Review of Groundwater–Surface Water Interaction between the Carrizo-Wilcox Aquifer Group, the Colorado and Brazos Rivers

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SUMMARY: The Colorado and Brazos river systems bisect the Central Carrizo-Wilcox and other minor aquifers in Groundwater Management Area 12 in Central Texas. These rivers "gain" water from the aquifers as they cross them, according to technical reports. However, over-pumping of groundwater in the region threatens to reverse this groundwater-surface water relationship and will cause the rivers to "lose" water to the aquifers within about 30-50 years. MODFLOW analyses, used to extract outflow information from the Central Carrizo-Wilcox Groundwater Availability Model for the GMA-12 adopted Desired Future Conditions, tend to validate this trend. The Colorado River water availability model indicates that all but a very minor portion of the surface water has been allocated to surface water rights in the Bastrop segment of the river. Therefore, any reduction in groundwater outflows to the river and its tributaries is likely to reduce the amount of river water available to meet surface water rights as well as environmental flows.

Water availability model analyses were run to estimate the potential impact of groundwater pumping on surface water rights. Reduction in groundwater outflows to the Colorado River equivalent to the currently estimated flow (32 cfs; 25,000 acre-feet per year) impacted 10,000 acre-feet per year of permits, and over 1000 water rights. Reductions in groundwater outflows in the Brazos River impacted over 29,000 acre-feet per year of permits, and over 800 water rights.

GAINING RIVERS

Colorado River – The Colorado River gains water from the Simsboro and other aquifer formations as it passes through Bastrop and Fayette counties within Groundwater Management Area 12. Historical records and recent studies indicate that the Colorado River has been, and remains, a gaining river as it passes through the river segment associated with the Carrizo-Wilcox aquifer group, especially the Simsboro outcrop. Low-flow studies conducted by the USGS in1918, and a flow-duration curve generated by Dutton, in 2003[1] indicate that these groundwater formations contribute approximately 25,000 acre-feet per year to the Colorado River.

More recently, the Lower Colorado River Authority (LCRA) conducted studies to assist in its management of water releases from the Highland Lakes to meet water rights and environmental flows obligations. These studies include information on the gains/losses of the river as it flows through Bastrop County and provide additional quantification of the amount of base flow the river gains during dry periods like the one that has occurred over the past several years.

In a study related to the LCRA Operations Project (Saunders, 2006[2]) the author concluded, "the lower Colorado River is a gaining stream that receives groundwater contributions from major and minor aquifers." Analysis of USGS data contained in the report, though inconclusive, shows a gain of about 50 cubic feet per second (cfs) in the reaches passing over the Carrizo-Wilcox between Utley and Smithville (about 99 acre-feet per day). Limited fieldwork in 2005 also suggested that the Colorado River has some stream flow gain from groundwater in these reaches.

The LCRA conducted a field investigation in November 2008 as a follow-up to above mentioned gain-loss studies (Saunders, 2009[3].). The study concluded "the total net gain to the Colorado River from the Carrizo-Wilcox aquifer in Bastrop County was estimated to be 30 cfs during the November 2008 low flow event. This compares to the USGS 1918 estimate of 36 cfs, and the LCRA estimate of 50 cfs in November 2005". Saunders further concluded

> "such contributions to the base flow from these sources can be important during critical low-flow conditions." *"A study of ground water-surface water interaction prepared as part of development of the Central Carrizo-Wilcox groundwater availability model (GAM) indicated that base-flow rates of rivers crossing the aquifer outcrop have not decreased over time, and seasonal variability in base flow for perennial streams may not fluctuate significantly (Dutton, et al., 2003). In addition, flow from bedrock aquifers through the alluvium to the river is a complicated system and deserves more understanding. As demands on ground water resources increase with future growth in the Central Texas region, ground water-surface water interactions may need to be periodically monitored to assess water availability in the decades to come."*

Based on the data reviewed in developing the Central Carrizo-Wilcox Groundwater Availability Model (GAM) (Dutton, 2003), the model was calibrated and verified to the historical period of 1980-2000 and included the Colorado River, Middle Yegua Creek, and the East Yegua Creek as calibration targets. The Colorado River base flow was calibrated to 26,100 acre-feet per year to correspond to the 1918 USGS study cited above. As such, it is clear that the GAM for the central part of the Carrizo-Wilcox has been calibrated to include base flows for the Colorado River and three tributaries in Bastrop and Lee counties.

As demonstrated by the five studies cited above, the contribution of the Carrizo-Wilcox and other aquifers in the Utley to Smithville segment of the Colorado River is in the range of 30-50 cubic feet per second (21,000 – 36,000 acre-feet per year). This agrees with the USGS 1918 estimate of 36 cubic feet per second (26,100 acre-feet per year) that forms the basis of the GAM used in Groundwater Management Area 12 to develop its desired future conditions; by the Texas Water Development Board in estimating the modeled available groundwater (MAG); and by the groundwater conservation districts in evaluating and managing permits. As such, it is expected that GAM analyses of various pumping regimes will have corresponding impacts on these surface water features and therefore can be used to predict the impact of these regimes on these surface waters.

Brazos River – The Brazos River gains water from the Simsboro and other aquifer formations as it passes through Brazos, Burleson, Milam and Robertson counties within Groundwater Management Area 12. Historical records and recent studies indicate that the Brazos River has been, and remains, a gaining river as it passes through the river segment associated with the Carrizo-Wilcox aquifer group, especially the Simsboro outcrop. Low-flow studies conducted by the USGS[4] in 2007, indicate that these groundwater formations contribute a 43% to 60% increase in stream flow (approximately xx,000 acre-feet per year) to the Brazos River. In summary, the study concludes: "This result is consistent with indications of a gaining reach on 1980 potentiometric-surface maps of the Carrizo-Wilcox and Queen City-Sparta aquifers.

PREDICTED IMPACTS OF GROUNDWATER PUMPING

The Colorado Regional Water Planning Group (Region K, 2006[5]), which includes Bastrop County, predicted in its water plan that, with currently planned groundwater pumping in the region, the Colorado River will become a "losing river" by 2050. According to the Region K Water Plan

> "the Carrizo-Wilcox aquifer's primary water quantity concern is the water-level declines anticipate through the year 2060 due to increased pumping. Groundwater withdrawals increased an estimated 270 percent between 1988 and 1996, from 10,100 to 37,200 acre-feet per year, from the mostly porous and permeable sandstone aquifer. The area in and around the Carrizo-Wilcox aquifer is expected to see continued population growth and increases in water demand. The Texas Water Development Board (Dutton, 1999[6]) co-sponsored a study of the Central Texas portion of the Carrizo-Wilcox aquifer using a computer model to assess the availability of groundwater in the area. Six water demand scenarios were simulated in the model, which ranged from considering only the current 1999 demand, to analyzing all projected future water demands through the year 2050. On the basis of the calibrated model, all withdrawal scenario water demands appear to be met by groundwater from the Carrizo-Wilcox aquifer through the year 2050. The simulations indicate that the aquifer units remain fully saturated over most of the study area. The simulated water-level declines in the Carrizo-Wilcox aquifer mainly reflect a pressure reduction within the aquifer's artesian zone. Some dewatering takes place in the center of certain pumping areas. In addition, simulations indicate that drawdown within the confined portion of the aquifer will significantly increase the movement of groundwater out of the shallow, unconfined portions to the deeper artesian portions of the aquifer. The relationships that currently exist between surface and groundwater may also change. Simulations indicate that the Colorado River, which currently gains water from the Carrizo-Wilcox aquifer, may begin to lose water to the aquifer by the year 2050." The TWDB report estimated a 38 cubic

feet per second (27,500 acre-feet per year) decrease in outflow to river with 188,700 acre feet per year of pumping (scenario 5).

Using the Texas Water Development Board report as a basis, the Colorado Regional Water Planning Group (Region K), on February 9, 2000, passed a resolution supporting sustainable management of the groundwater resources of the region discouraging over-pumping – “mining of groundwater” – of the aquifers. The resolution (Region K, 2006) strongly opposes the mining of groundwater, within its region. Region K defined groundwater mining as “the withdrawal of groundwater from an aquifer at an annualized rate, which exceeds the average annualized recharge rate to an aquifer where the recharge rate can be scientifically derived with reasonable accuracy.” This resolution addressed the concerns listed in its water plan for the Barton Springs segments of the Edwards (BFZ), Gulf Coast, Trinity, and Carrizo-Wilcox aquifers that are located within Region K. “Based on the projected future groundwater demand in Region K, the LCRWPG’s position on groundwater mining restricts the water supply strategies that can be considered for the Lower Colorado Regional Water Plan, which are discussed in more detail in Chapter 4.”

In response to a proposal by San Antonio Water Systems (SAWS) to pump 55,000 acre-feet per year from the Simsboro, a Lost Pines hydrologist studied the potential impact of 55,000 acre-feet per year of pumping in the District (Kier, 2000[7]). This Study concluded

> “extensive ‘dewatering’ of the Simsboro Aquifer would begin before the year 2040 if the proposed production for San Antonio occurs. Over time, the 55,000 acre-feet per year, in addition to other projected pumping in the area, would result in reduced artesian pressure, lower well water levels, and ultimately ‘dewatering,’ or ‘mining’ the aquifer – that is, the level of water in the Simsboro Aquifer would drop below the top of the aquifer.” The study further revealed, “by year 2040, extensive depressurization and dewatering of the Simsboro Aquifer would occur. Furthermore, the production for San Antonio would block movement of recharge to the Simsboro Aquifer, limiting future water production in deeper parts of the aquifer in Bastrop, Lee, Milam, and Burleson Counties.”

Lost Pines Groundwater Conservation District further recognized the threats of over-pumping in September 2004, when it published its first management plan and reiterated its concerns through the 2010 Revision (LPGCD, 2010[8]). Under the topic *Groundwater Supply Issues and Potential Solutions* the plan states:

> “Unfortunately the existence of artesian storage is critical because it is the pressure associated with this artesian storage that drives the natural behavior of the aquifers, most particularly the discharge of groundwater to surface water courses. Artesian pressure also likely influences the overall quality of water in the aquifers. While recognizing that some temporary decline in artesian pressure must occur for groundwater to be produced, the LPGCD believes that a long-term, continued reduction in artesian pressure is not in the best

> interests of the citizens and businesses in Bastrop and Lee counties, which depend on groundwater for a potable water supply." Based on the information available, the plan goes on to state: "The LPGCD's ability to achieve its mission statement -- to manage the groundwater resources within the District on a sustainable basis in perpetuity – is, thus, tenuous, at best." Due to out-of-District pressures, the plan concludes: "Thus, whether the LPGCD will be able to achieve its mission statement remains to be seen, even to meet only in-District demands. It is clear, though, that with major transfers of groundwater outside of the District, achieving the mission statement will be impossible. There appears to be no other solution at this point, since the LPGCD is precluded by law from discriminating between in-District operating permits and out-of-District transfers."

Many of these concerns, for whatever reason, are not incorporated into the 2012 Management Plan (LPGCD, 2012[9]).

Data developed by the Texas Water Development Board (Hutchinson, 2009[10]) supports the concerns raised by Region K. Groundwater outflow to surface waters in the GMA-12 area, which includes the Colorado River, decreased an average of 60,500 to 70,500 acre feet per year between 1980 and 1999, while pumping increased by 64,000 acre feet per year. Hutchinson presented data from a GMA-12 groundwater availability model (GAM) run to the Lost Pines Groundwater Conservation District Board in 2009. The GAM run calibrated the GMA-12 model to pre-desired future conditions and provided a water budget for the management area. As shown in Table 1, which is data extracted from the presentation, inflows to the area varied greatly during the study period and surface water and spring outflows decreased by a total of 134,000 acre feet per year. Evapotranspiration decreased by 30,700 acre-feet per year while pumping increased.

According to the Texas Water Development Board (Hutchison, 2009) a water budget is used along with the Desired Future Conditions Groundwater Availability Model to calculate the Modeled Available Groundwater (MAG) for each groundwater management area and groundwater management district. The use of the Central Carrizo-Wilcox GAM is based on the historical, pre-development, water budget, discussed above, which accounts for inflows, outflows, and changes in storage. In its natural state, an aquifer is in equilibrium: inflows = outflows. When an aquifer is pumped, inflows increase, outflows decrease, and storage decreases. These dynamic changes caused by pumping can be estimated with GAM analyses. Increased inflows and decreased outflows are "captured" flows that are available for pumping. In the water budget presented in Table 1, the total capture (65,500-75,500 acre-feet per year) is the sum of the increased inflow and decreased outflow, which is approximately equal to the increase in pumping. Any increase in pumping in excess of total capture is due to a change (decrease) in storage. Strictly speaking, though presented by Hutchison as a "pre-development" water budget, the fact that increased pumping had occurred during this period and the aquifer was not in equilibrium causes the author to characterize this period as the "pre-DFC Development" water budget.

Table 1. Hutchinson GMA-12 Pre-DFC Development Water Budget

GMA-12 GAM calibration water budget (Hutchinson, 2009)					
	1980-1999 (AF/yr)				
Component	**1980**	**1990**	**1999**	**Average**	**Average Capture**
Recharge from Precipitation	***250,000***	***325,000***	***175,000***	**270,237**	
Cross-formational Flow	***-700***	***2,700***	***4,200***	***2,881***	
Inflow from GMA 13	200	*2,200*	2,400	2,349	500
Inflow from GMA 14	-900	*500*	1,800	532	3,000
TOTAL INFLOW	**249,300**	**327,700**	**179,200**	**273,118**	
TOTAL INCREASED INFLOW					**3,500**
Pumping	**50,000**	***75,000***	**113,000**	**77,148**	
Surface Water Outflow	**225,000**	***130,000***	**100,000**	**143,276**	50,000
Evapotranspiration Outflow	***79,000***	***55,000***	***38,000***	**48,279**	0-10,000
Springs Outflow	**25,000**	***17,500***	**16,000**	**19,200**	5,000
Cross-formational flows	**21,230**	**19,390**	**18,030**	**19,331**	
Outflow to Younger Formations	5,100	*4,500*	4,300	4,550	500
Outflow to GMA 8	-70	*-10*	30	26	
Outflow to GMA 11	11,700	*11,200*	10,400	11,035	500
Outflow to GMA 15	4,500	*3,700*	3,300	3,720	1,000
TOTAL OUTFLOW	**400,230**	***316,280***	**303,060**	**326,565**	
TOTAL DECREASE OUTFLOW					**57-67,000**
Storage Change (Hutchinson)	*-140,000*	*30,000*	*-150,000*	**-34,107**	
TOTAL CAPTURE					**60,500-70,500**
Pumping Increase					**64,000**
Figures in Italics are estimated from graphs.					
Data from Bill Hutchison Presentation to LPGCD November 18, 2009					

In Figures 1-5, data from Hutchinson were compared to the same period for the GMA-12 DFC GAM to determine if there was reasonable agreement in the two GAM runs (Rice, 2011a[11]). All comparisons for the years 1980, 1990 and 1999 were consistent with the exception of stream flow, where the GMA-12 GAM runs were consistently higher. Likewise, data for the years 2000 and 2005 were consistent with the historical period except for recharge and stream flow. Variance with historical became extreme for recharge and outflows to streams in the post-development data (see GMA-12 Post-Development Water Budget).

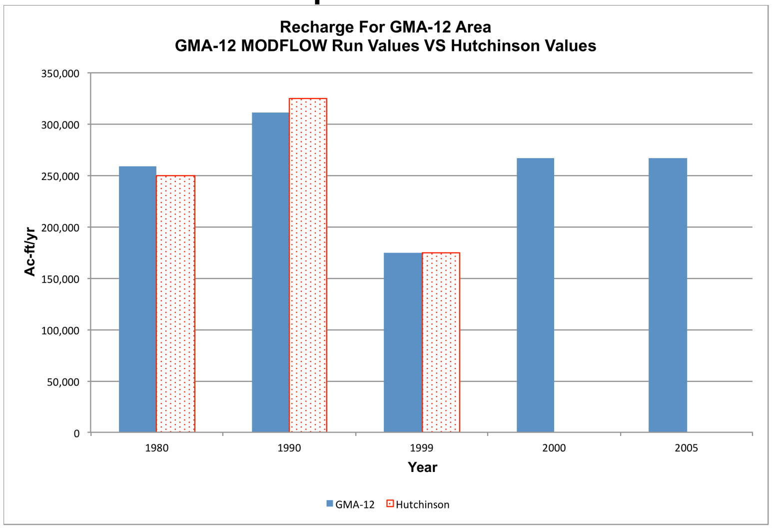

Figure 1. Recharge comparison

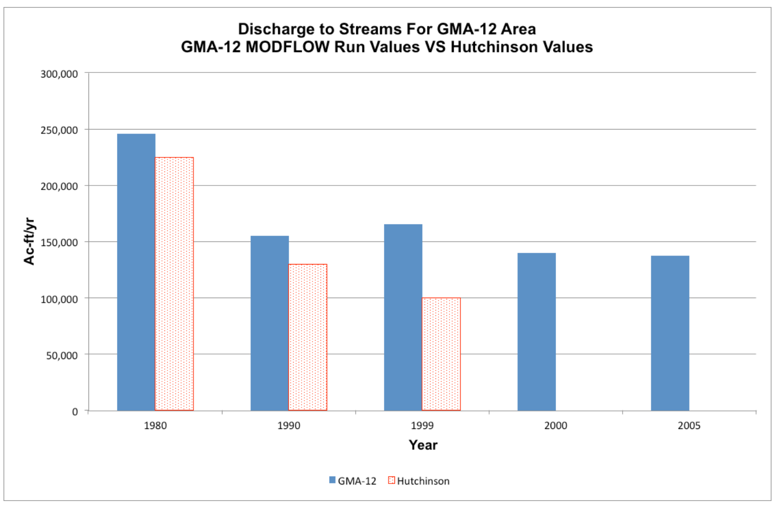

Figure 2. Discharge to streams comparison

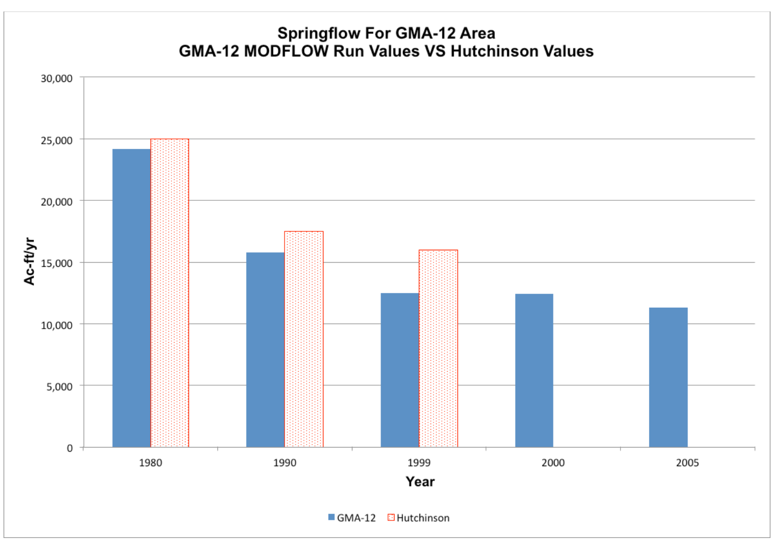

Figure 3. Discharge to springs comparison

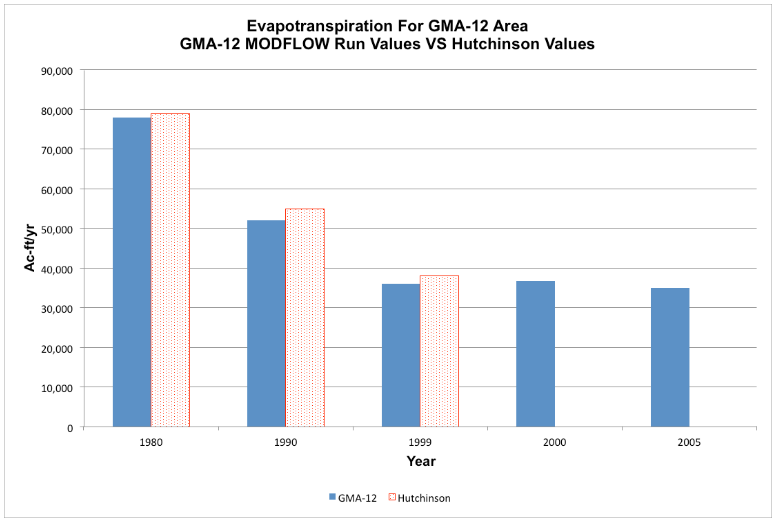

Figure 4. Evapotranspiration comparison

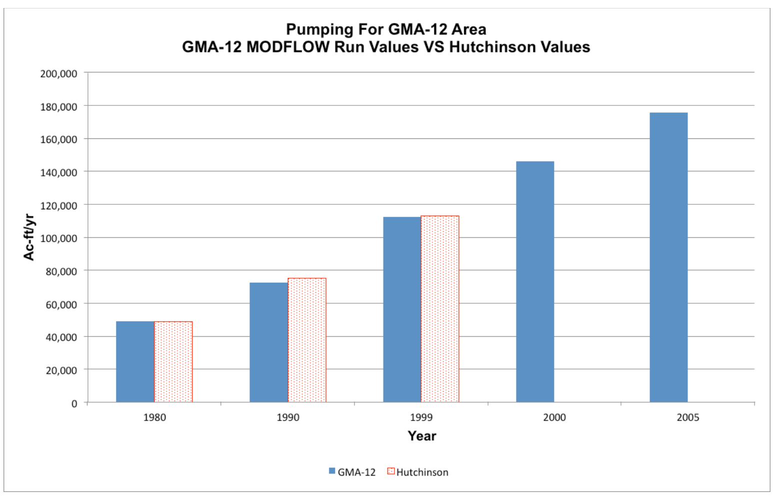

Figure 5. Pumping comparison

DESIRED FUTURE CONDITIONS (DFC) and MODELED AVAILABLE GROUNDWATER (MAG)

Lost Pines Groundwater Conservation District (LPGCD) is one of five groundwater districts in Groundwater Management Area 12 (GMA-12). GMA-12 adopted Desired Future Conditions (DFC) on May 27, 2010. The DFC for GMA-12 are characterized in a Groundwater Availability Model developed to ensure the drawdowns in each District are compatible with the drawdowns across the Districts (GMA-12, 2010[12]). Based on the DFC, expressed in feet of drawdown for each aquifer, the Texas Water Development Board estimated the Modeled Available Groundwater (MAG) for each groundwater conservation district. The same model is used herein to estimate impact trends of pumping on surface water outflows to the Colorado River basin.

Table 2. Lost Pines GCD Modeled Available Groundwater

Modeled Available Groundwater Totals for Lost Pines District

All values are in acre-feet/year

AQUIFER	2010	2020	2030	2040	2050	2060
Sparta	2,405	2,236	5,315	1,980	1,885	1,877
Queen City	1,315	1,215	2,880	1,144	1,134	1,133
Carrizo	6,610	7,618	8,358	9,263	11,800	12,052
Calvert Bluff	1,785	2,226	2,633	3,183	3,912	3,985
Simsboro	29,556	32,731	31,362	34,916	36,544	37,249
Hooper	1,174	1,427	1,715	2,095	2,589	2,592
TOTAL	42,845	47,453	52,263	52,581	57,864	58,888

TWDB GAM runs 10-044 MAG, 10-045 MAG, and 10-046 MAG

Table 1 in Lost Pines GCD Management Plan Revised September 19, 2012

Groundwater pumping permits have been issued for 75,564 acre-feet per year in the Simsboro aquifer as of May 2013. The End Op permit application for an additional 56,000 acre-feet per year is pending a contested case hearing review. Pumping in excess of the DFC/MAG will further threaten the flow and ecology of the Colorado River and Matagorda Bay, especially during periods of extreme drought.

Lost Pines GCD is mandated by state law to manage drawdown of the aquifers to the levels adopted in their DFC. However, since the Carrizo Sands and the Wilcox Group are considered to be a single unit because they are hydrologically connected (TWDB, 1970[13]), management of drawdowns to the DFC levels could become complicated as pumping develops.

> "The Carrizo-Wilcox aquifer ... is one of the most extensive aquifers in Texas. The aquifer provides large quantities of ground water to wells throughout the study area. The aquifer consists of hydrologically connected interbedded sands, clays, silts and discontinuous lignite beds of the Wilcox Group and overlying massive sands of the Carrizo. These sediments were deposited by large, fluvial-deltaic river systems which were sourced in the Rocky Mountains and Ouachita-Arbuckle Mountains. Above the Carrizo Sands are the clays and interbedded fine sands of the Reklaw Formation" (HDR Engineering, 1994[14]).

POST DEVELOPMENT WATER BUDGET AND MODFLOW ANALYSES

A post-development water budget was extracted from the GMA-12 DFC GAM files based on the model budget provided by the Texas Water Development Board (Hutchinson, 2009). Environmental Stewardship retained a groundwater hydrologist to extract the data necessary to characterize the post-development water budget and run MODFLOW analyses to estimate the modeled impact on the Colorado River. Table 3 presents the pre-DFC development water budget (1990-1999) along with the post-development water budget (DFC 2010-2060). In many ways there are disconnects between the ending point of the pre-DFC development period (1999/2000) and the initial period of the post-development water budget (2010). For example, recharge is considerably higher, characterizing total inflow to be much higher in the post development budget than in the pre-DFC budget, and is held constant for the entire planning period. Likewise, outflows to surface water (stream leakage) are much higher than historical and remains higher than historical throughout the planning period. This may well result in an underestimate of the impacts of pumping on outflows to the Colorado River. ***Thus, the recharge and precipitation assumptions for the 2010-2060 period should be reviewed and perhaps refined, especially in view of the impacts of the ongoing drought and climate change on the region (see Recommendations).***

Table 3. Post-development Water Budget

GMA-12 Water Budget 1980-1999 (Hutchinson) and 2010-2060 (the DFC Period)

GMA-12 data from file = GMA12_7B

	Hutchinson (AF/yr)			DFC 2010-2060 (AF/yr)					
Component	**1980**	**1990**	**1999/2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
INFLOWS									
Recharge from Precipitation	250,000	325,000	175,000	561,000	561,000	561,000	561,000	561,000	561,000
Cross-formational flow	-700	2,700	4,200	48,900	51,800	56,600	60,500	64,400	66,800
Reservoir Leakage				15,600	15,600	15,700	15,800	15,900	16,100
Stream Leakage				54,600	57,600	61,300	65,000	69,200	73,700
TOTAL INFLOW	**249,300**	**327,700**	**179,200**	**680,100**	**686,000**	**694,600**	**702,300**	**710,500**	**717,600**
TOTAL INCREASED INFLOW				**500,900**	**5,900**	**8,600**	**7,700**	**8,200**	**7,100**
OUTFLOWS									
Pumping	49,000	75,000	113,000	332,000	357,000	385,000	403,000	428,000	434,000
Surface Water (Stream leakage)	225,000	130,000	100,000	268,000	253,000	240,000	230,000	223,000	218,000
Colorado River Basin (MODFLO 2)		*27,300*	*5,410*	*13,400*	*10,700*	*6,970*	*3,960*	*1,360*	*-6,330*
Colorado River (MODFLOW 2)		*19,900*	*7,640*	*9,700*	*7,910*	*5,200*	*2,910*	*814*	*-703*
Colorado River (End Op)				*9,650*	*3,880*	*572*	*-2,820*	*-5,360*	*-7,410*
Evapotranspiration	79,000	55,000	38,000	119,000	120,000	121,000	121,000	124,000	125,000
Springs (Drains)	25,000	17,500	16,000	21,000	18,800	16,900	15,600	14,500	13,600
Cross-formational flow	21,230	19,390	18,030	49,800	47,800	44,800	42,500	40,600	38,800
TOTAL OUTFLOW	**399,230**	**296,890**	**285,030**	**789,800**	**796,600**	**807,700**	**812,100**	**830,100**	**829,400**
TOTAL DECREASE OUTFLOW		**-102,340**	**-11,860**	**504,770**	**6,800**	**11,100**	**4,400**	**18,000**	**-700**
Storage Change (Calculated)	**-150,930**	**11,420**	**-123,860**	**-109,700**	**-110,600**	**-113,100**	**-109,800**	**-119,600**	**-111,800**
Storage Change (Hutchinson)	**-140,000**	**30,000**	**-150,000**						
TOTAL CAPTURE									
Pumping Increase		**26,000**	**38,000**	**219,000**	**25,000**	**28,000**	**18,000**	**25,000**	**6,000**
Change in Stream and Spring Outflows									
River Status (Gain/Loss)	***Gaining***	***Gaining***	***Gaining***	***Gaining***	***Gaining***	***Gaining***	***Gaining***	***Gaining***	***Losing***
River Status (Gain/Loss) w/End Op							***Losing***	***Losing***	***Losing***

Setting aside the above-mentioned concerns, MODFLOW analyses were conducted to determine the potential impact of increased pumping on the Colorado River, Figures 6-7 (Rice, 2011). Mindful that groundwater availability models are, for the most part, useful in estimating broad regional trends, the MODFLOW analyses presented here are intended to be used to predict trends, and are not intended as quantified models of estimated impacts. Nonetheless, given the rigorous analysis and calibration used by Dutton in developing the models impact on the Colorado River and three of its tributaries, one can expect that the model will reliably predict general trends, and perhaps be more responsive than other groundwater models in predicting groundwater-surface water relationships.

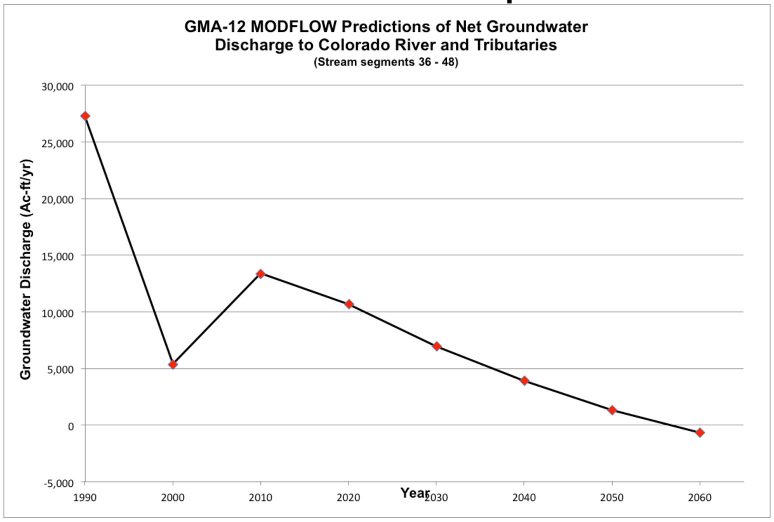

Figure 6. Outflows to the Colorado River and tributaries

The 1990 groundwater discharge for the Colorado River is consistent with the empirical "gaining" stream data that estimates the river was gaining 21,000 to 36,000 acre-feet per year both historically and in the 2005 and 2009 LCRA studies. The year 2000 data is consistent with Alcoa mining data reported to the Railroad Commission and obtained by Lost Pines GCD for the period of 1990-1999. The Alcoa pumping reports were consistent at around 23,000 acre-feet per year until 1999 when pumping increased dramatically to 37,737 acre-feet per year (LPGCD, 2011[15]). Thereafter, Alcoa pumping decreased dramatically and was recently reported to be 6,200 acre-feet per year in 2012 (LPGCD, 2013[16])

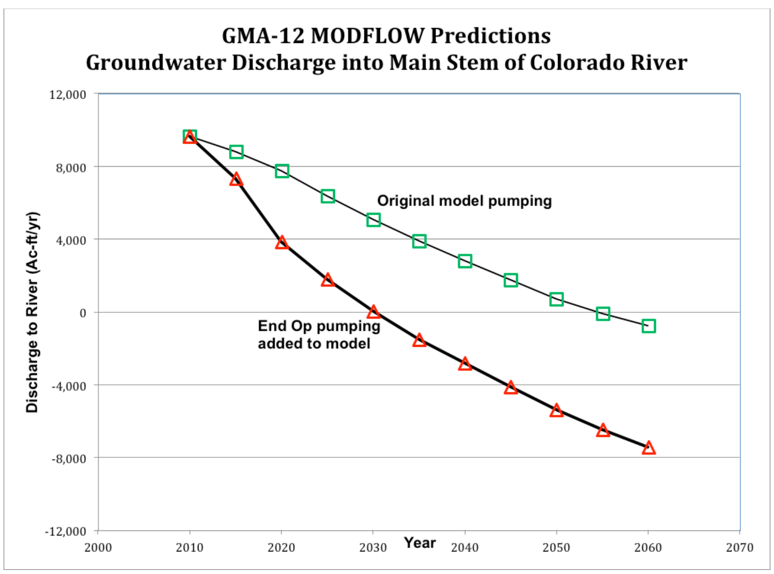

Figure 7. Outflows to the Colorado River with End Op pumping

The GMA-12 DFC GAM files did not include, per-se, the End Op requested pumping of an additional 56,000 acre-feet per year. To estimate the impact of the End Op pumping in excess of the desired future conditions, End Op's pumping was added to the file. The net impact is to accelerate the trend toward reversing the groundwater-surface water relationship, making the Colorado River a "losing" stream.

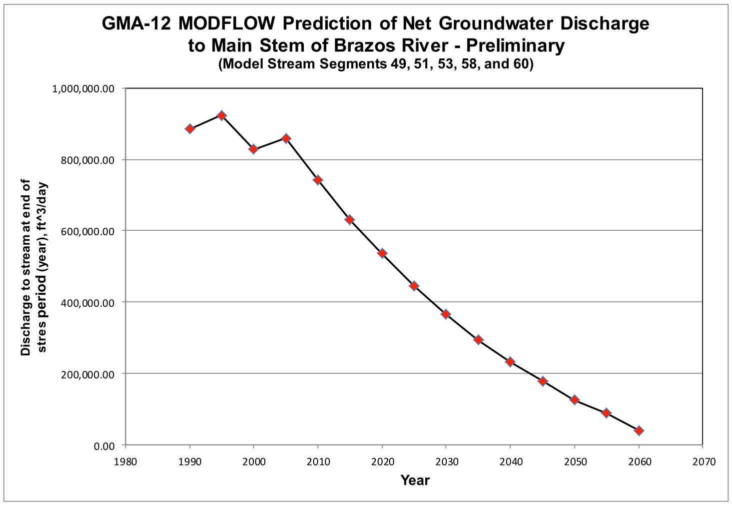

Figure 8. Outflows to the Brazos River

In summary, MODFLOW analyses of the GMA-12 desired future conditions groundwater availability model indicate a trend toward reversing the "gaining" stream status of both the Colorado and Brazos Rivers in the later periods of the 50 year planning cycle. Once reversed, these rivers will become "losing" streams and will provide surface water as recharge to the aquifers as pumping accelerates and/or holds steady at high levels in the mid-later part of the century.

SURFACE WATER FLOW and ALLOCATION

As demonstrated above, the contribution of the Carrizo-Wilcox and other aquifers to the Colorado River (as it intersects with the Simsboro and other Wilcox formations) is in the range of 25,000 – 36,000 acre-feet per year. The LCRA water availability model (WAM) for the Colorado River is based on gaged flows, and therefore incorporates the contributions of the aquifers through these river segments. Were these flows not available due to over-pumping of the aquifers during a drought-of-record or worse-than-drought-of-record, it is estimated that the Colorado River and Matagorda Bay would receive 50-75% less water than LCRA estimates is needed to help meet the "subsistence" level of instream flows and "threshold" level of freshwater inflows to Matagorda Bay. Were the "gaining" aspect of the river to be reversed to become "losing" to the extent of 10,000 or more acre-feet per year (as estimated by the Region K report and MODFLOW analyses of the GMA-12 DFC GAM), this threat to the Colorado River and Matagorda Bay is exacerbated. With surface water that is otherwise allocated, and with LCRA water management rules that allow environmental flows to be curtailed during a drought emergency, calls on water rights in the basin could easily go beyond the amount of water available were the "gaining inflows" to the river not available, leaving the river and estuary essentially dry.

Environmental flows for the Colorado River at Bastrop have been recommended by the Lower Colorado River Authority – San Antonio Water System Water Project (LSWP[17]) and re-affirmed by the Colorado and Lavaca Basins and

Matagorda and Lavaca Bays Expert Science Team (CL BBEST[18]). The Colorado and Lavaca Basins and Bays Area Stakeholder Committee (CL BBASC[19]) recommended environmental flow standards to the Texas Commission on Environmental Quality in 2011 that were codified into Texas Water Law by the Commission in 2012 (TCEQ, 2012 [20]).

The subsistence instream flow recommendations for Bastrop range from 123-275 cfs depending on the time of the year, with the higher flows during the months of February, March and May to protect spawning habitat of the State threatened blue sucker fish, *Cycleptus elongatus*. The contribution of water flow to the river, by the Carrizo-Wilcox aquifer of 30-50 cfs represents 14-41% of the total flow of the river during drought conditions in the Utley to Smithville reach. According to one of LCRA's model runs used to evaluate possible changes to the current 2010 Water Management Plan, about 48,600ac-ft/year (~67 cfs) needs to be released from the Highland Lakes to supplement the Carrizo-Wilcox contribution in order to help meet certain critical levels of instream flows and the freshwater inflows to the Matagorda Bay. The balance of 23-158 cfs would have to come from return-flows from the City of Austin, run-of-river, or storable inflows if inflows to the Highland Lakes are adequate, and other sources upstream of Bastrop. Without the gaining inflows that currently exist, there are implications on the management of the Highland Lakes, and there are ecological threats to the river and estuary during a serious drought.

The CL BBASC evaluated unappropriated flows at all gage sites on the Colorado River to determine the availability of water to be appropriated for environmental flows. The Bastrop Gage (USGS Gage 08159200 operated in cooperation with the United States Geological Survey), which has gage data from 1940-1998 (58 years), was included in the evaluation. Analysis using the TCEQ Water Availability Model (TCEQ, 2011[21]) revealed that 47.5% of these 58 years there was zero unappropriated flows at the Bastrop Gage (28 years, 9 consecutive years). Likewise 83.6% of the months there was zero unappropriated flow at Bastrop Gage (592 months, 122 consecutive months). The committee concluded that, for all practical purposes, there is zero unappropriated water at the Bastrop Gage at any given time. Historical water rights were adjudicated in 1988, and unappropriated water rights in the lower Colorado River basin were appropriated to the LCRA in 2010 (Permit 5731). Therefore, withdrawal of water from the Colorado River in segments of the river associated with the Bastrop gage could be construed as an unauthorized taking of appropriated surface water.

IMPACT OF GROUNDWATER WITHDRAWAL ON SURFACE WATER PERMITS

To investigate the impact of the planned withdrawals that would result from the GMA-12 DFCs, Environmental Stewardship retained a licensed geoscientist with the Texas Board of Professional Geoscientists. The naturalized flows of the Colorado River at Bastrop were modified by removing a volume of water equivalent to the historic outflows from the aquifers to the river. A volume of 25,000 acre-feet per year was selected to represent historical inflows from the Colorado River. The contractor provided Environmental Stewardship with information on each water right and how it was affected by the adjustment in flow (Kennedy, 2012)[22]. Tables 4-5 illustrate this information.

Two scenarios were run for the Colorado River. In the first scenario (Table 4) 25,000 acre-feet per year of water was removed to simulate the withdrawal of historic groundwater outflows. Over 1,100 water rights were impacted up and down the Colorado River, involving over 7,300 acre-feet per year of water (that's about 2.4 billion gallons of water per year). Freshwater inflows to Matagorda Bay were reduced by about 16,000 acre-feet per year.

Table 4. Impact of groundwater withdrawal of 25,000 acre-feet per year on Colorado River Water Rights

Colorado River Water Rights

Water Rights Negatively Impacted with 25,000 ac-ft/yr removed						
Ac-Ft/Yr Range of Impact:	>500	100-500	10-100	1-10	<1	TOTAL
No. Water Rights Impacted:	4	11	25	228	890	1,158
Average Ac-Ft/Yr Impacted:	3,271	2,421	889	544	231	7,356

Average % Reduced:	>= 4%	3.0-3.9%	2.0-2.9%	1.0-1.99%	<1.0%	TOTAL
No. Reduced:	2	8	25	237	879	1,151

- TCEQ WAM Run 3 for Colorado River with 1401 Water Records (1940-1998)
- Flow Adjustment Record was used to reduce naturalized flow at Bastrop by 25,000 ac-ft/yr
- Comparing Volume Reliability Indexes
- **No changes were made to any water rights records**
- **Freshwater inflows to Matagorda Bay are reduced 16,196 ac-ft/yr.**

In the second scenario (Table 5) 40,000 acre-feet per year was removed to simulate loss of the historical gain to the Colorado River (25,000 acre-feet per year) and an additional volume to model predicted inflow to the aquifers as the river becomes a "losing" stream (15,000 acre-feet per year). In this scenario, about the same number of water rights were impacted, involving about 10,800 acre-feet per year of surface water (about 3.5 billion gallons). In addition, and significantly, the uncommitted Highland Lakes water right had to be adjusted by 6,500 acre-feet per year to keep the modeled lakes from going dry. And freshwater inflows to Matagorda Bay were reduced by about 21,500 acre-feet per year.

Table 5. Impact of groundwater withdrawal of 40,000 acre-feet per year on Colorado River Water Rights

Colorado River Water Rights

Water Rights Negatively Impacted with 40,000 ac-ft/yr removed						
Ac-Ft/Yr Range of Impact:	>500	100-500	10-100	1-10	<1	TOTAL
No. impacted:	5	14	34	303	798	1,154
Average Ac-Ft/Yr Impacted:	5,383	3,161	1,245	800	237	10,826

Average % Reduced:	>= 4%	3.0-3.9%	2.0-2.9%	1.0-1.99%	<1.0%	TOTAL
No. Reduced:	16	10	116	473	547	1,162

- TCEQ WAM Run 3 for Colorado River with 1401 Water Rights (1940-1998)
- Flow Adjustment Record was used to reduce naturalized flow at Bastrop by 40,000 ac-ft/yr
- Comparing Volume Reliability Indexes

*** Uncommitted Highland Lakes Water Right was adjusted -6,500 ac-ft/yr to avoid taking lakes to zero**

*** Freshwater inflows to Matagorda Bay are reduced 21,522 ac-ft/yr.**

In the Brazos River scenario (Table 6) 265,700,000 acre-feet per year was removed to simulate loss of the historical gain to the Brazos River In this scenario, about 884 water rights were impacted, involving about 29,168 acre-feet per year of surface water.

Table 6. Impact of groundwater withdrawal of 40,000 acre-feet per year on Brazos River Water Rights

Brazos River Water Rights

Number of Water Rights Negatively Impacted with 265,700 ac-ft/yr removed						
Ac-Ft/Yr Range:	>1000	100-999	10-99	1-9.9	<1	TOTAL
No. impacted:	7	27	126	273	451	884
Average Ac-Ft/Yr Impacted:	17,044	7,151	3,910	916	147	29,168

Average % Reduced:	>= 10 %	5.0-9.9%	2.0-4.9%	1.0-1.9%	<1.0%	TOTAL
No. Reduced:	6	159	191	182	355	893

- TCEQ WAM Run 3 for Brazos River with 1307 Water Rights (1940-1997)
- Flow Adjustment Record was used to reduce naturalized flow at Hearn by 265,700 ac-ft/yr
- Comparing Volume Reliability Indexes
- **No changes were made to any water rights records**

USING ONLY WRID WITH 0 TARGET CHANGE (UNCOMPLICATED WATER RIGHTS)
DOES NOT CONSIDER WATER RIGHT RECORDS THAT HAD NO CHANGE OR POSITIVE CHANGE

The data shows that the water that GMA-12 intends to withdraw from the river to satisfy pumping is, for the most part, already allocated in surface water right permits. There is, for all practical purposes, no unallocated water available in the Bastrop segment of the Colorado River. That withdrawal of the historic groundwater inflows will impact the water rights of over 1,000 permit holders and involve over 10,000 acre-feet per year of surface water in the Colorado River basin and over 800 permit holders and involve over 29,000 acre-feet per year of surface water in the Brazos River basin. The water to implement the GMA-12 DFCs simply is not available without damaging surface water property rights and threatening river flows and freshwater inflows to the Bay, especially during extreme drought.

In reality, we know that the impact of a call on surface water rights does not spread the impact evenly among surface water right owners. To the contrary, since calls are made on a priority date basis, most of the impact is distributed among those water right permit holders that have a priority date later than that of the right being called.

CONCLUSIONS

The Colorado and Brazos rivers gain water from the Carrizo-Wilcox and related aquifers as they flow over aquifer outcrops, seeps, and springs that contribute water to the rivers. However, groundwater pumping, as contemplated in Groundwater Management Area 12's adopted Desired Future Conditions, threaten to reverse the "gaining" relationship of the river making it a "losing" stream by mid-late this century. This has implications on management of the Highland Lakes and threatens the water flows in the river and into Matagorda Bay during extreme drought conditions. Water budgets and MODFLOW analyses of the GMA-12 DFC/GAM tend to support the likelihood of this trend.

Environmental flow standards that have been developed and adopted for the Colorado River demonstrate that "subsistence" instream flows for the river and "threshold" freshwater inflows for Matagorda Bay are critical to the ecological health of these surface water resources. Surface water availability models confirm that essentially all of the water in the Colorado River is allocated as surface water property rights. Groundwater pumping that causes the river to lose water to the aquifers it bisects is likely an unauthorized taking of surface water, damaging the ecology of the river and bay, and depriving water to surface water rights owners. Environmental flow standards are being developed for the Brazos River.

Though a substantial body of literature, both published and unpublished, has been provided to the groundwater conservation districts in Groundwater Management Area 12 to substantiate these findings, they continue to ignore such information in favor of remaining uninformed on these issues, claiming that they do not have adequate tools to inform sound management practices. The General Manager of the Lost Pines Groundwater Conservation District, in recommendations regarding operating permits opined, "a quantitative evaluation of the impact of the proposed pumpage on surface water resources within the District is difficult to make. The only quantitative tool available is the GAM, and this model is a poor tool to effectively evaluate impacts to surface water within the District based on this application" (Cooper, 2013[23]). Certainly the tools used to quantify the groundwater-surface water relationship are not perfect; however, as demonstrated herein, tools do exist to inform management and decision making processes if groundwater districts and state agencies were to take the initiative to use and improve on the tools available to them.

RECOMMENDATIONS

1. Review recharge and precipitation assumptions in GMA-12 DFC GAM – see Predicted Impacts on Groundwater Pumping, page 10.

2. Collect Base flow gain/loss data to calibrate GAMs and WAMs – We have *very rare* opportunity to conduct a gain-loss hydrologic study on the lower Colorado River during a period of *severe drought and historic low flow conditions* resulting from the curtailment of irrigation water for rice farming (the first occurrence in over 85 years). There is limited knowledge about gains to and losses from the Colorado River between the Travis-Bastrop County border and the Gulf of Mexico as it crosses two major aquifers (Carrizo-Wilcox and Gulf Coast), and two minor aquifers (Queen City and Sparta). It is necessary to have a better understanding of how this system functions and recharges in order to help decision makers to utilize and protect this natural resource. For example, the information collected as part of this study could be used to assist in the calibration of a Groundwater Availability Model.

Environmental Stewardship and the United States Geological Survey have cooperated in developing a proposal to collect data to characterize the gain-loss relationship in the lower Colorado River basin (Braun, 2012[24]).

The groundwater-surface water relationship of the Colorado River as it flows through Bastrop County to Matagorda Bay in the Gulf of Mexico will be studied by seasoned USGS staff to gain *critical base-line data that is lacking* on the amount of groundwater gained by the river as it flows through these segments. With only a portion of the funding raised, the project has been on hold since the fall of 2012.

Current groundwater models are weak in modeling the discharge of groundwater into surface water bodies and need to be calibrated using gain-loss data in order to help decision makers protect the Carrizo-Wilcox and Gulf Coast major aquifers, the minor aquifers, and the river resources of the region. The Colorado River flows through five groundwater conservation districts in the study segment: Lost Pines, Fayette County, Colorado County, Gulf Coast and Gulf Plains GCDs, two groundwater management areas (GMAs 12 and 15), and the Colorado Regional Water Planning Group (Region K).

The Carrizo-Wilcox aquifer is present over more surface area than any other aquifer in Texas. It underlies all or parts of 66 counties, and has been targeted as a major water supply source for Central Texas. The Colorado River basin covers 16% of the surface area of Texas. ***Over-pumping of these aquifers threatens to reverse the long-established "gaining" nature of the Colorado river*****, causing it to become a "losing" river as it flows through Bastrop and Fayette Counties and before reaching the gulf coast.**

3. Use GAM MODFLOW data to inform WAM analyses – The WAM analysis conducted herein is a preliminary estimate of the impact of groundwater pumping on surface water resources and water rights. Since conducting this analysis, a publication has been discovered that provides instructions (Donnelly, 1998[25]) on converting MODFLOW data into a format that can be used as input to surface Water Availability Models (WAM). This publication (LBG-Guyton Associates, 1998[26]) uses MODFLOW analyses to demonstrate how streamflows respond to changes in groundwater levels, and also to demonstrate how water rights, streamflows, and freshwater inflows to the bay may be affected. The authors caution, "the models indicate an interaction between ground water and surface water. As ground-water levels change, surface-water discharge also changes, but we currently lack the data to accurately define the magnitude of these changes."

The Texas Commission on Environmental Quality (TCEQ) recently announced that further evaluation of the LCRA's Water Management Plan is appropriate in order to take into account information raised in public comments, including streamflow data. During this period of extreme drought when the lower Colorado River is at historically low flows (see recommendation 1), it is appropriate that the TCEQ and LCRA work cooperatively with the three groundwater conservation districts on the lower Colorado River to evaluate the impact of groundwater pumping on water availability and surface water rights in the lower basin. Evidence presented herein indicates that the Carrizo-Wilcox Groundwater Availability Model appears to be accurate enough to be used to evaluate the impacts of groundwater pumping on the low-flow conditions of the Colorado River.

4. Improve GAMs and WAMs to include more robust groundwater-surface water interface – Groundwater hydrologists cite weaknesses in groundwater availability models as the reason for not using these, or other models, to estimate the impact of pumping on surface waters. Given the importance of groundwater-surface water relationships to conjunctive management of water resources, the Texas Water Development Board (TWDB) and Texas Commission on Environmental Quality (TCEQ) should investigate methods of improving GAMs and WAMs to more effectively predict impacts on groundwater-surface water interactions. For the Colorado River/Highland Lakes water management area, recommendations 2 and 3 should be used to inform the development of improvements in the models in order to facilitate better regional planning.

5. Designated the Colorado River alluvium as a minor aquifer – To manage conjunctively the water resources of the Colorado River, the Colorado River Alluvium should be recognized as a minor aquifer. Saunders, 1996[27] proposed such a designation and provided qualifications for making such a finding. Until the alluvium is designated a minor aquifer, funding to develop a groundwater availability model will be difficult.

6. Monitoring to provide early warning and adaptive management – Having considered the water needs of Central Texas and the water available from the aquifers under the jurisdiction Groundwater Management Area 12 (GMA-12), and in consideration of the potential irreversible changes that might result from implementation of the GMA-12 adopted Desired Future Conditions, a monitoring system should be installed to provide an early warning of unintended impacts to the Colorado River, streams and springs within Bastrop and Lee counties. Studies cited herein estimate that over-pumping of these aquifers will cause the river to change from a “gaining” to a “losing” river by mid-late this century. It is reasonable and prudent therefore to take appropriate actions to monitor and protect against such impacts should they start to occur.

Monitoring of the groundwater–surface water relationship of the Colorado River and the Gulf Coast aquifer has been accomplished in the coastal portion of the basin, providing a model for a potential monitoring project. The LCRA-SAWS Water Project [28, 29, 30] developed and implemented such a program in Wharton and Matagorda counties where the river is associated with the Gulf Coast Aquifer. Such a project, where shallow wells are placed in close proximity to existing river and stream gage stations, would likely provide an adequate means of monitoring this relationship. The information gained would likewise be helpful in guiding remedial actions should they be needed to protect the integrity of the aquifers and surface waters. Therefore, it is recommended that this program be evaluated to determine whether it would be suitable for the Bastrop to Matagorda segment of the basin and, if appropriate, install a similar system in the region.

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