Evaluation of Gage Based Cross Section Data to Represent Habitat Conditions for Riverine Resources at the Reach Level

Prepared for:

The Texas Water Development Board

Contract: 1004831143

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May 10, 2015

Acknowledgments

Funding for this project was provided by the Texas Water Development Board contract No. 1004831143. The patience and guidance provided by Dr. Mark Wentzel is particularly appreciated. Dr. Nolan Raphelt also provided insightful discussion on the relationships of at-a-station hydraulic properties and response of river channels.

Executive Summary

At-a-station hydraulic properties from multiple gages in all eleven major river drainages across several Ecoregions in Texas were evaluated in light of similarities and differences both over time and from gages on the same longitudinal river segment. The relationship between cross sectional area and discharge was the most consistent in terms of both temporal and spatial scales. Both width and to a larger degree, velocity relationships with changes in discharge was greater spatially and temporally. Previous work that was reviewed clearly indicate that reach average at-a-station exponents of the continuity equations do not reflect the values from specific locations within a river reach. An examination of variability in channel morphology and the relationship in the velocity magnitudes and characteristics between runs (i.e., gage locations) and run versus riffle habitat showed a large difference. Given that velocity profiles are the most sensitive parameter in estimating fisheries habitat in instream flow assessments it is unlikely that use of at-a-station hydraulic parameters from gage locations can be utilized to assess reach level fisheries habitat.

Introduction

The principal research question of this project was to explore if available data at gage locations allow for inference of hydraulic habitat characteristics at the reach scale that could inform the evaluation of instream flow regimes. Reviews of instream flow programs in Texas, including the National Research Council (2005) and Science Advisory Committee (2009), recognized the potential benefit of desk-top methods (i.e. those that can be applied using generally readily-available data and information without conducting site-specific field studies). The majority of such methods are based exclusively on statistical relationships derived from hydrologic data. There have been only limited attempts to validate these methods for use in Texas. The Lyons Method, often relied on by Texas Commission on Environmental Quality to evaluate small water rights permits or amendments across the state, was developed based on cross-section data collected from only two locations on the Guadalupe River in Central Texas. To date, attempts to find improved desktop methods for use in Texas have focused on methods that employ only hydrologic data. One such attempt, the Technical Review Group that reported to Texas Commission on Environmental Quality (2008), was unsuccessful in finding a method significantly better than the Lyons Method. Through collaborative discussions with the Texas Water Development Board, the project focused on investigating the potential use of information collected at gage stations to inform relationships between available habitat and discharge at the reach level for use in evaluating ecological flow regimes. The rationale behind this approach in part is that from a regulatory perspective, water rights are associated with specific locations (i.e., gages) that determine flow levels at the corresponding downstream reaches. If it were possible to make inferences of the relationship between habitat characteristics at the reach level based on characteristics at a gage, it would provide a rapid assessment method for use in screening instream flows and implications of proposed water withdrawals on maintaining ecologically sound riverine conditions.

Background

One of the challenges facing implementation of the Texas Instream Flow Program (TIFP) through the Senate Bill 2 and 3 process is the high data requirements associated with a large number of potential quantification sites (e.g., see Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Basin and Bay Expert Science Team, 2011). Quantification approaches identified within the TIFP range from hydrology based methods to high spatial resolution multi-dimensional hydrodynamic models for predicting the relationship between discharge and available physical habitat. Excellent reviews of instream flow approaches in the United States can be found in Reiser et al. (1989), EPRI (1986), Gore and Nestler (1988), and Hardy (1998). Annear et al. (2004) and NRC (2005) synthesize additional work over the past decade and elucidate the multidisciplinary philosophies and application level challenges associated with the assessment of instream flows. A broader view of the status and future directions of instream flow science at the international level can be found in Harby et al. (2004). This later effort reviews the existing status of instream flow science used throughout the European Union and is comprehensive in its coverage of sampling, hydrology, hydraulic, water quality, temperature, and aquatic habitat modeling approaches.

Methods developed for assessing habitat availability vary in data requirements, cost, predictive ability, legal defensibility, and biological realism (Annear et. al. 2004). While some methods require rigorous, site-specific data collection and computer modeling, others rely more heavily on simplified approaches such as application of summary hydrologic-based statistics. Although the application of rigorous site-specific methodologies typically occurs for high-intensity instream flow studies, many management objectives can be achieved with less intensive efforts, especially for early project screening or broad level watershed planning (Stalnaker et al. 1995, NRC 2005).

Several widely applied screening methods allow practitioners to estimate flow requirements with no, or a minimum of, field-data collection efforts such as the Tennant Method and the New England Aquatic Base Flow method (Annear et al. 2004). This is characteristic of the Lyon's Method employed by the Texas Commission for Environmental Quality (TCEQ) in evaluation of water rights applications. Many of these approaches, however, vary in their ability to integrate or relate site-specific data with biological criteria in the assessment process. Some recent efforts to develop alternative methodologies for habitat assessment can be found in Jowett (1990, 1992, 1998), Lamouroux, Capra, and Pouilly (1996), and Annear et al. (2004).

Based on the recommendation of the NRC (2005), and consistent with Maidment et al. (2005), the SAC (2009) led the development of the Hydrology-Based Environmental Flow Regime (HEFR) Methodology. HEFR relies on a framework that quantifies key attributes of four components of the flow regime intended to support a sound ecological environment. These instream flow regime components are: subsistence flows, base flows, high flow pulses, and overbank flows (SAC 2009). For each of these flow regime components, HEFR was designed to assist in characterizing their attributes in terms of magnitude, volume, duration, timing, frequency, and in conjunction with IHA or MBFIT, the rate of change. HEFR results are then integrated with overlays of biology that include fisheries (i.e., physical habitat) and riparian components as well as overlays of water quality and geomorphology. A description of the ecological function of these flow components can be found in Richter et al. (2006), Richter and Thomas (2007), TIFP (2008) and SAC (2009).

Physical heterogeneity of riverine systems influences species richness and abundance (Hynes 1970, Vannote et al. 1980, Ward 1989). Furthermore, in riverine systems, the physical habitat structure (microhabitat and mesohabitat scales) is one of the critical factors that determine the distribution and abundance of aquatic organisms. In general, as spatial heterogeneity increases at the scale of aquatic organisms, there is greater microhabitat and hydraulic diversity that leads to greater biotic diversity. This variability in physical habitat from the microhabitat to mesohabitat scales is primarily derived from the physical processes of flow and sediment both within the channel as well as the lateral connectivity of floodplain habitats. The diversity and availability of these habitats are in turn maintained by variability in the flow regime and is a key process in the evolutionary response of aquatic species life history traits that allow them to exploit this variable and dynamic habitat mosaic. In many instances, the successful completion of various life history requirements requires use of different habitat types. For example, spawning and egg incubation may occur in riffles (turbulent velocities in conjunction with appropriate substrate sizes); upon hatching, the fry move to the slow side margins of the stream, while non-spawning adults may primarily inhabit deep pools. This variability in space and time of the habitat mosaic directly (or indirectly) influences the distribution and abundance of riverine species as well as overall ecosystem function (Poff and Allan 1995, Schlosser 1990, Sparks 1992, Stanford et al. 1996).

Because stream flow is one of the key factors that controls the temporal and spatial availability of stream hydraulics (interaction of depth and velocity), substrate, cover, food, and, to a lesser extent, temperature (e.g., Statzner and Higler 1986), stream flow within a given river system controls the abundance and diversity of physical habitat and ultimately the diversity of species that can exist. Ecological flow regimes are aimed at maintaining the natural diversity of habitats (i.e., riffles may only represent seven percent of available habitat types) rather than the often false assumption that flow regimes should optimize diversity. Optimizing habitat diversity is not the same as maintaining habitat diversity, which is required to maintain ecological integrity of aquatic ecosystems. One method of quantifying the effects of stream flow on riverine biota is to quantify the quantity and quality of habitat types (types inhabited by typical riverine fish guilds) versus flow (e.g., Aadland 1993, Bowen et al. 1998, BIO-WEST 2008). These relationships, particularly for key bottleneck habitats that may affect, for example, recruitment of fishes at various times of the year (e.g., nursery habitat), can be used to identify stream flows that maintain habitats for a diversity of species and life stages (Bain et al. 1988, Scheidegger and Bain 1995, Nehring and Anderson 1993).

In addition, fish use different microhabitats (depth, velocity) in different mesohabitats (pools, riffles, eddies) (Jackson 1992, Moody and Hardy 1992) and use different microhabitats at different flows (e.g., Shrivell 1994). They also use different habitats depending on localized predation threats (e.g., Power et al., 1985; Schlosser 1982), during different seasons (e.g., Baltz et al. 1991), during different parts of a day (night vs. day) and life stages. Fish swimming capabilities change with temperature (Brett and Glass 1973, Smith and Li 1983, Addley 1993) and the velocities that they use is dependent on temperature.

Clearly, hydraulic characteristics of a river as a function of changing discharge over micro to meso-scales at the reach level are important determinants for assessing quantity and quality of aquatic resource habitats and provide the basis for the evaluation of ecological flow regimes. The principal research question of this paper is to explore to what degree if any, available data at a gage location allow the inference of hydraulic habitat characteristics at the reach scale necessary to inform the evaluation of instream flow regimes. This question is further constrained by the goal of utilizing the gage data within the context of a rapid assessment or 'desk top' methodology that minimizes or eliminates the need for extensive field data collections. The following sections explore this question both from a theoretical perspective as well as from empirical work available from the literature and data from several river systems in Texas.

Theoretical and Empirical Considerations

Hydraulics overview

The basic hydraulic data collected at a gage are channel geometry, stage (or depth), velocity, and wetted width at a variety of discharges. Gage locations are typically located in straight channel sections with stream lines that are parallel to the downstream channel orientation and typically referred to as runs in aquatic habitat classification schemes. Ignoring high gradient step-pool type river channels that are rare and atypical of Texas streams and rivers, most channels are either riffle-pool or riffle-pool-run morphologically (e.g., Figure 1).

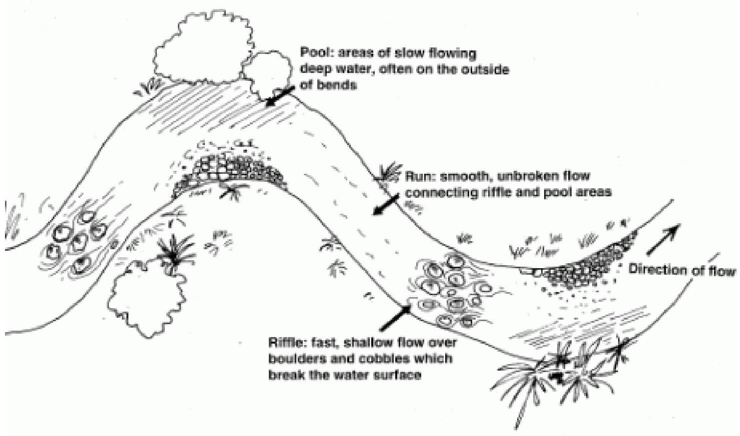

Figure 1. Characteristic riffle-pool-run sequence in a river channel.

The data collected at a gage represents the hydraulic geometry of the stream channel and is described by basic equations between discharge (Q) and water surface width (W), depth (D), velocity (V), Manning's roughness factor (n) and slope (S) (Leopold and Maddock, 1953; Park, 1977; Kellerhals and Church, 1989; Mosley, 1992).

$$W = aQ^b$$

$$D = cQ^f$$

$$V = kQ^m$$

$$n = NQ^p$$

$$S = sQ^y$$

The exponents b, f, m, p and y represent, respectively, the rate of change of the hydraulic variables W, D, V, n and S as Q changes while the coefficients a, c, k , N and s are scale factors that define the values of W, D, V, n and S when Q = 1 (see Figure 2). The hydraulic variables, width, depth and velocity, satisfy the continuity equation:

$$Q = WDV$$

Therefore the coefficients and exponents must satisfy:

$$ack = 1 \text{ and } b+f+m = 1$$

Note that this permits the calculation of velocity from:

$$V = (Q^{1-b-f}) / (ac)$$

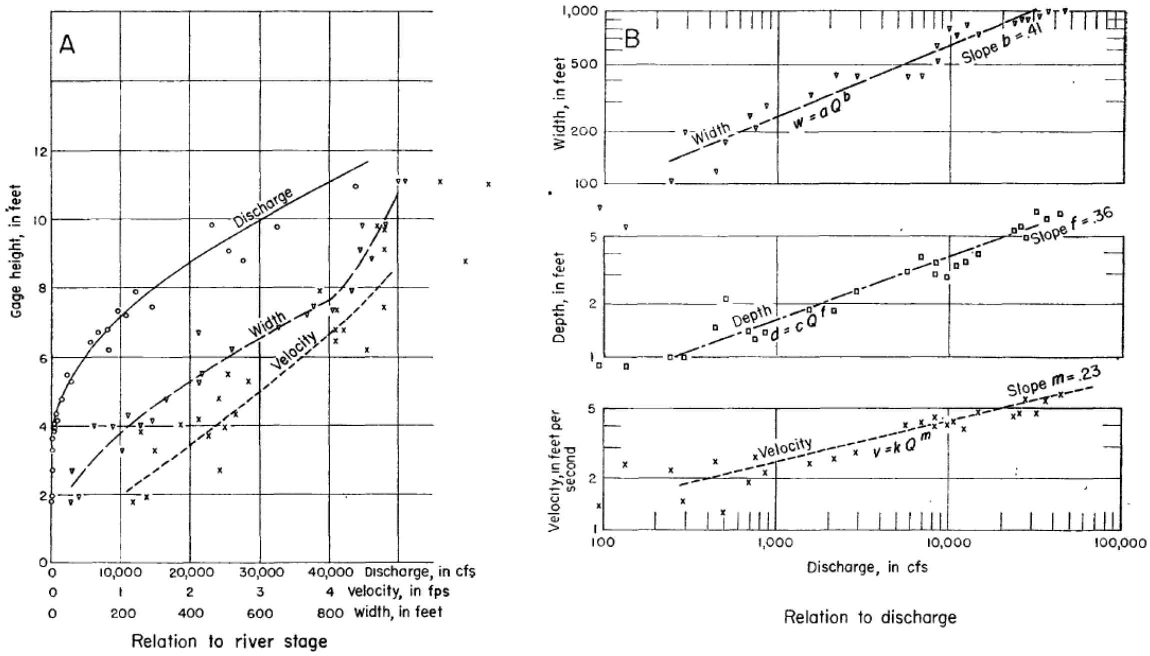

Figure 2. Variation of hydraulic parameters at a cross section in a river (A: discharge, width, and velocity versus stage; B; width, depth and velocity versus discharge. Adapted from Leopold and Maddock 1953).

These hydraulic geometry relationships can be examined in terms of downstream relationships which describe the variation in hydraulic geometry between reaches at one index discharge (commonly bankfull discharge), whereas 'at-a-station' relationships describe the variation of hydraulic geometry with changing discharge within a reach. The 'at-a-station' relationships are most germane to the present discussion given the desire to make inferences to the reach scale in the vicinity of the gage and not how these relationships change longitudinally at the basin level.

Although Parker (1979) suggests that the scale factors, a, c, and k, vary from locality to locality the exponents, b, f, and m, exhibit a remarkable degree of consistency, and would appear to be independent of location and only weakly dependent on channel type. One might assume that in a somewhat homogeneous reach with small spatial changes in channel topography that the relationships derived from the gage data might be representative of the reach level characteristics. However, Phillips and Harlin (1984) found that hydraulic exponents were not stable over space in a homogeneous subalpine stream. To further complicate the issue, Rhodes (1977, 1978) noted that the exponent values for high flow conditions can be vastly different from those for low flow conditions. Basically, the exponents and coefficients of these hydraulic geometry equations are expected to vary from location to location on the same river and from river to river, as well as from the high flow range to the low flow range. Given these facts, the question then becomes to what degree does this variability impact their potential use to infer hydraulic characteristics at the reach scale given properties at a specific gage (i.e., run) location.

Kolberg and Howard (1995) examined the variability in exponents of hydraulic geometry relations in the Midwestern United States for 318 alluvial channels and 50 Piedmont streams. Both data sets indicated that the width-discharge exponents ranged from 0.35 to 0.46 for groups of streams with width to depth ratios < 45 while in streams with the width to depth ratios > 45, the width-discharge exponents decreased to values below 0.15, suggesting a systematic variation in the exponents and a diminished influence of channel shape and consistent with the work of Osterkamp and Hedman (1982).

At-a-station hydraulic geometry

Kellerhals and Church (1989) demonstrated that the width of large rivers ($Q > 20\ m^3/s^{-1}$) from different location around the world are remarkably constant as shown in Figure 3. However, it is unknown to the degree this consistency holds for river systems with lower discharges.

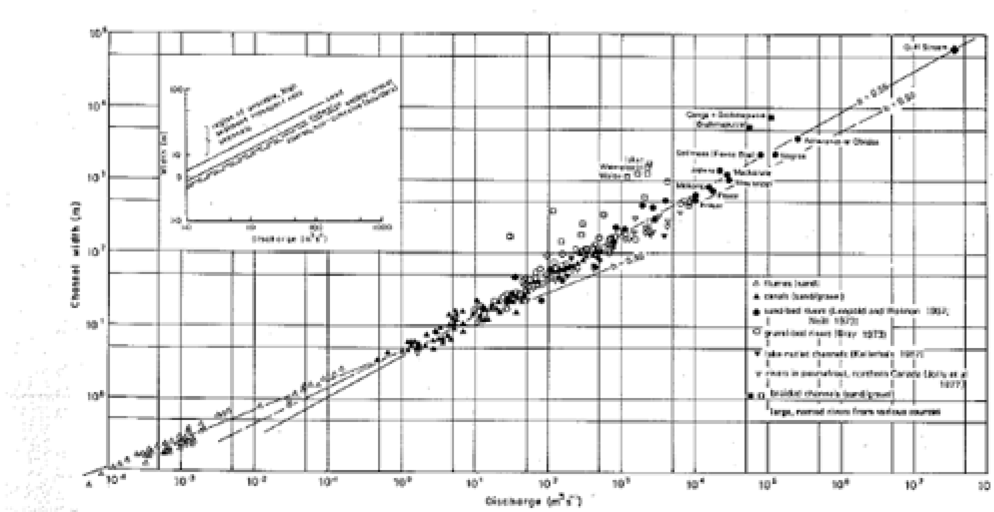

Figure 3. Relationship between magnitude of discharge and channel width from large rivers (adapted from Kellerhals and Church 1989).

Kellerhals and Church (1989) proposed that the geophysical basis of riverine habitat could be characterized by at-a-station relationships based on basic continuity equations:

$w = a_1Q^{b1}$

$d = a_2Qs^{b2}$

$Q = wdv$

Where Q is the backfull discharge, Qs is the sediment supply, w is the channel width, d is mean channel depth and v is the mean channel velocity. Therefore the velocity and cross sectional area (A) of the flow can be expressed as:

$v = (1/a_1a_2)Q^{1-(b1+b2)}$

$A = a_1a_2Q^{(b1+b2)}$

In essence the equation for Area describes the storage-discharge (volume) per unit length of channel (or total volume for the length of channel over which A is averaged) as flow varies. The velocity equation gives the relationship of mean velocity in the reach and the width equation will closely approximate the wetted area of the channel per unit length of channel. However, Kellerhals and Church note that these relationships vary widely due to channel cross sectional area characteristics.

Jowett (1998) utilized a large dataset of New Zealand Rivers to examine the use of the at-a-station hydraulic geometry equations for use in aquatic habitat assessments. Data collected from between 8 to 47 cross sections covering at least one pool/run/riffle sequence in each of 73 river reaches were examined. The number of cross sections collected in a given river increased with increased channel stream geometry. Field observations were used to develop calibrated hydraulic models. The hydraulic models were then used to simulate hydraulic properties as a function of discharge and the resulting water surface width, mean depth, and mean velocity calculated for each cross-section were then averaged for the reach, with each cross-section weighted by the distance between adjacent cross-sections. Water surface width, mean depth, and mean velocity were calculated at the mean annual discharge for the 73 study reaches. At-a-station exponents were calculated by linear regression of the logarithm of flow versus logarithms of water surface width, depth, and velocity at four levels of flow; mean annual, median, mean annual minimum, and 80% of mean annual minimum flow.

Jowett (1998) utilized an objective measure of the channel shape derived from the power relationship between channel width (W) and height or elevation (Y):

$$W = a_c\,(Y - Y_{min})^{bc}$$

Where bc is the shape exponent and Y_{min} is the height of the lowest point on the cross section (i.e., W = 0). The exponent bc was calculated for each cross section and averaged for the reach. When the shape exponent is less than unity, the cross section of the channel is U-shaped and when greater than unity is indicative of alluvial channels with large increases in channel width with height.

The channel width coefficients and depth coefficients of the hydraulic geometry equations can be determined from two field measurements of the wetted width (W_1, W_2) and mean depth (D_1, D_2) at two flow rates (Q_1, Q_2) as follows:

$$b = \log(W_1 / W_2) / \log(Q_1 / Q_2)$$

$$a = W_1 / Q_1^{b}$$

$$f = \log(D_1 / D_2) / \log(Q_1 / Q_2)$$

$$c = D_1 / Q_1^f$$

The simplified field procedure utilized 5 randomly selected cross sections from runs contained in a reach with a mixture of pool/run/riffle habitats. It is important to note that run habitats were selected as they contain depth and velocities intermediate between values in pools and riffles and more reflective of reach level average characteristics. In the context of this paper, runs are analogous to gage locations. To incorporate the change in width with average depth at the second discharge, (D_2) was calculated as:

$$D_2 = (W (D_1 + \Delta L) + (\Delta L(W_2 - W_1)/2) / W_2$$

Over the range of the two calibration flows used to calculate the hydraulic geometry relationships, predicted depth and velocity was within 2.8% on average (maximum difference less than 8%) of the mean depth and velocity predicted by hydraulic simulation techniques derived from modeling 15 cross-sections located in pool, run, and riffle habitats (see Figure 6 in Jowett 1998). The difference between predictions by the two methods increased with the flow extrapolation range, with less than a 15% difference at half of the lowest calibration flows and less than 10% difference at twice the higher calibration flow. Jowett (1998) concludes that repeated applications of this method would allow relationships between the mean flow of rivers and environmental flow requirements to be developed into regional formulae, similar to the Tennant method (1976) or in the context of Texas, the Lyon's Method.

Leopold and Maddock (1953) proposed the following continuity equations:

$w = aQ^b$ $\quad d = cQ^f$ $\quad v=kQ^m$

Where w is the width, d is the depth, and v is the mean channel velocity. Rhodes (1977) examined the relationship between the hydraulic exponents of these continuity equations utilizing a b-f-m diagram to plot data derived from 315 sets of at-a-station hydraulic geometry equations based on empirical data (Figure 4).

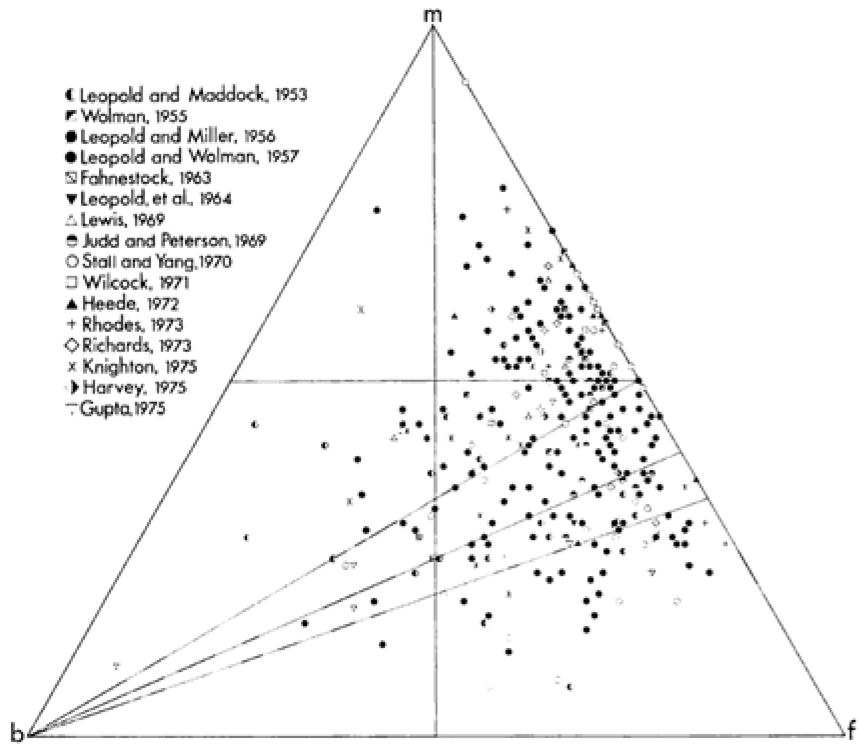

Figure 4. The b-f-m diagram showing plotting position of 315 sets of at-a-station hydraulic geometry exponents (after Rhodes 1977).

These results show a large variation in the relationships between the exponents of the continuity equations that reflect differential responses of the channel to discharge, sediment supply, slope, competence and other factors that relate to channel types as shown in Figure 5 (see Rhodes 1977).

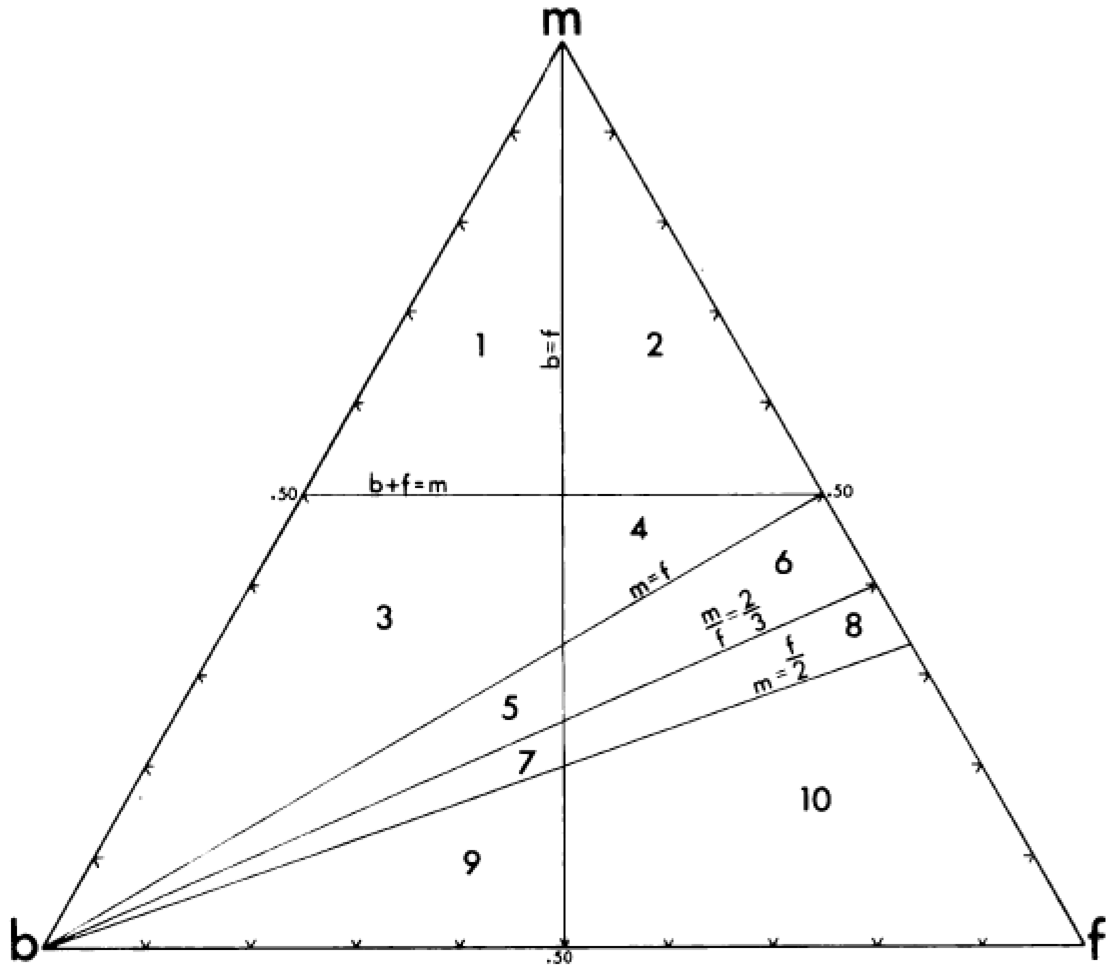

Figure 5. Divided b-f-m diagram showing 10 delineated regions associated with channel types (after Rhodes 1977).

The five main dividing lines represent constant values of width-depth ratio (b=f), competence (m=f), and Froude number (m=f/2), velocity-cross sectional area ratio (m=b+f) and is related to the Darcy-Weisbach friction factor, and slope-roughness ratio (m/f=2/3) which is related to Manning's equation. The ten corresponding regions refer to channel configuration and responses to changes in discharge. For example, if the width-to-depth ratio at a channel cross section does not change with discharge, b=f. If b>f (left side of the line), the width-to-depth ratio increases with increasing discharge. Conversely, f>b (right side of the line), the width to depth ratio decreases with increasing discharge. Rhodes (1977) relates these conditions to the (1) relative stability of bed and bank material; (2) channel shape, and (3) channel adjustment to transport of bed load. Rhodes (1977) provides a discussion of the relationships for each of these dividing lines. Of interest here is that a set of channel cross sections plotting in a particular area of the diagram should experience similar hydrologic and morphologic responses to changes in discharge regardless of the magnitude of their continuity equation exponents derived from at-a-station hydraulics.

However, as Rhodes (1977) demonstrates, use of reach level average values compared to individual at-a-station relationships is highly variable (Figure 6).

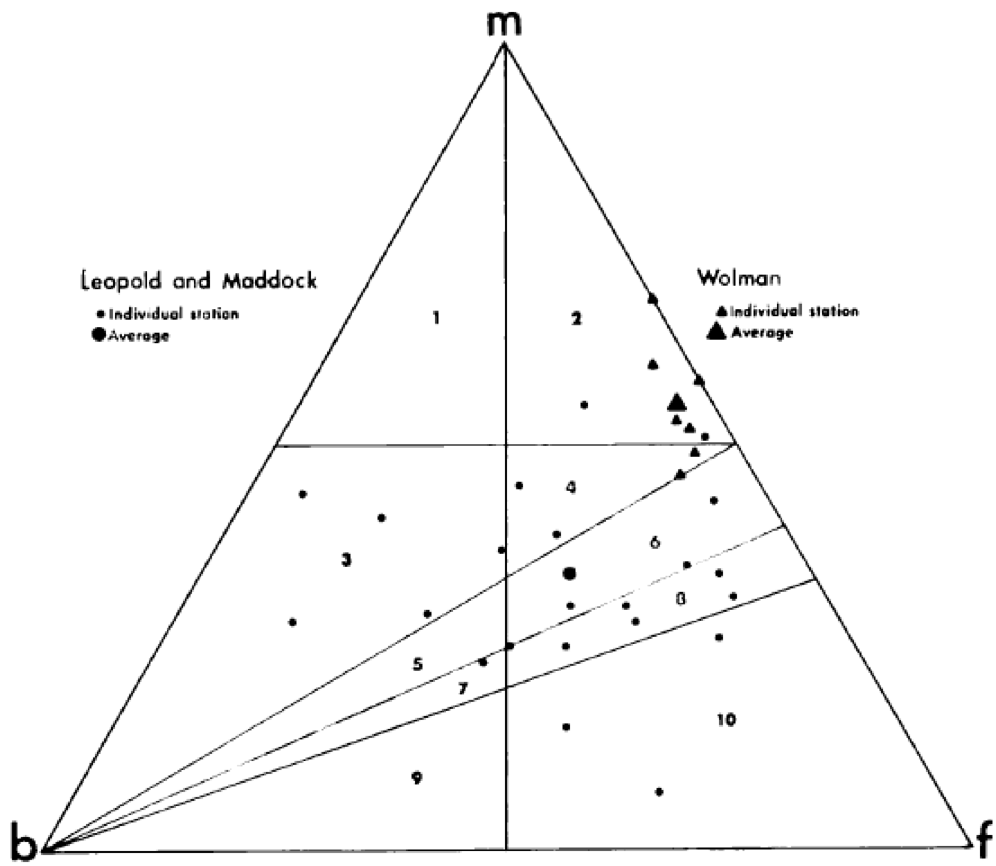

Figure 6. Comparison of b-f-m plotting position for individual at-a-station and reach averages (after Rhodes 1977).

It is apparent in Figure 6 that the individual and reach average values from Leopold and Maddock (1953) are markedly different. Note that the reach average value plot is sector 6, while the individual at-a-station values plot in 7 of the 10 regions of the b-f-m diagram indicating a wide variation in channel configuration and responses to changes in discharge. This variability in channel configuration related to the values of the exponents of the continuity equations suggests that reliance on the hydraulic characteristics at a gage site to estimate reach level average conditions, may not be characteristic given the variability of individual cross section locations as suggested by the work of Jowett (1998).

Evaluation of gage data

An initial assessment of the potential utility of gage data was made by selecting a number of gages from each of the major river drainages within Texas. Sites were selected to represent locations in different ecoregions within a given major drainage basin, spatially different locations as well as to include gage locations on the same stream reach. For each gage, the published rating curve data was downloaded from the USGS and several rating curves were selected at each gage to assess the variability over time as well as for comparisons between gage locations. Table 1 shows the river basin, gage number, name, and location of gages used in the evaluation of continuity relationships in Texas. Figure 7 shows an example of selected gage locations within the Brazos River Basin. Appendix A contains figures for all selected gage locations from all eleven river basins evaluated in this work.

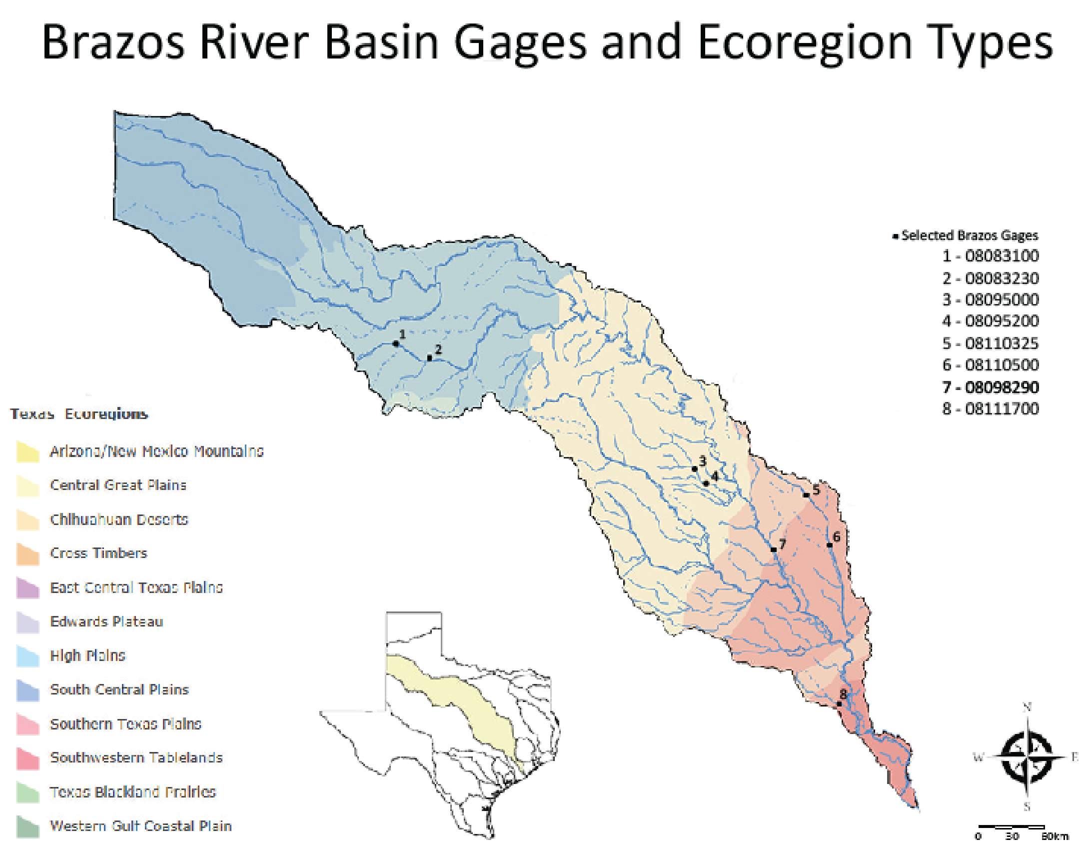

Figure 7. Selected gage location within the Brazos River drainage where at-a-station hydraulic geometry relationships were evaluated.

Table 1. USGS gage locations by major river drainages in Texas used in the evaluation of at-a-station hydraulic relationships.

River Basin	Gage	Name	Latitude	Longitude
Brazos				
	08083100	Clear Fk Brazos Rv near Roby, TX	32°47'15"	100°23'18"
	08083230	Clear Fk Brazos Rv near Noodle, TX	32°40'28"	100°04'20"
	08095000	N Bosque Rv near Clifton, TX	31°47'09"	97°34'04"
	08095200	N Bosque Rv at Valley Mills, TX	31°40'10"	97°28'09"
	08110325	Navasota Rv above Groesbeck, TX	31°34'27"	96°31'14"
	08110500	Navasota Rv near Easterly, TX	31°10'12"	96°17'51"
	08098290	Brazos Rv near Highbank, TX	31°08'02"	96°49'29"
	08111700	Mill Ck near Bellville, TX	29°52'51"	96°12'18"
Colorado				
	08133250	N Concho Rv above Sterling City, TX	31°53'50"	101°06'17"
	08134000	N Concho Rv near Calsbad, TX	31°35'33"	100°38'12"
	08136700	Colorado Rv near Stacy, TX	31°29'37"	99°34'25"
	08138000	Colorado Rv at Winchell TX	31°28'04"	99°09'43"
Guadalupe				
	08165300	N Fk Guadalupe Rv near Hunt, TX	30°03'50"	99°23'12"
	08167000	Gualaupe Rv at Comfort, TX	29°57'54.86"	98°53'49.80"
	08171000	Blanco Rv at Wimberley, TX	29°59'39"	98°05'19"
	08170500	San Marcos Rv at San Marcos, TX	29°53'20"	97°56'02"
	08173000	Plum Ck near Luling, TX	29°41'58"	97°36'12"
	08173900	Guadalupe Rv at Gonzales, TX	29°29'03"	97°27'00"
	08175000	Sandies Ck near Westhoff, TX	29°12'54"	97°26'57"
	08176550	Fifteenmile Ck near Wesner, TX	28°53'51"	97°21'17"
Lavaca Guadalupe				
	08164600	Garcitas Ck near Inez, TX	28°53'28"	96°49'08"
	08164800	Placedo Ck near Placedo, TX	28°43'30"	96°46'07"
Nueces				
	08193000	Nueces Rv near Asherton, TX	28°30'00"	99°40'54"
	08194000	Nueces Rv at Cotulla, TX	28°25'34"	99°14'23"
	08194500	Nueces Rv near Tilden, TX	28°18'31"	98°33'25"
	08210100	Nueces Rv at George West, TX	28°19'58"	98°05'08"
	08211200	Nueces Rv at Bluntzer, TX	27°56'15"	97°46'32"
	08211500	Nueces Rv at Calallen, TX	27°52'58"	97°37'30"
Red River				
	07301200	McClellan Ck near McLean, TX	35°19'45"	100°36'32"
	07301300	N Fk Red Rv near Shamrock, TX	35°15'51"	100°14'29"
	07311790	Wichita Rv at Ross Rh near Bejamin, TX	33°39'18"	100°00'49"
	07311800	S Wichita Rv near Benjamin, TX	33°38'39"	99°48'02"
	07311900	Wichita Rv near Seymour, TX	33°42'01"	99°23'18"
	07312100	Wichita Rv near Mabelle, TX	33°45'36"	99°08'33"
	07312500	Wichita Rv at Wichita Falls, TX	33°54'34"	98°32'00"
	07312700	Wichita Rv near Charlie, TX	34°03'11"	98°17'47"
Sabine				
	08018500	Sabine Rv near Mineola, TX	32°36'49"	95°29'08"
	08020000	Sabine Rv near Gladewater, TX	32°31'37"	94°57'36"
	08022040	Sabine Rv near Beckville, TX	32°19'38"	94°21'12"
	08028500	Sabine Rv near Bon Wier, TX	30°44'49"	93°36'30"
San Antonio Nueces				
	08189300	Medio Ck near Beeville, TX	28°28'58"	97°39'23"
	08189500	Mission RV at Refugio, TX	28°17'30"	97°16'44"
San Jacinto				
	08068000	W Fk San Jacinto Rv near Conroe, TX	30°14'40"	95°27'25"
	08068090	W Fk San Jacinto Rv above Lk Houston near Porter, TX	30°05'09"	95°17'59"
	08070000	E Fk San Jacinto Rv near Cleveland, TX	30°20'11"	95°06'14"
	08068800	Cypress Ck at Grant Rd near Cypress, TX	29°58'24"	95°35'54"
Sulphur				
	07342480	Middle Sulphur Rv at Commerce, TX	33°15'59"	95°54'55"
	07342465	S Sulphur Rv at Commerce, TX	33°12'42"	95°54'50"
	07342500	S Sulphur Rv near Cooper, TX	33°21'23"	95°35'41"
Trinity				
	08059400	Sister Grove Ck near Blue Ridge, TX	33°17'40"	96°28'58"
	08061750	E Fk Trinity Rv near Forney, TX	32°46'27"	96°30'12"
	08066100	White Rk Ck near Trinity, TX	31°03'06"	95°22'40"
	08067000	Trinity Rv at Liberty, TX	30°03'27"	94°49'05"
	08501130	Elm Fk Trinity Rv near Pilot Point, TX	33°21'01"	97°02'49"
	08053000	Elm Fk Trinity Rv near Lewisville, TX	33°02'44"	96°57'39"
	08062500	Trinity Rv near Rosser, TX	32°25'35"	96°27'46"
	08066250	Trinity Rv near Goodrich, TX	30°34'19"	94°56'55"

Figure 8 provides an example of the hydraulic properties between two gages and several rating curves within the Brazos River Basin for adjacent locations on the same river segment.

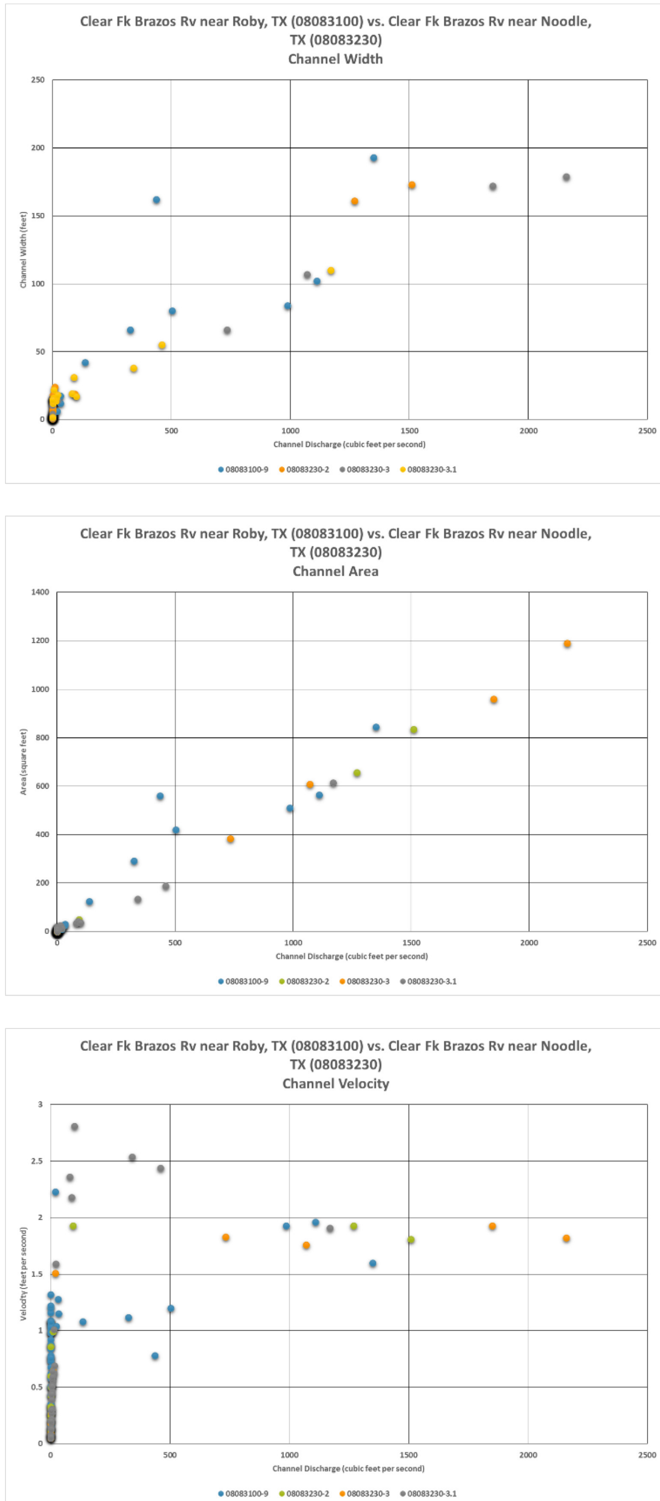

Figure 8. Width, area and mean channel velocity comparisons for two gages and different rating curves in the Brazos River Basin.

Figure 9 provides an example of the hydraulic properties between two gages and several rating curves within the San Jacinto River Basin for adjacent locations on the same river segment.

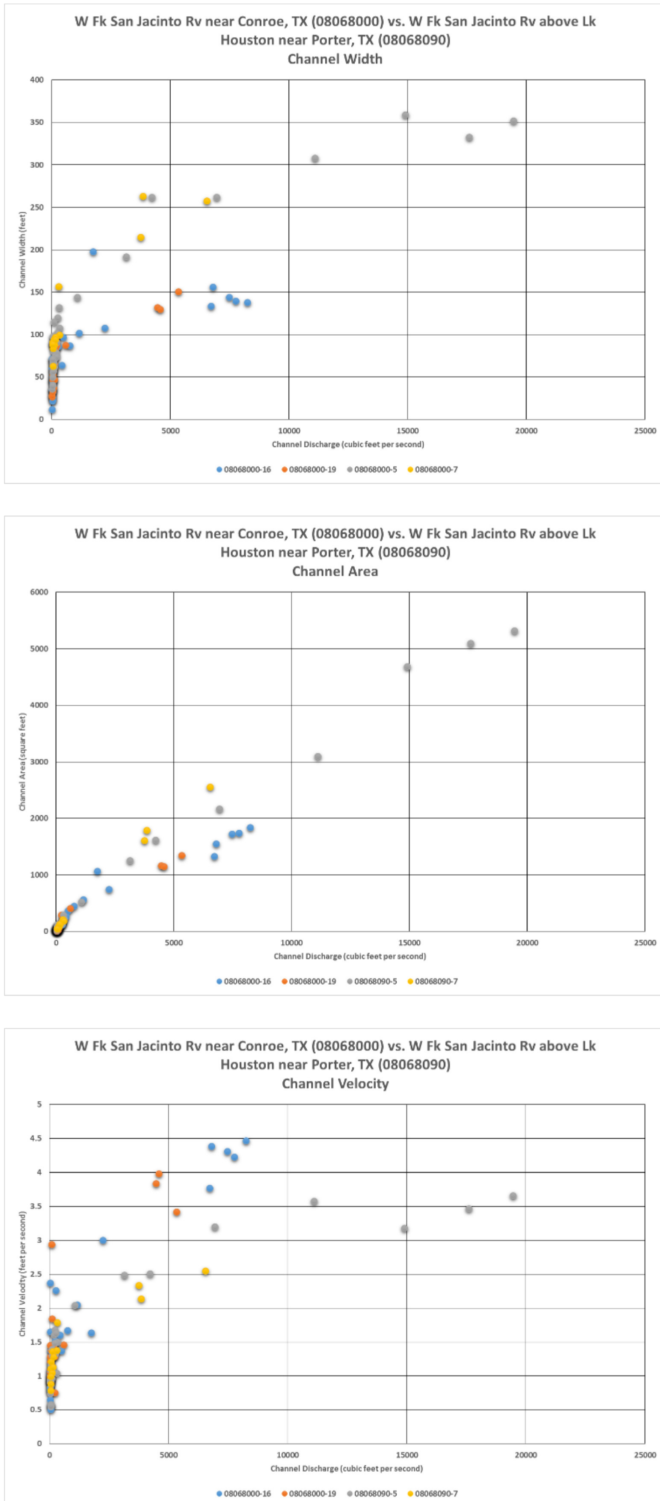

Figure 9. Width, area and mean channel velocity comparisons for two gages and different rating curves in the San Jacinto River Basin.

These results are indicative of the comparative analyses conducted between paired gage locations delineated in Table 1 and Appendix A. The results for all eleven drainages and gages indicated in Table 1 are provided in Appendix B (electronically).

The analyses illustrated in Figures 8 and 9 and in total in Appendix B clearly show that the at-a-station hydraulic properties vary considerably for a given gage location and as would be expected vary with spatial location even on the same river segment within all the basins. The results in these figures (and all sites examined) show that the most consistent at-a-station relationships over time are in channel cross sectional area and that both channel width and mean channel velocity relationships have a high degree of variation over time. It is noted that gage locations are typically characterized as 'run habitats' versus riffles or pools which are included in most instream flow assessments. The potential to utilize the at-a-station hydraulic properties to extrapolate to average reach conditions is likely problematic not only due to the variability at a single location over time but also the variation apparent over adjacent stream reaches. It is recognized that the longitudinal comparisons are expected to be highly variable even within river segments located in the same Ecoregion given the distances between these gage locations.

The importance of understanding the potential limitations of utilizing the at-a-station hydraulic properties from gage locations to represent reach level conditions is apparent from the work of Rhodes (1977) discussed above and the analysis of the temporal variation in the hydraulic properties at specific gage locations (see Appendix B). This is further supported by an examination of the data presented in Figure 10 which shows the variation in cross section geometry and differences in both magnitude and characteristics of the velocity profiles in run, pool and riffle habitats simulated over a range of discharge from the Guadalupe River at Victoria. Note that gages are typically associated with "run" habitats and as illustrated in Figure 10, the two run habitats have radically different velocity profiles and magnitudes over the same range of simulated discharges. It is also apparent that the differences between the run habitat versus riffle and pool habitats is even greater. This level of differences in channel morphology and velocity profile relationships between run versus pools versus riffles are indicative of all the Senate Bill 2 study data sets examined.

Implications on reach level habitat versus discharge relationships

It is well known that the most sensitive factor in the calculation of potential habitat for target species and life stages is the habitat suitability for velocity. The results highlighted above clearly show that there is a large degree of variability between gage locations (i.e., runs) and the corresponding differences associated with other mesohabitat types such as riffles and pools within the same longitudinal expanse of a river reach. It would appear that finding some rational relationship to expand the at-a-station hydraulic properties to represent reach level conditions is not likely to be feasible (see Figures 6 and 10).

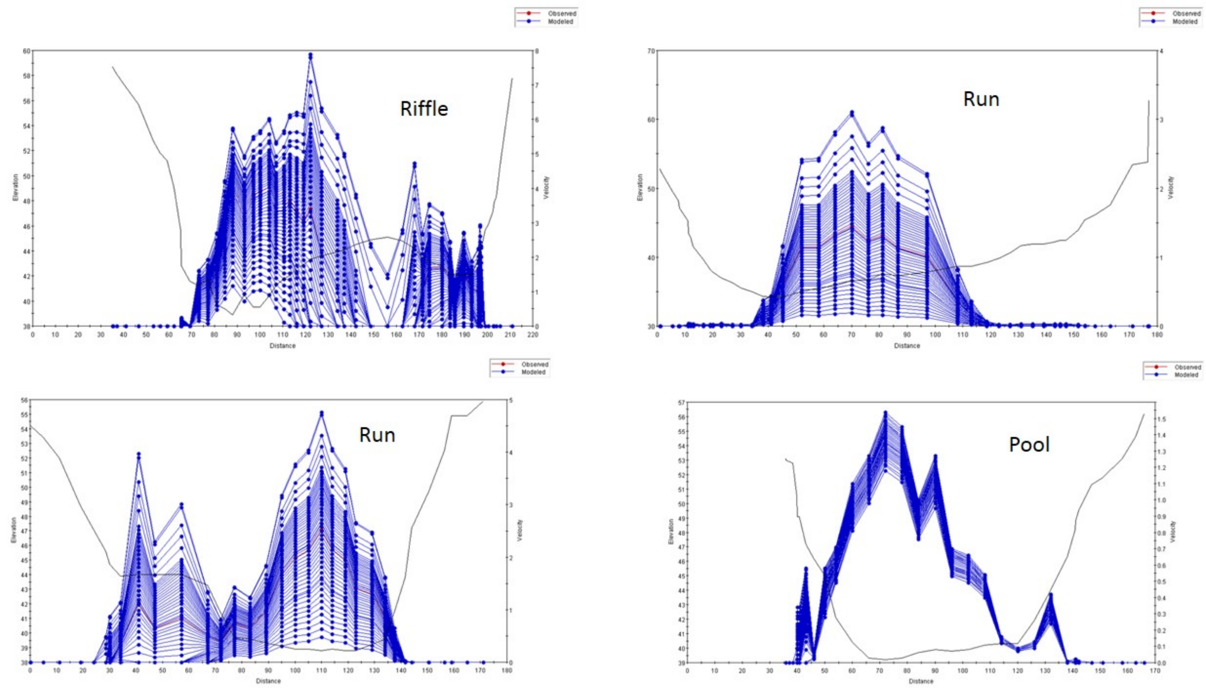

Figure 10. Channel morphology variation between run, pool, and riffle habitat and associated simulated velocity profiles as a function of discharge.

Other alternative approaches are likely more fruitful for future research. For example Lamouroux et al., (1995), Lamouroux (1998), and Saraeva and Hardy (2009) demonstrated that reach level distributions of depth and velocity as a function of discharge could be derived from channel shape factors. Given the more extensive availability of one meter DEM derived from LIDAR in support of Senate Bill 2 instream flow investigations, there is likely sufficient data within selected river basins where these later approaches might prove viable. The author is currently involved in a research project to evaluate use of channel shape parameters derived from high resolution DEMs over 40 miles of the Trinity River in California where eleven study sites have calibrated and validated two-dimensional hydrodynamic models. Similar efforts should be considered where high resolution DEMs are available that overlap with existing Senate Bill 2 study sites where 2-dimensional hydrodynamic models are available covering a range of different mesohabitats (i.e., run, pool, riffles).

Summary and Conclusions

Examination of at-a-station hydraulic properties from a theoretical and empirical basis shows little promise of using these data from gage locations to adequately represent reach average conditions to support a rapid assessment of fisheries habitat. The variation in at-a-station hydraulic properties, especially the relationship in velocity varies widely over time at specific locations as evidenced by the comparison of rating curve properties at numerous gages. Evaluations of existing instream flow study cross section data collected as part of Senate Bill 2, shows conclusively that the variation in channel morphology over even relative short stream reaches is highly variable and conditions within runs (i.e., gage locations) do not reflect either the magnitude nor characteristics of the velocity profiles with changing discharge within riffles and pools. The variation in the at-a-station hydraulic continuity equation exponents also suggest that formulating a rational 'translation' of properties using the gage values is not likely (i.e., see Figure 6. It would appear that alternative approaches such as Lamoroux et al., (1995), Lamoroux (1998) and Saraeva and Hardy (2009) may be more viable given the availability of high resolution DEM data over larger river reaches in combination with fine scale two-dimensional hydrodynamic models suitable for use by these later techniques.

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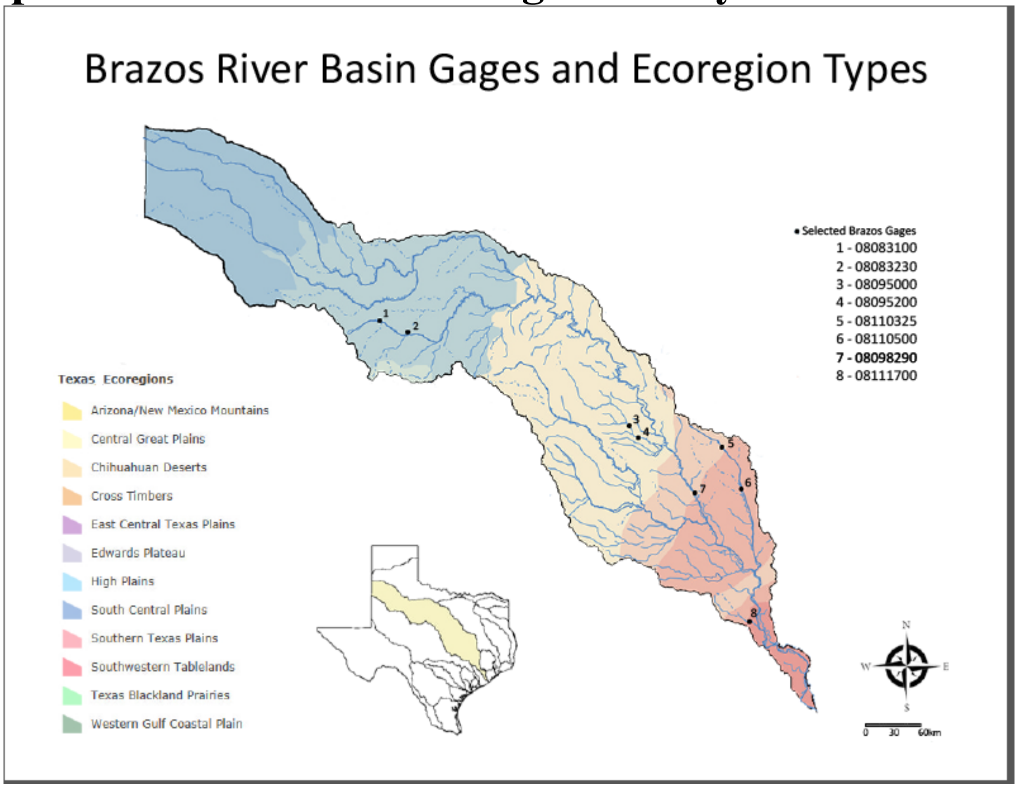
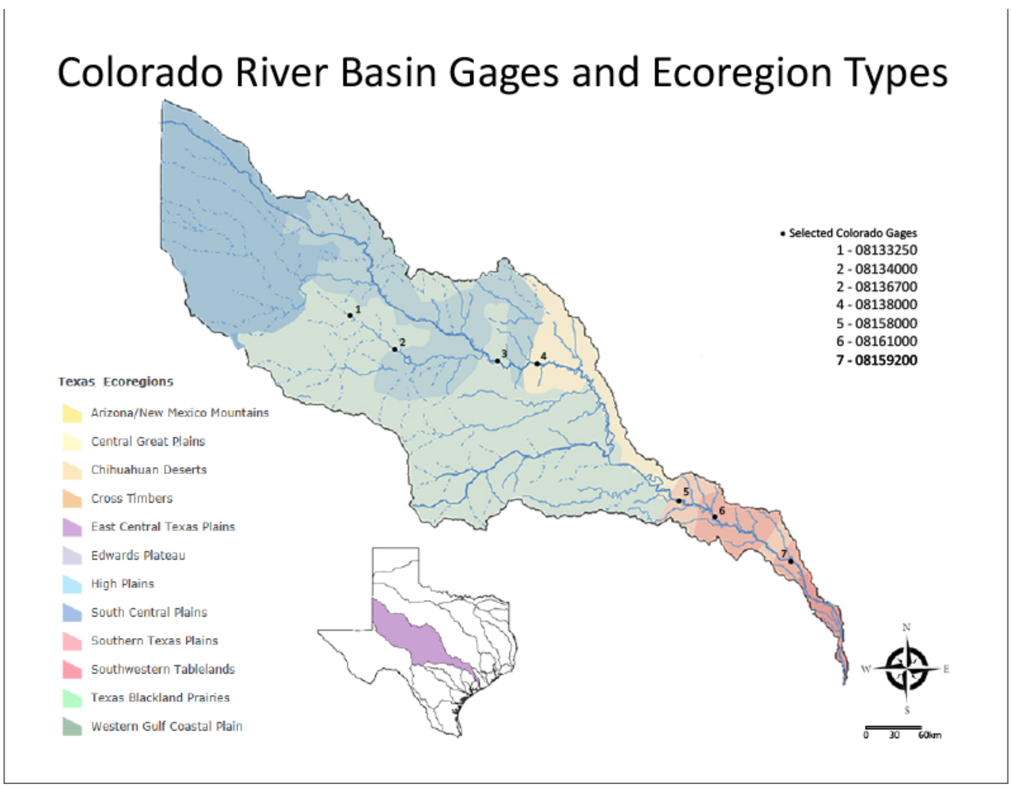
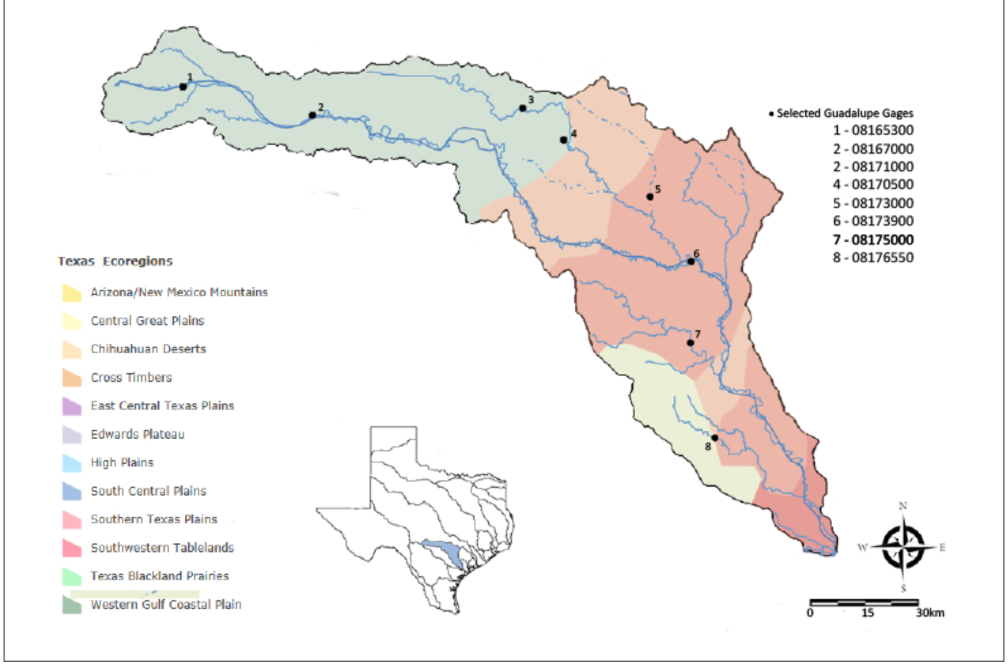
Appendix A – Evaluated Gage Data by River Drainage

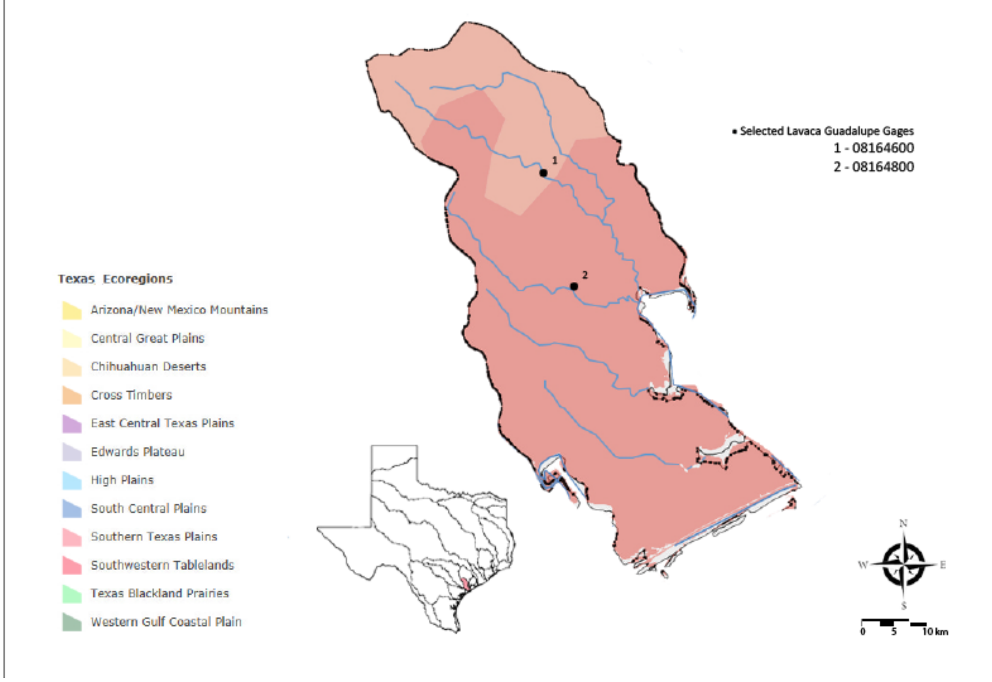


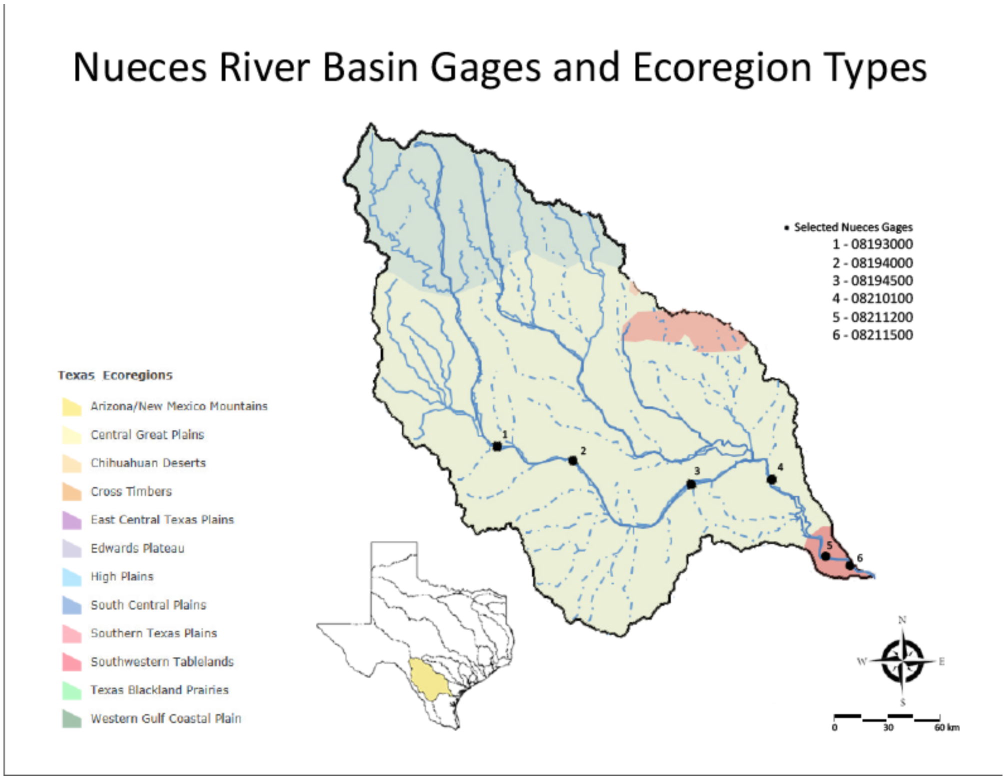


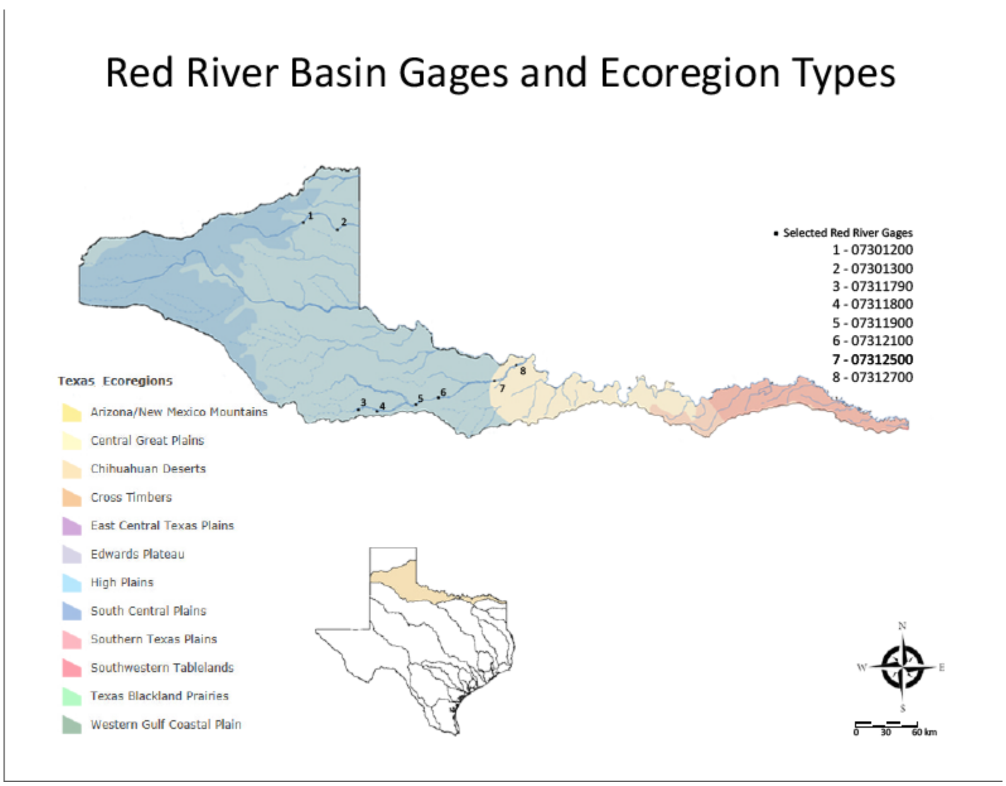
Guadalupe River Basin Gages and Ecoregion Types



Lavaca Guadalupe River Basin Gages and Ecoregion Types




Nueces River Basin Gages and Ecoregion Types
Selected Nueces Gages
1 - 08193000
2 - 08194000
3 - 08194500
4 - 08210100
5 - 08211200
6 - 08211500
Texas Ecoregions
Arizona/New Mexico Mountains
Central Great Plains
Chihuahuan Deserts
Cross Timbers
East Central Texas Plains
Edwards Plateau
High Plains
South Central Plains
Southern Texas Plains
Southwestern Tablelands
Texas Blackland Prairies
Western Gulf Coastal Plain
N
W
E
S
0
30
60 km


Red River Basin Gages and Ecoregion Types
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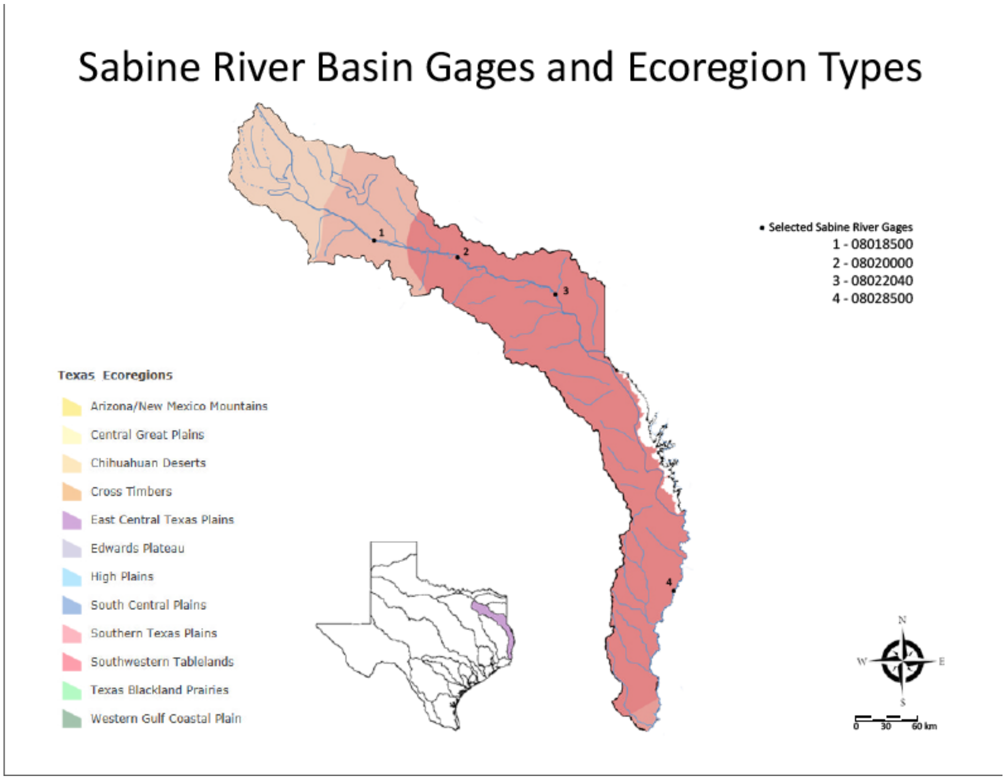
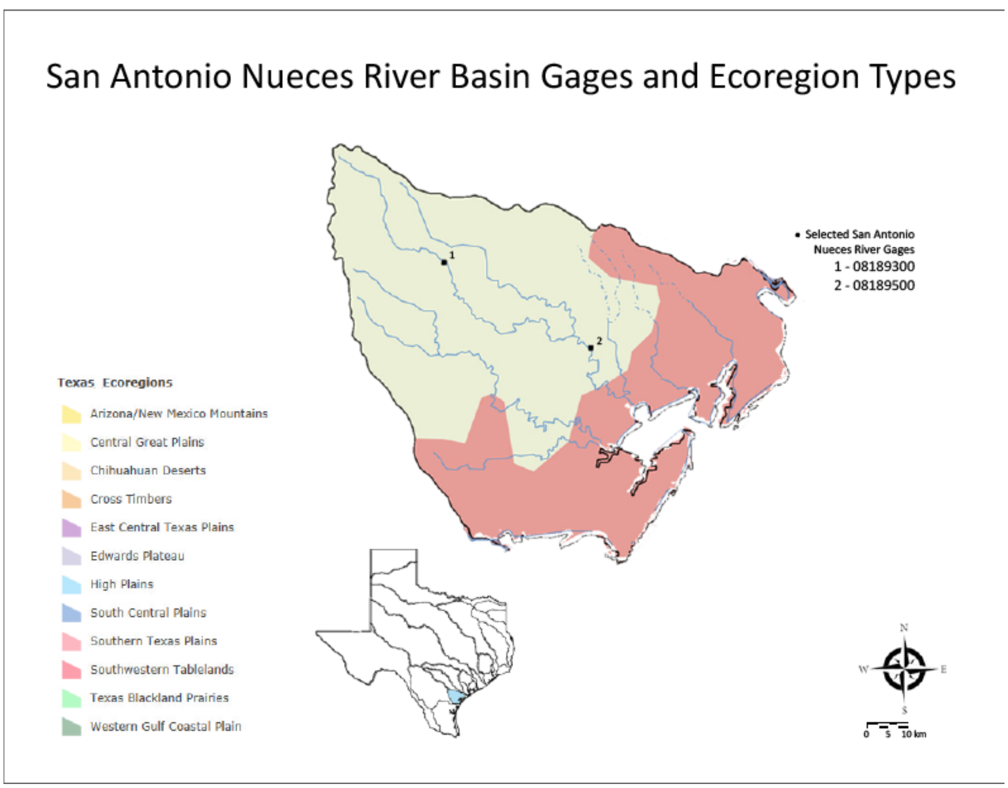
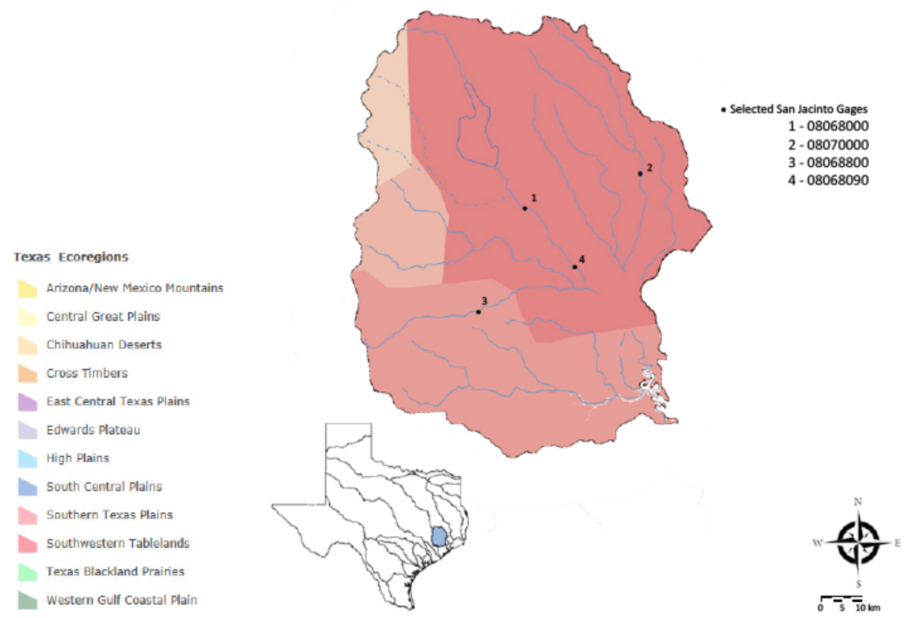
2 - 07301300
3 - 07311790
4 - 07311800
5 - 07311900
6 - 07312100
7 - 07312500
8 - 07312700
Texas Ecoregions
Arizona/New Mexico Mountains
Central Great Plains
Chihuahuan Deserts
Cross Timbers
East Central Texas Plains
Edwards Plateau
High Plains
South Central Plains
Southern Texas Plains
Southwestern Tablelands
Texas Blackland Prairies
Western Gulf Coastal Plain
N
W
E
S
0
30
60 km

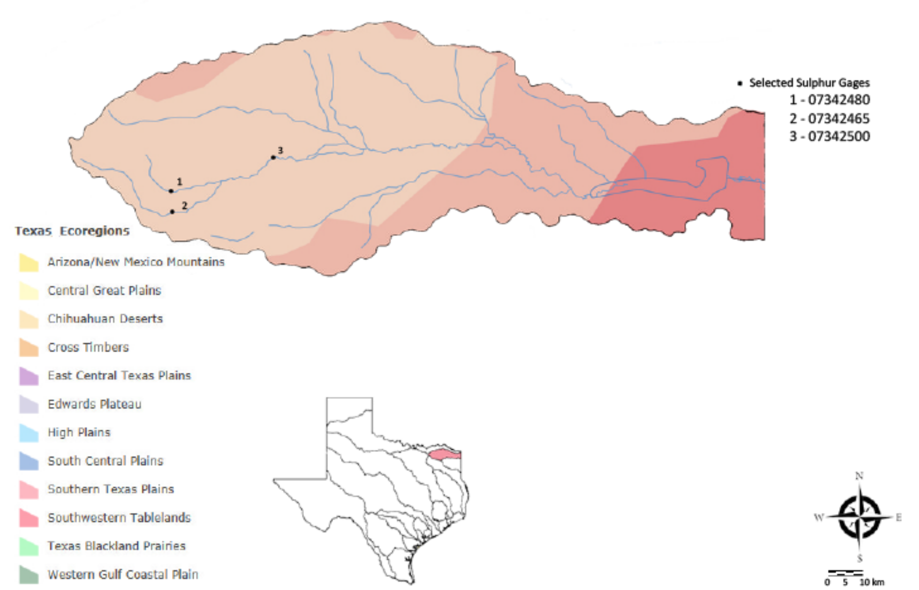

Sabine River Basin Gages and Ecoregion Types
• Selected Sabine River Gages
1 - 08018500
2 - 08020000
3 - 08022040
4 - 08028500
Texas Ecoregions
Arizona/New Mexico Mountains
Central Great Plains
Chihuahuan Deserts
Cross Timbers
East Central Texas Plains
Edwards Plateau
High Plains
South Central Plains
Southern Texas Plains
Southwestern Tablelands
Texas Blackland Prairies
Western Gulf Coastal Plain
N
W
E
S
0 30 60 km

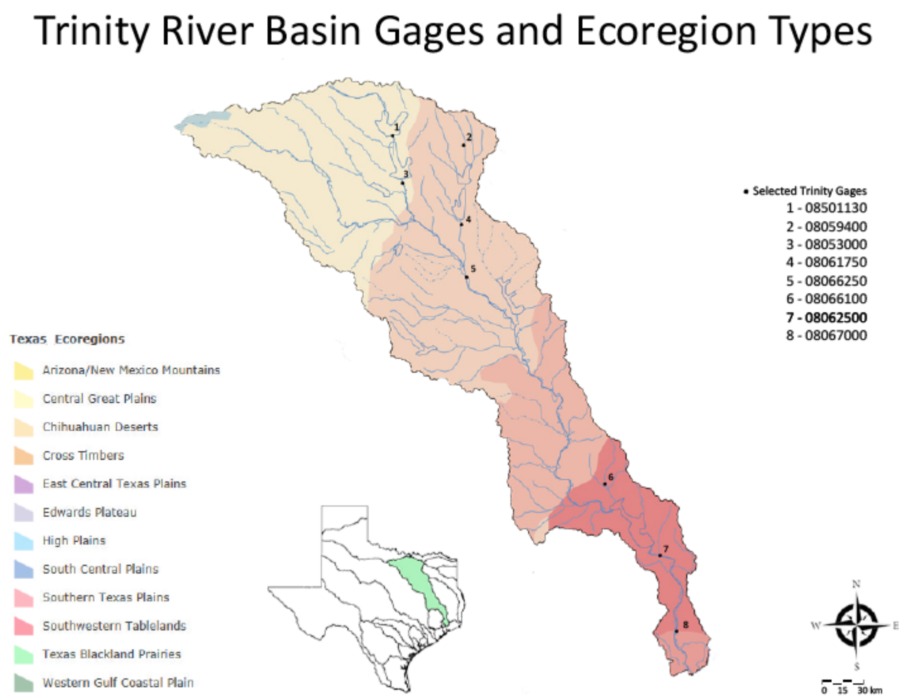

San Antonio Nueces River Basin Gages and Ecoregion Types
• Selected San Antonio Nueces River Gages
1 - 08189300
2 - 08189500
Texas Ecoregions
Arizona/New Mexico Mountains
Central Great Plains
Chihuahuan Deserts
Cross Timbers
East Central Texas Plains
Edwards Plateau
High Plains
South Central Plains
Southern Texas Plains
Southwestern Tablelands
Texas Blackland Prairies
Western Gulf Coastal Plain
N
W
E
S
0 5 10 km

San Jacinto River Basin Gages and Ecoregion Types



Sulphur River Basin Gages and Ecoregion Types





Trinity River Basin Gages and Ecoregion Types
• Selected Trinity Gages
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2 - 08059400
3 - 08053000
4 - 08061750
5 - 08066250
6 - 08066100
7 - 08062500
8 - 08067000
Texas Ecoregions
Arizona/New Mexico Mountains
Central Great Plains
Chihuahuan Deserts
Cross Timbers
East Central Texas Plains
Edwards Plateau
High Plains
South Central Plains
Southern Texas Plains
Southwestern Tablelands
Texas Blackland Prairies
Western Gulf Coastal Plain

Appendix B – Hydraulic Continuity Equations for Evaluated Gage Locations (Electronic)