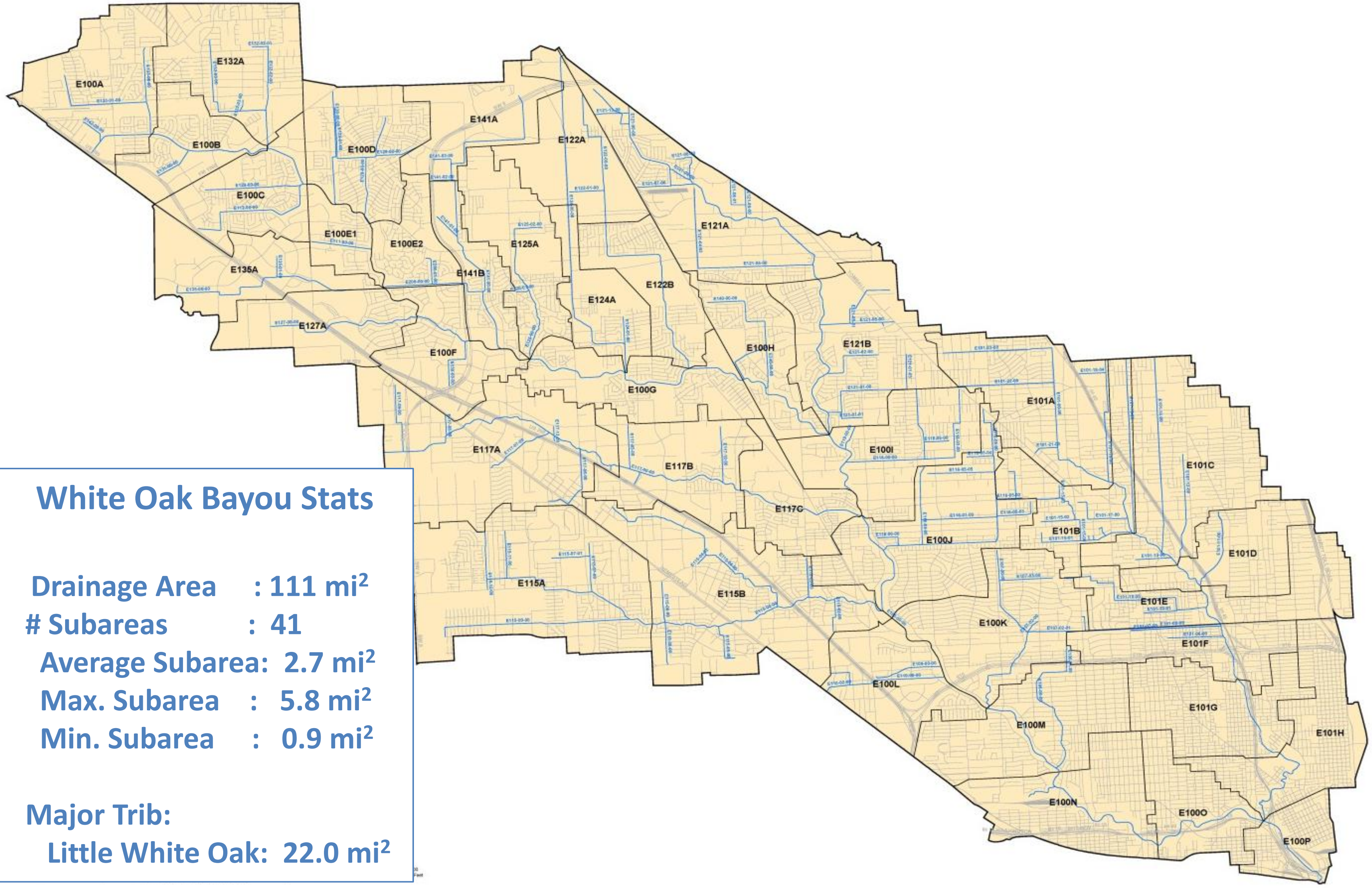
Min. Subarea : 0.1 mi^2

Major Tribs:

Halls Bayou : 44.6 mi^2

Garners Bayou : 33.9 mi^2

White Oak Bayou Watershed



White Oak Bayou Stats

Drainage Area : 111 mi^2
Subareas : 41
Average Subarea: 2.7 mi^2
Max. Subarea : 5.8 mi^2
Min. Subarea : 0.9 mi^2

Major Trib:
Little White Oak: 22.0 mi^2

Applying BDF to Determine Clark UH Parameters

Steps to Determine and Test Clark's TC & R using BDF –

(1) Select Watersheds to Test

Greens Bayou

White Oak Bayou

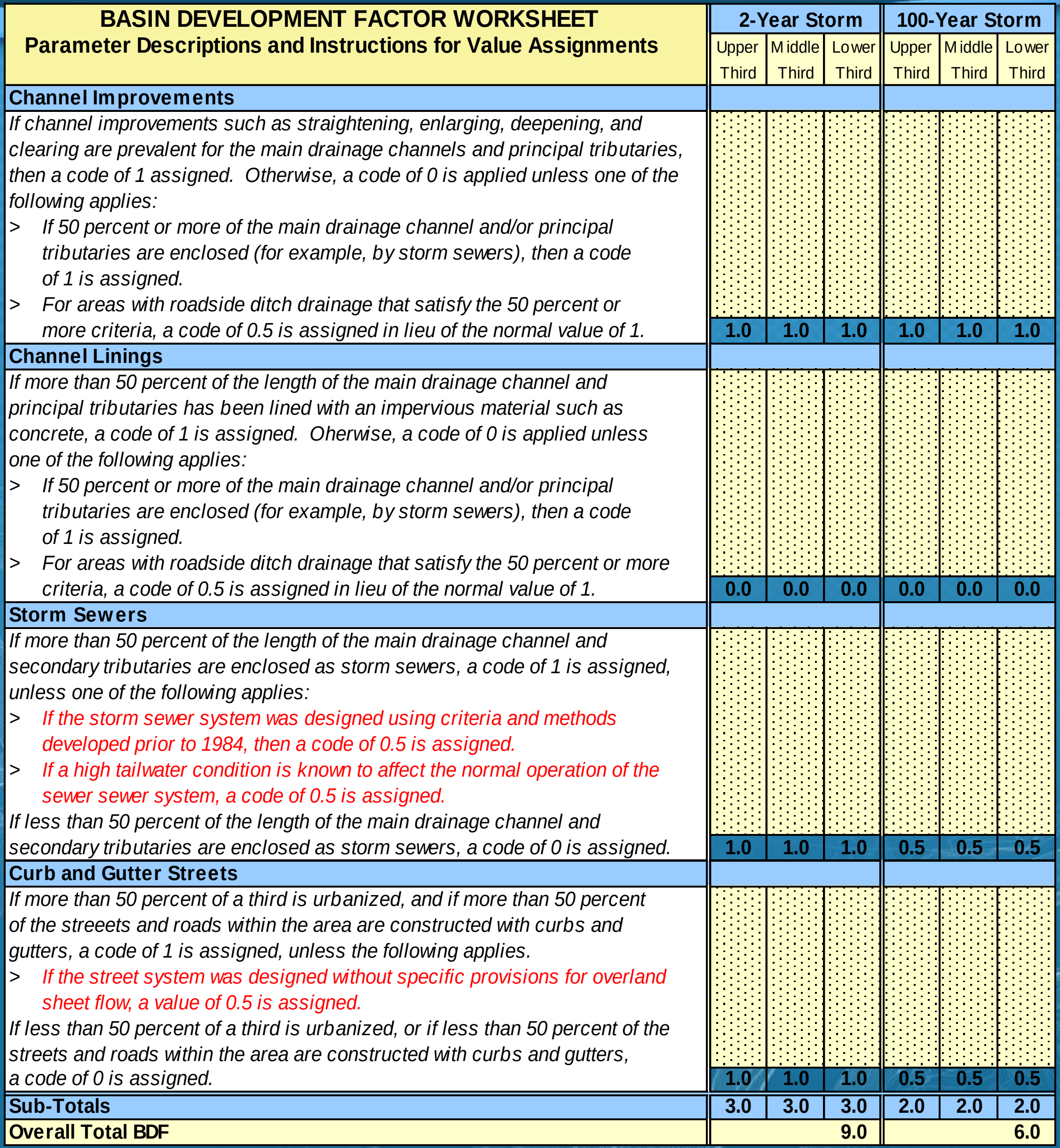
(2) Select Method to determine BDF for each Subarea

Step Method

Use Equation BDF=f(DLU, DCI, and DCL)

BDF = ((6 DLU) + (3 DCI) + (3 DCL))/100

Step Method for Determining BDF



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Channel Linings						
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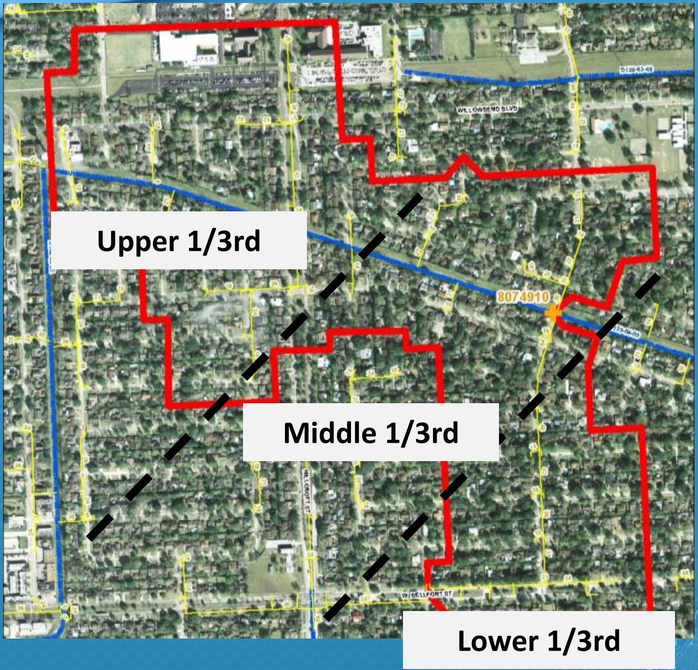

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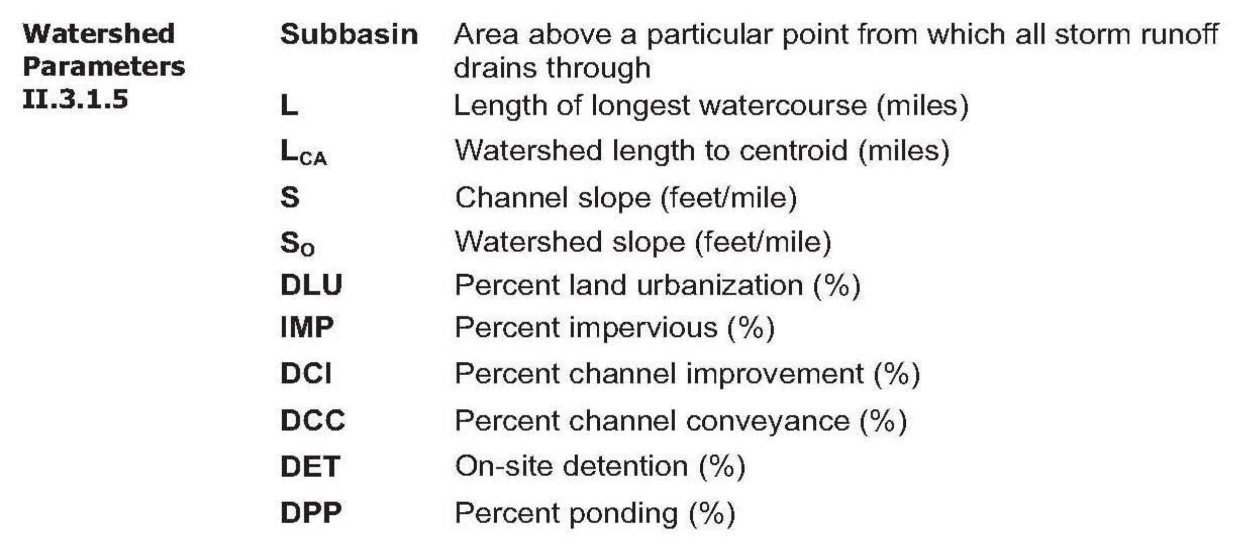
Linking HCFCD Standard Hydrologic Methodology to equation to predict BDF

$$BDF = ((6\ DLU) + (3\ DCI) + (3\ DCL))/100$$



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Steps to Determine and Test Clark's TC & R using BDF –

(1) Select Watersheds to Test

Greens Bayou

White Oak Bayou

(2) Select Method to determine BDF for each Subarea

Step Method

Use Equation BDF=f(DLU, DCI, and DCL)

$BDF = ((6\ DLU) + (3\ DCI) + (3\ DCL))/100$

(3) Compute Clark's TC and R for each BDF-method using

$TC = f(T_r, A)$ and derived equation for R

where $T_r = 10^{-0.05288BDF + 0.4028\log_{10} A + 0.3926}$

and $T_c = T_r + (A^{0.5}/2)$

$R = 8.27\ e^{-0.1167\ BDF}\ A^{0.3856}$

(4) Run HMS and view Results versus Effective HMS run

(5) What did we learn ----

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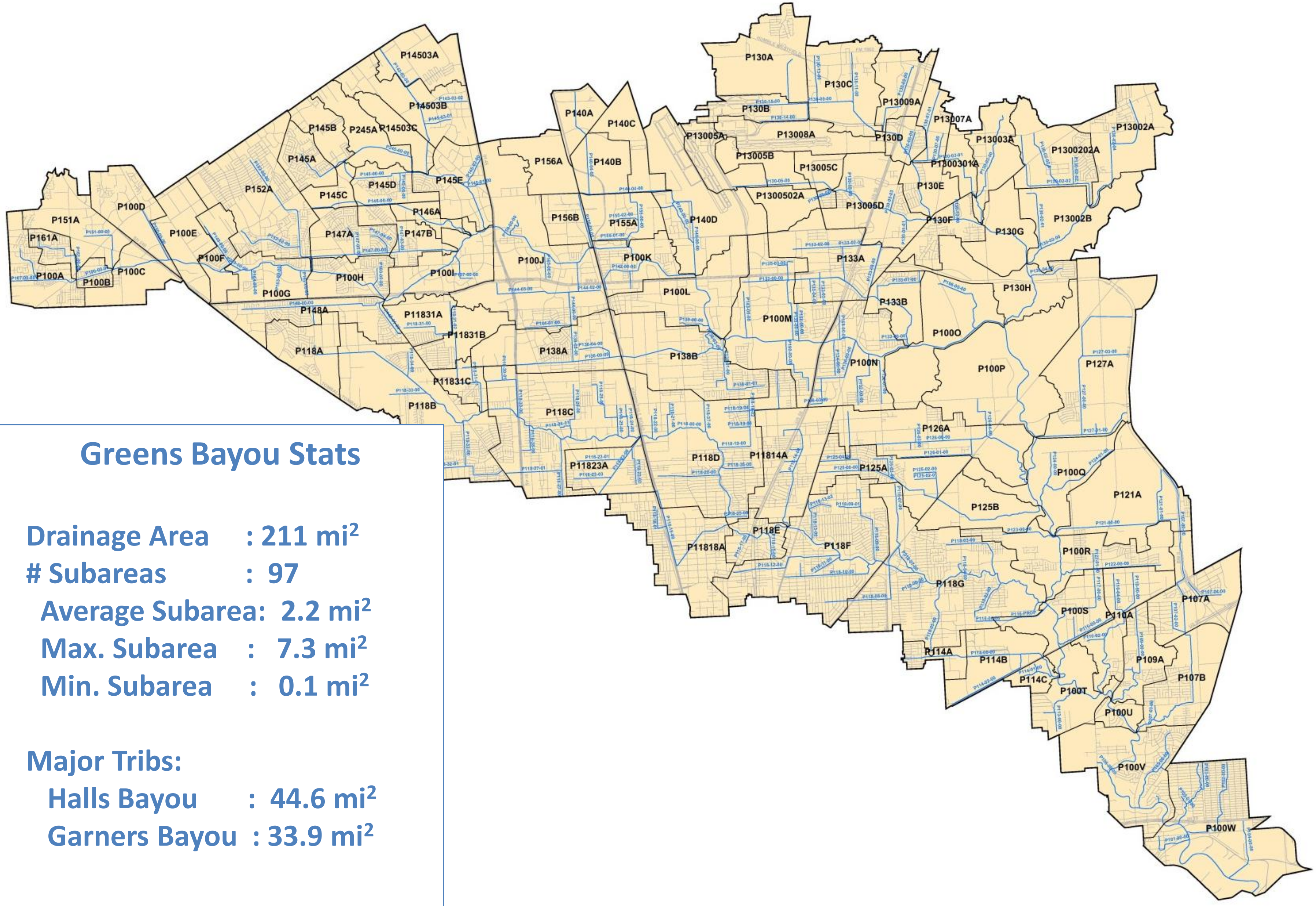
Greens Bayou Watershed



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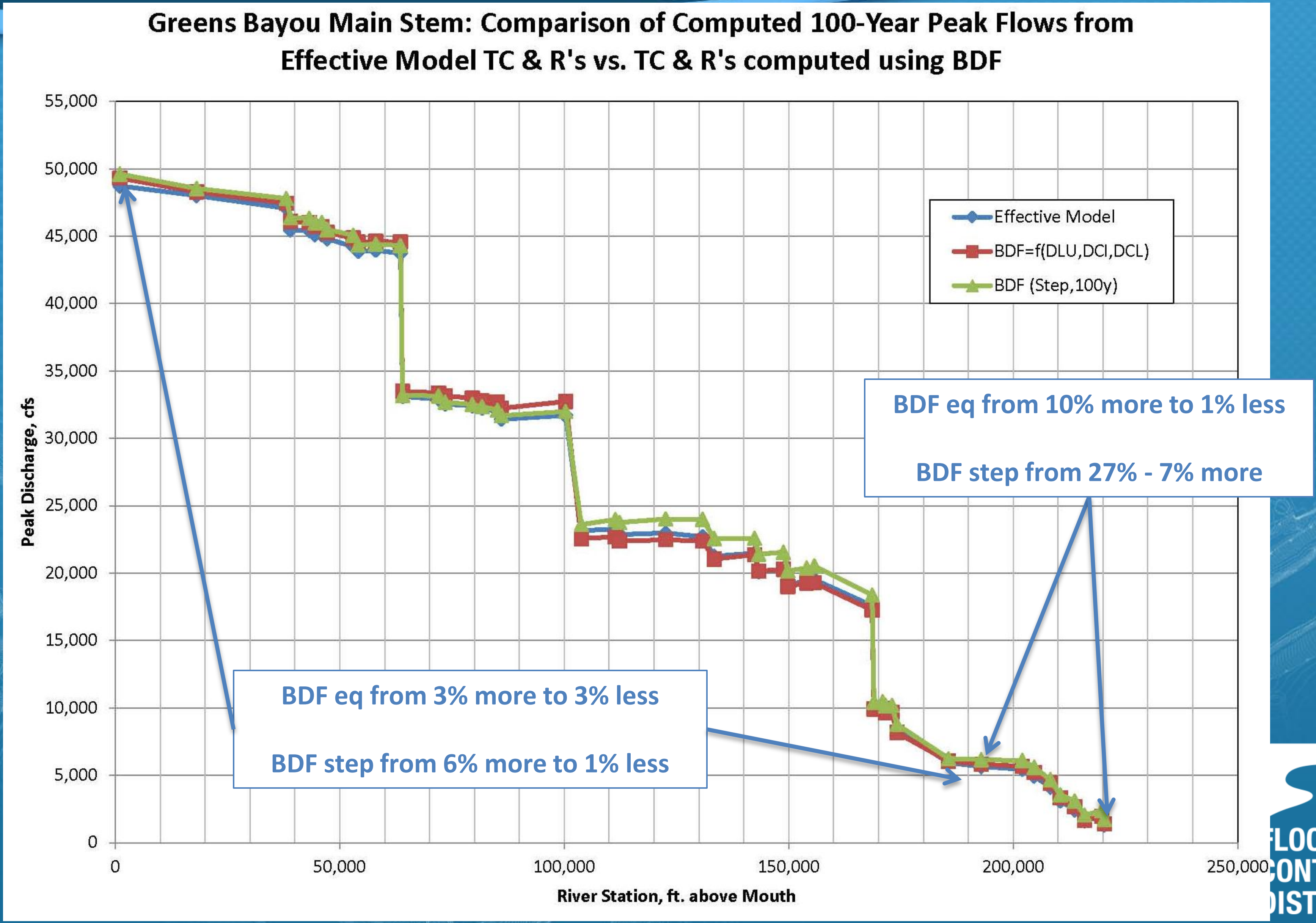
Halls Bayou : 44.6 mi^2
Garners Bayou : 33.9 mi^2

Test Results – Greens Bayou Main Stem



Greens Bayou Main Stem: Comparison of Computed 100-Year Peak Flows from Effective Model TC & R's vs. TC & R's computed using BDF

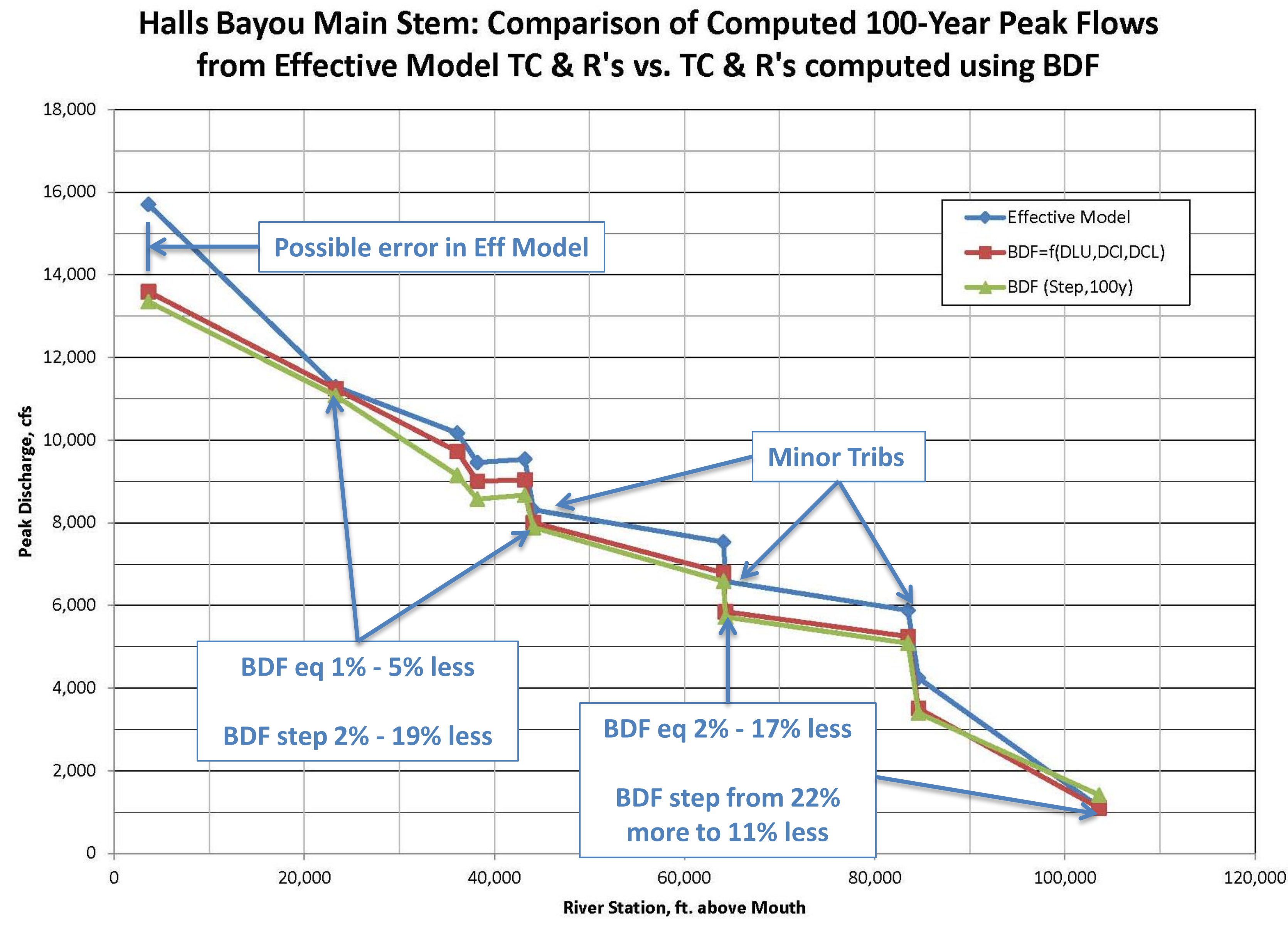
BDF eq from 10% more to 1% less

BDF step from 27% - 7% more

BDF eq from 3% more to 3% less

BDF step from 6% more to 1% less

Test Results – Halls Bayou Main Stem



Possible error in Eff Model

Minor Tribs

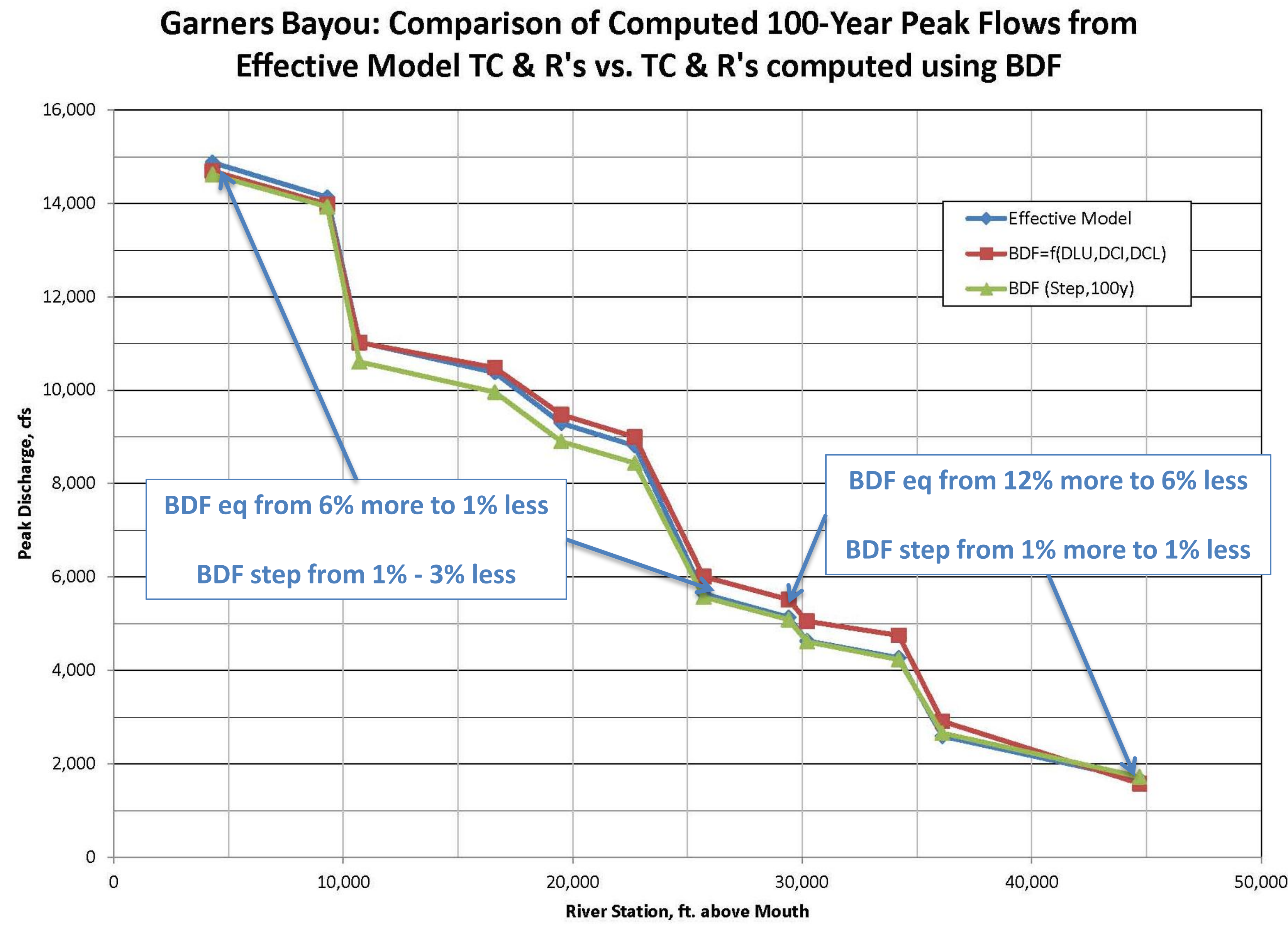
BDF eq 1% - 5% less

BDF step 2% - 19% less

BDF eq 2% - 17% less

BDF step from 22% more to 11% less

Test Results – Garners Bayou



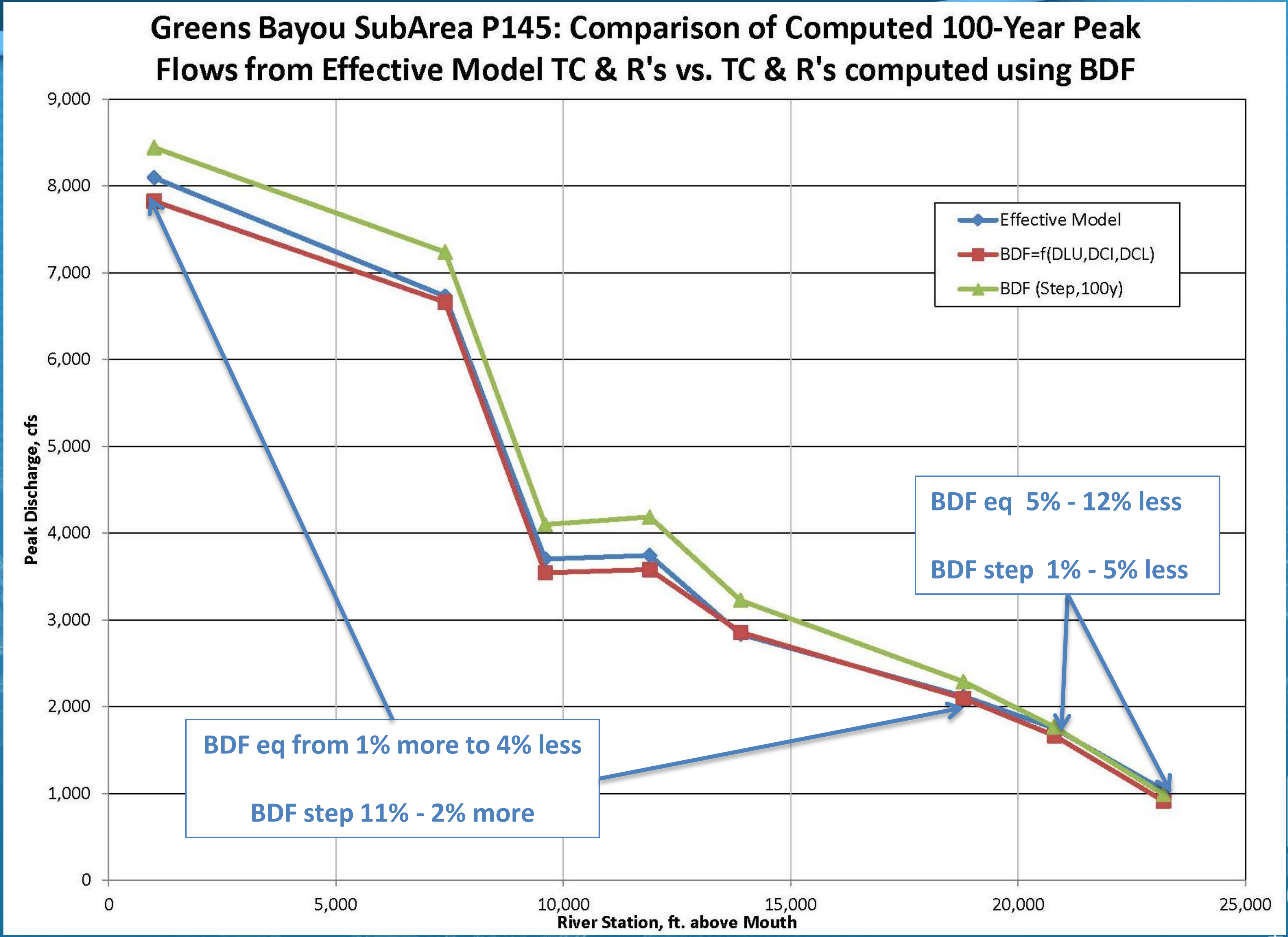
BDF eq from 6% more to 1% less

BDF step from 1% - 3% less

BDF eq from 12% more to 6% less

BDF step from 1% more to 1% less

Test Results – Greens Bayou SubArea P145



Greens Bayou SubArea P145: Comparison of Computed 100-Year Peak Flows from Effective Model TC & R's vs. TC & R's computed using BDF

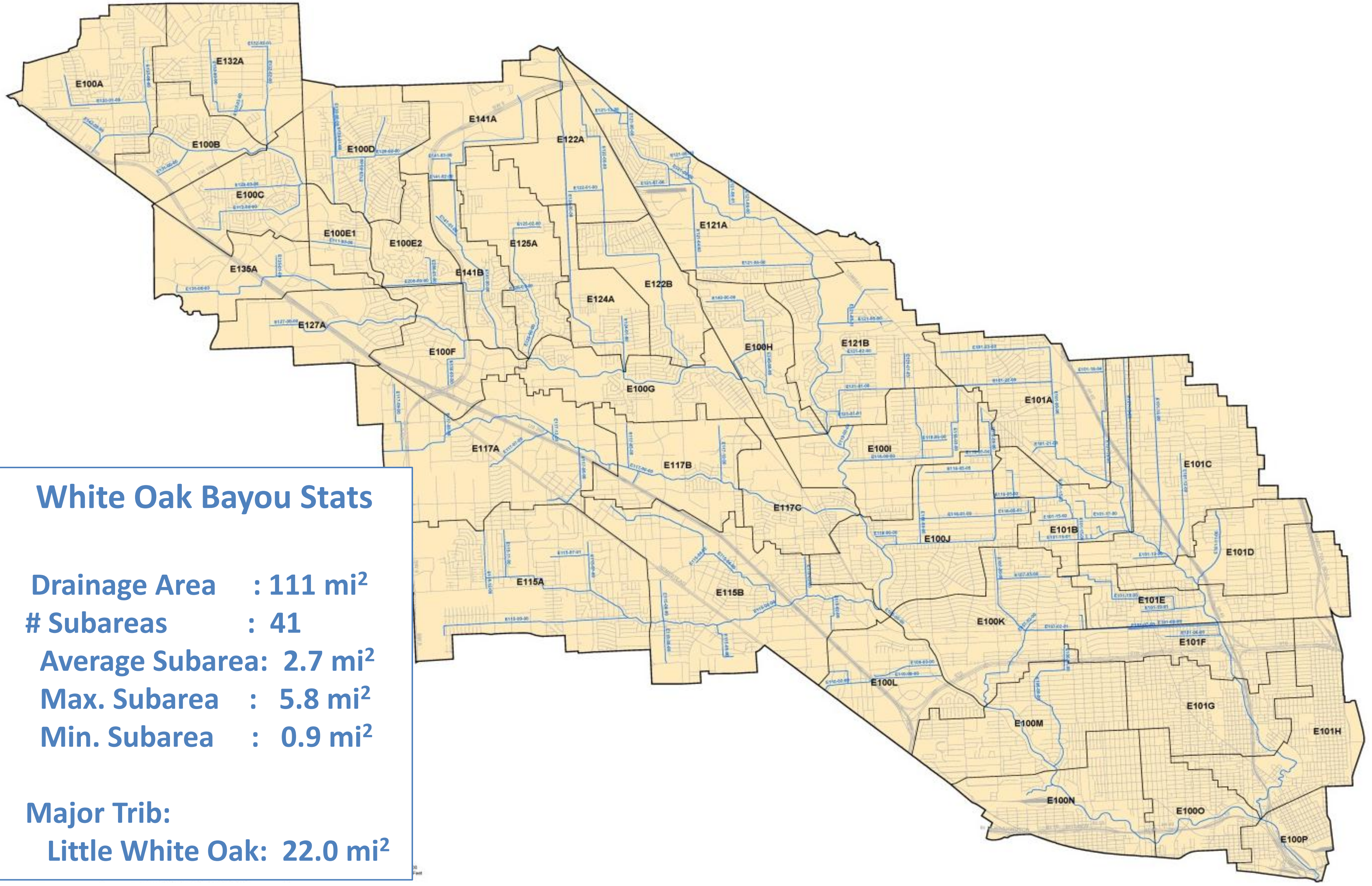
BDF eq 5% - 12% less

BDF step 1% - 5% less

BDF eq from 1% more to 4% less

BDF step 11% - 2% more

White Oak Bayou Watershed

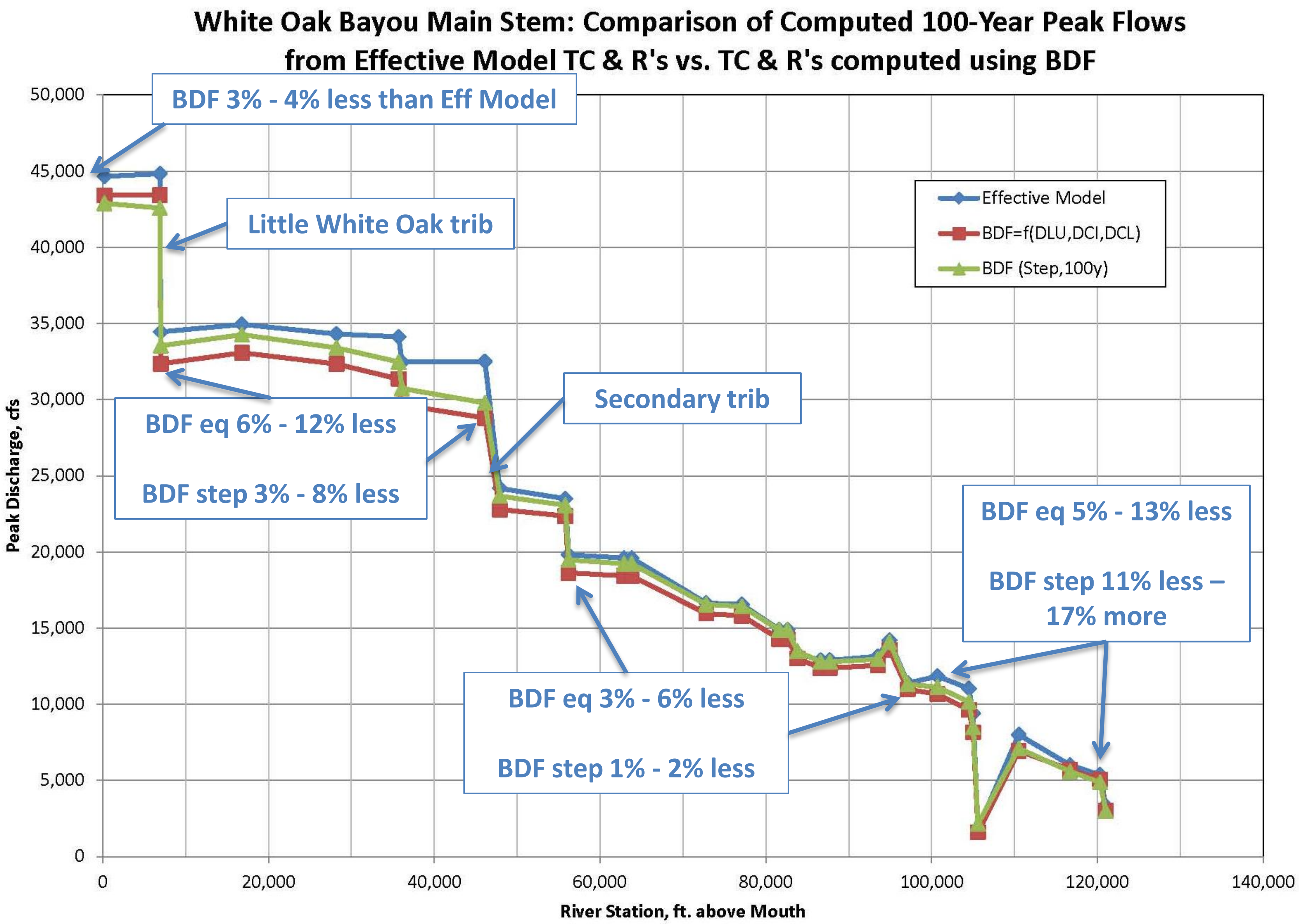


White Oak Bayou Stats

Drainage Area : 111 mi^2
Subareas : 41
Average Subarea: 2.7 mi^2
Max. Subarea : 5.8 mi^2
Min. Subarea : 0.9 mi^2

Major Trib:
Little White Oak: 22.0 mi^2

Test Results – White Oak Bayou Main Stem



White Oak Bayou Main Stem: Comparison of Computed 100-Year Peak Flows from Effective Model TC & R's vs. TC & R's computed using BDF

BDF 3% - 4% less than Eff Model

Little White Oak trib

BDF eq 6% - 12% less

BDF step 3% - 8% less

Secondary trib

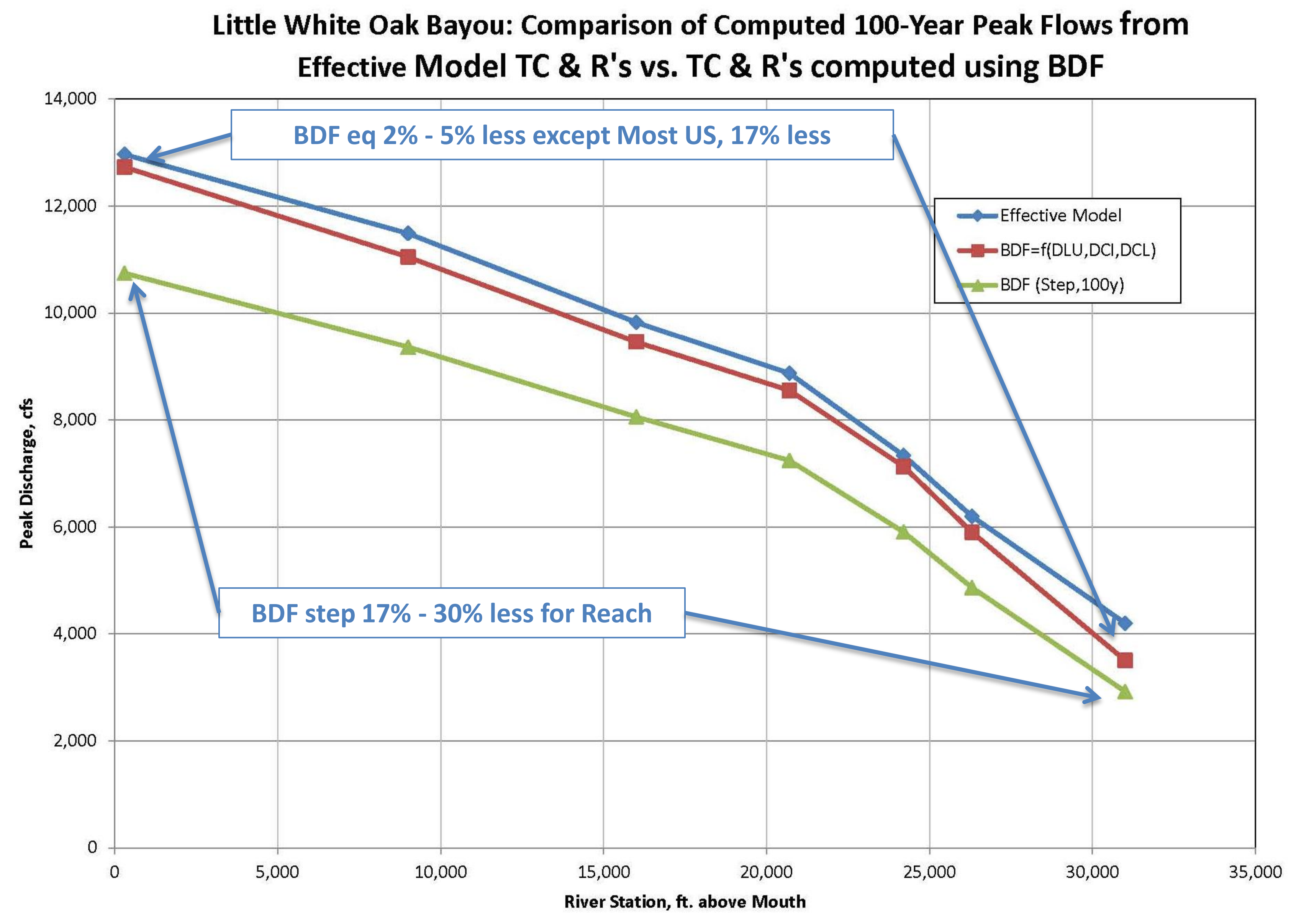
BDF eq 5% - 13% less

BDF step 11% less – 17% more

BDF eq 3% - 6% less

BDF step 1% - 2% less

Test Results – Little White Oak Bayou

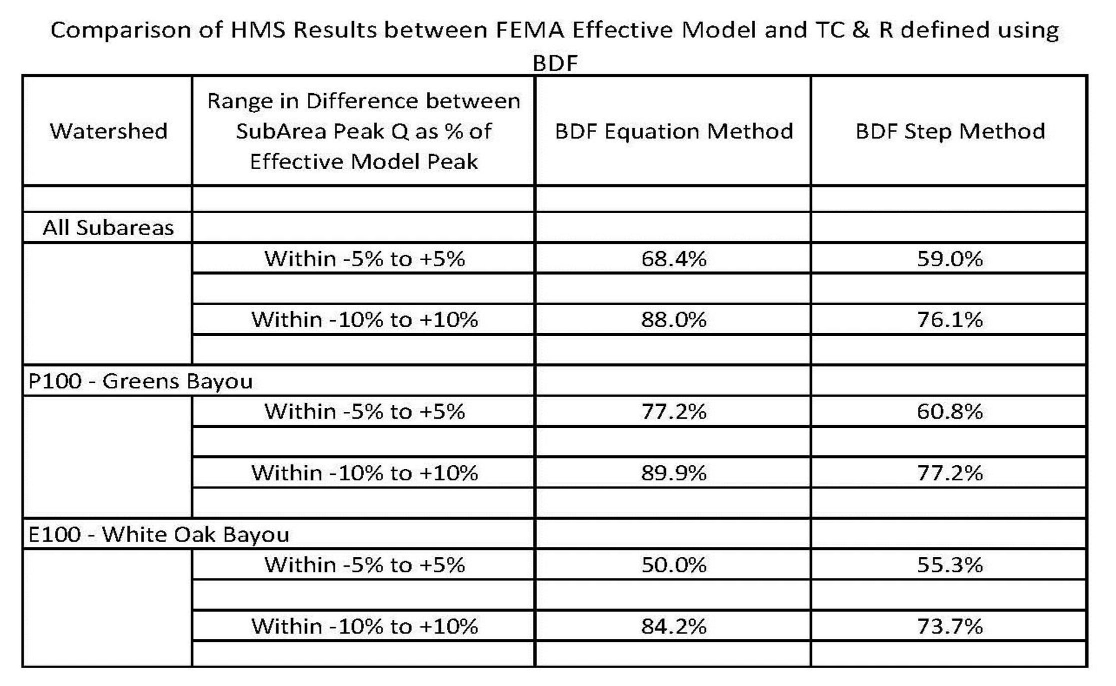


BDF eq 2% - 5% less except Most US, 17% less

BDF step 17% - 30% less for Reach

Applying BDF to Determine Clark UH Parameters

Summary of Results



Comparison of HMS Results between FEMA Effective Model and TC & R defined using BDF

Watershed	Range in Difference between SubArea Peak Q as % of Effective Model Peak	BDF Equation Method	BDF Step Method
All Subareas			
	Within -5% to +5%	68.4%	59.0%
	Within -10% to +10%	88.0%	76.1%
P100 - Greens Bayou			
	Within -5% to +5%	77.2%	60.8%
	Within -10% to +10%	89.9%	77.2%
E100 - White Oak Bayou			
	Within -5% to +5%	50.0%	55.3%
	Within -10% to +10%	84.2%	73.7%

(1) Use of BDF, regardless of method, produces reasonably values of TC & R.

(2) The BDF Equation Method gave slightly better results than the Step method.

(3) The BDF Step Method tended to give worse results in the Head Waters .

(4) Results for Greens Bayou (P100) were slightly better than those for White Oak (E100).

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Applying BDF to Determine Clark UH Parameters

Conclusions

(1) BDF can be used to define Clark UH parameters in flat basins

(2) BDF should not be used if Ponding or presences of Detention-basins need to be considered.

(3) The impact of higher slopes (both channel and overland) on BDF needs to be investigated. Preliminary studies on Upper Cypress shows higher slopes cause a problem using BDF as currently defined.

(4) BDF produced values of TC & R's tended to result in lower Qs than the Effective Models and should not be applied for mapping purposes. This was especially true for White Oak where 100% of subareas had lower Qs using the BDF Equation method, and 95% of subareas, lower Qs using the BDF Step method.

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Determination of Stream Flows for Unstudied Watersheds

?????? QUESTIONS ??????

Application of BDF to determine Clark Unit Hydrograph parameters

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References

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