Appendix G-6

Hydrologic Network Relationships and High Flow Pulses

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1.0 Hydrologic Network

This appendix investigates how pulses relate between adjacent selected measurement points.

USGS contributing drainage area for each MP is provided in Table 1. A schematic illustrating spatial relationship between measurement points (MP) is shown in Figure 1.

Table 1. USGS contributing drainage area of Measurement Points

Measurement Point	USGS Contributing Drainage Area (sq. mi.)	% of Richmond Contributing Drainage Area
Brazos River near South Bend	13,107	36.9%
Brazos River near Palo Pinto	14,245	40.1%
Brazos River near Glen Rose	16,252	45.7%
Brazos River at Waco	19,933	56.1%
Leon River at Gatesville	2,342	6.6%
Little River near Little River	5,228	14.7%
Little River near Cameron	7,065	19.9%
Brazos River at SH21 nr Bryan	29,483	82.9%
Navasota River near Easterly	968	2.7%
Brazos River near Hempstead	34,314	96.5%
Brazos River at Richmond	35,541	100%
Brazos River near Rosharon	35,773	101%

The Water Management Plan (WMP) considers a geographic area encompassing almost 700 miles of Brazos River channel, as well as additional tributaries. Because of the wide geographic range, travel time is a factor for basin hydrology and, pertinent to this WMP, travel time is a factor in water delivery and accounting. Travel time has historically been used by the Brazos River Authority (BRA) for purposes of estimating delivery time between upstream releases and downstream diversion destinations (Table 2). Because releases are relatively low flow within the baseflow range, the BRA estimates of travel time were derived from, and are most consistent with, baseflow conditions.

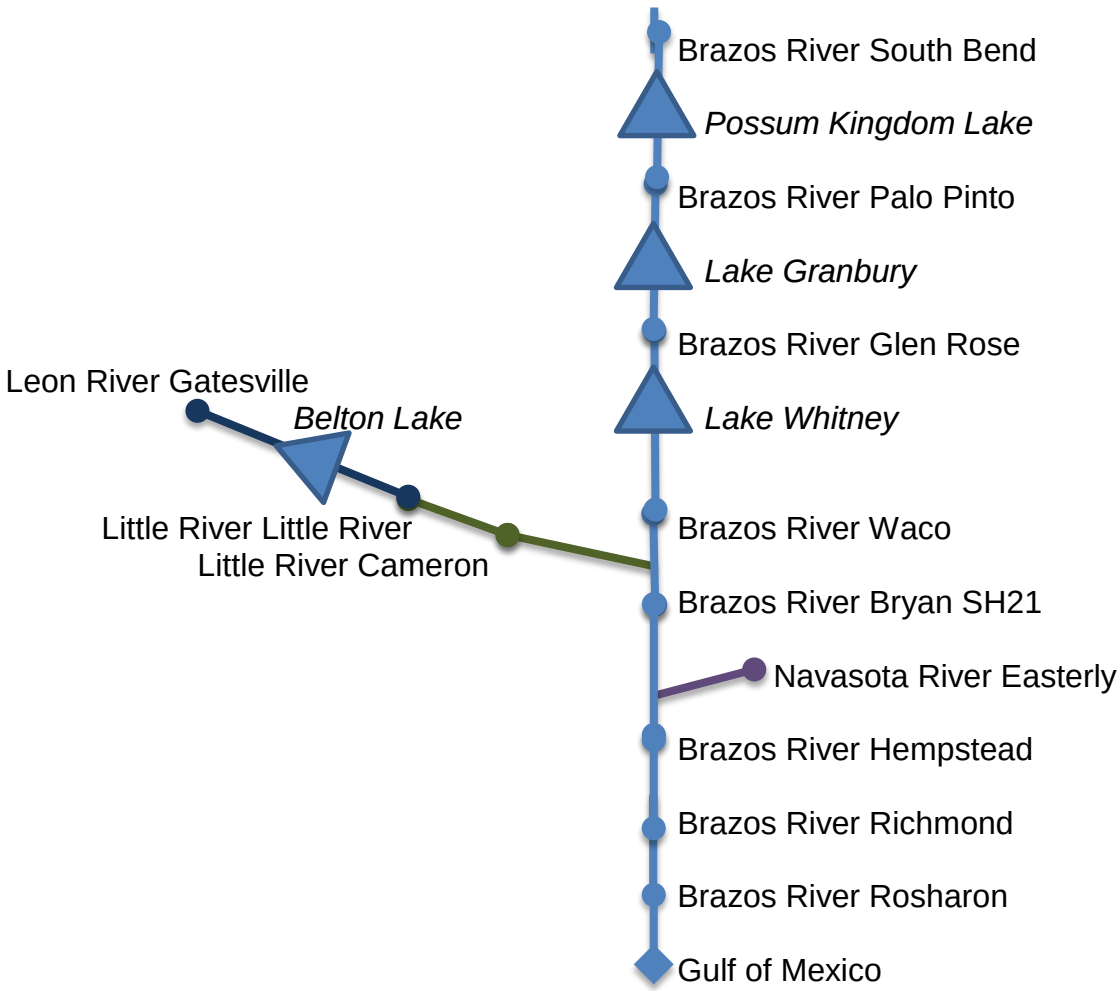

Figure 1 - Schematic of System Operation measurement points

Two additional methods were used to estimate travel times (1) across a broad range of flow conditions and (2) across a range of high flow pulses. Characterizing the broad spectrum of flow conditions, the National Hydrography Dataset-Plus (NHD+) was used to estimate travel time based upon data fields for average annual flow, average velocity and reach length. The NHD+ estimate of travel time is similar to the BRA estimates, indicative primarily of baseflow travel times. Pulse flow travel times were assessed visually for selected periods using flow hydrographs to estimate differences between time of upstream and downstream pulse peak flows (Table 2). An estimate derived from pulse start times may yield a slightly smaller range in travel time.

A travel time “analysis window” (Table 2) is estimated as a reasonable window of travel time that encompasses both baseflow and pulse flow events.

Table 2 - Travel times between selected Measurement Points and USGS gages

Location (USGS gauge) Upstream to Downstream	**BRA**[1] (days)	**Visual inspection of hydrograph, range of days between pulse peaks (min to max)** date range	(days)	**NHD+** (days)	**Analysis Window** (days)
To Brazos River near Rosharon					
Richmond to Rosharon	0.8	1973 Mar-Jun, 1991Dec-1992Jan, 1994 Oct, 2007Jan	0-3	0.9	3
To Brazos River at Richmond					
*Highbank to Richmond	5.5	1977 Jan-Jun, 1979 Mar-Jul, 1986 Dec, 1991 Dec-1992 Jan, 1994 Oct, 1998 Nov, 2007 Jan	3-8	5.1	8
Little R Cameron to Rich.	5.4		1-9	6.88	9
Navasota R Easterly to Rich.	8.6		1-9	7.7	9
*Yegua Ck Somerville to Richmond	4		na	4.75	5
Hempstead to Richmond	2.2	1973 Mar-Jun, 1991Dec-1992Jan, 1994 Oct, 2007Jan	1-3	2.6	3
To Brazos River near Hempstead					
SH21 near Bryan to Hempstead	2.3	1994 Oct, 2007Jan	1-2	2.39	2
*Highbank to Hempstead	3.3	1973 Mar-Jun, 1991Dec-1992Jan, 1994 Oct, 2007Jan	3-8	4.2	5
To Brazos River at SH21 near Bryan					
Little River near Cameron to SH21 near Bryan	1.9	1994 Oct, 2007Jan, 2009 Apr,	1-2	1.86	2
To Brazos River near Highbank					
Waco to *Highbank	1.2	1981 Jun, 1990 Mar-Jun, 1991Oct-1992Jan, 2007May-Jul	1-3	1.73	3
Glen Rose to *Highbank	4.9		2-8	7.22	8
To Little River near Cameron					
*Leon R Belton to LitR Cam.	2.3	1981 Jun-Jul, 1992 Jan-Mar, 2007 May-Jun, 2010 Jan-Feb	1-5	2.72	5
*LampasasR Belton to LRC	2.3[2]		1-3	2.79	3
*San Gabriel Laneport to LRC	0.6		1-5	1.45	5
To *San Gabriel River at Laneport					
*N Frk San Gabriel at G'town	na	1986 Jan-Feb, 1991Dec-1992May, 2007 Apr-Jul	0-4	2.81	4

NOTES

* . Asterisk identifies an intervening gauge, not a Measurement Point

1. Value provided by BRA staff
2. Travel time from Lampasas River at Belton was not available; assumed to be same as Leon River at Belton.

2.0 Environmental Flows Achievement within reaches at Applicable Measurement Points

Storage and diversion under the WMP is allowed within a river reach when environmental flow requirements are achieved at the measurement point applicable to that reach (see Technical Report Section 4.4.2.2). Day to day, operations will be adjusted by BRA to ensure that WMP operations do not hamper environmental flows achievement.

In addition to the required accounting plan, the Annual Environmental Flows Achievement Report submitted to TCEQ (see Technical Report Section 4.4.8) will demonstrate that water storage and diversion under the WMP does not impact achievement of the environmental flow standards. If a non-achievement is observed that results from the WMP, then operations will be adjusted to prevent another similar non-achievement.

2.1 High Flow Pulse Criteria

2.1.1 Pulse Correspondence between adjacent measurement points

The WMP contains high flow pulse environmental flow criteria developed through the Senate Bill 3 process and implemented by TCEQ (see Technical Report Section 4.4.2.1). The WMP criteria identify conditions at each measurement point to start a pulse based upon reported flow, and conditions to end a pulse based upon duration or volume of reported flow passing the MP.

For selected adjacent measurement points, an analysis of pulse correspondence was conducted using available historical flow records and WMP environmental flow criteria. A number of factors affect correspondence including: travel time, attenuation of the peak, intervening gains (or losses), and relative magnitude between the upstream pulse and downstream baseflow conditions. This analysis uses start and end date of pulses meeting at least the dry pulse criteria for each season. Pulses at an upstream MP were determined to correspond to pulses at a downstream MP when a pulse finish date occurred at the downstream MP within an analysis window (Table 2) following a pulse finish date at the upstream MP.

Two pairs of MPs were selected for analysis.

In the reaches where Little River near Cameron is the applicable MP, the maximum allowable run of river diversion rate may be large enough that the lowest levels of pulse criteria will apply to run of river flows. Since diversions are large enough to activate pulse criteria at the Cameron MP, the relationship to pulses occurring at the first downstream MP, Brazos River at SH21 near Bryan, is investigated.

Similarly, in the reaches where Brazos River near Hempstead is the applicable MP, the maximum allowable run of river diversion rate may be large enough that pulse criteria will apply to run of river flows. The relationship of pulses occurring at the first downstream MP, Brazos River at Richmond, is investigated.

Little River near Cameron and Brazos River at SH21 near Bryan

Flow records at Brazos River at SH21 near Bryan exhibited 131 dry condition qualifying pulses for the available period of record from July 1993 through May 2014. Little River near Cameron exhibited 124 dry condition qualifying pulses during the same period. Correspondence between pulse occurrence is evident by visual inspection during the spring of 1995 (Figure 2). This is a time period exhibiting high correspondence, where qualifying pulses occurred at both locations at approximately the same time.

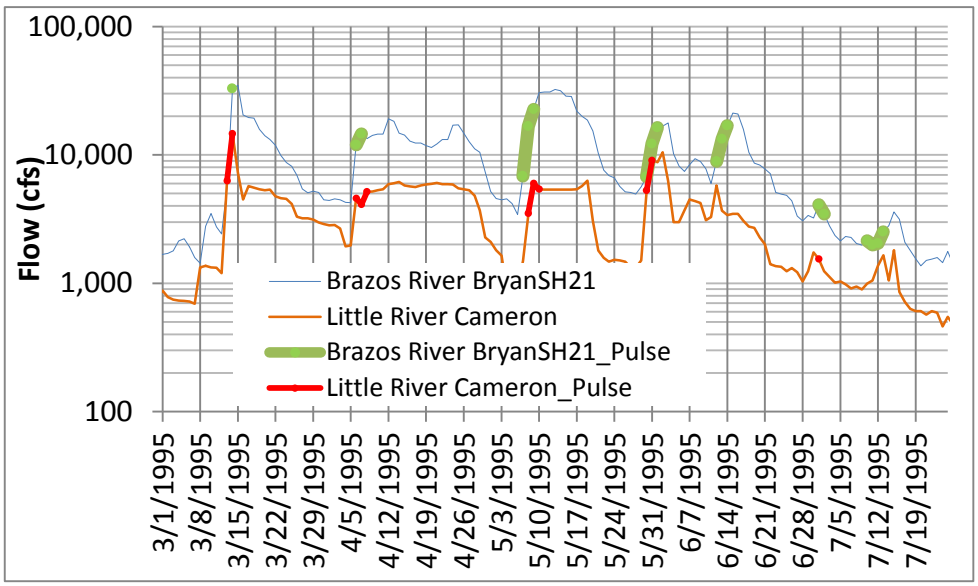

Figure 2. Flow and pulses at Little River Cameron and Brazos River SH21

Within an analysis window of 2 days (see Table 2), 43% of pulses occurring at Little River Cameron correspond to pulses occurring at the next downstream measurement point on the Brazos River at SH21 near Bryan. Of those corresponding pulses, the volume passing the Little River Cameron MP comprises approximately 44% volume of the pulses passing Brazos River at SH21 near Bryan MP. This indicates limited contribution of upstream pulses to downstream pulses, even at the lowest dry pulse level.

For Brazos River at SH21 near Bryan pulses exceeding volume thresholds for that MP, the distribution of corresponding pulses at Little River near Cameron are shown in Figure 3. In other words, for downstream pulses that qualify at Bryan, the lines in Figure 3 show the percent of upstream pulses that also qualify at Cameron. For Bryan pulses

exceeding the minimum pulse volume requirement at Bryan (Summer dry and average conditions, 12,700 ac-ft), all corresponding Cameron pulses exceeded the minimum (Summer dry) Cameron pulse requirement (see blue lines, Figure 3).

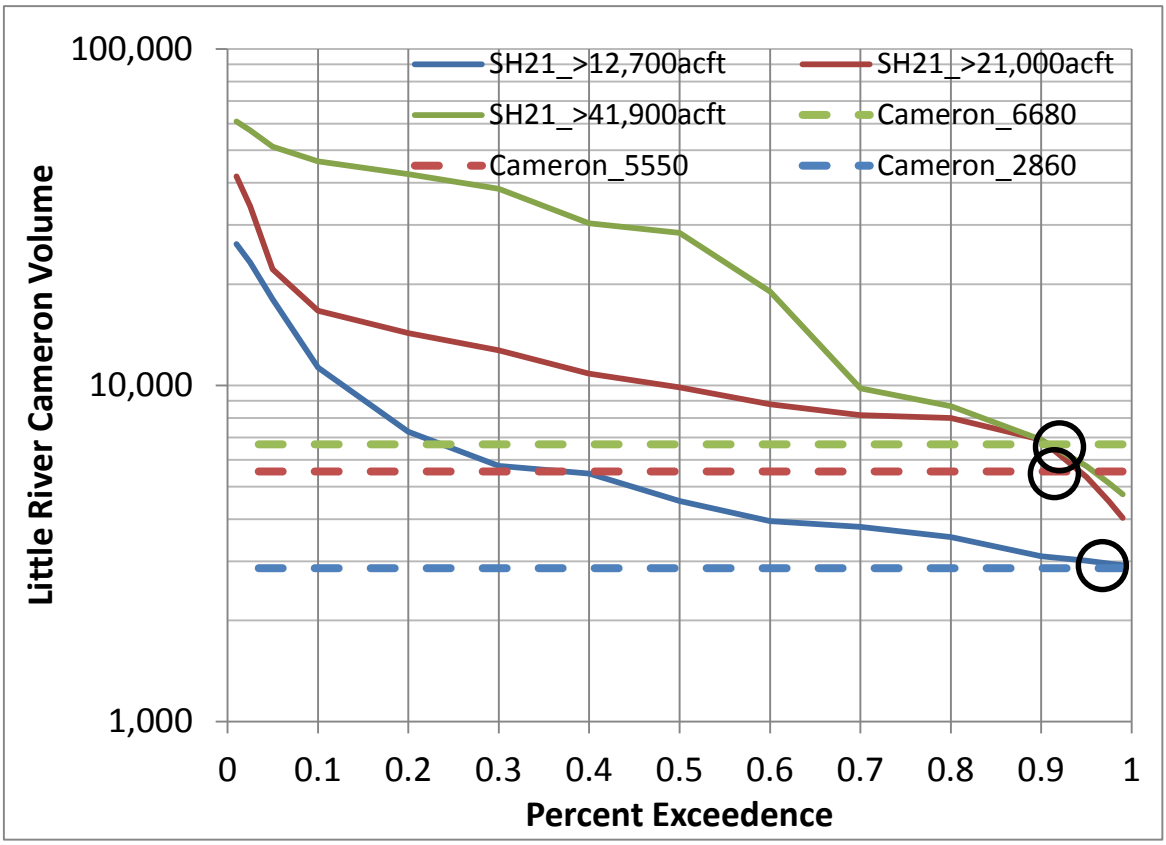

Figure 3. Little River Cameron pulse volume categorized by corresponding Brazos River at SH21 near Bryan pulse volume

<u>Brazos River near Hempstead and Brazos River at Richmond</u>

Flow records at Brazos River at Richmond exhibited 467 dry condition qualifying pulses for the period of record from October 1938 through May 2014. Brazos River near Hempstead also exhibited 467 dry condition qualifying pulses during the same period which is the period of record at Hempstead. Correspondence between pulse occurrence is evident by visual inspection during the spring of 1995 (Figure 4). This is a time period exhibiting high correspondence, where qualifying pulses occurred at both locations at approximately the same time.

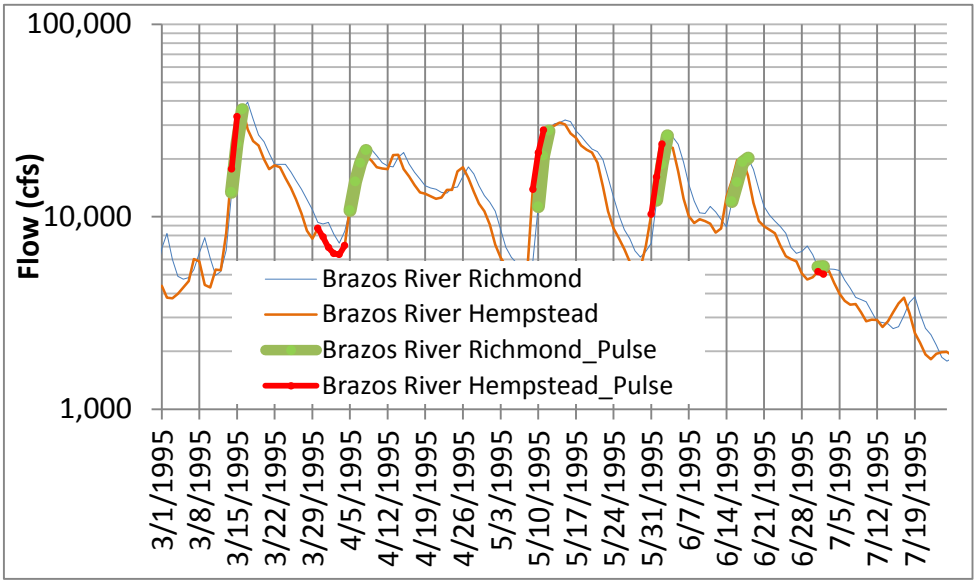

Figure 4. Flow and pulses at Brazos River near Hempstead and Brazos River at Richmond

Within an analysis window of 3 days (see Table 2), 73% of pulses occurring at Hempstead correspond to pulses occurring at the next downstream measurement point Brazos River at Richmond. Of those corresponding pulses, the volume passing the Hempstead MP was over 100% of the volume of pulses passing Richmond MP. This indicates high correspondence between upstream and downstream pulses.

For Brazos River at Richmond pulses exceeding volume thresholds for that MP, the distribution of corresponding pulses at Brazos River near Hempstead are shown in Figure 5. In other words, for downstream pulses that qualify at Richmond, the lines in Figure 5 show the percent of upstream pulses that also qualify at Hempstead. For Richmond pulses exceeding the minimum pulse volume requirement at Richmond (Summer dry and average conditions, 16,400 ac-ft), approximately 90% corresponding Hempstead pulses exceeded the minimum (Summer dry) Hempstead pulse requirement (see blue lines, Figure 5). For the larger magnitude Winter and Spring dry pulses, approximately 95% of corresponding Hempstead pulses exceeded the minimum Hempstead pulse requirement (Figure 5).

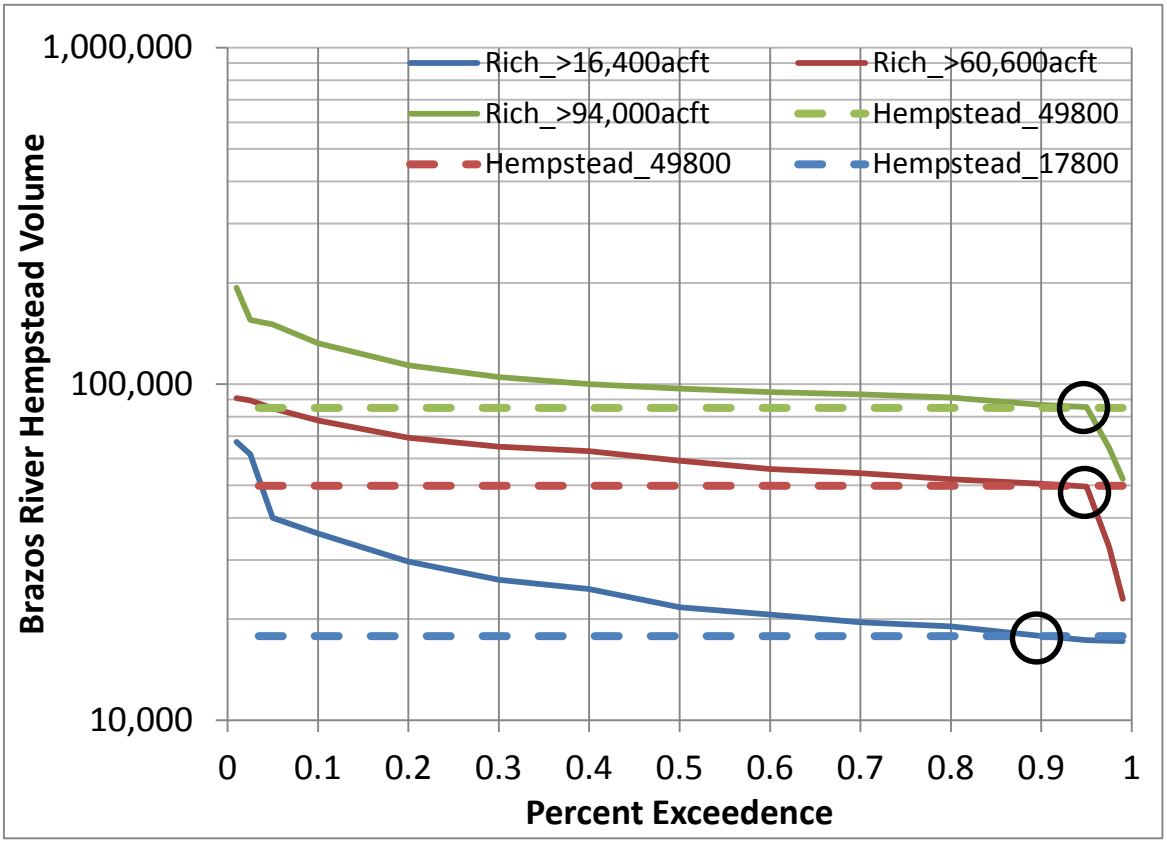

Figure 5. Brazos River near Hempstead pulse volume categorized by corresponding Brazos River at Richmond pulse volume

2.1.2 Pulse evaluation summary

Travel time is significant between measurement points. For example, the estimated travel time between the Brazos River Waco and Brazos River Richmond gages is 4 to 11 days (range of travel times between pulse peaks, Table 2). Considering that the WMP high flow pulse criteria for Waco and Richmond have a pulse duration ranging from 7 to 19 days, only limited ability exists to alter operations upstream of Waco in advance of a detected pulse start downstream at Richmond. Similar travel time conditions are evident between other adjacent and non-adjacent measurement points.

Pulse correspondence was evaluated at two selected pairs of adjacent measurement points. Achievement of pulse criteria at adjacent measurement points was found to be complex. The Cameron-Bryan pair exhibited limited correspondence, only half of the pulses occurring at Cameron corresponded to Bryan pulses and those Cameron pulses contributed only 40% of volume to Bryan pulses. This is not unexpected considering roughly 24% of the contributing drainage area to Bryan is comprised of area contributing to Cameron (Table 1).

The Hempstead-Richmond pair exhibited high correspondence of pulses, where over 70% of Hempstead pulses correspond to Richmond pulses and volume of those pulses passing Hempstead are a little higher than volume of corresponding pulses passing Richmond. Since drainage area contributing to Hempstead comprises over 96% of area contributing to Richmond (Table 1), the high level of correspondence is not surprising. For this pair, when environmental flow pulse conditions are met at the upstream MP, pulse conditions are expected to be met at the downstream location.

Since pulse correspondence is complex and since travel times are significant even between adjacent measurement points, operations and accounting under the WMP will manage storage and diversions within each reach according to the measurement points applicable to each reach. If environmental flows achievement is determined to be affected, then operations can be changed to ensure the WMP does not impact achievement of environmental flow standards.