PERALES, ALLMON & ICE, P.C.
ATTORNEYS AT LAW
1206 San Antonio Street
Austin, Texas 78701
(512) 469-6000 • (512) 482-9346 (facsimile)
info@txenvirolaw.com

Of Counsel:
David Frederick
Richard Lowerre
Brad Rockwell

September 20, 2022

Lost Pines Groundwater Conservation District President and Board of Directors

Via e-mail: lpgcd@lostpineswater.org

RE: Petition for adoption of Desired Future Conditions for Colorado River Alluvial Aquifer in Bastrop County, Texas, and input for development of Groundwater Management Plan.

Dear Ms. President and Board Members:

Environmental Stewardship greatly appreciates the opportunities that Environmental Stewardship has been provided to provide input to the Board as it makes crucial decisions that impact the conservation and protection of groundwater within boundaries of the Lost Pines Groundwater Conservation District.

Attached to this letter is a petition for the development of a Desired Future Condition and and Monitoring Network for the Colorado Alluvial Aquifer in Bastrop County, Texas, to sustain the Colorado River during a repeat of the Drought of Record. This document incorporates information learned from Environmental Stewardships' participation in management and permitting decisions of the District over the past decade, as well as additional technical information developed for this submission.

Environmental Stewardship provides this document for multiple reasons. In part, Environmental Stewardship hopes that the information presented in this document will inform the District as it engages in the process of developing future DFCs. Additionally, this information is provided to aid the District in its current process of developing a management plan. Ultimately, Environmental Stewardship provides this information in the hope that it will aid the District in fulfilling the trust placed in it by the Texas Legislature under the Texas Constitution and Texas Water Code to preserve and conserve the groundwater within the District's boundaries. Thank you for your service.

Respectfully submitted,

Eric Allmon

Eric Allmon
State Bar No. 24031819
PERALES, ALLMON & ICE, P.C.
1206 San Antonio
Austin, Texas 78701
512-469-6000 (t)
512-482-9346 (f)

COUNSEL FOR ENVIRONMENTAL STEWARDSHIP

cc: James Totten, General Manager

Petition
to timely adopt and implement Desired Future Conditions for the Colorado Alluvial Aquifer during the current Groundwater Management Area 12 review and adoption period ending January 2027.

Proposed Desired Future Condition and Monitoring Network for the Colorado Alluvial Aquifer in Bastrop County, Texas, to sustain the Colorado River during a repeat of the Drought of Record.

by

Steve Box, Executive Director
Environmental Stewardship

George Rice, Groundwater Hydrologist
Independent Resource Consultant

and
Eric Allmon, Attorney
Perales, Allmon, & Ice, P.C.

VOLUME I

Policy & Technical Justifications

ACKNOWLEDGEMENT: Environmental Stewardship wishes to acknowledge the contributions of George Rice and Eric Allmon in the preparation of this proposal and petition. The views expressed in this document are those of Environmental Stewardship, informed by the best available science and Texas Water Code.

George Rice, an independent contractor, has served as expert witness and resource consultant to Environmental Stewardship since 2013. Applying his professional skills using the best available science, George has used the groundwater availability model for GMA-12 and other tools to evaluate and report on the potential impacts of groundwater pumping on surface waters in Lost Pines Groundwater Conservation District and GMA-12. As the model has evolved over the past several years, he has evaluated the changes in how the model and its revisions handle and predict impacts on surface waters and the aquifers. In doing so, he has kept our understanding and assertions within the bounds of what the science and the models are able to predict. Based on his work with the models, George has guided and strengthened our understanding of groundwater and surface water interactions, and how those interactions are predicted to impact the Colorado River, its tributaries, the underlying aquifers, the landowners, and communities that depend upon these water resources in Central Texas. We are grateful for his unwavering dedication to truth and knowledge, and pleased to share his work with Lost Pines GCD and GMA-12.

Eric Allmon, Perales Allmon & Ice P.C., has served as counsel to Environmental Stewardship since 2011. Eric has led our attempts over the years to bring attention to, and seek compliance with, the statutory requirements of the Texas Water Code as they apply to the protection and conservation of surface and groundwaters as they naturally interact throughout the Texas Colorado River basin, and the rights of affected persons. He was our counsel in bringing an appeal of the first GMA-12 Desired Future Conditions in 2012, an affected persons appeal in the End Op contested case as it was taken to Bastrop District Court and beyond, and has guided our many interactions with Lost Pines GCD regarding permits, and GMA-12 regarding desired future conditions. Eric has helped us understand and maneuver the legal intricacies of water law in Texas. His grasp of the laws, how they are, their proper application, and how Texas Supreme Court decisions have shaped the statutes and findings of the courts, are reflected in the work that we have done, and what Environmental Stewardship has accomplished over these years. We are grateful for his persistence in seeking environmental sustainability, and are pleased to share his insights with Lost Pines GCD and GMA-12.

Table of Contents

VOLUME I
Policy & Technical Justifications

VOLUME II

APPENDICES

Colorado Alluvial Aquifer

Proposed Desired Future Condition and Monitoring Network for the Colorado Alluvial Aquifer in Bastrop County, Texas, to sustain the Colorado River during a repeat of the Drought of Record.

ABSTRACT: A desired future condition (DFC) is proposed for the Colorado Alluvium Aquifer in Bastrop County, Texas. The aquifers in Bastrop County are under the jurisdiction of the Lost Pines Groundwater Conservation District. Policy and technical justifications are given for the proposed desired future condition. Technical support is provided by original work by Environmental Stewardship's resource consultant George Rice using the GMA-12 groundwater availability model and other published studies. Where appropriate, and as required by the Texas Water Code, factors for considerations in establishing desired future conditions are discussed. A work plan is included to guide development of the final DFC and implementation monitoring network. All original reports by the resource consultant are included in the appendices.

Key Words: desired future conditions, Colorado River, Colorado Alluvium Aquifer, Carrizo-Wilcox Aquifer, water monitoring network, surface water-groundwater interaction, Lost Pines Groundwater Conservation District, Environmental Stewardship.

1. INTRODUCTION

Environmental Stewardship (ES) has advocated for desired future conditions (DFCs) that are protective of surface water to be developed since the initial Groundwater Management Area 12 Joint-Planning cycle in 2008. During the third cycle, ES proposed several scenarios to the GMA-12 representatives and received feedback that was constructive in developing the DFCs being proposed for the Colorado Alluvium Aquifer in this document. Desired Future Conditions for the Colorado Alluvial Aquifer (Colorado River Alluvium) are proposed that utilize existing stream gauges (river and tributary) along with alluvial wells as the means to quantitatively measure compliance with the proposed DFCs.

The methodology proposed for use in monitoring the DFCs was developed and tested as a part of the Lower Colorado River Authority - San Antonio Water Systems (LCRA-SAWS or LSWP) project between 2002 and 2011. The LSWP Groundwater for Agriculture Team installed a shallow water monitoring system on the Colorado River in Wharton and Matagorda Counties, Texas, to monitor the gain/loss relationship between the surface water (river) and groundwater to measure the impact of agricultural groundwater pumping on the Colorado River. The reports and experience from this project can inform the development and implementation of the DFCs being proposed. Key scientists from this original work are currently involved with GMA-12.

The use of a groundwater availability model (GAM) is not necessary to monitor and comply with the proposed DFCs. Even so, the ability to model the system and predict the impacts of groundwater pumping on the Colorado River and its tributaries in the Bastrop reach of the river will be beneficial. Using the updated GMA-12 GAM (2020) and the recently adopted 2022 DFCs (S-19) the model runs were conducted to test the extent to which the model can be used to predict impacts, identify limitations, and suggest modifications. Additional field data will help refine and verify the accuracy of the predictions. The DFC field data that will be collected while monitoring the surface water-groundwater relationship may also be used to inform the model. Finally, the recent surface water-groundwater impact pilot study conducted by LCRA for the TWDB in response to Senate Bill 3 work plan studies will be useful in designing and implementing a monitoring network in the Bastrop reach (RWH&A, 2021).

This document, including the appendices, is organized to respond to the factors that are stipulated in the statutes to be addressed in the explanatory report. These issues are addressed and presented for consideration by Lost Pines GCD and GMA-12.

Environmental Stewardship's interest is to have DFCs adopted for the Colorado River Alluvial Aquifer in the Bastrop reach and to have an ongoing monitoring program implemented to ensure that the surface water and groundwater interests of the communities and environment of Bastrop and Lee Counties are protected.

2. PROPOSED DESIRED FUTURE CONDITION FOR THE COLORADO ALLUVIAL AQUIFER.

Environmental Stewardship is requesting that a desired future condition be established for the Colorado Alluvial Aquifer with the following objective:

> To maintain the saturated depth of the Colorado Alluvial Aquifer at a minimum of [to be determined] feet above the most recent drought of record "DOR" [1] low-flow water level in the Colorado River to maintain a relationship between the river and the alluvium that is adequate to support a *sound ecological environment* during a repeat of the most recent DOR in the Bastrop reach of the river and protect surface water rights throughout the basin.

Since establishing a final DFC will be an iterative process over several years as field data are collected as described in the implementation work plan (Appendix 2), an "interim" DFC based on comparison of water levels in the river and alluvium is proposed to maintain the current gaining relationship between the water level in the river and the current water level in the alluvial aquifer.

The minimum head for the aquifer vs. low-flow level in the river should be determined per the work plan at several gauges along the Bastrop reach. As a starting point, a two (2) ft minimum is estimated from Figure 1 to be approximately 314 ft MSL for the alluvium vs 312 ft MSL for the river at the Bastrop gauge. Additional field data will better inform this estimate.

A minimal operating field monitoring network between river gauges and wells in the Colorado Alluvial Aquifer can be used to establish an interim desired future condition for the aquifer based on water levels alone. Hydraulic conductivity measurements, when available, will enable estimates of groundwater discharge to the river using the empirical gauged water levels.

Low-flow levels in the Colorado River experienced during the most recent drought of record can be used to establish the interim DFC limit and to set trigger points that can guide actions to

---

[1] The U.S. Drought Monitor started in 2000. Since 2000, the longest duration of drought (D1–D4) in Texas lasted 271 weeks beginning on May 4, 2010, and ending on July 7, 2015. The most intense period of drought occurred the week of October 4, 2011, where D4 affected 87.99% of Texas land. https://www.drought.gov/states/texas#historical-conditions

meet the planning goal of the DFC, including, as necessary, pumping curtailment. Table 1 is a summary of the low-flow data for the Colorado River at the Bastrop gauge during the recent DOR and the TCEQ Subsistence flow standards for each month of each season (TCEQ, 2012).

Once a fully operational network is in place, and water level and hydraulic conductivity data are available, a DFC based on discharge of groundwater to the river can be established that is adequate to support a sound ecological environment during a repeat of the most recent DOR.

TABLE 1. Monthly Low-flow levels for the Colorado River at Bastrop for DOR.

Monthly Low-Flows for Drought of Record 2010-15 by Season*
USGS 08159200 Colorado Rv at Bastrop

	Winter (cfs)			Spring (cfs)				Summer (cfs)		Fall (cfs)			
Year	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**Year Low**
2010		347	594	471	961	977	1130	906	772	695	342	332	332
2010-11	337	342	388	308	627	1010	1440	922	985	751	196	243	196
2011-12	212	243	352	332	507	**303**	**261**	**200**	200	261	176	**184**	184
2012-13	**196**	**225**	**200**	**208**	279	443	327	388	204	**126**	299	425	**126**
2013-14	370	356	276	249	**208**	336	351	226	**190**	271	**165**	194	165
2014-15	285	285	346	341	341	308	765	324	262	200	219	562	200
Month Low	196	225	200	208	208	303	261	200	190	**126**	165	184	
Subsistence**	186	208	274	274	184	275	202	137	123	123	127	180	

* Seasons are as described for Colorado River Environmental Flow Standards: TCEQ, Chapter 36, Subchapter D, Section 298.305 Definitions

** Susbsistance flow standard for the Colorado River at the Bastrop Gauge. Texas Commission on Environmental Quality Chapter 298 - Environmental Flow Standards for Surface Water SUBCHAPTER D: COLORADO AND LAVACA RIVERS, AND MATAGORDA AND LAVACA BAYS §§298.300, 298.305, 298.310, 298.315, 298.320, 298.325, 298.330, 298.335, 298.340 Effective August 30, 2012

Figure 1 contrasts the predicted water levels in the Colorado Alluvial Aquifer for the years 2010 and 2070 in relationship to the GAM water levels in the Colorado River in the Bastrop reach of the river[2]. The GAM predicts that water levels in the alluvium will decline but are higher than the river. The effect of this (not shown in Figure 1) is that groundwater discharge to the river will decline.

[2] The water levels in the Colorado River are constant throughout the GAM simulation. They do not change from 2010 to 2070. As field data becomes available, water levels in the alluvium should be compared to water levels in the river during the recent drought of record at each station where historical data are available.

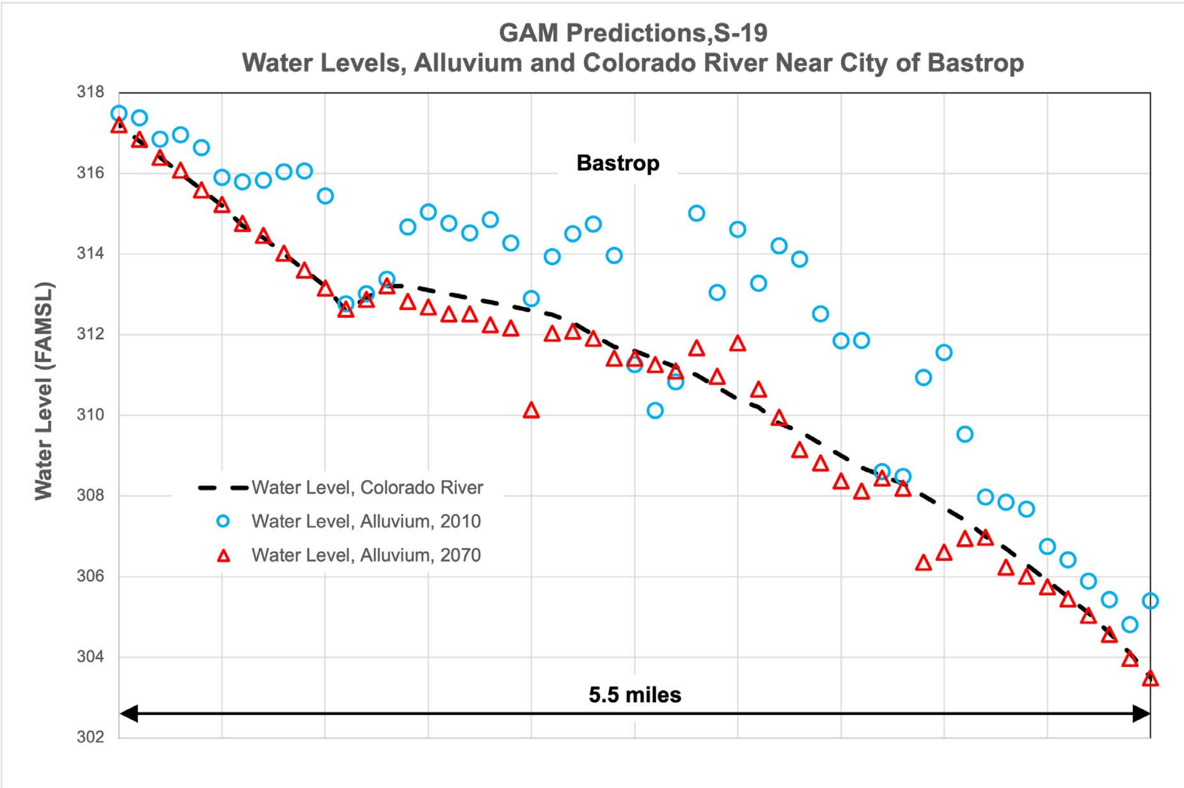


Figure 1. 2010 and 2070 Water Levels in Colorado Alluvial Aquifer vs. Colorado River.

2.1 <u>Water level based Desired Future Condition (DFC)</u>

Establishing a defensible DFC using measurable conditions such as described herein is equivalent to the established practice of setting a DFC for an aquifer based on drawdown of the aquifer due to pumping. In this way, the groundwater availability model (GAM) is only needed to evaluate scenarios based on the physical conditions of the alluvial aquifer *desired* or *anticipated* in the future.

The ability to measure parameters that quantitatively describe the aquifer and river stages has long been recognized as a key element to manage water resources. The ability to link these parameters to better understand and quantify the relationships between these resources has been demonstrated both in the lower Colorado Basin (See Section 2.2) and in a recent pilot project in the Bastrop reach (RWH&A, 2021). Most of the river gauges, and some of the aquifer wells, are already available, can be identified, can be re-activated, or can be installed. Technology to gather and store data electronically is practiced by both the local river authority and the District. The mathematical equations that are needed to calculate anticipated impacts have been developed. <u>As such, all the key elements to establish a monitoring network are accessible.</u>

The demonstrated methodology can be used to compare water levels in the river to water levels in the surrounding alluvial aquifer to determine if the relationship of the river to the alluvial aquifer is resilient enough to support a sound ecological environment in the Bastrop reach of the river.[3] The environmental flow criteria to provide a sound ecological environment have been established for the Bastrop reach of the river[4]. As such the primary scientific information that is needed to establish a defensible and enforceable desired future condition is already available.

This concept was introduced to the GMA-12 representatives. (Environmental Stewardship, April 20, 2021). The primary reason for reluctance was the amount of data available. While Environmental Stewardship maintains that adequate data was available at that time, efforts to gather further data will enable adoption of such a DFC in the current (4th) round of review.

2.2 River Gauge and Alluvium Well Monitoring System

The Lower Colorado River Authority-San Antonio Water System Water (LCRA-SAWS) Project in the lower Colorado River Basin at Wharton and Bay City included gain/loss studies using stream gauges and nearby alluvial water wells as described above. Two reports are available that describe the shallow monitoring well installation (USR and Baer Engineering, 2006) and a final monitoring data report (USR and Baer Engineering, 2007-08). These two reports will be instructive to the design, installation and monitoring of the Colorado Alluvium Aquifer in Bastrop County, Texas.

The Monitoring Data Report from April 2006 to December 2007 for the LSWP Shallow Wells Installed in Wharton and Matagorda Counties, Texas, cited above provides detailed information regarding installation, operation, and the results of the monitoring project (See Appendix 4).[5] That data reflected the direct relationship between water levels in the Alluvium and the Colorado River, as well as the ability to quantify that relationship.

2.3 Other Considerations; Special Management Zone

2.3.1. Special Management Zone (See also Section 5.3.3)

The Colorado Alluvial Aquifer (CAA) and the shallow flow zones[6], are distinct features throughout the District in that they are the only zones where groundwater and surface waters are directly exchanged between the aquifers and the rivers and streams of the District. The geologic strata associated with these geographically unconfined areas are functionally different from the strata of the other aquifers, and have a functional condition of use – directly exchanging water with surface waters -- that is unique to these zones in the District.

Authority to create special management zones comes from Water Code Section 36.116(d).

---

[3] The monitoring methods may use those in section 4.1 of Steve Young's 2017 report to the Colorado Lavaca Basin and Bay Area Stakeholder Committee (CL-BBASC) (See References)
[4] Chapter 298 - Environmental Flow Standards for Surface Water, SUBCHAPTER D: COLORADO AND LAVACA RIVERS, AND MATAGORDA AND LAVACA BAYS §§298.300, 298.305, 298.310, 298.315, 298.320, 298.325, 298.330, 298.335, 298.340 Effective August 30, 2012
[5] See Appendix 1, at Section 5.4.3., Environmental Flows.
[6] Shallow flow zones are collectively represented by Layer 2 in the GAM. See Young et. al. 2017 for description of shallow aquifers and their relationship to surface water interactions.

2.4 Proposed Surface Water Monitoring Network Configuration

Several monitoring stations should be located close to existing river/stream gauges for several reasons[7]. In addition to the reasons given in the referenced publication, the location of a few reference monitoring stations near existing river gauges for which historical data are available provide context for the adopted DFC levels. The DFCs proposed are intended to provide resilience through a DOR. River gauge data for the most recent DOR and, where possible, the DOR of the 1950's, provide the desired information to make such a determination. For example, the data provided in Table 1 provide a context for selecting a low-flow level for the DFCs that relate to both the low-flow levels during the 2010-15 DOR and the environmental flow standards set for the river at the Bastrop gauge.

Each station should consist of a monitoring well into the Colorado Alluvial Aquifer outfitted with automated data collection and transmitting equipment to provide depth and physical/chemical properties on a regular basis that are collected at a central location.

The data from each station can be used to compare the water level in the alluvial aquifer with the level in the river or stream as measured by the existing river/stream gauge to determine a gaining/losing relationship. That is, higher water levels (actually, higher differences in water levels between the alluvium and the river) result in greater flows between the alluvium and the river.

Measuring hydraulic conductivity of the alluvium at each of the monitoring stations and other locations will enable quantitative estimates of discharge rates. Having empirical data on hydraulic conductivity can also be used to improve the predictive ability of the model. Water quality (physical/chemical) data will help characterize the approximate ratio of river/stream water as compared to the alluvial aquifer water that may contain groundwater coming from communicating major and minor aquifers in the region.

Well monitoring sites should be located near the following existing USGS gauges:

There are several gauge locations available in the Bastrop reach of the Colorado River (CR). A minimum of three gauges should be selected and three monitoring wells located and outfitted.[8]

Gauge Location	Selection Preference
CR at Utley	Preferred river site
CR at Bastrop	Preferred river site
CR near Upton	Optional river site
CR at Smithville	Preferred river site
Wilbarger Creek near Utley	Optional stream site
Big Sandy Creek near Bastrop	Optional stream site
Cedar Creek south of Bastrop	Optional stream site

[7] See Young et. al. (2017), Table 7-1: Factors considered in identifying locations to investigate the dynamics of water transfer between the Colorado River and the Colorado River alluvium including bank storage. Location near a river gauge was ranked very high importance since a river gauge is essential for surface water-groundwater interaction studies, are very expensive to install, and suitable location sites are limited.

[8] Low-flow data are not currently available online via USGS or the LCRA Hydromet for the following gauge locations: Colorado River at Utley and Webberville, Wilbarger Creek and perhaps other.

2.5 Include DFC and monitoring work plan in Lost Pines' Management Plan.

Lost Pines GCD is on track to review and revise its management plan this year to include changes in the adopted 2022 DFCs. As a part of the revision, it would be appropriate to include plans to remedy or mitigate the potential impacts of groundwater pumping within the district, and outside the district, on surface waters within the district such as the Colorado River and its tributaries.

A Lost Pines GCD Board member requested input from Environmental Stewardship regarding the goal, objectives and performance standards that might be included in its management plan. Proposed District specific goal for the Management Plan:

> **Goal:** Address surface water and groundwater interactions in the Colorado Alluvial Aquifer to enable management of the impact of groundwater pumping on the Colorado River and its tributaries, to maintain a relationship between the river and the alluvium that is adequate to support a *sound ecological environment* during a repeat of the most recent DOR in the Bastrop reach of the river and protect surface water rights throughout the basin and protect property rights.
>
> **Objective:** To better understand how, and to what extent, local aquifers contribute to streamflows under wet, dry, and drought conditions. Determine what level of contribution sustains a sound ecological environment and protect property rights through extraordinary drought conditions.
>
> **Performance standard:** Perform studies to determine the current relationship between the river, alluvial aquifer, and the major and minor aquifers. Determine under what conditions the aquifers are contributing to a sound ecological environment, what conditions could cause the river to reverse its historical gaining condition and start contributing water to the aquifers on a continuous basis, and determine what conditions cause a shift in equilibrium.[9]
>
> **Performance standard:** Install a surface water and groundwater network of wells and gauges to collect groundwater elevations and basic water chemistry data from alluvial water wells that are directly comparable to water stage and chemistry data from established river gauges. Compare the data from the alluvial well network to the data being collected on major and minor aquifer wells through the Monitoring Well Program.
>
> **Performance standard**: Set DFC to maintain a gaining relationship between the river and the alluvial aquifer and sustain a sound ecological environment in the river during a repeat of the most recent DOR.
>
> **Performance standard:** Track and map the exempt water users in the District to determine reliance on the alluvial aquifer (this might be a performance standard under Drought goal whereby the District determines how many exempt water wells might be impacted by declining stream.)

---

[2] Water budget analysis, as described by Hutchison 2021, will be useful in describing and understanding these conditions.

> **Performance standard:** Monitor water quality in alluvium water wells to determine if industrial and municipal activities upstream and in Bastrop County are degrading water quality.
>
> NOTE: water chemistry and water quality are differentiated here with water chemistry associated with characterizing a water source, i.e. Simsboro vs. river. Water quality is associated with detecting pollution and pollutants.

Environmental Stewardship is submitting this proposal to establish a desired future condition on the Colorado Alluvial Aquifer (Colorado River Alluvium) and to monitor the surface water-groundwater relationship to facilitate the work of the District to establish a plan to manage, and potentially mitigate, the risks that have been identified. By including a plan related to the protection of surface waters and the river in the management plan, the District will take an important step in recognizing its duty and responsibility to conjunctively manage water resources and to conserve and protect those resources for the benefit of the citizens of Bastrop and Lee Counties, and Texas.

3. POLICY JUSTIFICATION

It is responsible policy to evaluate the impacts of groundwater pumping on surface waters like the Colorado River and its tributaries using both the groundwater and surface water availability models (GAMs and WAMs), consider the advice of expert witnesses and administrative law judges, consider decisions of the Lost Pines Board of Directors on related matters, and take appropriate actions to remedy or mitigate the situation before damage occurs.

Authority for groundwater conservation districts to take such actions are provided for in the Conservation Amendments to the Texas Constitution and the Texas Water Code[10]. This authority is not limited to protecting aquifers where commercial (non-exempt) development has occurred, but extends to conserving and protecting the water resources of the state (both surface and groundwater) and property rights of both exempt and non-exempt wells and property ownership associated with such development.

Both groundwater and surface water technical analysis predict potentially unreasonable impacts to the Colorado River and its tributaries due to the amount of groundwater production adopted in the 2022 DFCs (GAM run S-19) (See Appendix 1, Sections 5.4.1, 5.4.2, 5.7, and Appendix 3). A responsible means of remedying this situation would be to reduce adopted DFCs to a level that is sustainable and does not unreasonably damage the river and other surface water resources. However, such an approach was rejected by GMA-12 in the adoption of the 2022 DFCs.

[10] Tex. Water Code § 36.108(d)(3) requiring that in developing a DFC, hydrological conditions, including "average *annual recharge, inflows, and discharge*" be considered, (d)(4) requiring that in developing a DFC "other environmental impacts, including impacts on spring flow and other interactions between groundwater and surface water;" be considered, Tex. Water Code §36.0015 (Purpose), *"[C]onsistent with the objectives of Section 59, Article XVI, Texas Constitution*, groundwater conservation districts may be created as provided by this chapter," Texas Constitution Article XVI, Section 59, providing that:

> The conservation and development of all of the natural resources of this State, . . . including . . . the waters of its rivers and streams . . . and the preservation and conservation of all such natural resources of the State are each and all hereby declared public rights and duties[.]

An expert on surface water-groundwater interaction and groundwater management opined after evaluating GAM runs for pumping scenarios in Lost Pines GCD in Bastrop County,

Quoting Dr. Hutchison (2019):

> "From a regional groundwater perspective, the [new] model does show a reduction in groundwater discharge to surface water under the base case in Bastrop County, and shows that [a] scenario that adds [...] pumping would eventually result in a condition where surface water in Bastrop County would recharge the groundwater system".
>
> "it is unreasonable to summarily dismiss the potential for impacts [on surface waters]."

Analysis of the impact of reducing water in the Colorado River due to groundwater pumping was evaluated using the surface water availability model (WAM) are described in Appendix 1, Section 5.7.2, and in Appendix 3. The removal of 25,000 and 40,000 acre-feet per year impacted about 11,000 water rights involving an average of about 7,000 - 10,000 acre-feet per year per water right. Overall natural flow at Bastrop was reduce by about 16,000 - 21,500 acre-feet per year. Freshwater flow to Matagorda Bay was reduced by a similar amount. This is a direct impact on the environment and property rights that have not typically been considered when adopting DFCs but are statutorily relevant to a consideration of DFCs.

Based on the above expert opinion and analysis, and the technical justifications, the only responsible policy is to take remedial action by establishing a desired future condition that protects the Colorado River by protecting the relationship between the river and the alluvium to ensure that the discharge of groundwater is adequate to support a *sound ecological environment*, and *surface water rights* by setting trigger points for taking actions to better understand and predict impacts, and being prepared to take further actions should conditions require. <u>The proposed remedial action is to establish a desired future condition (DFC) on the Colorado Alluvium Aquifer with the intent to maintain a resilient gaining relationship for the river that is adequate to support an ecologically sound environment, protection of property rights of domestic and commercial wells operating in the alluvium, and protection of impacted surface water rights.</u>

4. TECHNICAL JUSTIFICATION

Several technical methods were used to evaluate the impact of groundwater pumping on surface waters, including the Colorado River and its tributaries. The GMA-12 Groundwater availability model (GAM 2020) was used in developing such technical information as: water budgets to predict the impact of pumping on the outflow of groundwater to surface waters, drawdown in aquifers, induced leakage between aquifers, and induced flows to/from other districts, and to evaluate direct impact on the Colorado Alluvial Aquifer.

Additionally, a surface water availability model (WAM) was used to predict the impact of removing groundwater baseflows from surface water flows in the Colorado River in relationship to predicted (modelled) pumping. These impacts were measured in terms of changes in established environmental flows under wet, dry and drought conditions at several gauge stations in the lower Colorado River basin.

Finally, original technical evaluation of existing field studies and datum were done by the author to better quantify the amount of groundwater discharge that has historically been contributed by the Carrizo-Wilcox aquifer group to Colorado River baseflow. (See Appendix 1, Section 5.0.)

Taken together, these models indicate that a Colorado River Alluvium DFC is needed to address potential unreasonable impacts to the environment and property rights.

Groundwater Availability Analysis (GAM):

When the impact of groundwater pumping was evaluated using the groundwater availability model (GAM), the historical trend toward a decreased outflow of groundwater is predicted to continue to decrease flow in the river. In other words, under the various pumping scenarios evaluated, such as the adopted 2022 DFCs (S-19), the Colorado River is predicted to contribute "captured" water[11] to the aquifers because of the increase in groundwater pumping.

Though a gain/loss relationship has been used to denote a significant and unreasonable impact on the river in establishing a DFC for the alluvium that is adequate to support a sound ecological environment during a repeat of the recent DOR, it is important to recognize that when the "losing stream" status is reached, the resiliency of the river has already been compromised and damaged.

Lost Pines GCD Board voted to adopt a "conservation standard" that reduced pumping and reduce impacts on the river as represented by GAM Run S-20. Though this was rejected by GMA-12, once the 10% variance is applied to reduce the amount of pumping adopted in S-19, the result will be a 54% reduction in pumping from the originally proposed DFC and a 31% reduction in drawdown from the originally proposed DFC[12]. This action is a significant shift that helps protect the river and its tributaries in Lost Pines GCD. Though this is a significant reduction in the amount of pumping anticipated, and a similar reduction in drawdown, it is not protective of the Colorado River or exempt domestic wells because *both scenarios* come perilously close to the same unreasonable results, 1) damage to the resiliency of the river and its ability to support a *sound ecological environment,* and 2) an eventual reverse in the gain/loss relationship.

<u>Since additional field data would improve these predictions and enable refinement of a DFC that protects outflows to the river at an ecologically acceptable level, a monitoring plan should be developed and implemented.</u>

Surface Water Availability Analysis (WAM):

Surface water availability analysis (WAM) -- used by TCEQ and others to evaluate the impact of surface water removal in granting surface water rights -- also predicted that the impact of removing the amount of groundwater from surface water availability would cause unreasonable impacts on the environment and on water use allocations to surface water permit holders (water rights). See Appendices 3 and 11.

Surface water availability analysis also indicates that water in the Colorado River at Bastrop and below has, for all intents and purposes, been fully appropriated, *i.e.,* no more water remains

[11] Hutchison's September 1, 2021, recent presentation to TAGD
[12] Environmental Stewardship, Success Reining In DFCs, https://www.environmental-stewardship.org/2021/11/24/success-reigning-in-proposed-dfcs/

available for future appropriation as a water right. As a result, any reductions in flows negatively impact existing water rights holders. Groundwater pumping appears to create a gradual reduction of reliable streamflow over a relatively long period of time.

Environmental flow standards are not being met at recommended frequencies, and additional groundwater pumping will likely result in further reduction in these attainment frequencies.

In summary, the effect of the proposed groundwater pumping on surface water resources is unreasonable because it increases the shortfalls in meeting environmental flow targets. Since the flows in the river are already often below levels needed to maintain the ecological health of the river, any additional pumping that causes further instream flow reduction is unreasonable.

Percent of groundwater produced coming from surface water

To aid in developing a basis for a conservation standard that considers sustainable pumping without causing damage to surface waters, Rice used Run S-19 to develop water budgets that were used to compare the change in surface water captured as a percent of total groundwater production. Use of these analytical tools to describe conditions in the aquifers and how they relate to surface water are described by Hutchison (Hutchison, September 1, 2021).

In the Lost Pines GCD, the increased outflow was due to increased pumping and to an increase in the amount of groundwater flowing into neighboring counties. In GMA 12, almost all the increased outflow was due to increased pumping. For both areas, the largest source of water for the increased outflow was a reduction in the amount of groundwater discharged to streams. For the Lost Pines GCD, the reduction in discharge to streams accounted for 52% of the increased outflow. For GMA 12, the reduction in discharge to streams accounted for 64% of the increased outflow. Details of the water budgets for Lost Pines GCD and GMA 12 are presented in Appendix 7, Parts 1 and 2 respectively.

In the Lost Pines GCD, direct groundwater discharges to streams decreased by approximately 52,000 AFY. In GMA-12, the decrease was about 210,000 AFY.

In addition to the direct impacts on streams, there are indirect impacts. The indirect impact of groundwater pumping on streams includes the reduction of outflows to drains (primarily springs), and any reduction in recharge to streams that are caused by captured (induced) recharge to aquifers that would otherwise flow to streams. Recharge from precipitation is naturally distributed between streams (surface water) and groundwater aquifers. When the aquifers are "full", as they have historically been, they reject recharge[13], and the recharge goes

[13] Dutton, Alan R., Bob Harden, Jean-Philippe Nicot, and David O'Rourke. February 2003. GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX AQUIFER IN TEXAS, Page 81 - Rejected recharge is the concept that much of the water that reaches the water table as recharge in the unconfined part of the aquifer does not travel downdip into the confined part of the aquifer. Rejected recharge leaves the unconfined part of the aquifer by discharge to seeps and springs in valleys, discharge to rivers and streams, and evapotranspiration in river bottomland areas. Rejected recharge generally does not include withdrawal of groundwater by wells in the unconfined aquifer. The water that cycles through the unconfined aquifer, therefore, is not available for withdrawal by wells in the confined part of the aquifer. Captured recharge is the concept that drawdown of water levels in the confined part of the aquifer increases the gradient in hydraulic head and draws more groundwater from the unconfined to confined parts of the aquifer. In addition, drawdown of water levels in the unconfined aquifer, owing to pumping of wells in either the unconfined or confined parts of the aquifer, results in a decrease in the discharge of groundwater to rivers and streams and may reduce actual evapotranspiration. Groundwater that is "captured" by the confined aquifer reflects a change in the water budget of the aquifer.

to streams. As the aquifers are pumped and are less than 100% full, recharge to the aquifers is induced (captured), and less recharge from precipitation goes to streams.

The indirect impact of groundwater pumping, as described above, can also be seen in the water budgets in Appendix 7. In Lost Pines GCD the reduction in outflows to drains and increased recharge to aquifers was about 17% (about 17,000 AFY) between Period 1 (2001-2010) and Period 2 (2061-2070). In GMA-12 the reduction in outflows to drains and increased recharge to aquifers was about 18% (about 52,000 AFY) between the two periods.

Overall, in Lost Pines the net impact on streams was a decrease of about 69% (about 69,000 AFY), and for GMA-12 the net decrease was about 82% (about 262,000 AFY).

5.0 FACTORS CONSIDERED FOR DESIRED FUTURE - See Appendix 1 for details of the following topics considered:

5.1 Aquifer Uses and Conditions
5.2 Water Supply Needs and Water Management Strategies
5.3 Hydrological Conditions
5.4 Environmental Factors
5.5 Subsidence
5.6 Socioeconomic
5.7 Private Property Rights
5.8 Feasibility of Achieving Desired Future Conditions
5.9 Any Other Relevant Information

6.0 OTHER DESIRED CONDITIONS CONSIDERED

Environmental Stewardship (March 18, 2021) proposed a scenario to GMA-12 for establishing DFCs for the Colorado River that used the updated GAM to set and enforce DFCs. After discussion and feedback from the representatives, it was the opinion of the GMA-12 representatives that before they would consider a DFC based on the GAM field data would be needed to better quantitative inform predictions to be enforceable. The activities recommended herein would remedy such concerns.

ES made numerous presentations to GMA-12 over the 5-year review cycle that demonstrated the potential impacts of various GAM scenarios being considered for DFCs on the Colorado River where the GAMs predicted a reversal in gain/loss relationship during the planning horizon.

7.0 RECOMMENDATIONS AND COMMENTS RECEIVED

Carlos Rubenstein - Policy considerations

William R. Hutchison - Technical considerations

8.0 SUMMARY

Groundwater and surface water naturally interact in river basins where shallow groundwater formations are in contact with the river directly and through alluvial aquifers that follow the course of the river and its tributaries. Analysis of the interaction between the Colorado River, the Colorado Alluvial Aquifer, and the major and minor aquifers indicate that there is a potential for unreasonable impacts on the river and its tributaries and private property rights due to groundwater pumping.

Desired future conditions for the aquifers are the State's preferred method of managing aquifers to protect surface waters and property rights. Desired future conditions and a monitoring network are proposed to avoid or mitigate the potential impacts of groundwater pumping on the Colorado River and to protect the property rights of domestic and commercial well owners.

Policy and technical justifications for the proposed DFC and monitoring network are provided along with the technical analysis that support the need to implement the Lost Pines GCD management plan.

9.0 IMPLEMENTATION WORK PLAN - See Appendix 2

Sections 2 of this document provides a basis and template for developing a desired future condition (DFC) for the Colorado Alluvial Aquifer in Bastrop County, Texas. The information provided forms the foundation for the requested DFC and describes the methodology to collect and analyze data in order to fully develop the details of the DFC. The implementation of the DFC will, of necessity, take place over a period of several years as a surface water-groundwater monitoring network is developed, data are collected, and analyses are made to inform interim and final decisions. The Implementation Plan (Appendix 2) provides more details regarding how this process might proceed once protection of the river and property rights are included in the Lost Pines GCD Management Plan.

10.0 REFERENCES

Butler, J.J., Jr., 1997. *The Design, Performance, and Analysis of Slug Tests*.

Driscoll, F.G., 1986, *Groundwater and Wells.*

EPA (Environmental Protection Agency), 1993, *Suggested Operating Procedures for Aquifer Pumping Tests,* Office of Solid Waste and Emergency Response, EPA/540/S-93/503, February 1993, Paul S. Osborne.

Environmental Stewardship, April 20, 2021. GMA-12 DFCs: Environmental Stewardship's Proposal, Discussion of Current and Proposed DFCs. PowerPoint Presentation by Steve Box.

Environmental Stewardship. March 18, 2021. Supplemental to Consideration 4. on GMA-12 DFC form.

Eric Allmon, Frederick, Allmon, Perales and Rockwell, P.C., October 28, 2020. Environmental Stewardship Comments on GMA-12 Proposed Desired Future Conditions. https://posgcd.org/wp-content/uploads/2020/11/2020.10.28-Environmental-Stewardships-Comments-to-GMA-12.pdf

GMA-11 public information google drive https://drive.google.com/drive/folders/1ronw7ke38_IU4BHGEHbQQ0j9D7fYmFr?usp=sharing

Hutchison, William J. July 25, 2019. Expert Report for the General Manager of the Lost Pines Groundwater Conservation District. Dr. Hutchison is currently an expert witness for the State of Texas in Texas vs. Mexico and Colorado in the United States Supreme Court on these same groundwater pumping impacts on surface water related to the Rio Grande River in New Mexico. Among his many other credentials, he is a consultant for our neighboring GMA-11, and Dr. Hutchison has also been a consultant for Lost Pines on these same matters pertaining to the potential impacts of groundwater pumping on surface waters, including the Colorado River in Bastrop County, Texas.

Hutchison, William R, Ph.D., P.E., P.G. December 30, 2020. GMA 11 Technical Memorandum 20-05. Base Simulation for Joint Planning with Updated Groundwater Availability Model for the Sparta, Queen City, and Carrizo-Wilcox Aquifers

Hutchison, William R, Ph.D., P.E., P.G. February 28, 2021. Desired Future Condition Explanatory Report (Draft 2) Carrizo-Wilcox/Queen City/Sparta Aquifers for Groundwater Management Area 11.

Hutchison, William R, Ph.D., P.E., P.G. February 28, 2021. GMA 11 Technical Memorandum 21-01Draft 2. March 4, 2021. Adjusted Pumping Simulations for Joint Planning with Updated Groundwater Availability Model for the Sparta, Queen City, and Carrizo-Wilcox Aquifers.

Hutchison, William R. Ph.D., P.E., P.G. September 1, 2021. Analytical Tools for the Regional Evaluation of Surface Water-Groundwater Interactions. Texas Groundwater Summit Texas Alliance of Groundwater Districts, San Antonio, TX.

Kruseman, G.P. and de Ridder, N.A. (2000) *Analysis and Evaluation of Pumping Test Data*, 2nd Edition, International Institute for Land Reclamation, and Improvement.

LCRA, authored by Jobald Kabir, with help from Quentin Martin, David Smith, Steve Glenn, and Nora Mullarkey. June 1991. Water Supply and Demand Assessment for Bastrop County - Draft.

LCRA, Saunders, Jeoffrey P., P.G. C.G.W.P. 2005., Low Flow Gain-Loss Study of the Colorado River in Texas, Chapter 19, pages 293-297.

RWH&A, 2021, (R.W. Harden & Associates, Inc.), *DRAFT Surface Water-Groundwater Interaction Pilot Study*, TWDB Order No. 109025, Contract No. 3916, May 2021.

Saunders, Jeoffrey P., 1996. Transactions of the Gulf Coast Association of Geological Societies Volume XLVI, 1996, pages 363-366. Quoting: Geological Setting paragraphs. See publication for references.

Saunders, G.P., 2009, *Low-Flow Gain-Loss Study of the Colorado River in Bastrop County, Texas*.

TCEQ, 2012. Subsistence flow standard for the Colorado River at the Bastrop Gauge. Texas Commission on Environmental Quality Chapter 298 - Environmental Flow Standards for Surface Water SUBCHAPTER D: COLORADO AND LAVACA RIVERS, AND MATAGORDA AND LAVACA BAYS §§298.300, 298.305, 298.310, 298.315, 298.320, 298.325, 298.330, 298.335, 298.340 Effective August 30, 2012

Trungale, Joe. April 20, 2021. Trungale Engineering. Presentation to GMA-12: Ecological impacts of reduced surface water flows due to groundwater pumping

URS and Baer Engineering. June 2006. Final Report: Shallow Monitoring Well Installation Wharton and Matagorda Counties, Texas. Prepared for LCRA by LSWP Groundwater for Agriculture Team URS Corporation Engineering and Environmental Consulting, Inc.

URS and Baer Engineering. March 2007/2008. Final Report: Monitoring Data Report from April 2006 to December 2007 for the LSWP Shallow Wells Installed in Wharton and Matagorda Counties, Texas. Prepared LCRA by LSWP Groundwater for Agriculture Team URS Corporation Baer Engineering and Environmental Consulting, Inc.

USGS in cooperation with the TWDB. Raymond M. Slade, Jr., J. Taylor Bentley, and Dana Michaud. 2002. Results of Streamflow Gain-Loss Studies in Texas, With Emphasis on Gains From and Losses to Major and Minor Aquifers.

Young et al. (2017), Steven Young, Toya Jones, Marius Jigmo. August 2017. Final Report: Field Studies and Updates to the Central Carrizo-Wilcox, Queen City, and Sparta GAM to Improve the Quantification of Surface Water-Groundwater Interaction in the Colorado River Basin

VOLUME II

APPENDICES

Compiled in support of
Environmental Stewardship's
Petition for Desired Future Conditions
for the
Colorado Alluvial Aquifer.

to
Lost Pines Groundwater Conservation District

The compilation includes reports by
George Rice, Joe Trungale
(Resource Consultants)

and
Other Resource Studies

September 19, 2022

TABLE OF CONTENTS

These appendices are compiled in support of Environmental Stewardship, request for Desired Future Conditions to be established on the Colorado Alluvial Aquifer. The following technical sections are also intended to provide the support materials needed for the explanatory report that follows adoption of DFCs. The numbering in Appendices 1 and 2 follow from Volume 1, Policy, and Technical Justifications for the proposed DFCs.

APPENDIX 1

FACTORS CONSIDERED FOR DESIRED FUTURE CONDITIONS
(Section 5.0 of the policy and technical justifications report, Volume 1)

Technical Discussion

by

Steve Box, Executive Director
Environmental Stewardship

George Rice, Groundwater Hydrologist
Independent Resource Consultant

and
Eric Allmon, Attorney
Perales, Allmon, & Ice, P.C.

September 19, 2022

APPENDIX 1: 5.0. FACTORS CONSIDERED FOR DESIRED FUTURE

5.1 Aquifer Uses and Conditions (TBD Cycle 4)
5.2 Water Supply Needs and Water Management Strategies (TBD Cycle 4)

5.3 Hydrological Conditions
5.3.1. Geology and hydrology of the river and alluvium

Saunders (1996) described the geology and hydrology of the river and alluvium, and Environmental Stewardship agrees with his characterization (see Appendix 5).[1]

Studies have consistently found that as duration of a drought increased, bank storage is depleted and river baseflow is dependent upon aquifer discharge (outflow) to surface water.

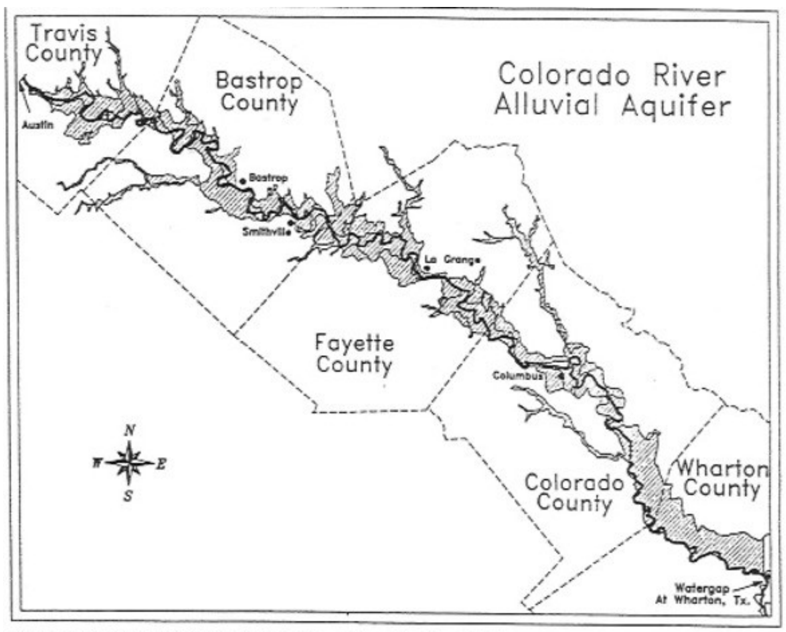


Figure 1. Extent of the Colorado River Alluvium, south-central Texas (after Barnes, 1974).

Figure 2. Extent of the Colorado River Alluvium, south-central Texas (after Barnes, 1974)

Steven Young (Young et al. 2017) also reviewed alluvium characterization studies in Section 4 of the 2017 report to the Colorado Lavaca Basin and Bay Area Stakeholder Committee (CL-BBASC). He confirmed the relationship of the Colorado River as dependent upon water from the Colorado River Alluvium, and confirmed the flow of groundwater from the Carrizo Wilcox, Queen City Aquifer, and Sparta Aquifer.

The reach of interest in this report extends from river mile 186 in Fayette County to mile 272 in Bastrop County where the Carrizo-Wilcox, Queen City and Sparta Aquifers are reported to be contributing to the flow of the river, making it a "gaining" stream in this reach (See Appendix 6).

Young et al. 2017 also discussed the hydraulic properties (excerpt from publication):

> ***4.2.3 Hydraulic Properties***
> As a result of its bedload-fluvial deposition, the Colorado River alluvium consists primarily of sand with some gravel and cobbles and disconnect lenses or layers of silt and clay (Follett, 1970; Rogers, 1975; Hibbs and Sharp,

---
[1] See Saunders 1996 (see Appendix 5)

1993; Barnes, 1979). Across much of the alluvium and terrace deposits, and especially toward the base where bedload deposits of sands and gravels are preserved, the Colorado River alluvium is a highly transmissive aquifer.

Table 4-8 *(from the original report)* provides values for hydraulic properties of the Colorado River alluvium that were obtained from three field studies performed in Travis and Bastrop counties (Hibbs and Sharp, 1993; Gerecht and others, 2011; Francis and others, 2010). Hibbs and Sharp (1993) collected data to characterize and model stream bank storage. Gerecht and others (2011) collected data to characterize and model flow and heat transport in the hyporeic zone. Francis and others (2010) collected data to characterize and model the effects of dam operations on the hyporeic zone in a large fluvial island. The field data from these studies indicate that the average horizontal hydraulic conductivity of the alluvial deposits is likely 100 feet per day or greater (Table 4-8). In addition to characterizing the alluvium properties, Hibbs and Sharp (1993) and Gerecht and others (2011) characterize the hydraulic conductivity of the streambed though grain size analysis and modeling sensitivity analyses. Both studies concluded that the streambed was not impeding flow exchange between the stream and the aquifer.

Table 4-8 of the original report provides a summary of aquifer properties from surface water-groundwater studies on the Colorado River alluvium.

5.3.2 Water Levels and Groundwater Flow in the Alluvium

A comparison of groundwater level gradients in relationship to the location of surface water features within the Colorado River Alluvium Aquifer reflects the movement of water from the Colorado Alluvial Aquifer into surface waters. Figure 4 is a map of the study area for the Colorado Alluvial Aquifer (Colorado River Alluvium) in Steven Young et al. (2017). This map provides the names and locations of major tributaries in Bastrop County.

Comparing the maps in Figures 4 and 5 indicate that the Colorado River Alluvium includes significant portions of the confluence of Wilbarger and Cedar creeks, but not Big Sandy and Walnut creeks in Bastrop County; Bartons and Pin Oak creeks are included, but not Cedar creek in Fayette County.

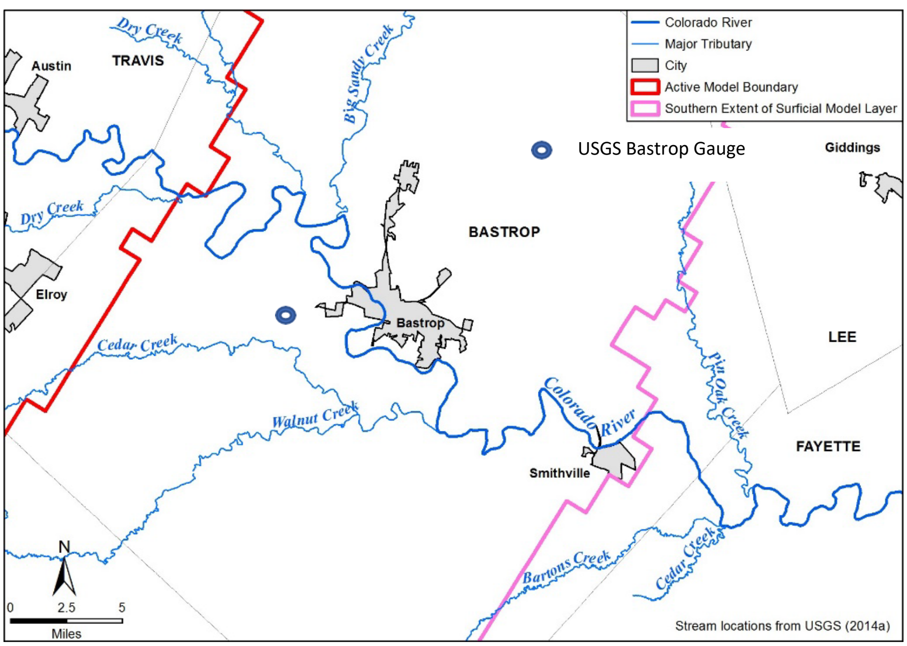


Figure 4. Colorado River Alluvium Study Area within Bastrop and Fayette Counties, Texas. Figure 5-2 from the report.

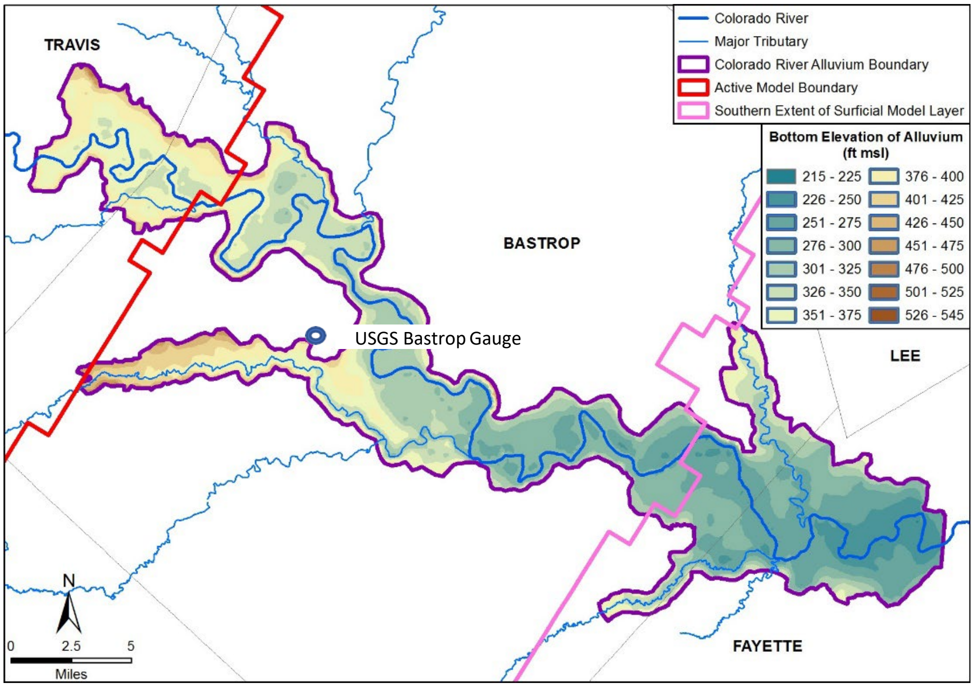


Figure 5. Bottom elevation in feet above mean sea level for the Colorado River alluvium. Figure 5-8 from report.

5.3.3 Special Management Zone

The Colorado Alluvial Aquifer (CAA) and the shallow flow zones[2], are distinct features throughout the District in that they are the only zones where groundwater and surface waters are directly exchanged between the rivers and streams and the major and minor aquifers of the District. The geologic strata associated with these unconfined areas are functionally different from the strata of the other aquifers, and have a functional condition of use -- exchanging water with surface waters -- that is unique to these zones in the District.

Geographically, the alluvial aquifer has a northwest-southeast orientation that flows parallel to the river. The major and minor aquifers are generally oriented east-west, somewhat perpendicular to the river with the outcrop zones having regions that exchange water with the river alluvium and the river, often referred to as baseflow. The direction of flow in the major and minor aquifers relative to the river is determined by the elevation of the water in the aquifer, alluvium and river. When the elevation of the water in the aquifer is higher than the alluvium, groundwater discharges from the major or minor aquifer to the alluvial aquifer. Likewise, when the elevation of the water in the alluvium is higher than the river, water discharges from the alluvial aquifer into the river. This is often termed a "gaining" relationship and the river or stream is a "gaining" stream. When the situation is reversed, the river or stream is a "losing" stream. The greater the difference between elevations, the greater the amount of water that is exchanged.

The source of the major or minor aquifer from which the groundwater is derived can generally be inferred by the geographic location of the outcrop of the aquifer and the river. Water chemistry can also be a more specific indicator of the aquifer from which the water is sourced. As such, elevation measurements can, therefore, be used to indicated direction and relative rate of flow, and water chemistry can be used to indicate the aquifer formation from which the water is sourced in a specific reach of the river. A more precise measure of the amount of water gained or lost in a reach of a river or stream can be measured by taking quantitative flow measurements in an up-river and down-river location, calculating the difference, and accounting for known inflows and outflows -- otherwise known as a gain-loss study. Hydraulic conductivity measurements will also enable quantitative flow measurements.

---

[2] Shallow flow zones are collectively represented by Layer 2 in the GAM. . See Young et. al. 2017 for description of shallow aquifers and their relationship to surface water interactions.

By measuring and monitoring elevations and water chemistry as described above, it should be possible to gain a better understanding of the relationship between the river and the aquifers impacting river flow, especially during low-flow periods when bank storage and other phenomenon have the least impact. Since pumping in one aquifer or aquifer formation can induce flows from other aquifers and aquifer formations, the impact on the river may be realized in an aquifer or formation other than the aquifer being pumped. To better understand these induced flow relationships between aquifers, elevation and test-pumping data can be measured in wells that are known to be completed in different, but adjacent, aquifer formations. The final impact on river flow can best be measured, monitored, and managed based on this data.

Rice has demonstrated in his reports that the Colorado Alluvial Aquifer is functionally represented in the 2020 GAM in a way that allows the model to currently be used to make predictions that are qualitatively reasonable and expected from what is known about the fundamental interactions between surface waters and groundwater that take place in these unique strata. When field data are available from a monitoring network, the model should be suitable to make quantitative predictions. As such, these strata meet the criteria needed to be authorized as a special management zone.

The Texas Water Code authorizes Special Management Zones if the District determined that substantially different conditions exist in a particular area of an aquifer or geologic strata.

Establishing a management zone for the Colorado Alluvial Aquifer would require adoption of a rule. To this end, Environmental Stewardship has assembled data to distinguish the conditions in the Colorado Alluvium and shallow layers as a substantially different contributing zone for the Colorado River within the District.

For the purposes described above, one portion of the alluvium is focused on here - the alluvium along the main stem of the Colorado River. This river alluvium exchanges water with the river. The river alluvium also exchanges water with other alluvium that is not in direct contact with the river, and with the underlying shallow flow layers[3]. The alluvium also receives recharge from precipitation. The flow relationships simulated by the GAM are illustrated in Figure 6 below (Figure 1 of Rice Report, Appendix 8).

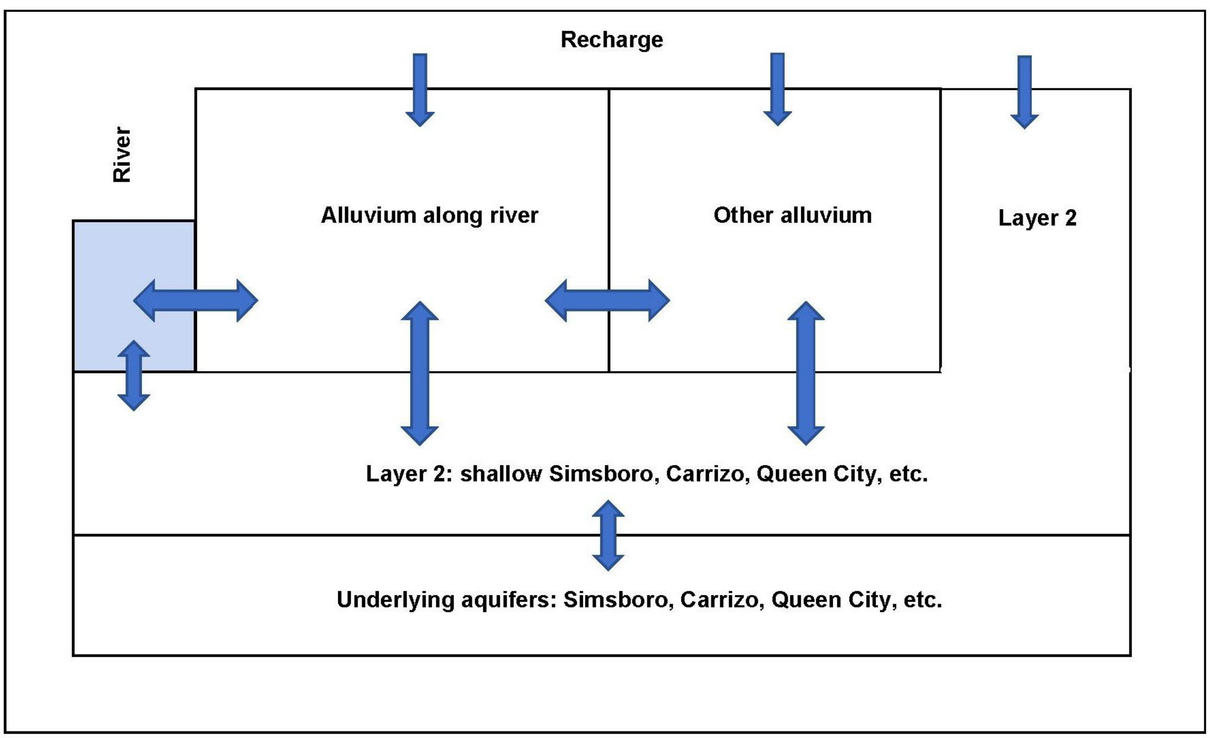


Figure 6. **Schematic of flow relationships simulated by the GAM.** (Figure 1 in Rice Report, Appendix 8)

[3] Shallow flow zones are collectively represented by Layer 2 in the GAM

Figure 7 shows GAM predictions of net flows between the river alluvium and the Colorado River, the other alluvium, and layer 2. Pumping from LPGCD and the contribution from recharge is also shown. As shown in figure 7, the river alluvium (main stem alluvium) receives most of its water from layer 2 and from the other alluvium that surrounds it. The GAM simulation can be summarized as a series of events that begins with pumping and ends with reduced flow to the Colorado River. These events are outlined below.

- Pumping reduces water levels in the underlying aquifers.
- The reduced water levels induce flow from Layer 2 into the underlying aquifers.
- Because more water is flowing from layer 2 into underlying aquifers, less water from layer 2 flows into the river alluvium.
- Less water in the river alluvium results in less flow from the alluvium to the Colorado River.

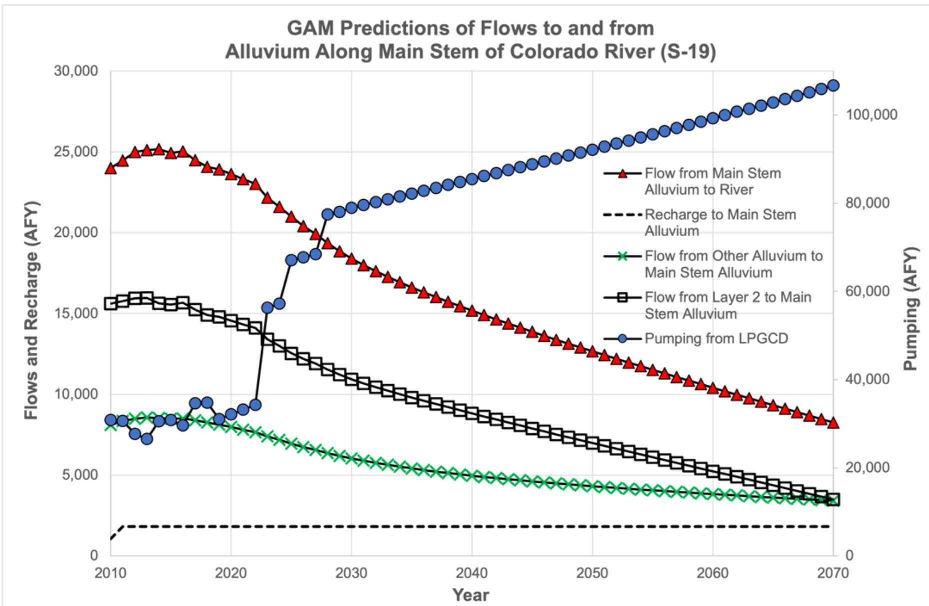


Figure 7. GAM predictions of flows to and from the Colorado River using S-19 pumping file (Figure 2 in The Rice Reports, Appendix 8).

Rice provides several additional graphs to illustrate the details regarding the magnitude and direction of these flows (See: Rice Report, Appendix 8).

5.4 Environmental Factors

5.4.1 GAM predicts unreasonable impacts on Surface Waters due to pumping from Adopted DFC as compared to conservation DFCs.

Environmental Stewardship (Eric Allmon, October 2020) provided a comprehensive report of its initial GAM work, findings, and requests to GMA-12 on October 28, 2020. The report served as a foundation for Environmental Stewardship's discussions with the GMA-12 representatives in subsequent meetings, and contains additional details regarding some of the information provided herein, and is cited for reference purposes.

In addition to the above-referenced report, Environmental Stewardship has now employed several additional technical methods to evaluate the impact of groundwater pumping on surface waters, including the Colorado River and its tributaries. The GMA-12 Groundwater availability model (GAM 2020) was used to develop water budgets and to predict the impact of pumping on outflow of groundwater to surface waters, drawdown in aquifers, induced leakage between aquifers, induced flows to/from other districts.

As discussed above, use of the GAM demonstrates that pumping consistent with the adopted DFCs would unreasonably result in a trend of decreasing outflows to the Colorado River that would potentially result in a relationship that will no longer support a *sound ecological environment*, and, in time, likely result in a reverse in its current status as a gaining stream.

Figure 8 shows the reduction in impact from the originally proposed DFCs (S-12) to the adopted DFCs (S-19) before the allowed 10% variance is applied.[4] This figure demonstrates that the objective of maintaining environmental flows necessary to support a sound ecological environment is not attained by the adopted DFCs.

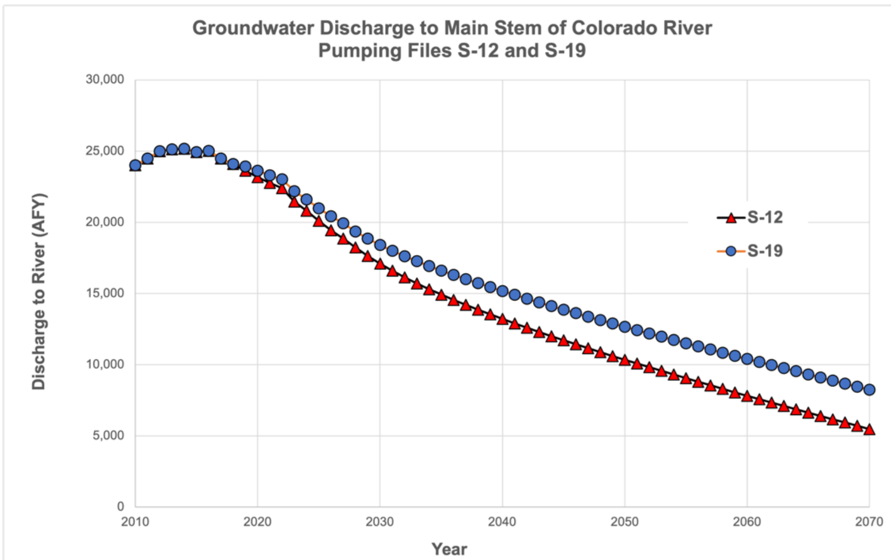


Figure 8. Effects of S-19 and S-12 Pumping on Groundwater Discharge to the Colorado River

Figure 9 compares the adopted DFCs (S-19), and the adopted DFCs after the 10% variance is applied to the Simsboro aquifer (0.9XS-19), to the conservation DFCs Lost Pines adopted and requested (S-20). See The Rice Reports, Appendix 10, Figure 1. This graphic demonstrates that, even with the 10% variance applied, the model predicts that groundwater flows to the Colorado River will be substantially reduced. This, along with the predicted capture of surface water (Section 5.4.3) is justification for including and implementing a Colorado Alluvium Aquifer DFC and monitoring plan in Lost Pines management plan that is protective of the Colorado River and provides opportunity to anticipate, minimize and mitigate damages before they happen.

[4] See The Rice Report's Appendix 9, Figure 2.

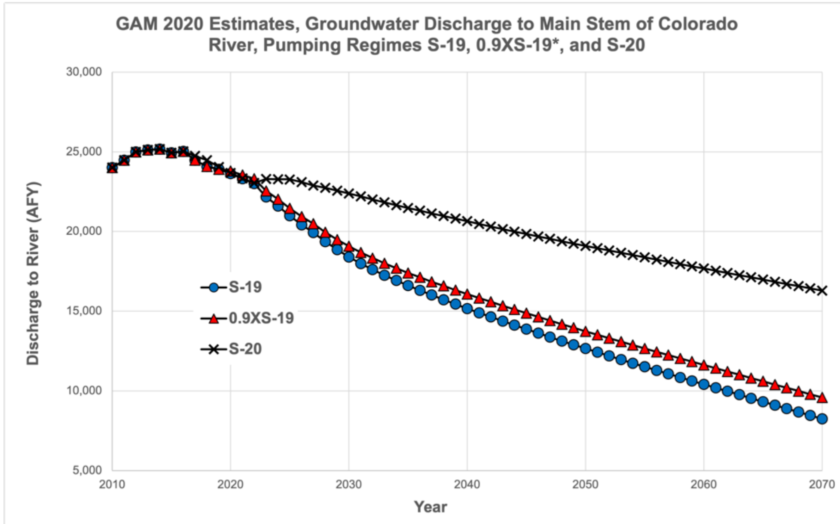


Figure 9. Effects of S-19 with 10% variance applied (0.9XS-19) compared to S-19 and S-20 Pumping on Groundwater Discharge to the Colorado River

Table 2 shows the difference in the amount of pumping that results from each of the three scenarios, (S-19, 0.9XS-19, and S-20). Applying a 10% reduction in the amount of pumping allowed[5] reduces the amount of allowed pumping in the Simsboro and Carrizo aquifers in LPGCD by about 8,500 AFY and reduces pumping from all aquifers by about 9,200 AFY.

Table 2
Pumping Rates Under Pumping Regimes for the year 2070

Pumping regime	Pumping from all aquifers in LPGCD (AFY)	Pumping from only Simsboro and Carrizo aquifers in LPGCD (AFY)
S-19	106,800	92,300
90% S-19	97,600	83,800
S-20	59,700	45,900

5.4.2 WAM predicts unreasonable impacts on Surface Waters

Surface water availability analysis (WAM) -- used by TCEQ and others to evaluate the impact of surface water removal in granting surface water rights -- also predicted that the impact of removing the amount of groundwater from surface water availability would cause unreasonable impacts on the environment and on water use allocations to surface water permit holders (water rights).

Joe Trungale (2021) presented his evaluation of the ecological impacts of reduced surface water flows due to groundwater pumping using the surface water WAM at the April 20, 2021, GMA-12 meeting. The details of his evaluation can be found in Environmental Stewardship's extensive report to GMA-12 (Eric Allmon, October 28, 2020) and Appendix 11.

The following is a summary of Mr. Trungale's findings:

[5] A reduction in the adopted DFC drawdown in the Simsboro and Carrizo aquifers of 10% can be applied by Lost Pines GCD in accordance with GMA-12 agreed practices as confirmed at the GMA-12 November 30, 2021, meeting. Most other GCD took these reductions prior to adopting the DFCs, however, LPGCD elected to wait until the TWDB has found the adopted 2022 DFCs to be administratively complete before applying the reduction. The reduced pumping will be adopted in LPGCD management plan revision to take place in 2022.

Water in the Colorado River at Bastrop and below has, for all intents and purposes, been fully appropriated, *i.e.,* no more water remains available for future appropriation as a water right.

- Any reductions in flows negatively impact existing water rights holders.
- Groundwater pumping appears to create a gradual reduction of reliable streamflows, over a relatively long period of time.

The reduction in flows impact the ecological health of the Colorado River.

- Instream flow standards were adopted for the Colorado Rivers that included subsistence, base, high flow pulse, and bankfull flows necessary to maintain a sound environment for the Colorado River.
- Subsistence flows should be considered “hands off flows” with the goal that flows should be met 100% of the time.

Environmental flow standards are not being met at recommended frequencies, and additional groundwater pumping will likely result in further reduction in these attainment frequencies.

- Attainment frequencies need to be met below Bastrop during spring when the *base dry and base average flows* are important to maintain the spawning habitat for the Blue Sucker.

In Summary:

- The effect of the proposed groundwater pumping on surface water resources is unreasonable because it increases the shortfalls in meeting environmental flow targets.
- Since the flows in the river are already often below levels needed to maintain the ecological health of the river, then any additional pumping that causes further instream flow reduction is unreasonable.

5.4.3 A Sound Ecological Environment: Environmental Flows

Fortunately, the District and GMA-12 need not re-invent the wheel to determine the level of flow in the Colorado River that would provide a minimal level of protection for the environment. Prior legislation adopted by the Texas Legislature established a broad stakeholder process that develop target flow levels after an extensive development and evaluation of technical data and consideration of various policy perspectives. The legislative objective was to maintain the *biological soundness* of Texas’ surface waters. The Legislature’s charge that groundwater district’s consider environmental impacts upon surface waters must be read in conjunction with this legislative standard for the protection of flow levels in surface waters. This process resulted in the development of specific flow quantity targets for the Colorado River within the area of Bastrop County, which can be incorporated into the process of developing a DFC for the Colorado River Alluvium within the District.

Studies by Saunders and others determined that the Colorado River was gaining 30-50 cfs within the Carrizo-Wilcox reach during the 2008 low-flow event, which is comparable to the 36 cfs estimate by USGS in 1918, and the 50 cfs inflow found by the LCRA in November of 2005. Saunders' estimate of groundwater discharge of 30 cfs in this reach of the river in November 2008, demonstrates that the Carrizo-Wilcox aquifer group provides about 25% of the low-water flowing in the river during drought conditions. This water would have traveled through the Colorado River Alluvium in order to reach the Colorado River, and, thus, would be protected by a Colorado River Alluvium DFC.

<u>Based on this analysis, the DFC for the Colorado River Alluvium should be targeted to contribute 30-50 cfs[6] of groundwater discharge to the Colorado River when the basin is in Extraordinary Drought Conditions</u>[7].

[6] The GAM estimate of groundwater discharge to the Colorado River in 2010 is about 24,000 AFY. This is about 33 cfs.

[7] See LCRA 2020 Highland Lakes Water Plan for details on Colorado River Basin Conditions and how they are determined.

The legislature encourages voluntary[8] water and land stewardship to benefit the water in the state. Environmental Stewardship also encourages state agencies, such as river authorities and groundwater conservation districts, to accept the challenge of protecting our water resources by working together to manage these water resources conjunctively and sustainably in territories under their jurisdictions.

5.4.4 Sustainable management predictions: Water budgets predict increase in surface water capture due to pumping

The consideration of a revision to the adopted 2017 DFCs (or 2022 DFCs) that protects surface waters requires a sound understanding of the consequences of the currently adopted DFCs.

To aid in developing a basis for a conservation standard that considers sustainable pumping without causing damage to surface waters, Rice used Run S-19 to develop water budgets that were used to compare the change in surface water captured as a percent of total groundwater production. Use of these analytical tools to describe conditions in the aquifers and how they relate to surface water are described by Hutchison (Hutchison, September 1, 2021).

In the GMA-11 process, the results of a base simulation (Hutchison, 2020, Technical Memorandum 20-05) were developed. Using that baseline, and with the desire to provide a steady pumping rate for use in regional water planning, GMA 11 ran an additional set of simulations that resulted in a constant pumping scenario for each county-river basin-aquifer unit in GMA 11. Technical Memorandum21-01 (Hutchison, March 2021) Draft 2 reports on the development and results of the 33 iterations used to reach a constant pumping scenario[9] that would be expected to be sustained if the model were run for a longer period. The process is discussed in GMA-11's Explanatory Report, Draft 2 (Hutchison, February 2021). All these GMA-11 documents are available on its public information Google Drive. (GMA-11)

Water budgets predict increase in surface water capture due to pumping

Initial work performed by Mr. Rice can inform the District's current consideration of next steps in the DFC process. Mr. Rice developed water budgets for Lost Pines GCD and GMA-12 as a whole. These water budget provide a model for what can be done for each District to better understand the impact of groundwater pumping on surface waters. The GAM2020 output was analyzed to produce water balances for two areas: the Lost Pines GCD and GMA 12. Pumping file S-19 was used for both budgets. Water balances were prepared for two time periods: period 1 (2001 – 2010) and period 2 (2061–2070). As would be expected, the outflow from both areas increased between period 1 and period 2. See The Rice Report, Appendix 7, Parts 1 and 2.

In the Lost Pines GCD, the increased outflow was due to increased pumping and to an increase in the amount of groundwater flowing into neighboring counties. In GMA 12, almost all the increased outflow was due to increased pumping. For both areas, the largest source of water for the increased outflow was a reduction in the amount of groundwater discharged to streams.

In the LPGCD, net outflow to streams in period 1 is about 49,659 AFY, in period 2 it is -2,446 AFY, a decrease of 52,105 AFY, or -105%. In GMA-12, net outflow to streams in period 1 is 283,037 AFY, in period 2 it is 73,154 AFY, a decrease of 209,883, or -74%.

For the Lost Pines GCD, the reduction in discharge to streams accounted for 52% of the increased outflow. For GMA 12, the reduction in discharge to streams accounted for 64% of the increased outflow.

[8] Texas Water Code, Section 11. 0235 (b) Maintaining the biological soundness of the state's rivers, lakes, bays, and estuaries is of great importance to the public's economic health and general well-being. The legislature encourages voluntary water and land stewardship to benefit the water in the state, as defined by Section 26.001.

[9] Note: This scenario did not include the protection of surface waters and resulted in a pumping quantity that sources 54% of the water from surface waters (Induced inflow from the alluvium). The final proposed DFCs sources 72% of the pumped water from surface waters.

In the LPGCD, net outflow to wells in period 1 is about 26,680 AFY, in period 2 it is 103,320 AFY, an increase of 76,640 AFY, or 278%. In GMA-12, net outflow to wells in period 1 is 167,618 AFY, in period 2 it is 491,698 AFY, an increase of 324,080, or 193%.

In the LPGCD, net from storage in period 1 is about 16,710 AFY, in period 2 it is 46,838 AFY, an increase of 30,128 AFY, or 180%. In GMA-12 net from storage in period 1 is about 74,307 AFY, in period 2 it is 124,493 AFY, an increase of 50,186 AFY, or 68%

In the Lost Pines GCD, the net amount of water derived from storage increased between periods 1 and 2. This increase accounts for about 30% of the increased outflows from Lost Pines. For GMA-12, the increase derived from storage represents about 15% of the increase in outflows.

Sustainable management predictions

To gain insights on potential approaches to achieve sustainable management while protecting the resilience of surface water through a drought of record, and to estimate a conservation standard, several runs were made where different limitations were placed on GAM DFCRun3 (Appendix 7, Part 3).

Initially the pumping rates in GMA 12 were adjusted so that the discharge of groundwater to the Colorado River was approximately equal to average rate for the period 2001 – 2010.[10] This simulation did not result in groundwater discharges to the river that would maintain the average discharge rate to the Colorado River in a range approximating the 2001-2010 period.

To achieve a resilience of the river in a range comparable to the average 2001-2010 groundwater discharge rate to the Colorado River the GAM predicts that a 90% reduction in pumping rate would be required. Considering that the pumping rates in DFCRun3 are nowhere near the adopted pumping rates in the adopted 2022 DFCs, and recognizing that this amount of reduction in allowed pumping is unlikely, it appears that a better alternative is to establish a DFC on the alluvial aquifer and monitor the water levels in the alluvium.

This work, along with Run S-20, provide a conservation standard ("bookend"), and methodology that can be used in understanding the balance between conservation and development when evaluating proposed DFC GAM runs as required in consideration 4.

5.4.5 Include DFC and monitoring work plan in Lost Pines' Management Plan.

Lost Pines GCD is on track to review and revise its management plan this year to include changes in the adopted 2022 DFCs. As a part of the revision, it would be appropriate to include plans to remedy or mitigate the potential impacts of groundwater pumping within the district, and outside the district, on surface waters within the district such as the Colorado River and its tributaries.

Lost Pines GCD has requested input from Environmental Stewardship regarding the goal, objectives and performance standards that might be included in its management plan.

Proposed District specific goal for the Management Plan (See Volume 1, Section 2.5)

5.5 Subsidence (TBD Cycle 4)
5.6 Socioeconomic (TBD Cycle 4)
5.7 Private Property Rights
5.7.1 Domestic Alluvial Wells

Domestic wells currently exist that are completed within the Colorado River Alluvium, and numerous landowners possess property rights within the water contained in the Colorado River Alluvium. Currently, no DFC directly protects the property rights in that groundwater. Development of a Colorado River Alluvium DFC would better protect such property rights in groundwater.

[10] A gaining relationship to the aquifers.

5.7.2 Surface Water Rights

Surface water rights are property rights. The reduction of groundwater discharge to the river reduces the amount of water in the river available to those who own surface water rights granted by the State of Texas, thereby impacting property rights.

Environmental Stewardship commissioned a study in 2012 to examine the impact of withdrawing groundwater on surface water rights in the Colorado Rivers (Appendix 3).

TCEQ WAM Run3 for the Colorado River containing 1401 water records (1940-1998) was used to evaluate the impact of a 25,000 and 40,000 acre-feet per year reductions in naturalized flow at Bastrop. No changes were made to water rights records.

In summary, a reduction of 25,000 acre-feet per year in naturalized flow impacted 1158 water rights, averaging 7,356 acre-feet per year of water. Flow at Bastrop was reduced by 16,196 acre-feet per year, and freshwater inflows to Matagorda Bay were reduce by the same amount.

A reduction of 40,000 acre-feet per year in naturalized flow impacted 1154 water rights, averaging 10,826 acre-feet per year of water. Flow at Bastrop was reduced by 21,522 acre-feet per year, and freshwater inflows to Matagorda Bay were reduce by the same amount.

5.8 Feasibility of Achieving Desired Future Conditions (TBD Cycle 4)

5.9 Any Other Relevant Information

APPENDIX 2

IMPLEMENTATION WORK PLAN
(Section 9.0 of main report)

Technical Discussion

by

Steve Box, Executive Director
Environmental Stewardship

George Rice, Groundwater Hydrologist
Independent Resource Consultant

and
Eric Allmon, Attorney
Perales, Allmon, & Ice, P.C.

September 19, 2022

APPENDIX 2 9.0 IMPLIMENTATION WORK PLAN

A basic monitoring network of river/stream gauges and well water depth gauges will need to be operational to develop the data necessary to establish a DFC for the Colorado Alluvium Aquifer that is quantitatively linked to river flow and river stage. The following workplan tasks can guide the site selection and data gathering that will be useful in setting up an operational monitoring network and developing a desired future condition for the alluvium.

The network of stream and well gauges will serve to:

- Inform the establishment, monitoring, and enforcement of desired future conditions (DFCs), and
- Conduct primary research on how surface water and groundwater interact in the Bastrop reach of the Colorado River to further inform decision-making regarding the conjunctive and sustainable management of these water resource.

9.1 Colorado Alluvial Aquifer

To establish a fully operational desired future condition on the Colorado Alluvial Aquifer that supports a sound ecological environment means that a relationship between water levels in the alluvium and the discharge of groundwater to the river will be established and maintained. In a nutshell, this depends on the difference between the water levels in the alluvium and the river, and the hydraulic conductivity of the alluvium. (See Environmental Stewardship, April 20, 2021).

To Establish DFC

Task 1. Develop overlay map(s) of the Colorado River Alluvium such as in Figure 2, Appendix 1, GMA-12 GAM cell grid surrounding the alluvial aquifer, and the Geological Atlas of Texas, Austin Sheet.

Task 2. Identify river gauges and river/stream nodes on the overlay map such that grid cells are identified, and a graphic can be made to show the conceptual work. Check to see if the Wilbarger, Big Sandy, Cedar Creek stream gauges are located within the river alluvium. If so, include these gauges.

Task 3. Measure water levels and hydraulic conductivity of the alluvium at monitoring wells sites and other sites as needed to characterize the alluvium.

Task 4. Determine relationship between water levels in alluvium and discharge of groundwater to the Colorado River by developing a hypothetical curve between water level in the alluvium and discharge to the river (Figure 10). Convert gauge records and alluvium levels to a common standard (datum), such as NAVD88 levels (Figure 11), to serve as a proxy for mean sea level (msl). This will allow a direct comparison to measured water levels in wells, and saturated depth of the alluvium, to river low-flow levels. This should allow calculation of a minimum saturated depth of the alluvial aquifer that will maintain a sound ecological condition in the river relative to the aquifer.

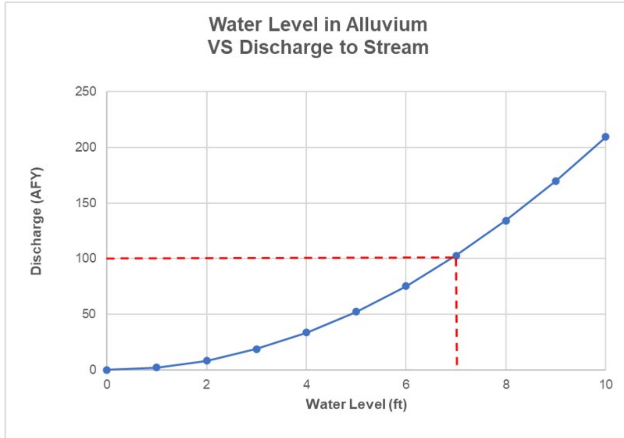


Figure 10. Hypothetical Discharge rate curve between water levels in the alluvial aquifer and discharge to streams.

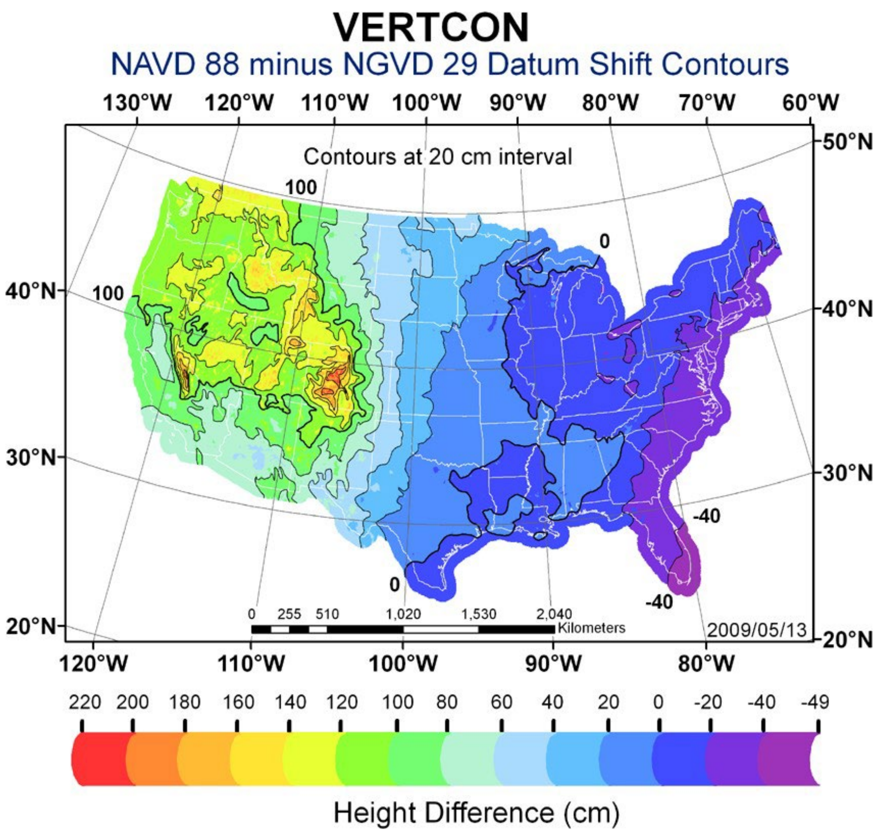


Figure 11. Comparison of NAVD 88 minus NGVD 29 datum in the Bastrop area of Texas is 0 to 20 cm.

Task 5. Use the empirical hydraulic conductivity data to improve the GAM's ability to predict discharge levels from the alluvium to the river.

Task 6. Agree on minimum acceptable discharge rate that is an adequate to contribute to subsistence flow during a repeat of the drought of record to support a *sound ecological environment*.

Task 7. Set DFC for water levels in alluvium corresponding toa minimum discharge rate.

Measuring Hydraulic Conductivity

Hydraulic conductivity should be measured via pumped aquifer tests (pump tests)[11]. This is a standard technique that consists of pumping water from a well at a known rate, and measuring the rate at which water levels decline in the pumped well and in nearby observation wells. The hydraulic conductivity is then calculated from the pump test data. Descriptions of pump tests and techniques for analyzing the data may be found in many standard texts including Driscoll (1986), and Kruseman and de Ridder (2000).

9.2 River Gauges

<u>Task 1.</u> Established a low-water baseline for the Bastrop reach of the Colorado River by examining river gauge data for the period of January 2010 through December of 2015 (see Table 1, Volume 1). The low-flow gauge readings (river stage in feet and flow in cubic feet per second, cfs) in Table 1 were determined using USGS gauge records and by subdividing each year into seasons that agree with environmental flow standards established by TCEQ for the Colorado River below Travis Lake[12].

The seasons are:

Winter	December through February
Spring	March through June
Summer	July through August
Fall	September through November

Gauge records to be reviewed:

CR at Utley (Priority)	Wilbarger near Utley (Priority)
CR at Bastrop (Table 1)	Big Sandy Creek near Elgin (Priority)
CR at Sims Gideon	Cedar Creek south of Bastrop
CR near Upton	
CR at Smithville	

Additional consideration should be given to records that may be available at the LCRA intake structure for Lake Bastrop and the Sims Gideon Power Plant. This gauge is located between Utley and Bastrop. The LCRA Pope Bend SW-GW monitoring station will not have historical records.

NOTE: Three river gauges were not active on LCRA Hydromet for a period in 2022. When back online, they no longer have historical data. The three gauges, CR @ Webberville, CR @ Utley, and Wilbarger Creek @ Elgin, are exclusively owned and operated by LCRA according to USGS information. The websites below retrieve the most recent 180 days or less of available data. Hopefully the data base from which this data is drawn contains history back to the recent drought of record, 2010 -15.

LCRA Historical Data by Gauge: (180 days or less)

https://hydromet.lcra.org/HistoricalData

LCRA Colorado River Gauge @ Utley:

https://hydromet.lcra.org/Charts/?siteNumber=5450&siteType=flow&agency=LCRA

[11] Slug tests are often used to measure hydraulic conductivity. The advantages of slug tests are that they are inexpensive and easy to perform. However, hydraulic conductivities derived from slug test data are often unreliable. According to the EPA: *It should be emphasized that slug tests provide very limited information on the hydraulic properties of the aquifer and often produce estimates which are only accurate within an order of magnitude* (EPA 1993, page 1). And Butler states: *Thus, the hydraulic-conductivity estimate obtained from a slug test should virtually always be viewed as a lower bound on the hydraulic conductivity of the formation in the vicinity of the well* (Butler, 1997, page 5).

[12] TCEQ, Chapter 36, Subchapter D, Section 298.305 Definitions.

9.2.1 Gauging Station Location in Bastrop and Fayette Counties that are potential sites for stationary monitoring wells/geoprobes:

COLORADO RIVER WATERSHED

1. CR @ Webberville - Site 5423
   a. Location: unknown location down-river from Webberville.
   b. Description: Gauge located in river alluvium surrounded by fluviatile terrace deposits with Midway Group deposits down river. This site is above the intersection of the Carrizo-Wilcox Group intersection with the river.
   c. Gauge within alluvium (see CRA Figures 5-2 and 5-8)

2. Colorado River @ Utley - Site 5450
   a. Location: Hwy 969 bridge south of Utley, TX
   b. Description: Gauge located at river bridge in Colorado River alluvium with fluviatile QT terrace deposits associated with the Hooper and Simsboro outcrops on the North and the Hooper, Simsboro and Calvert Bluff to the South. This location is above the confluence of both Wilbarger and Sandy Creeks with the Colorado River.
   c. Gauge within alluvium (see CRA Figures 5-2 and 5-8)

3. Wilbarger Creek @ Elgin - Site 5464
   a. Location: 2810-2814 FM 1704
   b. Description: Gauge located on Wilbarger Creek in fluviatile terrace deposits with Hooper outcrop on both banks. Simsboro outcrop just down-stream on north bank at confluence with Colorado River. Calvert Bluff outcrop below confluence.
   c. Gauge likely within alluvium (see CRA Figures 5-2 and 5-8)

4. Big Sandy Creek near Elgin - Site 5473
   a. Location: 2333-2361 N Hwy 95, Elgin, TX
   b. Description: Gauge located on Big Sandy Creek with Calvert Bluff outcrop on both banks and Camp Swift Military Reservation immediately East. Simsboro outcrop located on North and South sides of Calvert Bluff outcrop.
   c. Gauge not likely within alluvium (see CRA Figures 5-2 and 5-8)

5. LCRA at Sims Gideon water intake structure - Site 5476
   a. Location: Upriver from Bastrop.
   b. Description: gauge measures river stage only, not stream flow.
   c. Gauge within alluvium (see CRA Figures 5-2 and 5-8)

6. Colorado River @ Bastrop - LCRA Site 5499, USGS 08159200
   a. Location: Hwy 21/71 bridge in Bastrop
   b. Description: Gauge located on bridge with alluvium and fluviatile QT terrace deposits associated with the Carrizo outcrop on the East bank. Calvert Bluff outcrop just up-river associated with the Piney Creek watershed, Bastrop Lake, and LCRA Power Plant.
   c. Gauge within alluvium (see CRA Figures 5-2 and 5-8)
   d. Datum of gauge: 307.38 feet above NGVD29

7. Cedar Creek near Bastrop - Site 5521
   a. Location: 581-599 FM 20, Bastrop, TX
   b. Description: Gauge located on bridge with alluvium and flluviatile QT terrace deposits associated with the Calvert Bluff and Simsboro aquifers on the north banks and the Wilcox Group (Ewi) sands on the south bank.
   c. Gauge likely within alluvium (see CRA Figures 5-2 and 5-8)

8. Colorado River near Upton - Site 5525
   a. Gauge within alluvium (see CRA Figures 5-2 and 5-8)

9. Colorado River at Smithville - Site 5541
    a. Location: Below river bridge going into Smithville on Hwy
    b. Gauge within alluvium (see CRA Figures 5-2 and 5-8)

10. Bartons Creek, Fayette County
    a. If gauge, likely within alluvium (see CRA Figures 5-2 and 5-8)

11. Cedar Creek, Fayette County
    a. If gauge, not likely within alluvium (see CRA Figures 5-2 and 5-8)

12. Pin Oak Creek, Fayette County
    a. If gauge, likely within alluvium (see CRA Figures 5-2 and 5-8)

13. Colorado River at La Grange.
    a. Gauge within alluvium (see CRA Figures 5-2 and 5-8)

9.3 Exempt (Domestic) and Non-Exempt Groundwater Wells

Task 1. Identify registered exempt domestic wells that are located within or near the alluvium, and non-exempt commercial wells that are in Bastrop County.

Task 2. Locate on maps such that grid cells are identified, and river nodes can be identified in the GAM.

Task 3. Obtain well records from Lost Pines GCD and TWDB sources.

Task 4. Identify owners of the domestic wells so they can be encouraged to participate in the monitoring network either directly, or through a volunteer program to collect and monitor surface and well water in Bastrop and Lee counties.

9.4 Groundwater Availability Model (GAM) Scenario Runs

Regarding the interaction between groundwater pumping and the discharge of groundwater to the Colorado River, the GAM runs performed by Rice predict the following.

- Increased pumping in the LPGCD and GMA12 (pumping file S-19) will decrease the amount of groundwater discharged to the Colorado River. Between 2020 and 2070, the decrease is predicted to be approximately 15,000 AFY (see appendix 9).

- The following are the processes that lead to reduced discharges to the river (see appendix 8).
  1) Pumping reduces water levels in the underlying aquifers (e.g., Simsboro, Carrizo).
  2) This induces flow from the shallow portions of the aquifers (GAM layer 2) to the underlying aquifers.
  3) Because more water is flowing from layer 2 into underlying aquifers, less water from layer 2 flows into the river alluvium.
  4) Less water in the river alluvium results in less flow from the alluvium to the river.

- Most of the water pumped from wells is water that would otherwise be discharged to the Colorado River and other streams (see appendix 7).

- Groundwater discharges to the Colorado River could be maintained at current levels if groundwater pumping from the Simsboro and other aquifers was reduced. However, the reductions would have to be quite large (see appendix 7).

Appendix 3

Surface Water Rights Impacted in the Colorado River Basin from withdrawal of 25,000 and 40,000 AFY of Pumping

from studies conducted by

Kirk Kennedy

as presented in

Environmental Stewardship's Petition of the Unreasonableness of GMA-12 DFCs to the Texas Water Development Board

March 7, 2012

APPENDIX 3 Surface Water Rights Impacted in the Colorado River Basin from withdrawal of 25,000 and 40,000 AFY of Pumping

(From Volume 1, Section 4, Surface Water Availability Analysis (WAM))

Colorado River Water Rights

Number of Water Rights Negatively Impacted with 25,000 ac-ft/yr removed						
Ac-Ft/Yr Range:	>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.**

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

SCENARIO	FLOW to Bay (avg, ac-ft/yr 1940-1998)	
	Average	Change
BASELINE (TCEQ R3)	876,591	
With 25,000 af/y reduction in nat flow at Bastrop	860,395	-16,196
With 40,000 af/y reduction in nat flow at Bastrop	855,069	-21,522

Colorado River Water Rights

Number of Water Rights Negatively Impacted with 40,000 ac-ft/yr removed						
Ac-Ft/Yr Range:	>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.**

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

Scenario Impact on Bay	**FLOW to Matagorda Bay (avg, ac-ft/yr 1940-1998)**	
	Average	Change
BASELINE (TCEQ R3)	876,591	
With 25,000 af/y reduction in nat flow at Bastrop	860,395	-16,196
With 40,000 af/y reduction in nat flow at Bastrop	855,069	-21,522

Appendix 4

Description of Monitoring Well Configuration and Summary of Results

an excerpt from

Steven Young, et al.

as referenced in
Volume I, Section 2.2, footnote 3

APPENDIX 4: Description of Monitoring Well Configuration/ Summary of Results (from Volume 1, Section 2.2, Footnote 3)

The following are a few excerpts from the executive summary, Steve Young's 2017 report to the Colorado Lavaca Basin and Bay Area Stakeholder Committee (CL-BBASC) :

> *"Four wells were installed to monitor the groundwater elevation at two points near the Colorado River (in the cities of Wharton and Bay City) and at two points in irrigated agricultural areas (near the cities of Eagle Lake and Wadsworth)".*
>
> *"Water level data were collected from each well during an equilibration period from April 11 to April 28, 2006."*
>
> *"Variations in water level in individual wells during this time ranged from 0.4 to 0.7 foot, showing gradual or interrupted increases over the 17-day span. Wells in Wharton and Bay City that are adjacent to the Colorado River had water levels higher than the river over almost the entire period, indicating a groundwater gradient component directed from the well toward the river. River hydrographs show a fluctuation in levels of several feet during the last 6 days of the initial period. Well levels reflected changes in river levels with very little time lag, but well level changes were less than river level changes."*
>
> *"These four new shallow monitoring wells will provide accurate documentation of groundwater/surface water interactions that are critical to evaluations of aquifer recharge, discharge, and withdrawal in the Lower Colorado River Basin."*

Appendix 5

Description of the Colorado River Alluvium
an excerpt from

Jeoffrey P. Saunders, 1976

as referenced in
Volume II, Appendix 1, Section 5.3.1, Footnote 1

APPENDIX 5: Description of the Colorado River Alluvium

(From Appendix 1, Section 5.3.1, Footnote 1, Volume II)

Saunders, 1996

Saunders description of the Colorado River Alluvium.

The Colorado River of Texas stretches from its headwaters in the Trans-Pecos region to the Gulf of Mexico. After passing through the Edwards Plateau where it has eroded canyons in Cretaceous age limestone, which are now impounded by the Highland Lakes chain, the Colorado River flowed through the BaIcones Escarpment near Austin. At this point the ancestral river encountered a gently sloping area with low stream gradients, and the river deposited its sediment load in broad floodplain and terrace deposits. Continuing through the Blackland Prairie, the Colorado River eroded the soft Eocene age sediments as it meandered within a restricted floodplain. Multiple older terrace deposits were isolated as the river continued to erode. Younger alluvial deposits were laid down in the newer, more narrow floodplain. These deposits consisted of rounded sand, pebbles, and cobbles of quartz. chert and other minerals which were more resistant to chemical weathering than the granite and limestone from which they were derived.

The Colorado River Alluvial Aquifer is a laterally continuous, hydraulically interconnected series of alluvial and terrace deposits. These deposits are mapped in Travis, Bastrop, Fayette, Colorado, and Wharton counties (Barnes. 1974). At a point near the town of Wharton, the Colorado River passes through a "watergap" where it has eroded a narrow valley through underlying formations, effectively dividing the deposits of the Colorado River from the Gulf Aquifer (Figure 2). *The total area of mapped alluvial deposits is 14,500 acres (5,870 hectares). The alluvium is variable in width and depth, but it is found at all points along the Colorado River between Austin and Wharton. The alluvium is up to 4 miles in width mostly depending on the resistance to erosion of underlying formations. Depth of the alluvium is not well defined at all locations, but is described as being between 20 to 40 feet (6 to 12 m) deep (Rodda et aI., 1969). The isopach thickness of the alluvium has been mapped in the Austin area; average thickness is about 30 feet (9 m), ranging from less than 10 feet (3 m) to about 60 feet (18 m) (Gamer and Young, 1976).*

<u>*Aquifer characteristics*</u>*: The Colorado River Alluvium is a shallow, unconfined aquifer with moderate hydraulic conductivity, which is interactive with changes in stage and flow in the Colorado River (Harden & Assoc, 1988; Hibbs and Sharp, 199I). During periods of increasing stage and flow in the river, there is a corresponding increase in water table elevation and water storage in the alluvium. Likewise, during periods of decreasing flow in the river, the alluvium loses water from bank storage. The same features are identified in the description of the Brazos River Alluvium as a minor aquifer (Ashworth and Flores, 1991).*

Appendix 6

Location of Gaining and Losing Stream Reaches

an excerpt from

Steven Young, et al.

as referenced in
Volume II, Appendix 1,Section 5.3.1

APPENDIX 6: Location of Gaining and Losing Stream Reaches

(From Appendix 1,Section 5.3.1, Volume II)

Steven Young (Young et al 2017) also reviewed alluvium characterization studies in Section 4 of the 2017 report to the Colorado Lavaca Basin and Bay Area Stakeholder Committee (CL-BBASC) He confirmed the relationship of the Colorado River as dependent upon water from the Colorado River Alluvium, and confirmed the flow of groundwater from the Carrizo Wilcox, Queen City Aquifer, and Sparta Aquifer.

Young reported:

4.2.2 Hydraulic Head Gradient

Woodward (1989) assembled and developed contours of hydraulic head data for the Lower Colorado River Valley using data from the files of the United States Geological Survey and the TWDB from 1970 to 1985. The study area focused on the Lower Colorado River Valley, which includes Travis, Bastrop, Fayette, Colorado, Wharton, and Matagorda counties. Woodward (1989) developed contour maps for regional aquifers to determine the groundwater flow direction in the vicinity of the Colorado River. Among his findings are:

Carrizo-Wilcox and Queen City Aquifers: Water in the Carrizo-Wilcox and Queen City aquifers flows toward the lower Colorado River and the major tributaries of the river.
Sparta Aquifer: Groundwater in the Sparta Aquifer moves easterly and toward the Colorado River and its major tributaries Pin Oak, Buckners, and Live Oak creeks.

Figure 3. (*Figure 4-12 in the original report*) summarizes the findings of Woodward (1989) in a map that identifies the Colorado River from Lake Travis to Matagorda Bay as either a losing or gaining stream. All of the 318 miles in the Colorado River are mapped as gaining reaches, except for approximately 40 miles in the southwest region of Wharton County.

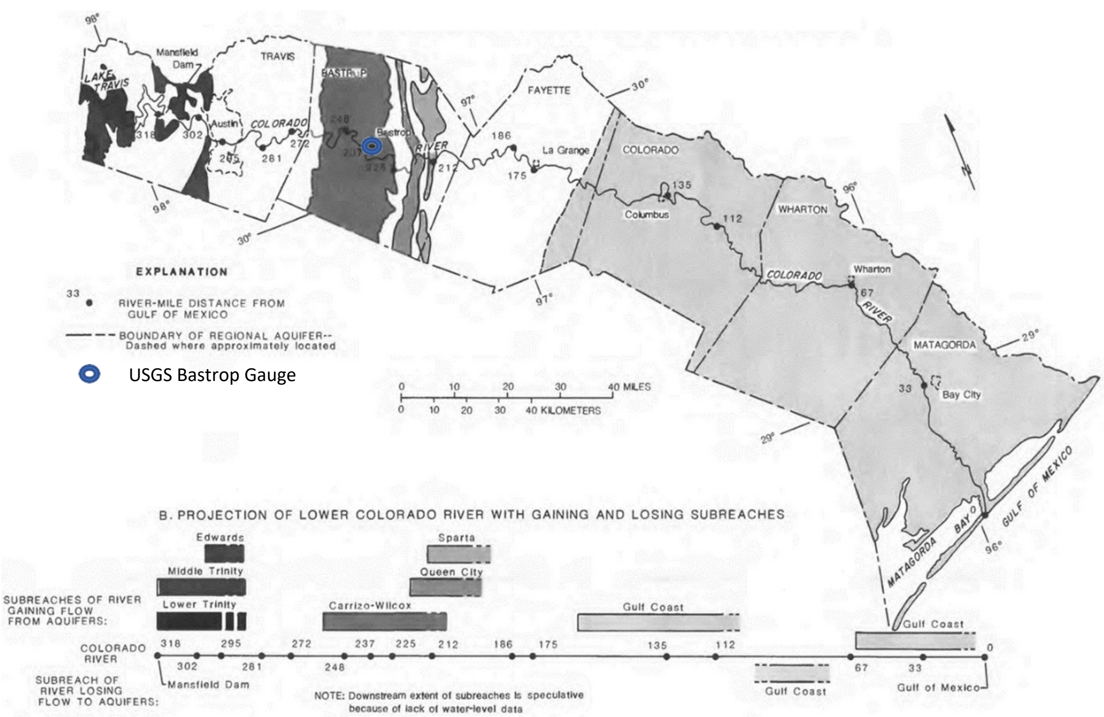


Figure 3. Location of gaining and losing stream reaches along the Colorado River based on contours of water level developed using data from 1970 to 1985 and from regional aquifers in the lower Colorado River Basin (from Woodward, 1989). From Young et al. 2017, Figure 4-12.

The Rice Reports[1]

Compiled for

Environmental Stewardship's
Desired Future Conditions Request

to

Lost Pines Groundwater Conservation District

September 2021 - June 2022

[1] The reports in these appendices have been revised to reflect a new definition of the main stem of the Colorado River. The old definition included some tributary nodes adjacent to the river. The tributary nodes were eliminated in the new definition.

Appendix 7

Water Budgets

for

Lost Pines Groundwater Conservation District (LPGCD)

and

Groundwater Management Area 12 (GMA-12)

and

Effects of Reducing Pumping in GMA-12

prepared by

George Rice

September 7, 2021

Rice Report, Part 1[1]

Groundwater Balance for LPGCD

The GAM2020 model was run using the pumping file S-19[2]. The results for two periods were examined: period 1 (2001 – 2010) and period 2 (2061 – 2070). Tables A1 -1 and A1-2 list the predicted inflows and outflows for each period.

Some of the flow components are both inflows and outflows. This is the case for streams. Some stream nodes are losing water to the underlying aquifers (inflow) while others are receiving discharge from the aquifers (outflows). For the storage component, the GAM treats water released from storage as an inflow, and water that enters storage as an outflow.[3] Net inflows and outflows are shown in tables A1-3 and A1-4.

Note that the stream values in this section are for all streams in the LPGCD, not only for the Colorado River and its tributaries.

Inflows and Outflows[4]

Table A1-1
LPGCD Inflows

Component	Period 1 2001-2010 (AFY)	Period 2 2061-2070 (AFY)	Difference P2 – P1 (AFY)
Streams	78342	92,691	14,349
Overlying Units	91	266	175
Recharge	76,941	86,466	9,525
Outside LPGCD	17,646	40,900	23,254
From Storage	25,725	46,838	21,113
Sum	198,745	267,161	68,416

[1] Parts 1 and 2 of this section are changed from the original report of September 7, 2021. First, the S-19 pumping file was used in the GAM simulations instead of the DFCRun3 file. Second, the nodes that are considered to constitute the main stem of the Colorado River were changed. Third, the text has been clarified.
[2] The pumping values from file DFCRun3 were used for the years 1930 – 2010, then the S-19 pumping values were used for the years 2011 – 2070.
[3] This can be seen by comparing the storage values in table A1-1. The storage value for period 2 (46838) is larger than for period 1 (25725), even though water levels have declined, and the amount of water stored in period 2 is less than the amount stored in period 1.
[4] Inflows and outflows are from ZoneBudget output.

Table A1-2
LPGCD Outflows

Component	Period 1 2001-2010 (AFY)	Period 2 2061-2070 (AFY)	Difference P2 – P1 (AFY)
Wells	26,680	103,320	76,640
Drains	9,707	2,292	-7,415
Streams	128,001	90,245	-37,756
ET	261	148	-113
Overlying Units	3,576	2,651	-925
Outside LPGCD	21,504	68,516	47,012
To Storage	9,015	0.12	-9,015
Sum	198,744	267,172	68,428

Inflows and outflows balance (within 1%) for both periods (compare tables A1-1 and A1-2).

Net Inflows and Outflows

Table A1-3
Net Inflows

Component	Period 1 Inflows - Outflows (AFY)	Period 2 Inflows - Outflows (AFY)	Change in Inflows P2 – P1 (AFY)
Recharge	76,941	86,466	9,525
From Storage	16,710	46,838	30,128
Sum	93,651	133,304	39,653

Table A1-4
Net Outflows

Component	Period 1 Outflows - Inflows (AFY)	Period 2 Outflows - Inflows (AFY)	Change in Outflows P2 – P1 (AFY)
Wells	26,680	103,320	76,640
Drains	9,707	2,292	-7,415
Streams	49,659	-2,446	-52,105
ET	261	148	-113
Overlying Units	34,85	2,385	-1,100
Outside LPGCD	38,58	27,616	23,758
Sum	93,650	133,315	39,665

Again, the inflows and outflows balance (within 1%).

Components Contributing to Increased Outflows

The increased outflows and the sources contributing to the increase are shown in tables A1-5 through A1-8.

Table A1-5
Increased Outflows, Period 1 – Period 2

Component	Increase from P1 to P2 (AFY)
Wells	76,640
Outside LPGCD	23,758
Total	100,398

Table A1-6
Increased Inflow, Period 1 – Period 2

Component	Increase from P1 to P2 (AFY)	Percentage of Increased Outflows
Recharge	9,525	9.49

Table A1-7
Decreased Outflows, Period 1 – Period 2

Component	Decrease from P1 to P2 (AFY)	Percentage of Increased Outflows
Discharge to Streams	52,105	51.90
Discharge to Drains	7,415	7.39
ET	113	0.11
To Overlying Units	1,100	1.10
Sum	60,733	60.49

Table A1-8
Increased Contribution from Storage, Period 1 – Period 2

Component	Increase from P1 to P2 (AFY)	Percentage of Increased Outflows
From Storage	30,128	30.01

Total Percent = 99.99

Note that most of the increased outflow is balanced not by increased inflows, but by a decrease in outflows from other components, primarily from streams. This is because pumping captures some of the groundwater that would otherwise be discharged to the streams. The increased recharge is due to the fact that, after 2010, recharge in the GAM is held to a constant value. Prior to 2010, recharge varies yearly.

Rice Report, Part 2

Groundwater Balance for GMA-12

The same type of balance performed for the LPGCD (part 1) was also performed for GMA 12. The stream values in this section are for all streams in GMA12.

Inflows and Outflows

Table A2-1
GMA 12 Inflows

Component	Period 1 2001-2010 (AFY)	Period 2 2061-2070 (AFY)	Difference P2 – P1 (AFY)
Streams	283,515	361,359	77,844
Overlying Units	1,195	4,397	3,202
Recharge	483,041	526,795	43,754
Outside GMA12	21,078	40,594	19,516
From Storage	121,077	124,500	3,423
Sum	909,906	1,057,645	147,739

Table A2-2
GMA 12 Outflows

Component	Period 1 2001-2010 (AFY)	Period 2 2061-2070 (AFY)	Difference P2 – P1 (AFY)
Wells	167,618	491,698	324,080
Drains	88,476	71,432	-17,044
Streams	566,552	434,513	-132,039
ET	3,603	2,227	-1,376
Overlying Units	10,309	5,244	-5,065
Outside GMA12	26,589	52,522	25,933
To Storage	46,770	7	-46,763
Sum	909,917	1,057,643	147,726

Between periods 1 and 2, outflows from GMA 12 increased by over 147,000 AFY. The majority of this increase was due to increased pumping. At the same time, groundwater discharge to streams decreased by about 132,000 AFY. Inflows and outflows balance (within 1%) for both periods (compare tables A2-1 and A2-2).

Net Inflows and Outflows

Table A2-3
Net Inflows

Component	Period 1 Inflows - Outflows (AFY)	Period 2 Inflows - Outflows (AFY)	Difference P2 – P1 (AFY)
Recharge	483,041	526,795	43,754
From Storage	74,307	124,493	50,186
Sum	557,348	651,288	93,940

Table A2-4
Net Outflows

Component	Period 1 Outflows - Inflows (AFY)	Period 2 Outflows - Inflows (AFY)	Difference P2 – P1 (AFY)
Wells	167,618	491,698	324,080
Drains	88,476	71,432	-17,044
Streams	283,037	73,154	-209,883
ET	3,603	2,227	-1,376
Overlying Units	9,114	847	-8,267
Outside GMA12	5,511	1,1928	6,417
Sum	1,120,308	1,083,572	93,927

Again, the inflows and outflows balance.

Components Contributing to Increased Outflows

The increased outflows and the sources contributing to the increase are shown in tables A2-5 through A2-8.

Table A2-5
Increased Outflows, Period 1 – Period 2

Component	Increase from P1 to P2 (AFY)
Wells	324,080
To outside GMA 12	6,417
Sum	330,497

Table A2-6
Increased Inflow, Period 1 – Period 2

Component	Increase from P1 to P2 (AFY)	Percentage of Increased Outflows
Recharge	43,754	13.24

Table A2-7
Decreased Outflows, Period 1 – Period 2

Component	Decrease from P1 to P2 (AFY)	Percentage of Increased Outflows
Discharge to Drains	17,044	5.16
Discharge to Streams	209,883	63.51
ET	1,376	0.04
Discharge to Overlying Units	8,267	2.50

Table A2-8
Decreased Contribution from Storage

Component	Increase from P1 to P2 (AFY)	Percentage of Increased Outflows
From Storage	50,186	15.19

Total Percent = 99.64

Note that most of the increased outflow is balanced not by increased inflows, but by a decrease in outflows from other components, primarily from streams. This is caused by pumping capturing some of the groundwater that would otherwise be discharged to the streams. The increased recharge is due to the fact that after 2010, recharge in the GAM is held to a constant value. Prior to 2010, recharge varies yearly.

Rice Report, Part 3

Effects of Reducing Pumping in GMA-12

Pumping file DFCRun3

Between 2001 and 2010, the average discharge of groundwater to the main stem of the Colorado River was approximately 26,000 AFY. This value is based on a GAM2020 run using the pumping file DFCRun3. GAM runs predict that groundwater pumping will cause discharges to the Colorado River to decline. Between 2061 and 2070, the average predicted discharge rate is approximately 15,000 AFY.

The question addressed in this appendix is: How much would pumping have to be reduced to restore groundwater discharges to the earlier rate, approximately 26,000 AFY?

To answer this question, pumping rates throughout GMA-12 were reduced by varying amounts. The reductions started in 2020. As shown in figure A3-1, a reduction of 90% would result in an average discharge of 27,000 AFY between 2061 and 2070. The results of reducing pumping by 50% are also shown.

There may be ways, other than a uniform reduction in pumping, to restore discharges to a desired level. Figure A3-1 also shows the results for a scenario where the pumping rates from 2001 to 2010 were repeated for each decade from 2020 to 2070.

Figure A3-2 shows the effects of reduced pumping on all streams in GMA-12, not just the main stem of the Colorado River.

Figure A3-3 shows pumping rates for: unaltered DFCRun3 pumping, a 90 percent reduction in pumping, and the repetition of the pumping rates from 2001 to 2010.

Pumping file S-12

The same type of analysis described above was performed using the S-12 pumping file. The major difference between the pumping files is the amount pumped in GMA-12. By 2070, the pumping rate in DFCRUN3 is approximately 355,000 AFY. For S-12 the rate in 2070 is about 547,000 AFY. As shown in figure A3-4, a 90 percent reduction in S-12 pumping results in a discharge greater than 26,000 AFY. Figure A3-5 shows pumping rates for unaltered S-12 pumping, and a 90 percent reduction in pumping.

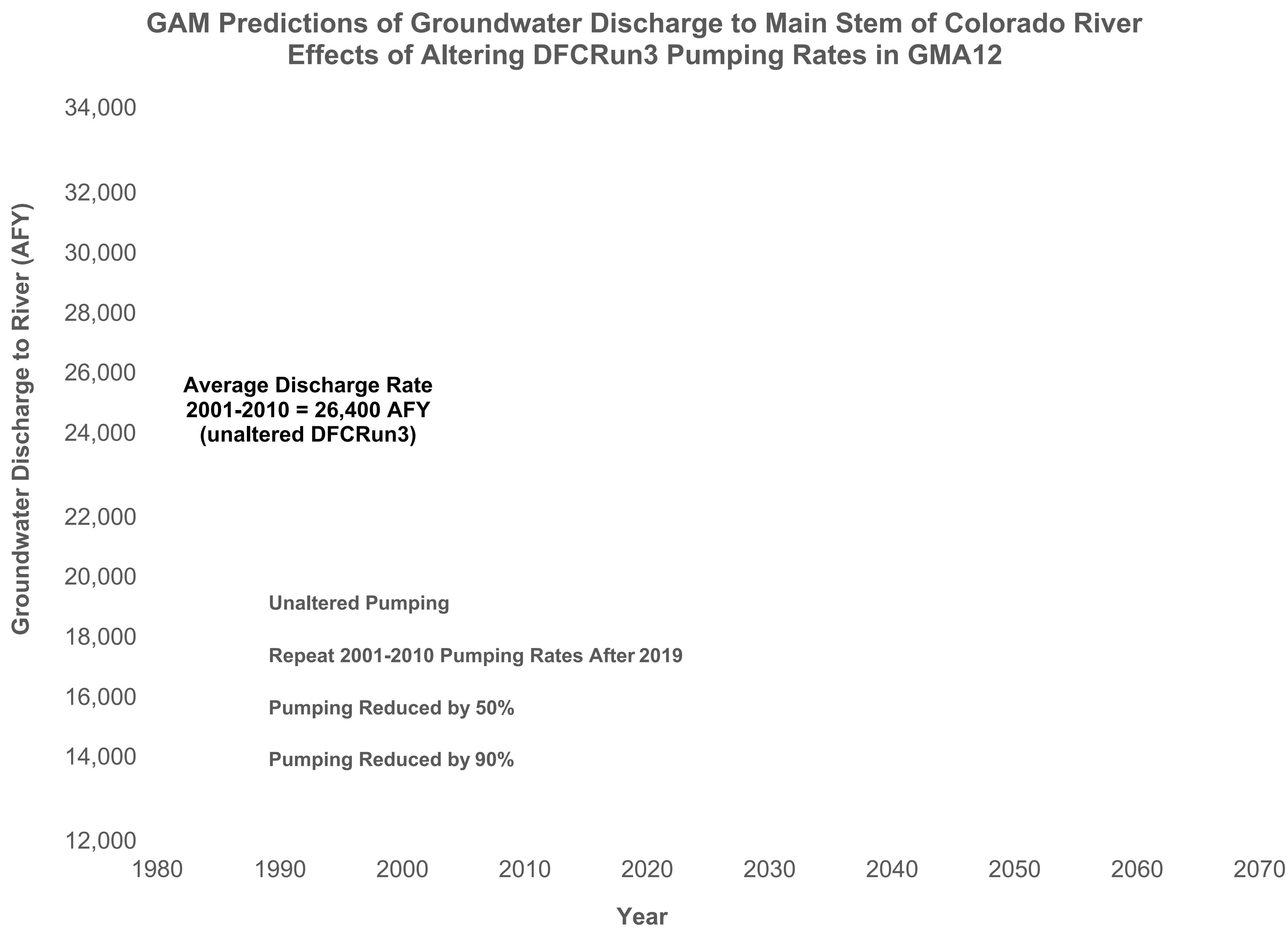

GAM Predictions of Groundwater Discharge to Main Stem of Colorado River
Effects of Altering DFCRun3 Pumping Rates in GMA12
Groundwater Discharge to River (AFY)
34,000
32,000
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
Average Discharge Rate
2001-2010 = 26,400 AFY
(unaltered DFCRun3)
Unaltered Pumping
Repeat 2001-2010 Pumping Rates After 2019
Pumping Reduced by 50%
Pumping Reduced by 90%
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year

Figure A3-1
Pumping File DFCRun3, Effects of Reduced Pumping on Groundwater Discharge to the Colorado River

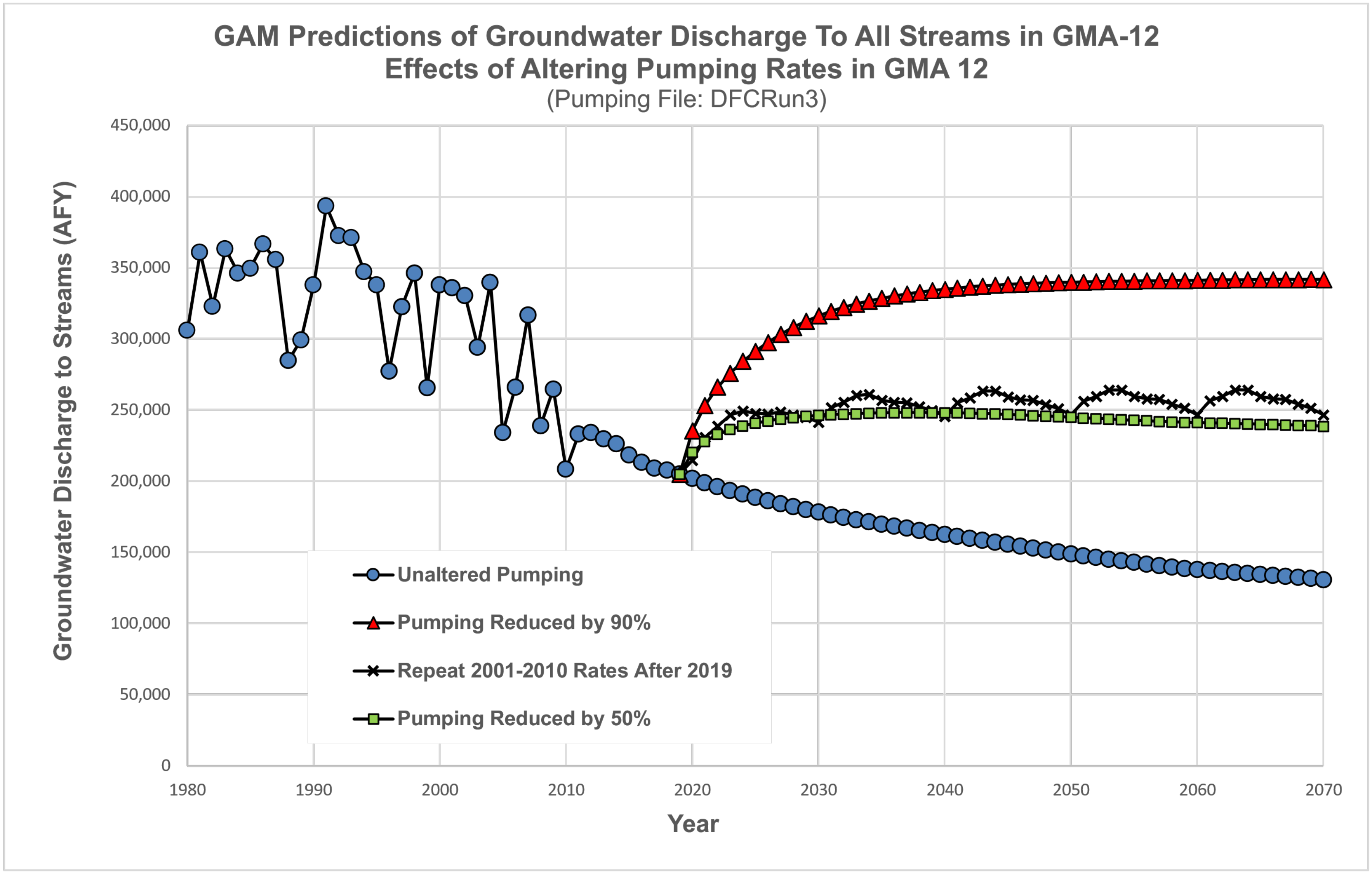


Figure A3-2

Pumping File DFCRun3, Effects of Reduced Pumping on Groundwater Discharge to All Streams in GMA-12

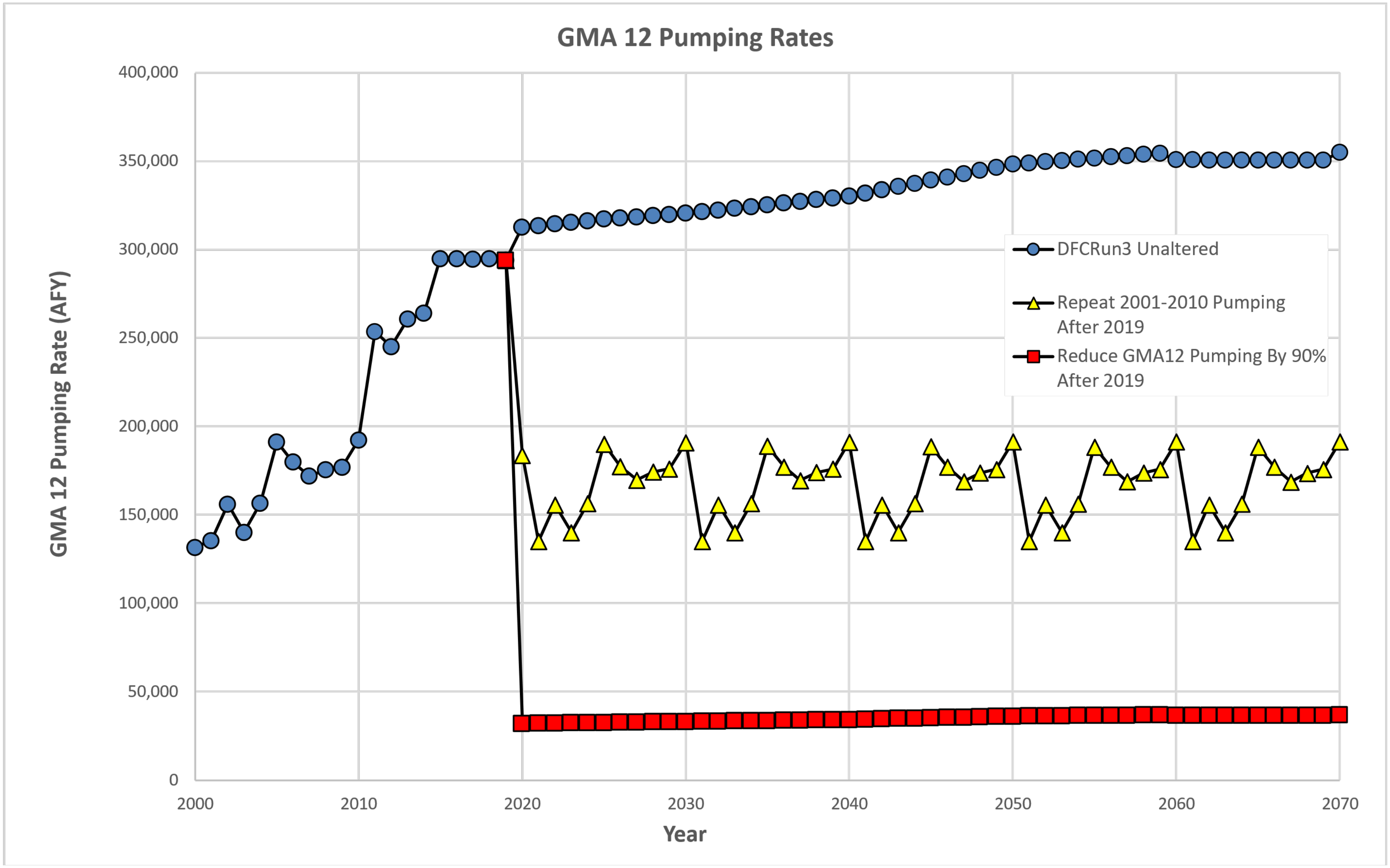


Figure A3-3
DFCRun3, Pumping Rates in GMA-12

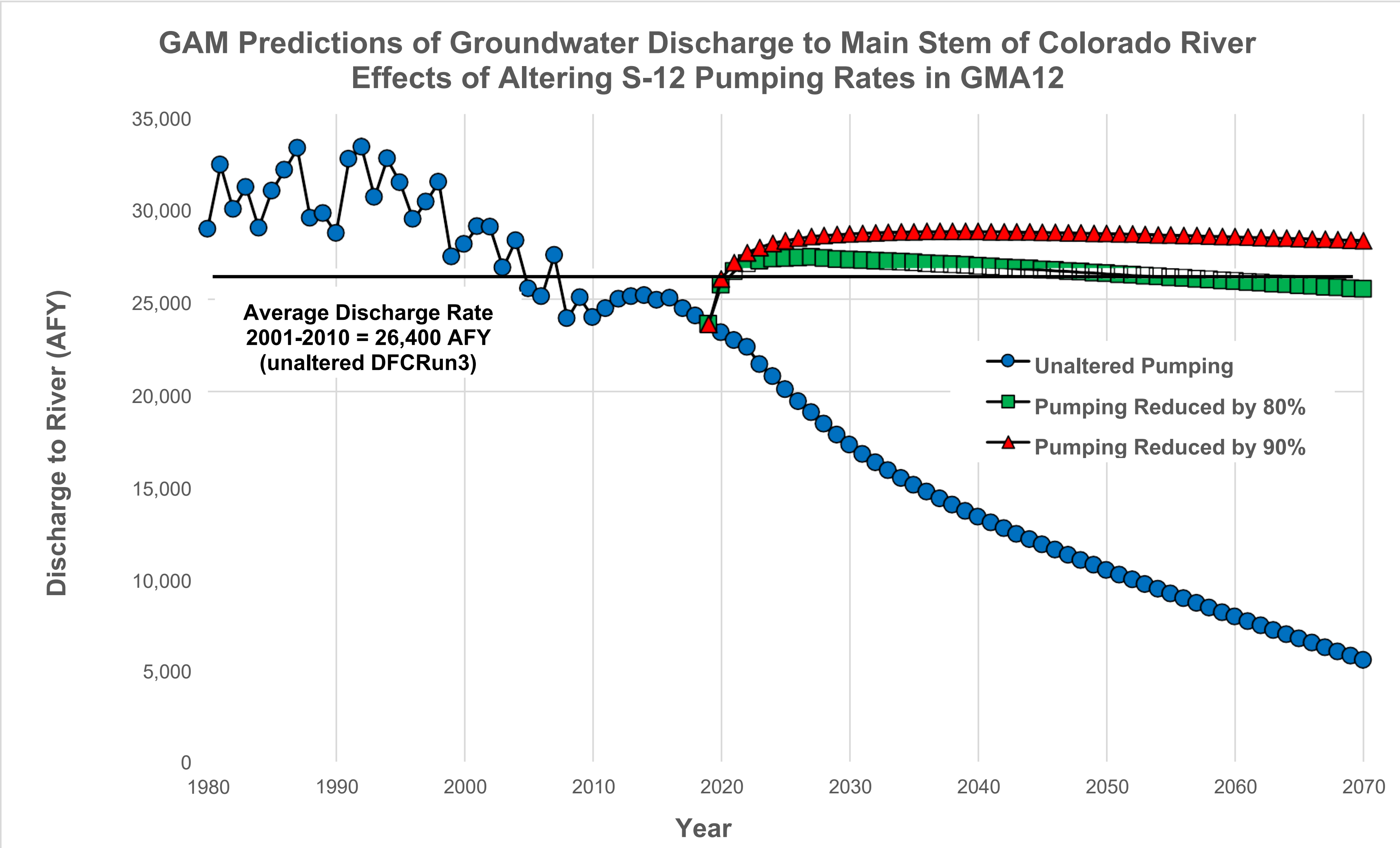


Figure A3-4
Pumping File S-12, Effects of Reduced Pumping on Groundwater Discharge to the Colorado River

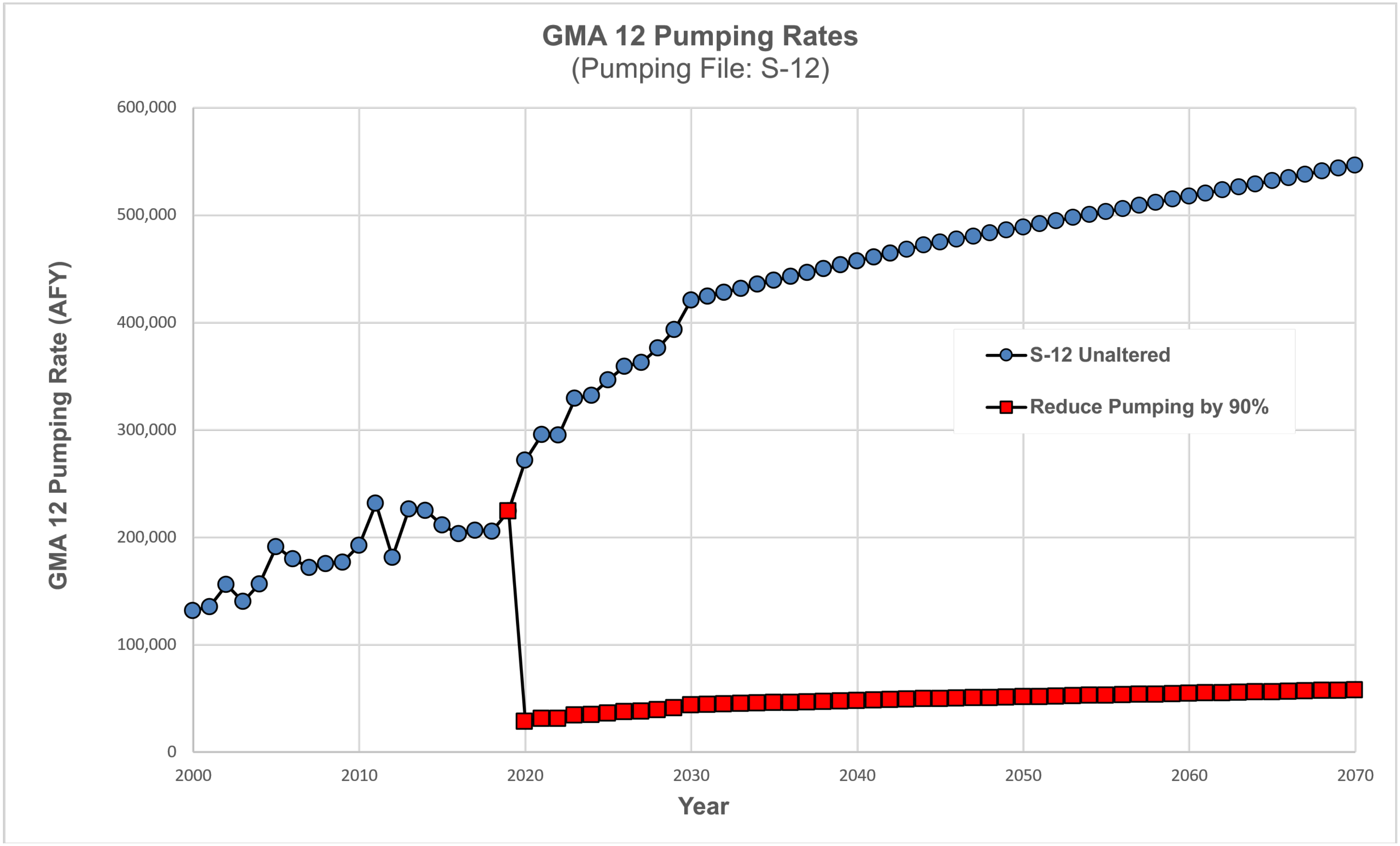


Figure A3-5
S-12 Pumping Rates in GMA-12

Appendix 8

GAM Predictions of Flows to and from the Alluvium Along the Main Stem of the Colorado River

prepared by

George Rice

May 30, 2022

GAM Predictions of Flows to and from the Alluvium Along the Main Stem of the Colorado River[1]

George Rice
May 30, 2022

The new GAM consists of ten layers but only two layers exchange water directly with streams: layer 1 (alluvium) and layer 2. Layer 2 consists of the shallow portions of the other eight layers. These are, in ascending order, the Carrizo-Wilcox aquifers (Hooper, Simsboro, Calvert Bluff, and Carrizo), the Reklaw[2], Queen City Aquifer, Weches, and Sparta Aquifer.

One portion of the alluvium is focused on here - the alluvium along the main stem of the Colorado River. This river alluvium exchanges water with the river. The river alluvium also exchanges water with other alluvium that is not in direct contact with the river[3], and with the underlying layer 2. The alluvium also receives recharge from precipitation. The flow relationships simulated by the GAM are illustrated in figure 1.

Figure 2 shows GAM predictions [4] of net flows between the river alluvium and; the Colorado River, the other alluvium, and layer 2. Pumping from LPGCD and the contribution from recharge are also shown[5]. Until about 2070 the river alluvium receives most of its water from layer 2. After 2070 the river alluvium receives most of its water from recharge and the other alluvium.

The GAM simulation can be summarized as a series of events that begins with pumping and ends with reduced flow to the Colorado River. These events are outlined below.

- Pumping (figure 2) reduces water levels in the underlying aquifers.
- The reduced water levels induce flow from Layer 2[6] into the underlying aquifers (figure 3).

[1] This report has been revised. In the original report, the GAM nodes that were defined to be the main stem of the Colorado River included some tributary nodes adjacent to the river. In this report, the tributary nodes have been eliminated.
[2] Although there are some wells in the Reklaw and Weches formations, they are generally not considered to be aquifers.
[3] In contrast to the river alluvium, the 'other' alluvium is all the alluvium in Bastrop County that does not directly exchange water with the Colorado River. It includes the alluvium adjacent to the river alluvium, and alluvium along the tributaries to the Colorado River.
[4] The S-19 pumping file was used.
[5] Recharge remains constant throughout the GAM simulation, approximately 2500 AFY.
[6] Although layer 2 includes the upper portions of the underlying aquifers, the GAM treats it as a separate aquifer.

- Because more water is flowing from layer 2 into underlying aquifers, less water from layer 2 flows into the river alluvium (figure 2).
- Less water in the river alluvium results in less flow from the alluvium to the Colorado River (figure 2).

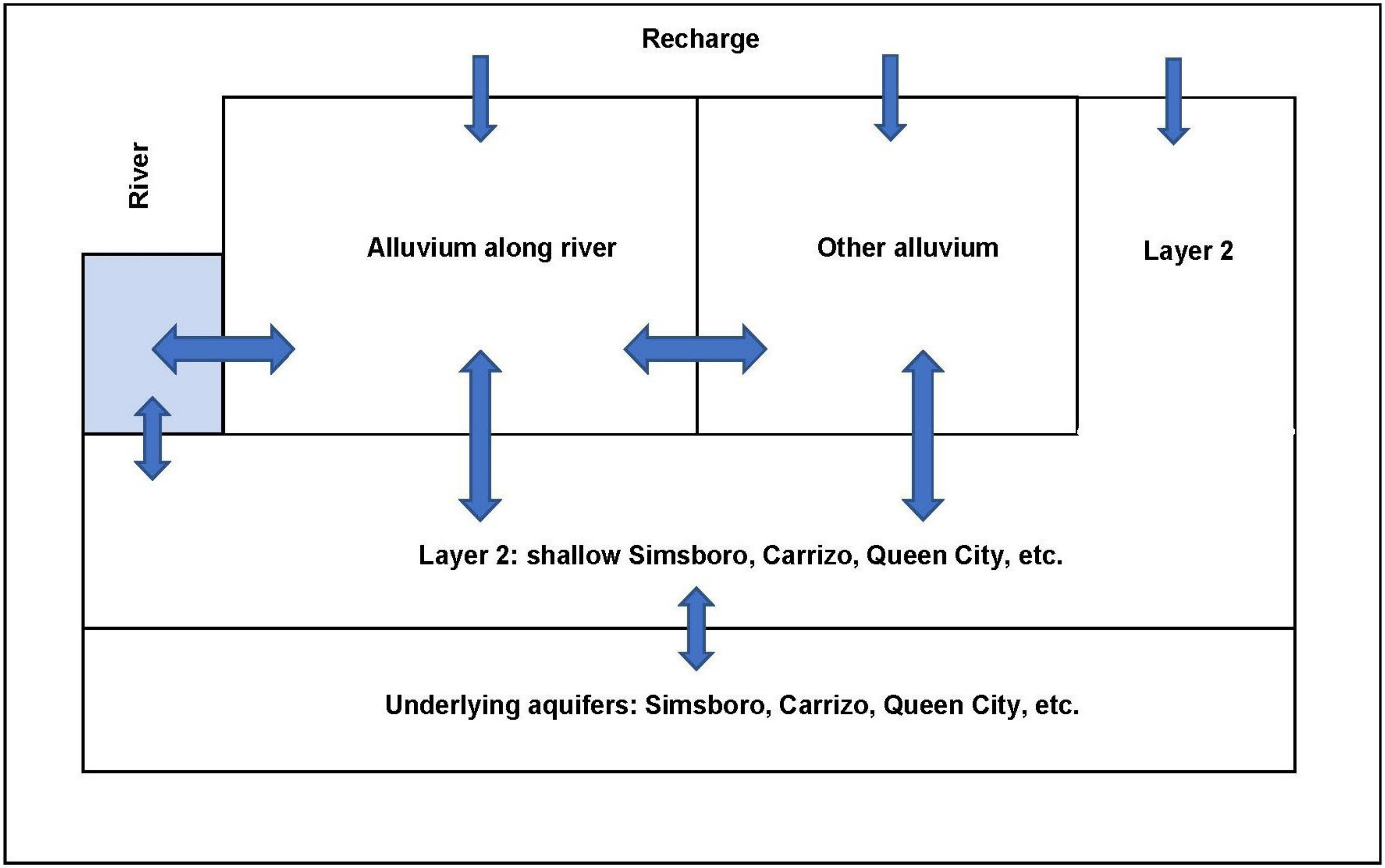


Figure 1 Schematic of flow relationships simulated by the GAM

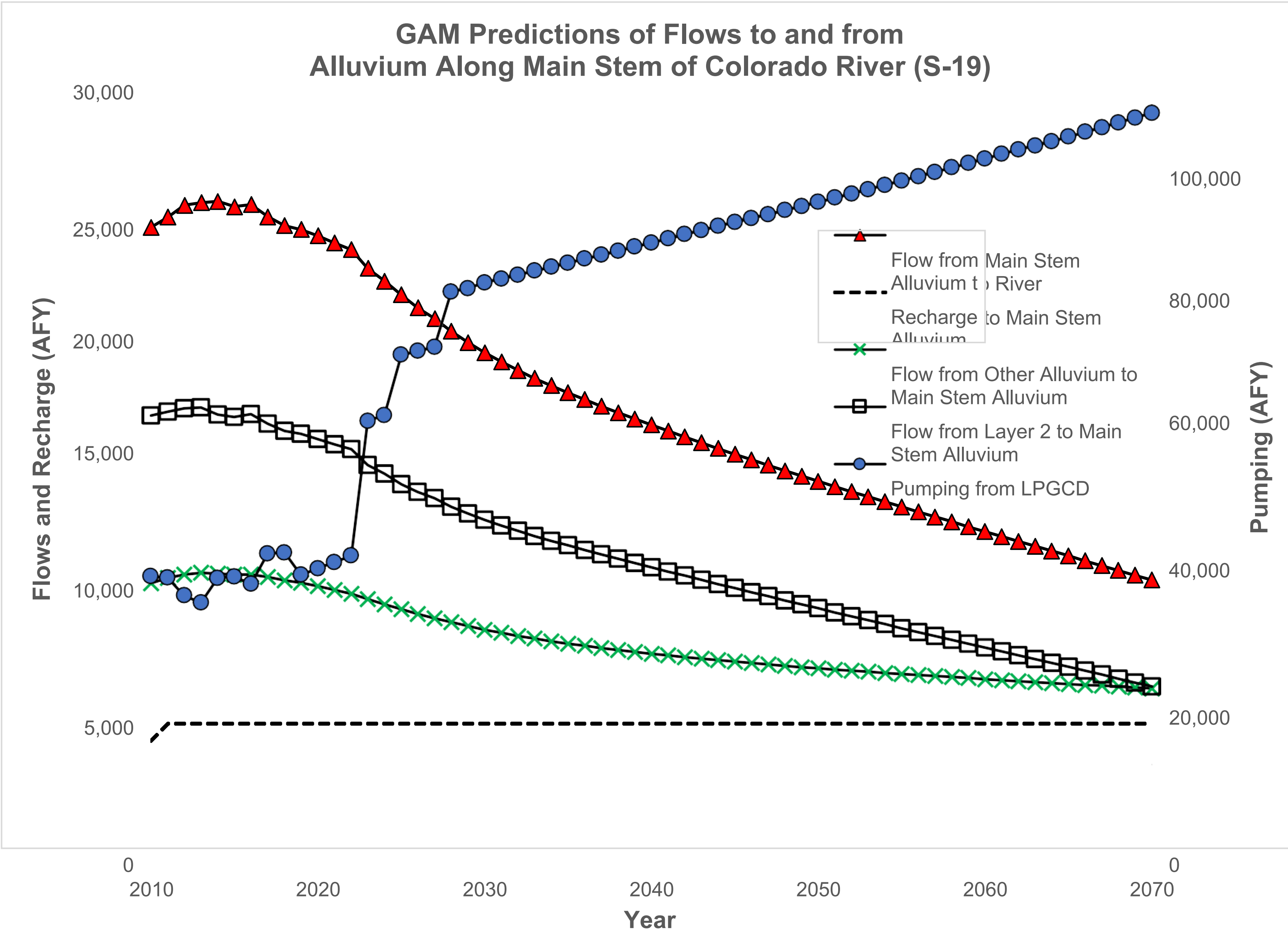


Figure 2
GAM predictions of flows. S-19 pumping file.

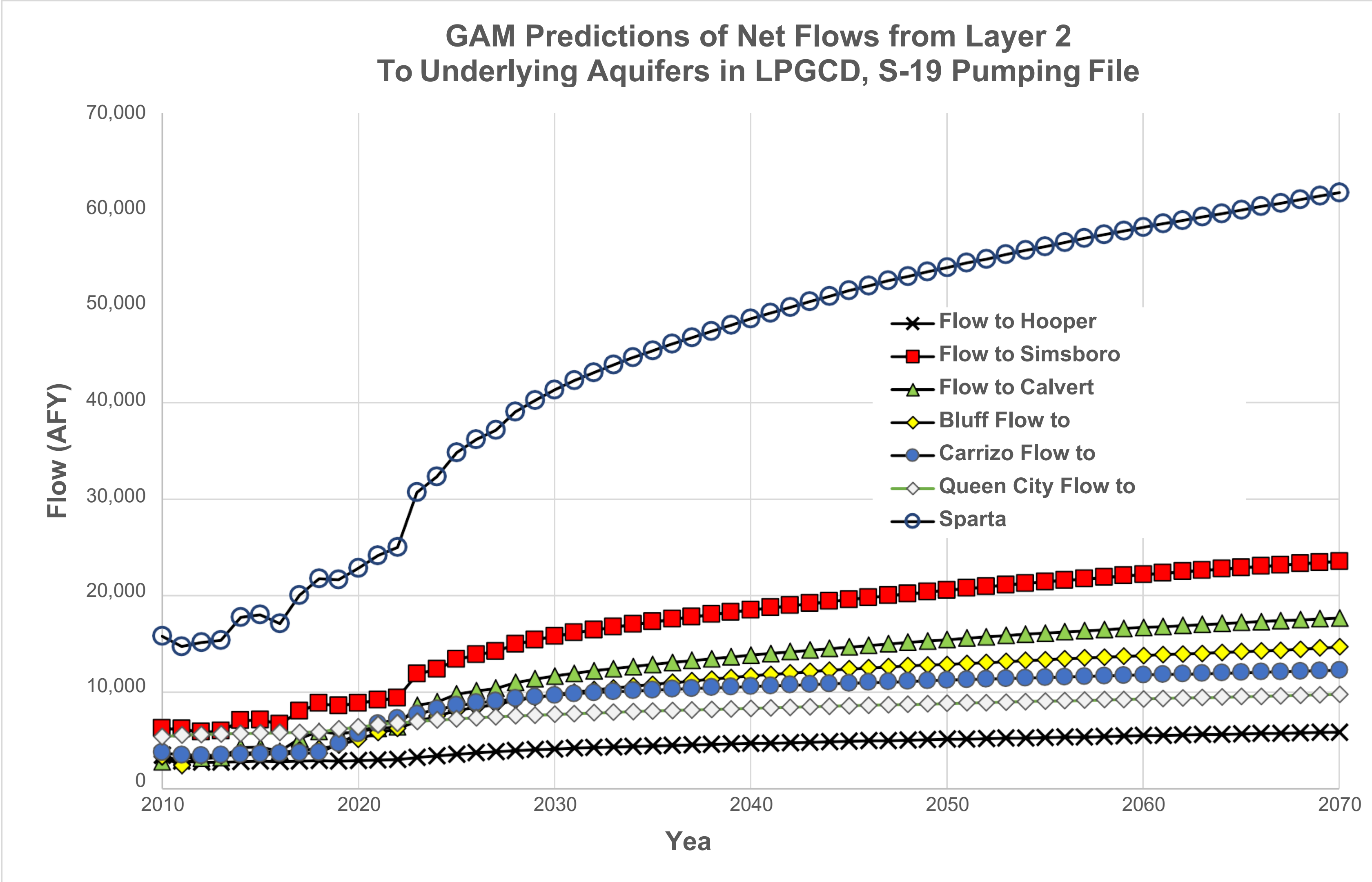


Figure 3
GAM predictions of flows between layer 2 and underlying aquifers. S-19 pumping file.

Note to S. Box from G. Rice

The attached plots are pictorial representations of water balances for the alluvium along the main stem of the Colorado River. They are the same as the plot I sent a few days ago except they include two more factors: 1) flow from the Queen City and Simsboro to the alluvium. and 2) flow from unassigned nodes to the alluvium[1].

The plot labeled (a) includes all the factors that contribute to the water balance. The plot labeled (b) is a blow-up of (a), showing the minor factors that contribute to the water balance.

The water balance is:

Flows in – flows out = change in storage

For the main stem alluvium in 2070:

Flows in = recharge + other alluvium + layer 2 + unassigned

Flows out = pumping[2] + river + Queen City and Simsboro

Values for 2070 (AFY):

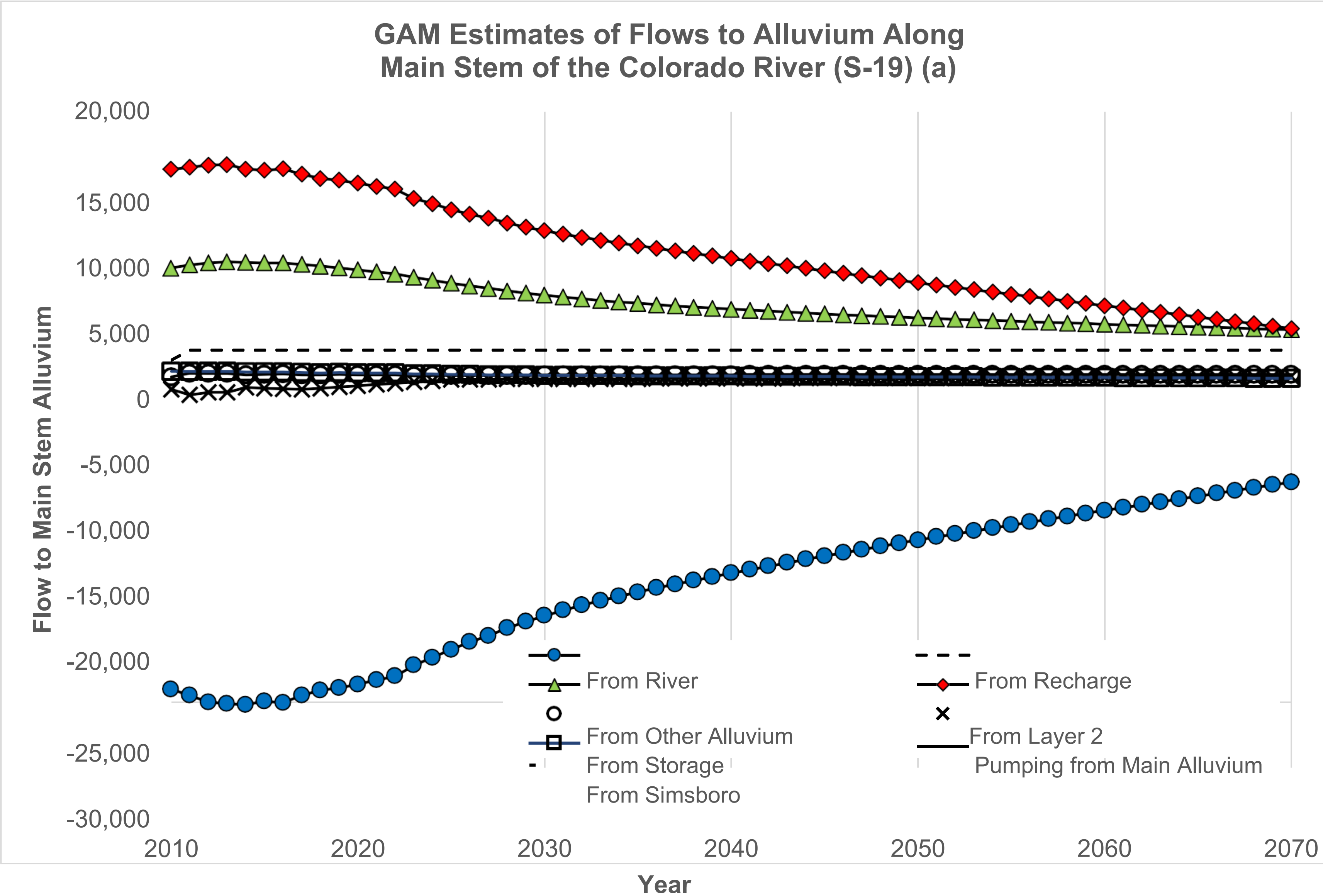
(1823 + 3414 + 3502 + 2) – (200 + 8248 + 330) = -39

The negative change in storage (-39) means that water levels in the main stem alluvium are declining.

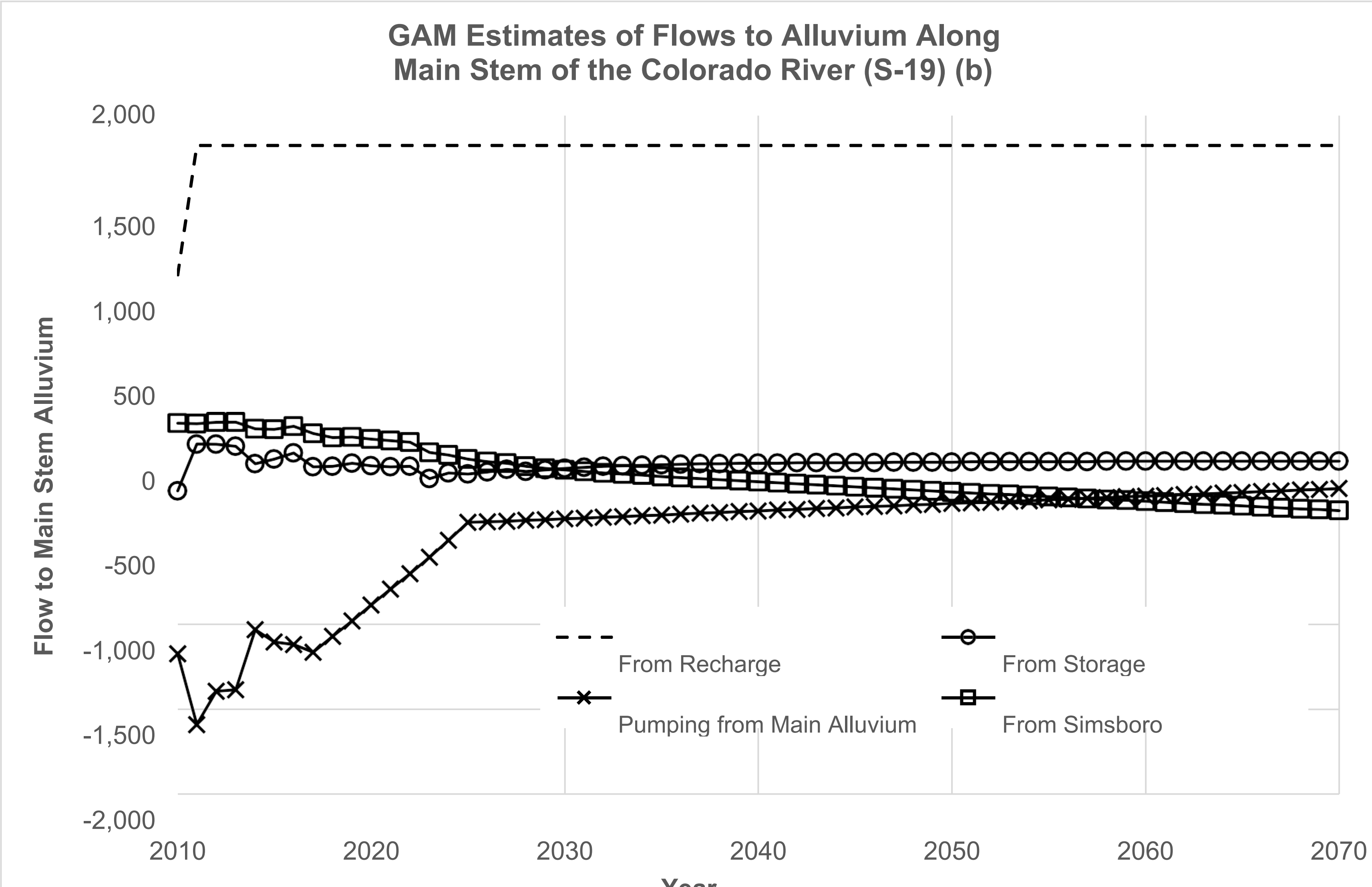
---

[1] Unassigned: in ZoneBudget, these nodes are not assigned to a particular unit.

[2] Pumping from main stem alluvium.



GAM Estimates of Flows to Alluvium Along
Main Stem of the Colorado River (S-19) (a)
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
-25,000
-30,000
Flow to Main Stem Alluvium
2010
2020
2030
2040
2050
2060
2070
Year
From River
From Recharge
From Other Alluvium
From Layer 2
From Storage
Pumping from Main Alluvium
From Simsboro


GAM Estimates of Flows to Alluvium Along
Main Stem of the Colorado River (S-19) (b)
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
-2,000
Flow to Main Stem Alluvium
2010
2020
2030
2040
2050
2060
2070
Year
From Recharge
From Storage
Pumping from Main Alluvium
From Simsboro

Appendix 9

Varying Pumping in the LPGCD Simsboro Aquifer S-19 Pumping File

prepared by

George Rice

November 22, 2021

Varying Pumping in the LPGCD Simsboro Aquifer
S-19 Pumping File[1]

George Rice

November 22, 2021

GAM2020 runs were performed to examine the effects of varying pumping rates on drawdowns in the Simsboro Aquifer in the Lost Pines Groundwater Conservation District (LPGCD).

Pumping rates in file S-19[2] were varied from 2020 through 2070. The Simsboro pumping rate for each year was multiplied by factors of 0.7, 0.9, and 1.

Pumping was varied only in the Simsboro Aquifer (layers 2 and 9) and only in the LPGCD. Average drawdowns were calculated for the period 2010 – 2070.[34]

Table 1 shows how pumping was varied and the resulting drawdowns. A graph of pumping versus drawdown is shown in figure 1.

Table 1 Variations in S-19 Pumping Rates and Resulting Drawdowns Simsboro Aquifer in LPGCD

Pumping Rate in 2070 (AFY) [3]	Average Drawdown in 2070 (ft)
78,000 (1.0X)	244
72,100 (0.9X)	235
56,500 (0.7X)	216

The effect of S-19 pumping[5] on groundwater discharge to the Colorado River is shown in figure 2.

[1] This report has been revised. In the original report, the GAM nodes that were defined to be the main stem of the Colorado River included some tributary nodes adjacent to the river. In this report, the tributary nodes have been eliminated.
[2] File provided by Andy Donnelly, November 15, 2021.
[3] The drawdowns were averaged across all layer 9 and layer 2 nodes in the LPGCD. In cases where layer 9 nodes are overlain by layer 2 nodes, the node with the highest head was used in the drawdown calculation.
[4] The GAM automatically reduces pumping if water levels approach the bottom of a node. The pumping values shown here are the values actually applied by the model – after the automatic reduction. These values are less than the pumping rates specified in the pumping file.
[5] Pumping rates unaltered.

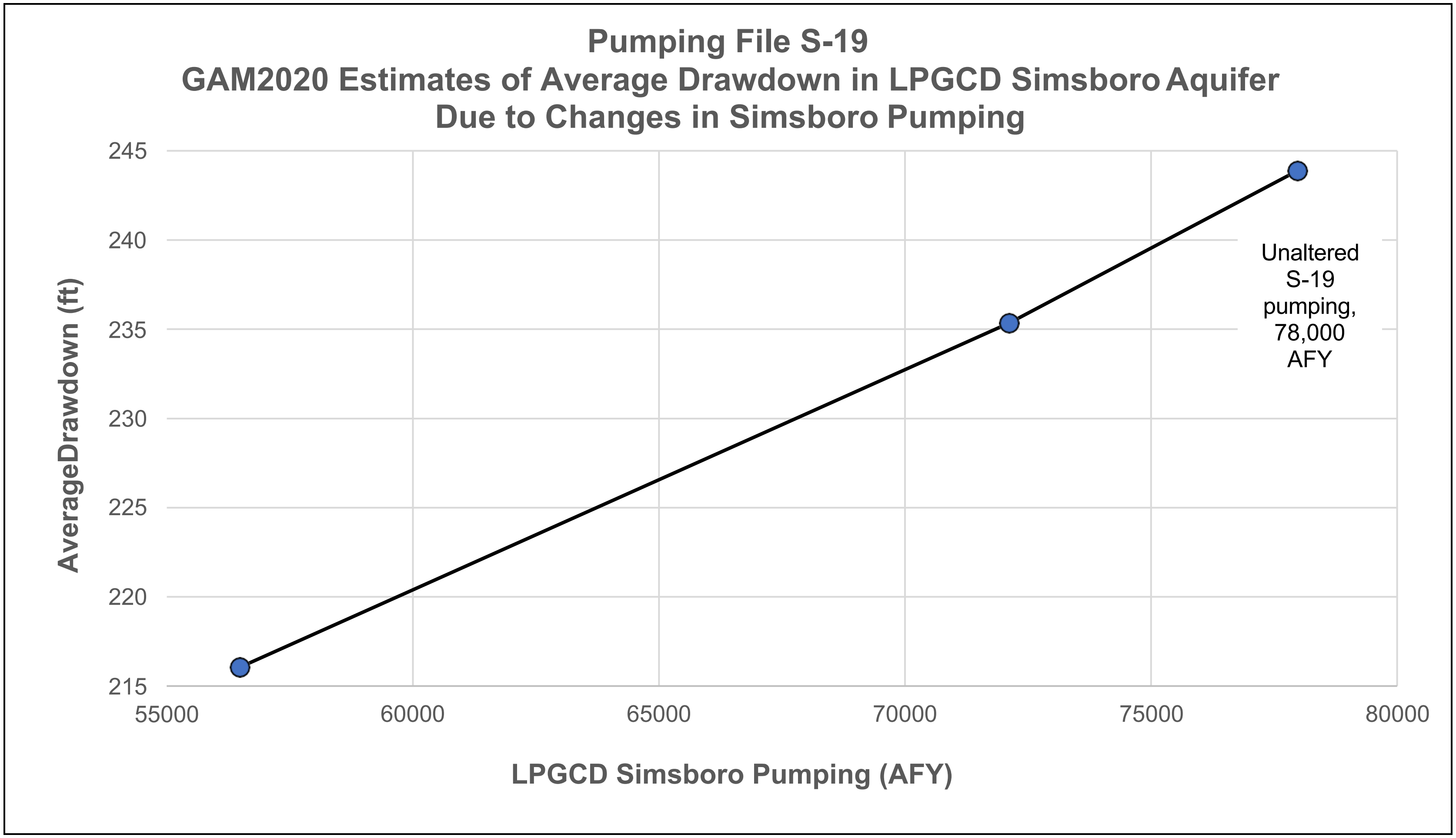


Figure 1
Effects of Varying S-19 Pumping on Average Simsboro Drawdowns in LPGCD

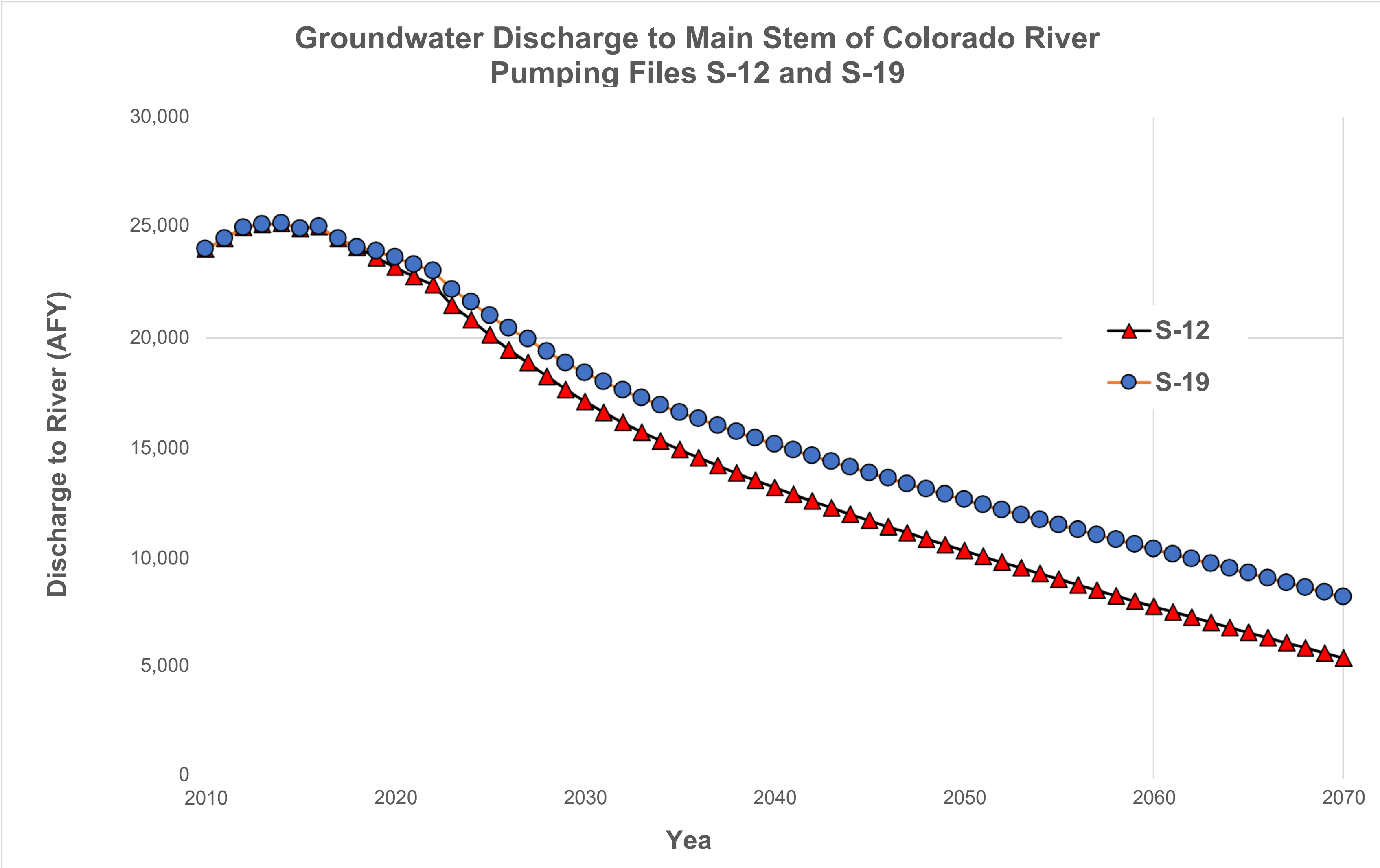


Figure 2
Effects of S-19 and S-12 Pumping on Groundwater Discharge to the Colorado River

Appendix 10

Effects of Three Pumping Regimes on Discharge of Groundwater to the Main Stem of the Colorado River

Comparison of S-19, 0.9XS-19, and S-20 GAM Runs

prepared by

George Rice

March 13, 2022

Effects of Three Pumping Regimes on Discharge of Groundwater to the Main Stem of the Colorado River[1]

George Rice
March 13, 2022

GAM2020 was used to simulate the effects of three pumping regimes on the discharge of groundwater to the main stem of the Colorado River. The three pumping regimes were: S-19, 0.9XS-19, and S-20. In the 0.9XS-19 regime pumping from the Simsboro and Carrizo aquifers in the LPGCD was reduced by 10 percent.

The pumping rates for each regime are shown in table 1.

Figure 1 shows the discharge of groundwater to the main stem of the Colorado River under the three pumping regimes.

Table 1 Pumping Rates Under Pumping Regimes

Pumping regime	Pumping from all aquifers in LPGCD (AFY)	Pumping from only Simsboro and Carrizo aquifers in LPGCD (AFY)
S-19	106,800	92,300
90% S-19	97,600	83,800
S-20	59,700	45,900

[1] This report has been revised. In the original report, the GAM nodes that were defined to be the main stem of the Colorado River included some tributary nodes adjacent to the river. In this report, the tributary nodes have been eliminated.

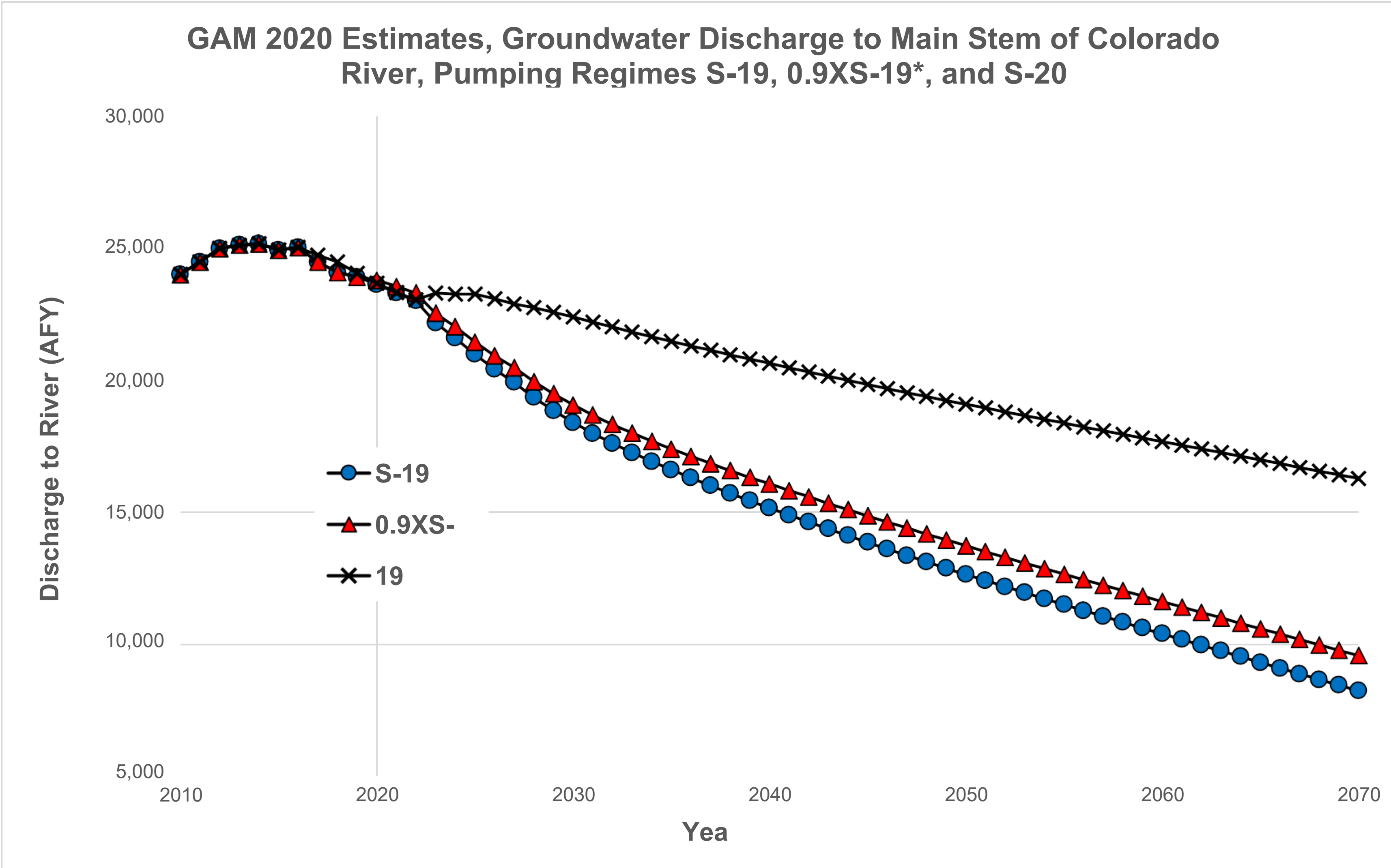


Figure 1
Effect of Pumping Regimes on Groundwater Discharge to Main Stem of Colorado River
(*Pumping from the Simsboro and Carrizo aquifers in the LPGCD decreased by 10%)

Appendix 11

Evaluation of the ecological impacts of reduced surface water flows due to groundwater pumping using the surface water WAM

from studies conducted by

Joe Trungale
Resource Consultant

as presented in
Appendix 1, Section 5.4.2

and
Environmental Stewardship's
comments to GMA-12
(Eric Allmon, October 28, 2020)

October 28, 2020

APPENDIX 11 Trungale Report: Evaluation of the ecological impacts of reduced surface water flows due to groundwater pumping using the surface water WAM

Evaluation by surface water expert:

Environmental Stewardship's surface water expert, Joe Trungale, used the current surface water availability model (WAM) to evaluate the impact of reduced inflows to the Colorado River and its tributaries to predict changes in critical environmental flow attainment rates that have been adopted by the State to protect the Colorado River as intended by Senate Bill 3.

Mr. Trungale used inflow reduction quantities resulting from by Mr. Rice's analysis of DFC Run 3 and Scenario S-7 as discussed above.

Based on Mr. Trungale's analysis Environmental Stewardship concludes that:

- **Water in the Colorado River at Bastrop and below has, for all intents and purposes, been fully appropriated.; *i.e.* no more water remains available for future appropriation as a water right.** A decrease in streamflows, including a decrease as a result of increased pumping of groundwater, would likely come at the expense of existing water rights holders, and these reduced flows would have an adverse effect on flows needed to maintain a sound ecological environment.

  - **The fact that the river is already over appropriated means that any reductions in flows will negatively impact existing water rights holders.** Specifically, existing water rights holders will be able to divert less of the water that they are legally entitled to than they would be able to divert if there were no reductions in flow due to groundwater pumping. The WAM allows for a quantification of how many water rights holders would be negatively impacted.

  - There are about 1,300 active water rights in the Colorado basin though not all include authorization to divert water. The reliability decreases for almost every water right in the basin. It should be noted that the reduction in reliability was generally relatively small with less than a 3 percent reduction in reliability in almost all cases. However, the *prior appropriation doctrine* is intended to ensure that senior water rights are protected from new (junior) water development projects. New water development projects, generally, cannot be permitted if they would result in reducing the reliability of flows available to satisfy existing water rights, at the full appropriation amount permitted. Groundwater pumping appears to create a gradual reduction of reliable streamflows, over a relatively long period of time (versus an immediate reduction of streamflows from a single development project).

- **Environmental flow standards are not being met at recommended frequencies, and additional groundwater pumping would likely result in further reduction in these attainment frequencies.** While there were some small changes in the results, the frequencies of meeting the flow standards are still below their recommended levels, and these shortfalls are further exacerbated by the decrease in flow as a result of the groundwater pumping. This reduction continues to be most concerning in the segments below Bastrop during spring when the *base dry and base average flows*, which are important for maintenance of habitat for the state-threatened Blue Sucker, drop further below already undesirable frequencies.
  - The Blue Sucker[i] *Cycleptus elongatus* is listed as a species of greatest conservation need, threatened, presumed extirpated, or endangered by 19 of the 23 states it inhabits. Their status in these 19 states is concerning, and an indication of potential trouble for the species. Blue Sucker are well known for occupying swift moving waters and have even been referred to

colloquially as swift water sucker. The status of Blue Sucker in Texas is unclear and attempts to elucidate information at the population level have proven difficult due to their life history, behavior, and cryptic nature. *However, their sensitivity to anthropogenic modifications makes them a good indicator species for overall ecosystem health*. A report by Bio-West (2008) described instream flows necessary to maintain spawning habitat availability in the lower Colorado River that were later used to inform water policy. The resulting 2010 Water Management Plan (WMP) for the lower Colorado River had flow requirements at or above 500 cfs to last for at least six weeks during the months of March, April, and May. These flow requirements were specifically to keep Blue Sucker spawning habitat available. However, a severe drought affected the implementation of environmental releases for Blue Sucker from 2010-2012. The Lower Colorado River Authority (LCRA) frequently requested emergency suspensions or reductions in required releases.

- **The reduction in flows impact the ecological health of the Colorado River**.

  - A sound ecological environment is defined as "a functioning ecosystem characterized by intact, natural processes, resilience, and a balanced, integrated, and adaptive community of organisms comparable to that of the natural habitat of a region." (Texas Instream Flow Program, Technical Overview, May 2008). Instream flow standards were recommended and adopted that included subsistence, base, high flow pulse, and bankfull flows necessary to maintain a sound environment for the Colorado River. These recommendations, consistent with literature on the science of instream flows recommended that flows be managed to mimic natural patterns. **The Instream Flow Program further recommended that subsistence flows should be considered "hands off flows" with the goal that flows do not fall below the subsistence flow guidelines and thus should be met 100% of the time**. For base flows, which provide for variable instream habitat conditions that differ during dry and average times, the recommendation was that base-dry and base-average flow magnitude occur 80 and 60 percent of the time.

  - The above flow recommendations were adopted by the Senate Bill 3 Colorado Bay and Basin Expert Science Team and the Bay and Basin Stakeholder Advisory Group.

  - **<u>Impacts of reduced groundwater outflows to the Colorado River due to current and proposed DFCs:</u>**

    Table 1 to this Report provides detailed information regarding the attainment frequencies of the Senate Bill 3 Flow Standards in the Lower Colorado River. The values in the table show the percentage of months when flows in the river are predicted, based on the WAM model, to meet or exceed the TCEQ adopted flow standards. Results are provided for the three sites on the lower Colorado river where flow standards have been adopted (Bastrop, Columbus, and Wharton). The table presents results based on the naturalized flows, which are an input to the WAM models and three distinct WAM simulations.

    - <u>Surface water flow simulations</u>: The first model simulation, labeled TCEQ3, is the official state water rights permitting model which assumes all water rights are exercised at their fully permitted authorization and assumes that there are no return flows. The other two runs, DFCRun3 and S7, are built on the TCEQ3 run but in these simulation streamflows have been adjusted to account for losses that are predicted by the respective GAM runs described above.

- The first thing to note in the table is the percent of time that subsistence, base-dry and base-average flow standards are met or exceeded under each of the scenarios. As discussed above subsistence flow should be met 100% of the time, base-dry 80% of the time and base-average 60% of the time based on the results of the instream flow study upon which these standards were developed.
  - Except for some of the subsistence flows, the naturalized flows generally meet the flow frequency targets.
  - The simulations based on the TCEQ3 simulation, in many months at multiple sites, do not meet the target frequencies.
  - **Of particular concern is the failure to achieve the desire frequency of 60% of the time for the base average flows in the spring (March and April) in the Columbus reach.** Base average flows were developed in part to provide optimal spawning habitat for the state threatened blue sucker.

TCEQ Adopted Flow standards vs DFCs: These frequencies under the two scenarios which account for streamflow loss due to increased groundwater pumping demonstrate that **further diminishment of groundwater inflow into the Colorado River has the potential for additional adverse impacts on wildlife dependent upon the Colorado River.**

- The column labeled "TCEQ3-DFC3" shows how much the attainment frequencies would be expected to fall due to the pumping that is projected by the New GAM run that **represents the currently adopted DFCs.**
- The column labeled "DFC3-G7" show the additional decrease that would be expected **if Scenario S7 were to be adopted**.
- While the percent changes may appear small. It is important to note that **in months were the attainment frequencies are already failing to meet the target** frequencies, such as the base-average targets in March and April at Columbus, **an unsound environmental condition would be made even worse.**
- It is also important also to note that the flow standards were developed to support the full community of species in the lower Colorado and that **these negative trends extend the entire length of the river and into Matagorda Bay**.

- **Texas groundwater law requires that permits for wells shall consider whether the proposed use of water unreasonably affects existing groundwater and surface water resources for existing permit holders**.

  - **The effect of the proposed groundwater pumping on surface water resources is unreasonable because it increases the shortfalls in meeting environmental flow targets.** Since the flows in the river are already often below levels needed to maintain the ecological health of the river, then any additional pumping that causes further instream flow reduction is unreasonable.

- **Groundwater and surface water sources are physically connected and considering them as independent and disjointed is contrary to reality.** The best available science concludes, logically, that pumping water from aquifers near the Colorado River and its tributaries will reduce the flow in the river and the tributaries.

  - **Since this river is already fully appropriated, this reduction will adversely impact the reliability of water for existing senior water rights holders.** The reduction in flow will also mean that the flows needed to maintain a sound environment, which in some cases are already not being meet, would be further reduced below levels recommended by the best available science.

- **The uncertainty regarding the precise magnitude of the river flow decline does not change the fundamental dynamics**. Groundwater pumping will decrease flows in the river and the tributaries, and for the reasons stated above, the river cannot afford the reduction.

In summary:

The water of the Colorado River at Bastrop has already been fully allocated and simulations of groundwater production using surface water modeling have shown groundwater pumping to negatively impact both water rights holders and the ecological health of the river. The state has adopted environmental flow standards to maintain the biological health of the river and Matagorda Bay and instructed the TCEQ, to the extent practicable, provide for the freshwater inflows and instream flows necessary to maintain the viability of the state's streams, rivers, and bay and estuary systems. The Legislature has further instructed groundwater conservation districts to consider the impacts of groundwater pumping on surface waters and existing permits before granting operating permits or adopting desired future conditions.

Groundwater pumping volumes already authorized and under the currently adopted DFCs have the potential to negatively and unreasonably impact surface water environmental flows and thereby the ecological health of the Colorado River and its tributaries. Additional pumping volumes as proposed by Scenario S-7 further threaten the health of the river. These negative trends extend the entire length of the river and into Matagorda Bay.

It is appropriate that GMA-12 Districts adopt desired future conditions that maintain the flow of the river at levels that protect threatened biological communities at and below Bastrop.

Table 1. Attainment Frequencies of Senate Bill 3 Flow Standards in the Lower Colorado River

		TARGET ATTAINMENT FREQUENCY							TARGET ATTAINMENT FREQUENCY							TARGET ATTAINMENT FREQUENCY						
		100%							80%							60%						
		SUBSISTENCE FLOWS							BASE FLOWS - DRY CONDITIONS							BASE FLOWS - AVERAGE CONDITIONS						
CP J30000	MONTH	FLOW	NAT	TCEQ3	DFC3	TCEQ3-DFC3	S7	DFC3-S7	FLOW	NAT	TCEQ3	DFC3	TCEQ3-DFC3	S7	DFC3-S7	FLOW	NAT	TCEQ3	DFC3	TCEQ3-DFC3	S7	DFC3-S7
		(AC-FT/MO)	% TIME MET	% TIME MET	% TIME MET	%	% TIME MET	%	(AC-FT/MO)	% TIME MET	% TIME MET	% TIME MET	%	% TIME MET	%	(AC-FT/MO)	% TIME MET	% TIME MET	% TIME MET	%	% TIME MET	%
Bastrop	Jan	12,789	100.0%	94.6%	94.6%	0.0%	94.6%	0.0%	19,245	97.3%	85.1%	86.5%	1.4%	85.1%	-1.4%	26,624	93.2%	56.8%	56.8%	0.0%	56.8%	0.0%
	Feb	15,217	98.6%	91.9%	93.2%	1.4%	91.9%	-1.4%	17,605	98.6%	83.8%	85.1%	1.4%	85.1%	0.0%	27,601	94.6%	52.7%	52.7%	0.0%	52.7%	0.0%
	Mar	16,847	97.3%	98.6%	98.6%	0.0%	98.6%	0.0%	16,847	97.3%	98.6%	98.6%	0.0%	98.6%	0.0%	30,559	87.8%	74.3%	68.9%	-5.4%	67.6%	-1.4%
	Apr	10,948	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	17,077	100.0%	98.6%	98.6%	0.0%	98.6%	0.0%	37,785	95.9%	77.0%	75.7%	-1.4%	75.7%	0.0%
	May	16,909	100.0%	97.3%	97.3%	0.0%	97.3%	0.0%	35,601	98.6%	95.9%	95.9%	0.0%	95.9%	0.0%	50,665	93.2%	89.2%	89.2%	0.0%	89.2%	0.0%
	Jun	12,019	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	24,872	100.0%	98.6%	98.6%	0.0%	98.6%	0.0%	43,616	87.8%	93.2%	93.2%	0.0%	93.2%	0.0%
	Jul	8,423	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	21,336	98.6%	98.6%	100.0%	1.4%	100.0%	0.0%	37,507	87.8%	93.2%	93.2%	0.0%	93.2%	0.0%
	Aug	7,562	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	11,928	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	23,426	91.9%	97.3%	97.3%	0.0%	97.3%	0.0%
	Sep	7,319	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	14,042	98.6%	98.6%	98.6%	0.0%	98.6%	0.0%	25,170	94.6%	91.9%	89.2%	-2.7%	87.8%	-1.4%
	Oct	7,808	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	15,064	98.6%	95.9%	95.9%	0.0%	94.6%	-1.4%	26,624	93.2%	74.3%	68.9%	-5.4%	66.2%	-2.7%
	Nov	10,710	100.0%	98.6%	97.3%	-1.4%	97.3%	0.0%	16,839	97.3%	70.3%	63.5%	-6.8%	62.2%	-1.4%	25,229	87.8%	47.3%	47.3%	0.0%	47.3%	0.0%
	Dec	11,436	100.0%	95.9%	95.9%	0.0%	94.6%	-1.4%	19,122	98.6%	73.0%	71.6%	-1.4%	71.6%	0.0%	27,669	86.5%	54.1%	52.7%	-1.4%	52.7%	0.0%
	Non-Attainment		2	6	6		6			0	2	2		2			0	4	4		4	

		SUBSISTENCE FLOWS							BASE FLOWS - DRY CONDITIONS							BASE FLOWS - AVERAGE CONDITIONS						
CP J10000	MONTH	FLOW	NAT	TCEQ3	DFC3	TCEQ3-DFC3	S7	DFC3-S7	FLOW	NAT	TCEQ3	DFC3	TCEQ3-DFC3	S7	DFC3-S7	FLOW	NAT	TCEQ3	DFC3	TCEQ3-DFC3	S7	DFC3-S7
		(AC-FT/MO)	% TIME MET	% TIME MET	% TIME MET	%	% TIME MET	%	(AC-FT/MO)	% TIME MET	% TIME MET	% TIME MET	%	% TIME MET	%	(AC-FT/MO)	% TIME MET	% TIME MET	% TIME MET	%	% TIME MET	%
Columbus	Jan	20,905	97.3%	100.0%	100.0%	0.0%	100.0%	0.0%	29,944	93.2%	68.9%	68.9%	0.0%	68.9%	0.0%	50,911	75.7%	50.0%	50.0%	0.0%	50.0%	0.0%
	Feb	20,826	98.6%	94.6%	94.6%	0.0%	94.6%	0.0%	32,766	93.2%	64.9%	60.8%	-4.1%	60.8%	0.0%	49,705	81.1%	45.9%	47.3%	1.4%	45.9%	-1.4%
	Mar	23,057	91.9%	98.6%	97.3%	-1.4%	97.3%	0.0%	32,280	90.5%	73.0%	73.0%	0.0%	71.6%	-1.4%	62,717	73.0%	50.0%	45.9%	-4.1%	45.9%	0.0%
	Apr	17,791	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	32,965	95.9%	93.2%	93.2%	0.0%	93.2%	0.0%	58,135	82.4%	52.7%	48.6%	-4.1%	48.6%	0.0%
	May	26,132	98.6%	100.0%	100.0%	0.0%	100.0%	0.0%	59,397	91.9%	93.2%	93.2%	0.0%	93.2%	0.0%	80,917	87.8%	86.5%	86.5%	0.0%	85.1%	-1.4%
	Jun	31,775	98.6%	100.0%	100.0%	0.0%	100.0%	0.0%	57,540	89.2%	93.2%	93.2%	0.0%	93.2%	0.0%	85,685	78.4%	86.5%	86.5%	0.0%	86.5%	0.0%
	Jul	21,028	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	35,047	91.9%	98.6%	98.6%	0.0%	98.6%	0.0%	55,031	75.7%	87.8%	85.1%	-2.7%	85.1%	0.0%
	Aug	11,682	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	19,061	98.6%	100.0%	100.0%	0.0%	100.0%	0.0%	31,727	89.2%	90.5%	86.5%	-4.1%	85.1%	-1.4%
	Sep	16,601	98.6%	100.0%	100.0%	0.0%	100.0%	0.0%	24,099	95.9%	100.0%	100.0%	0.0%	98.6%	-1.4%	36,297	93.2%	82.4%	78.4%	-4.1%	79.7%	1.4%
	Oct	11,682	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	21,889	98.6%	91.9%	87.8%	-4.1%	87.8%	0.0%	45,562	86.5%	62.2%	62.2%	0.0%	59.5%	-2.7%
	Nov	12,019	100.0%	97.3%	100.0%	2.7%	100.0%	0.0%	28,561	86.5%	50.0%	50.0%	0.0%	47.3%	-2.7%	44,925	75.7%	43.2%	43.2%	0.0%	43.2%	0.0%
	Dec	18,507	98.6%	94.6%	91.9%	-2.7%	91.9%	0.0%	28,530	91.9%	63.5%	60.8%	-2.7%	60.8%	0.0%	45,316	75.7%	41.9%	36.5%	-5.4%	36.5%	0.0%
	Non-Attainment		7	4	3		3			0	5	5		5			0	6	6		7	

		SUBSISTENCE FLOWS							BASE FLOWS - DRY CONDITIONS							BASE FLOWS - AVERAGE CONDITIONS						
CP K20000	MONTH	FLOW	NAT	TCEQ3	DFC3	TCEQ3-DFC3	S7	DFC3-S7	FLOW	NAT	TCEQ3	DFC3	TCEQ3-DFC3	S7	DFC3-S7	FLOW	NAT	TCEQ3	DFC3	TCEQ3-DFC3	S7	DFC3-S7
		(AC-FT/MO)	% TIME MET	% TIME MET	% TIME MET	%	% TIME MET	%	(AC-FT/MO)	% TIME MET	% TIME MET	% TIME MET	%	% TIME MET	%	(AC-FT/MO)	% TIME MET	% TIME MET	% TIME MET	%	% TIME MET	%
Wharton	Jan	19,368	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	30,251	97.3%	73.0%	73.0%	0.0%	73.0%	0.0%	51,526	77.0%	58.1%	56.8%	-1.4%	56.8%	0.0%
	Feb	16,827	98.6%	98.6%	100.0%	1.4%	100.0%	0.0%	33,155	93.2%	71.6%	67.6%	-4.1%	64.9%	-2.7%	50,316	83.8%	48.6%	48.6%	0.0%	48.6%	0.0%
	Mar	12,543	97.3%	98.6%	98.6%	0.0%	98.6%	0.0%	32,649	91.9%	62.2%	62.2%	0.0%	62.2%	0.0%	63,701	74.3%	44.6%	43.2%	-1.4%	43.2%	0.0%
	Apr	16,066	100.0%	98.6%	100.0%	1.4%	100.0%	0.0%	33,381	97.3%	59.5%	59.5%	0.0%	59.5%	0.0%	60,158	85.1%	48.6%	45.9%	-2.7%	45.9%	0.0%
	May	18,692	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	60,565	91.9%	54.1%	56.8%	2.7%	55.4%	-1.4%	85,898	85.1%	44.6%	44.6%	0.0%	44.6%	0.0%
	Jun	22,076	100.0%	97.3%	97.3%	0.0%	97.3%	0.0%	58,552	89.2%	60.8%	59.5%	-1.4%	58.1%	-1.4%	89,970	77.0%	32.4%	33.8%	1.4%	33.8%	0.0%
	Jul	13,035	100.0%	98.6%	98.6%	0.0%	98.6%	0.0%	35,478	93.2%	79.7%	74.3%	-5.4%	73.0%	-1.4%	55,707	78.4%	44.6%	36.5%	-8.1%	37.8%	1.4%
	Aug	6,579	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	19,307	97.3%	79.7%	77.0%	-2.7%	77.0%	0.0%	32,096	90.5%	73.0%	73.0%	0.0%	70.3%	-2.7%
	Sep	11,186	100.0%	98.6%	98.6%	0.0%	97.3%	-1.4%	24,396	95.9%	73.0%	67.6%	-5.4%	67.6%	0.0%	36,714	94.6%	51.4%	48.6%	-2.7%	48.6%	0.0%
	Oct	9,038	100.0%	98.6%	100.0%	1.4%	100.0%	0.0%	22,135	100.0%	71.6%	71.6%	0.0%	70.3%	-1.4%	46,054	87.8%	48.6%	48.6%	0.0%	47.3%	-1.4%
	Nov	10,294	100.0%	98.6%	100.0%	1.4%	100.0%	0.0%	28,919	91.9%	62.2%	60.8%	-1.4%	59.5%	-1.4%	45,461	79.7%	41.9%	40.5%	-1.4%	40.5%	0.0%
	Dec	12,420	100.0%	97.3%	94.6%	-2.7%	94.6%	0.0%	28,899	93.2%	68.9%	68.9%	0.0%	67.6%	-1.4%	45,869	78.4%	54.1%	52.7%	-1.4%	52.7%	0.0%
	Non-Attainment		2	9	5		5			0	12	12		12			0	11	11		11	

---

[i] Acre, Matthew R., January 2019. Doctor of Philosophy Dissertation. Assessing demography, habitat use, and flow regime effects on spawning migrations of Blue Sucker in the lower Colorado River, Texas. Texas Tech University. Link: https://ttu-ir.tdl.org/handle/2346/84963.