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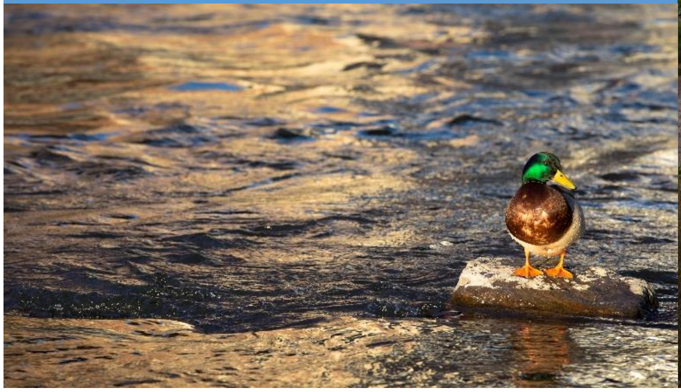

Final Report: Effects of Recommended Reuse Strategies on Brazos Basin Streamflow

Texas Water Development Board Contract #2100012470

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October 4, 2021

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October 2021

Pursuant to House Bill 1, as approved by the 86th Texas Legislature, this study report was funded for the purpose of studying environmental flow needs for Texas rivers and estuaries as part of the adaptive management phase of the Senate Bill 3 process for environmental flows established by the 80th Texas Legislature. The views and conclusions expressed herein are those of the author(s) and do not necessarily reflect the views of the Texas Water Development Board.

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Appendix

TWDB Comments Received on the Draft Report and Responses

List of Acronyms

acft	acre-feet
acft/mo	acre-feet per month
acft/yr	acre-feet per year
ASR	aquifer storage and recovery
BOD	biochemical oxygen demand
BRA	Brazos River Authority
cfs	cubic feet per second
e-flows	environmental flows
mgd	million gallons per day
NPDES	National Pollutant Discharge Elimination System
RO	reverse osmosis
RWP	regional water plan
RWPG	regional water planning group
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TPDES	Texas Pollutant Discharge Elimination System
TSS	total suspended solids
TPWD	Texas Parks and Wildlife Department
TWDB	Texas Water Development Board
TWDB CERST	TWDB Cumulative Effects of Recommended Strategies Tool
USEPA	United States Environmental Protection Agency
WAM	water availability model
WMS	water management strategies
WWTP	wastewater treatment plant

Executive summary

The Texas Water Development Board (TWDB) contracted with the consulting team of HDR Engineering, Inc., Freese and Nichols, Inc., and Watearth, Inc. to develop a methodology and tool for evaluating the cumulative effects on streamflow of strategies recommended in the regional water plans. The intent of the project was to develop a guidance document and a User's Guide for the tool to assist regional water planning groups in the evaluations required in *Chapter 6. Impacts of Regional Water Plan and Consistency with Protection of Resources* in alignment with the guiding principles described in Texas Administrative code §358.3(8) for State Water Plan development.

One task during the project was to evaluate the specific effects of recommended reuse water management strategies on streamflow. This report summarizes an analysis of the effects of reuse strategies recommended in the 2021 Region O, Brazos G, and Region H Regional Water Plans on streamflow in the Brazos River Basin. This report includes a literature review related to the impacts of reuse on environmental flows and a summary of the regulatory and legal issues related to reuse of return flows. Flows and flow changes are assessed using modeling results from the Brazos Basin Water Availability Model (WAM) maintained by the Texas Commission on Environmental Quality (TCEQ).

ES-1 Literature review – impacts of reuse on environmental flows

Return flow is defined as water that reaches a groundwater or surface water source after it is released from the point of use (Solley et al., 1988; Wolfenden et al., 2018). Return flows have multiple sources including municipal wastewater treatment, leaks in water distribution and sewer lines, septic tanks, industrial uses, excess irrigation water, recharge to surface water from dewatering, and release of water from flooded fields, which all help mitigate the effect of withdrawals on water sources (Trotta & Horn, 1990). In the U.S. an average of 70% of all water withdrawn from freshwater sources is returned to those sources after use (Solley et al., 1998).

The most monitored, quantifiable and impactful return flow that is the focus of this literature review is municipal or industrial wastewater returned to surface streams. Return flows from wastewater treatment facilities are important in arid and semiarid regions, as they can maintain the base flow and support perennial-stream ecosystems and aquatic habitats that would not otherwise exist (Luthy et al., 2015; Plumlee et al., 2012; Novak, 2016).

One of the main advantages of return flows is maintaining the stream flow that may have been lost through diversions or other activities. This can offer various benefits, including enhanced and unique riparian and aquatic habitats, improved aesthetic values, and higher rates of groundwater recharge (Luthy et al., 2015; Wolfenden et al., 2018; Bischel et al., 2013; Hamdhani et al., 2020; Plumlee et al., 2012). However, there are also risk factors with municipal or industrial wastewater return flows that could create undesirable impacts. Although limited through regulatory discharge limits, treated wastewater contains nutrients, often providing excess food which can fuel algae blooms that consume oxygen and lead to low dissolved oxygen concentrations in lakes, streams, and rivers. This can lead to oxygen depletions, triggering hypoxic blackwater events leading to fish kills and dispersal of pest taxa such as European carp (Wolfenden et al., 2018). It can also impact the biodiversity of fish species where a species that can withstand low dissolved oxygen conditions will dominate in these rivers (Luthy et al., 2015; Onnis-Hayden et al., 2006). These concerns can particularly exist when return flows are from agricultural land, which contain high amounts of nitrogen fertilizer (Grafton et al., 2018).

When wastewater return flows dominate streams, it can result in increased water temperature, which can affect sex ratios in some species, rates of parasitism, growth rates, and a variety of other population-level factors (Brooks et al., 2006). Another concern with wastewater return flows is sediment composition (*e.g.*, total suspended solids (TSS)) which may impact habitat availability for some species.

Steroid hormones, pharmaceuticals, and personal care products found in wastewater-effluent discharges can also affect fish and other aquatic organisms by resulting in the feminization of male fish and the collapse of certain fish populations (Johnson and Sumpter, 2014; Luthy et al., 2015; Plumlee et al., 2012).

Another impact of wastewater return flows is transforming traditionally intermittent streams into perennial ones, which may cause a change in the stability of natural systems, alter floral and faunal composition, and facilitate the establishment of invasive species (Kidd et al., 2007; Novak, 2016). The potential for human health impacts may also be of concern in cases where there is recreational access downstream from a wastewater discharge site (Plumlee et al., 2012).

It is important to note that the adverse impacts of nutrients, temperature, TSS, and emerging contaminants from wastewater effluent discharges can specifically impair water quality near discharge points (Hamdhani et al., 2020); however, many of these impacts are mitigated further downstream from discharge locations.

Sustaining instream flows in arid and semi-arid regions during dry conditions is challenging. One method to overcome this challenge is through using return flows from wastewater treatment facilities. Existing literature reveals that wastewater return flows can be beneficial in maintaining stream flow and aquatic habitat. However, it is important for lead agencies to consider project-specific conditions and establish water quality standards, including acceptable levels of nutrients, for wastewater discharges used for augmenting stream flows.

ES-2 Regulatory and legal issues related to reuse

The water used by an entity, whether sourced from groundwater or surface water, is fully available for consumptive use by that entity (*i.e.*, it does not need to be returned to the stream). However, if an entity discharges return flows to a state watercourse, a permit is required to subsequently divert and reuse the flows, regardless of whether the original source water is groundwater (a private resource) or surface water (a state-owned resource).

Water reuse projects reclaim water from a variety of sources, treat it, and reuse it for beneficial purposes such as agricultural irrigation, potable water supplies, groundwater recharge, industrial processes, and environmental flows (USEPA).

Regulatory and legal issues for reuse vary with the type of project. The most important legal distinction is between direct and indirect reuse.

Direct reuse occurs when treated wastewater is delivered directly from a wastewater treatment facility to a user without discharging to a state watercourse. Common types of direct reuse are for agricultural or landscape irrigation applications and industrial and power plant cooling. In general, water right holders in Texas can directly reuse all of their treated wastewater effluent. Direct reuse generally requires an authorization from TCEQ under 30 TAC 210. The authorization is granted to the holder of the Texas Pollutant Discharge Elimination System (TPDES) wastewater discharge permit from the TCEQ, and the requirements for authorization focus on water quality.

Indirect reuse occurs when treated wastewater is returned to a state watercourse (a stream or lake) before being diverted downstream for reuse. In this case, the bed and banks of the surface watercourse are used to transport the discharged water (return flows) from the discharge point to the diversion location. This requires a TCEQ water right permit. Water rights for indirect reuse may have measures to protect instream flows for senior water rights and the environment, including specific environmental flow levels that must be met before water can be diverted for indirect reuse. These environmental flow levels in some basins may be based in part or entirely on environmental flow standards adopted by TCEQ.

TCEQ requires a reuse permit applicant to own either the source water or the TPDES permit. The owning entities are not necessarily the same, which means that two entities may apply for indirect reuse of the same return flows. Typically, there are agreements between entities where this may occur.

The regulatory framework for indirect reuse of water in Texas can be complicated, and unique conditions apply to each permit and application of reclaimed water. Interpretations of reuse permits may vary between permit holders, adding further complexity.

Because of the complexity required to model reuse projects and the uniqueness of each permit and permit application, we recommend that each RWPG be allowed to determine the extent and method by which to include reuse water management strategies (WMS) in its analysis of cumulative effects of recommended WMS on environmental flows.

ES-3 Impacts of reuse strategies on streamflow in the Brazos River Basin

Reuse projects recommended in the Brazos River basin during the TWDB regional water planning process are distributed across three regional water planning areas. Recommended reuse water management strategies (WMS) in the 2021 regional water plans (RWPs) for Region O, Brazos G, and Region H were modeled using the Brazos G Water Availability Model (WAM) for the Brazos River Basin. This model was used to assess the cumulative effects of the 2021 regional water plans (RWPs) on streamflow in the basin.

Three modeling scenarios were developed, from which to compare regulated flows output by the WAM:

1. No Return Flows – This scenario is the base Brazos WAM with no return flows. It was developed to demonstrate the relative impact of return flows in comparison to the naturalized flows in the WAM and includes no water management strategies.
2. Current Return Flows – This scenario includes all current return flows from wastewater treatment plants (WWTPs) authorized to discharge one million gallons per day (mgd) or greater. No water management strategies (reuse or other) are modeled in this scenario.
3. Reuse Water Management Strategies – This scenario includes all current return flows from the second scenario plus reuse water management strategies recommended in the 2021 Region O, Brazos G, and Region H Regional Water Plans. No other water management strategies recommended in the regional water plans are modeled in this scenario.

Discharge records from 58 WWTPs permitted to discharge one mgd (1,120 acre-feet per year [acft/yr]) or greater were used to reflect current levels of return flows, which totaled 146,326 acft/yr.

Return flows were reduced at 11 current wastewater discharge locations to reflect the reuse strategies recommended in the three regional water plans. The current return flows from the 11 associated wastewater treatment facilities total 68,012 acft/yr. Return flows from these facilities will be reduced by 33,061 acft/yr, or 48.6 percent, by the reuse strategies.

Nine locations were selected to demonstrate the impacts on streamflow of upstream return flows and reuse of those return flows. The Texas Parks and Wildlife Department (TPWD) has identified several stream segments in the Brazos Basin as ecologically significant. Five of the nine locations evaluated in this study are within or adjacent to those TPWD-designated stream segments. Similarly, the TCEQ has adopted environmental flow standards (e-flows) at multiple locations in the Brazos Basin, including six of the nine locations evaluated.

The analysis results reveal that the reuse strategies have varying impacts on the monthly median flows for different months of the year at each control point and generally decrease the monthly median flow volumes by 1% to 3%. However, these reductions are much greater for some months for the Double Mountain Fork of the Brazos River near Aspermont in the upper basin. At this location, January medians are reduced by 16.1% (from 747 to 604 acft/mo) and August medians by 5.6% (from 2,175 to 2,053 acft/mo). The median annual flow is reduced by 2.7% (from 67,411 to 65,852 acft/mo). Low-flow frequencies, as characterized by the 95% exceedance frequency, are reduced an even greater amount. The 95% exceedance flow for January is reduced 51.1% (from 221 to 108 acft/mo) and the 95% exceedance flow for August is reduced 50.6% (from 241 to 119 acft/mo). The return flows above this location (from the City of Lubbock) are relatively large in comparison to the smaller, naturally occurring streamflow at this site.

The cumulative return flows represent a smaller portion of the total flow at locations in the lower basin, resulting in the effects of reuse strategies being smaller in the lower basin, as demonstrated by the Brazos River at Richmond, for which changes (reductions) generally are less than one percent.

The cumulative effects of implementing the reuse water management strategies recommended in the 2021 Regional Water Plans for Region O, Brazos G, and Region H will tend to decrease streamflow slightly in all months, with occasional increases, relative to conditions under current return flows. Increases are generally caused by use of return flows modifying how priority calls are made by downstream senior water rights, sometimes increasing the flows that must be passed through a given control point.

Overall, the flow regimes, as characterized by flow frequency curves, show that changes due to plan implementation relative to current return flow conditions occur mostly to low flows that are exceeded 75 percent of the time. Locations directly downstream of proposed reuse projects would experience the most noticeable reductions in streamflow. This study clearly identifies at least one site (i.e., Double Mountain Fork near Aspermont) where implementation of reuse water management strategies that are recommended in the 2021 regional water plan will significantly affect low flow hydrology, which has already been affected by the return flows themselves. Both the return flows and reductions in return flows caused by implementation of the reuse strategies will potentially affect the aquatic environment.

In summary, none of the locations is expected to experience significantly different streamflow with implementation of the reuse water management strategies that are recommended in the 2021 regional water plans, except for the Double Mountain Fork of the Brazos River at Aspermont.

The approach used in this analysis is limited in application due to differences between the time bases of the WAMs and of e-flow standards. Regulated flows obtained from a WAM are monthly while e-flows standards (subsistence and base flows) are based on daily flow values. Therefore, comparison of regulated flows from a WAM to e-flows (subsistence and base flows) can be misleading and interpretations should be made with these differences in mind.

1. Introduction

During the development of a regional water plan, each regional water planning group (RWPG) is required to prepare *Chapter 6. Impacts of Regional Water Plan and Consistency with Protection of Resources* in alignment with the guiding principles described in Texas Administrative Code (TAC) §358.3(8) for State Water Plan development. Regional water planning groups utilize a variety of methods to assess the cumulative effects of water management strategies on streamflow. Based on these various approaches and the overall objective of the Texas Water Development Board (TWDB) to standardize the approach for these assessments in the regional water plans, the TWDB contracted with the consulting team of HDR Engineering, Inc., Freese and Nichols, Inc. and Watearth, Inc. to develop a methodology generally applicable to each regional water plan.

This project included four primary tasks:

1. Identify a set of metrics and develop a generalized assessment methodology that is applicable to most regional water planning areas. This methodology must also consider environmental flow standards (e-flows) when e-flows are adopted for a river basin.
2. Develop a tool that will facilitate the analysis for use by RWPGs and their technical consultants.
3. Prepare a demonstration evaluation for a river basin that includes strategies recommended in multiple regional water plans.
4. Develop a Users' Guide for the tool that:
   a. Presents the generalized assessment methodology,
   b. Presents the assessment tool and describes its application, and
   c. Demonstrates the methodology and the use of the assessment tool.

During the execution of this project, an additional task was added to evaluate the specific effects of recommended <u>reuse</u> strategies on streamflow in the Brazos River Basin, including a literature review on the impacts of reuse on environmental flows and a summary of the regulatory and legal issues of reuse. This report summarizes the additional task and presents an analysis of the effects of the reuse strategies recommended in the 2021 Region O, Brazos G, and Region H Regional Water Plans on streamflow in the Brazos River Basin.

2. Literature review – impacts of reuse on environmental flows

2.1 Introduction

Watearth completed a review of literature focusing on the role of return flows on the ecological health of rivers in arid and subtropical climates. The literature review used several online resources and publications which discussed how return flows can impact the ecological environments of streams and rivers.

2.2 Literature review

Return flow is defined as water that reaches a groundwater or surface water source after it is released from the point of use (Solley et al., 1988; Wolfenden et al., 2018). Return flows have multiple sources including municipal wastewater treatment, leaks in water distribution and sewer lines, septic tanks, industrial uses, excess irrigation water, recharge to surface water from dewatering, and release of water from flooded fields which all help mitigate the effect of withdrawals on water sources (Trotta & Horn, 1990). In the U.S. an average of 70% of all water withdrawn from freshwater sources is returned to those sources after use (Solley et al., 1998). It is important to understand and estimate withdrawals and return flows to determine the effects of water use on the availability and distribution of water resources (Trotta & Horn, 1990).

The most monitored, quantifiable and impactful return flow that is the focus of this literature review is surface water flow returned by municipal or industrial wastewater treatment facilities. Return flows from wastewater treatment facilities are important in arid and semiarid regions, as they can maintain the base flow and support perennial-stream ecosystems and aquatic habitats that would not otherwise exist (Luthy et al., 2015; Plumlee et al., 2012; Novak, 2016).

Wastewater reuse is becoming a popular non-potable water supply option for many communities. Reuse is classified into two forms: direct and indirect. Direct reuse is piped directly from the wastewater treatment plant to the point of use, while indirect reuse discharges treated wastewater to a stream for subsequent diversion downstream (BBEST, 2012). Accordingly, direct reuse will reduce return flows to receiving streams.

Treated wastewater effluent is used for a variety of direct reuse, non-consumptive purposes including irrigation of public and recreational lands, cooling tower water for power generation, and other specific industrial uses. An example of direct reuse is effluent irrigation of golf courses, which is common in Texas and the southwest. Typically, treated wastewater receives additional filtration and chlorine treatment to meet effluent standards prior to application. Reuse for cooling towers typically receives reverse osmosis (RO) treatment prior to application (BBEST, 2012).

An increasing use of effluent in the southwest is direct potable re-use, which is conversion of effluent to potable drinking water through RO treatment. Wichita Falls and Big Spring, Texas have recently implemented this “toilet to tap water” process (University of Texas, 2021).

Wastewater return flows can be a significant contributor of total flow in low streamflow environments and help to maintain stream flow and aquatic habitat. An example of a wastewater return flow dominated stream is the Trinity River south of the Dallas–Fort Worth metroplex whose base flow consists almost entirely of treated wastewater discharges. This has allowed the river to transition from an intermittent dry river to a year-round perennial river with improved habitat and subsequent increase in the number of fish species (Luthy et al., 2015; Onnis-Hayden et al., 2006). The improvements in wastewater treatment have enhanced water quality and reduced biological impacts of wastewater in this river (Luthy et al., 2015). Following such improvements, studies on the Trinity River show that average annual dissolved oxygen, which is one water quality indicators necessary for fish and other aquatic life, has greatly increased since 1970 (TRA, 2010). Another measure of water quality, biochemical oxygen demand (BOD), also decreased with an increase in flow from wastewater treatment plants into the Trinity River (TRA, 2007).

On the other hand, excess nutrient loads can impair the environmental soundness of the aquatic ecosystem. Most stream nutrient loadings come from non-point agricultural runoff (nitrogen and phosphorous) based fertilizers, with point sources (municipal wastewater treatment plants) contributing much smaller amounts. The United States Environmental Protection Agency (USEPA) and Texas Commission on Environmental Quality (TCEQ) have promulgated more stringent National Pollutant Discharge Elimination System (NPDES) and TCEQ Texas Pollutant Discharge Elimination System (TPDES) nutrient discharge limits, respectively, to mitigate stream impacts.

An ongoing Brazos River Authority (BRA) evaluation of the lower Brazos River has revealed elevated nutrient loading and potentially associated aquatic life effects (BBEST, 2012). In addition, a potential for Gulf of Mexico dead zones exists at the mouth of the Brazos and would be magnified by further increases in Brazos River nutrient loading (BBEST, 2012). Accordingly, the characteristics of a receiving stream need to be evaluated to determine if wastewater return flows will contribute to or impair environmental and aquatic habitat conditions.

Further, while return flows can be beneficial for being a source of freshwater inflows into estuaries (Chen et al., 2013), they can also have negative impacts on these ecological systems if containing high amounts of salt or pollutants (Quinn, 2009; Montagna et al., 2012; Terrado et al., 2007). The sections below describe the advantages and disadvantages that return flows have for the ecological health of river systems.

2.2.1 *Advantages*

One of the main advantages of return flows is in river restoration and maintaining the stream flow that may have been lost through diversions or other activities. This can offer various benefits, including enhanced and unique riparian and aquatic habitats, improved aesthetic values, and higher rates of groundwater recharge (Luthy et al., 2015; Wolfenden et al., 2018; Bischel et al., 2013; Hamdhani et al., 2020; Plumlee et al., 2012).

Environmental return flows in the form of delivery of wetland water to an adjacent river has been used to facilitate natural ecosystem connectivity and enable the transfer of nutrients, energy, and biota from wetland habitats to the river (Wolfenden et al., 2018). Additionally, the higher nutrients from treated wastewater can be a resource for downstream agriculture in the case of wastewater effluent stream augmentation (Onnis-Hayden et al., 2006).

Provided there are no existing nutrient stream impairments, flow augmentation through indirect reuse can improve water quality (Plumlee et al., 2012) and impact various biological traits of freshwater and riparian plants. For instance, the greater quantities of organic matter commonly found in treated effluent can benefit filter feeders by providing improved food sources. Increased water availability can also provide better conditions for large-bodied fish and allow prey with strong swimming ability to better escape predators (Luthy et al., 2015). Treated wastewater also allows algae to develop at a faster rate as it provides nutrients for algal growth. Like all green plants, algae produce oxygen during the daylight hours as a by-product of photosynthesis. This is usually a major source of oxygen in fishponds (Freshwater Aquaculture, 2019). Although algae in combination with bacteria and certain chemicals consume oxygen during nighttime hours, normal concentrations of algae in water bodies result in a net production of oxygen and are a main source of food for invertebrates and some fish (Onnis-Hayden et al., 2006).

Through diluting concentrations of harmful constituents, wastewater return flows can facilitate return of pollutant-sensitive fish species. In addition, aquatic amphibians and reptiles can also benefit from increased water levels. Increased body size and weight in certain fish species is another reported benefit to aquatic life (Pottinger et al., 2013; Luthy et al., 2015; Plumlee et al., 2012; Hamdhani et al., 2020).

A reduction in mosquito populations mainly due to flow changes and elimination of breeding pools are also among other benefits of stream renewal facilitated by wastewater return flows. The increased water and nutrient availability following effluent discharges can result in trees and shrubs in the riparian zone to develop more flexible tissues, transport oxygen more efficiently, and allow native species to repopulate riparian habitats (Lawrence et al., 2014; Luthy et al., 2015).

2.2.2 *Disadvantages*

As discussed above return flows can have several benefits on receiving waters. However, there are also risk factors that could create undesirable impacts. Although limited through NPDES and TPDES discharge limits, treated wastewater contains nutrients, often providing excess food which can fuel algae blooms. Although filter feeders consume a portion of the excess algae, much of it is not consumed and will be decomposed by bacteria that consume oxygen and lead to low dissolved oxygen concentrations in lakes, streams, and rivers. This resulting bacterial decomposition and loss of normal oxygen production can lead to oxygen depletions, triggering hypoxic blackwater events leading to fish kills and dispersal of pest taxa such as European carp (Wolfenden et al., 2018). It can also impact the biodiversity of fish species where a species that can withstand low dissolved oxygen conditions will dominate in these rivers (Luthy et al., 2015; Onnis-Hayden et al., 2006). These concerns can particularly exist when return flows are from agricultural land, which contain high amounts of nitrogen fertilizer (Grafton et al., 2018).

Wastewater return flow dominant streams can also exhibit increased water temperature, which can affect sex ratios in some species, rates of parasitism, growth rates, and a variety of other population-level factors (Brooks et al., 2006). Another concern with wastewater return flows is sediment composition (*e.g.*, total suspended solids (TSS) which may impact habitat availability for some species.

Steroid hormones, pharmaceuticals, and personal care products found in wastewater-effluent discharges can also affect fish and other aquatic organisms by resulting in the feminization of male fish and the collapse of certain fish populations (Johnson and Sumpter, 2015; Luthy et al., 2015; Plumlee et al., 2012).

Another impact of wastewater return flows is transforming traditionally intermittent streams into perennial ones, which may cause a change in the stability of natural systems, alter floral and faunal composition, and facilitate the establishment of invasive species (Kidd et al., 2007; Novak, 2016). The potential for human health impacts may also be of concern in cases where there is recreational access downstream from a wastewater discharge site (Plumlee et al., 2012).

It is important to note that the adverse impacts of nutrients, temperature, TSS, and emerging contaminants from wastewater effluent discharges can specifically impair water quality near discharge points (Hamdhani et al., 2020); however, many of these impacts are mitigated further downstream from a discharge location.

2.3 Conclusions

Sustaining instream flows in arid and semi-arid regions is challenging. One method to overcome this challenge is through using return flows from wastewater treatment facilities. A review of existing literature reveals that wastewater return flows can be beneficial in maintaining stream flow and aquatic habitat.

However, it is important for lead agencies to consider project-specific conditions and establish water quality standards, including acceptable levels of nutrients, for wastewater discharges used for augmenting stream flows. Although more stringent USEPA NPDES and TCEQ TPDES permit limits have reduced wastewater plant (WWTP) nutrient discharge levels, additional wastewater treatment may be necessary prior to entering waterways to ensure water quality and minimize environmental and aquatic habitat impacts.

3. Regulatory and legal issues relevant to reuse and the effects of reuse on environmental flows

Water reuse projects reclaim water from a variety of sources, treat it, and reuse it for beneficial purposes such as agricultural irrigation, potable water supplies, groundwater recharge, industrial processes, and environmental flows (USEPA). Regulatory and legal issues for reuse vary with the type of project. The most important legal distinction is between direct and indirect reuse. In direct reuse, treated wastewater is delivered directly from wastewater treatment to another use without entering a state watercourse. In indirect reuse, treated wastewater is returned to a state watercourse (a stream or lake), before being diverted downstream for reuse.

The representation of reuse in water rights and water planning paradigms in Texas is also complicated. For example, water rights applications not related to reuse must consider Run 3 of the relevant Water Availability Model (WAM), which considers full consumptive use of all permanent water rights and thus excludes return flows and subsequent reuse thereof. Additionally, the availability of surface water supplies is evaluated for regional water planning purposes based on the WAMs, and individual regional water planning groups (RWPGs) may choose to incorporate some or all return flows in a WAM to best represent supplies in their region. Most regional water plans (RWPs) use modified Run 3 WAMs[1] with no return flows, but some regions have incorporated limited return flows for specific basins. Thus, reuse strategies recommended in the RWP are typically not modeled using WAMs; projected supplies are calculated outside of the WAM in individual project analyses. However, reuse strategies may have an impact on stream flows. Depending on the source water, future return flow levels and type of reuse project, stream flows could increase or decrease with the implementation of recommended water management strategies. This section describes the legal and regulatory framework for developing reuse strategies in Texas and considers potential impacts of such strategies on instream flows. More information on reuse in Texas, including specific reuse projects that have been implemented in the state, can be found through TWDB's Innovative Water Technologies section (TWDB)[2].

3.1 Authorization of reuse

3.1.1 *General requirements*

The following discussion of authorization requirements for direct and indirect reuse in Texas is based on the State Bar Association of Texas publication Essentials of Texas Water Resources (Gooch, Sloan, and Acevedo, 2020). Both direct and indirect reuse require authorization from the TCEQ, but the two types of reuse are authorized under different frameworks. Indirect reuse requires a water right which permits the user to divert the return flows downstream of the discharge point. Use of reclaimed water (direct reuse) must be authorized by TCEQ under the rules in Title 30 TAC Chapter 210. For both direct and indirect reuse, TCEQ does not authorize reuse of a greater amount of water than the user is currently permitted to discharge as treated wastewater effluent under the entity's TPDES permit.

It should be noted the water used by an entity, whether sourced from groundwater or surface water, is fully available for consumptive use by that entity (*i.e.*, it does not need to be returned to the stream). However, if an entity discharges return flows to a state watercourse, a permit is required to subsequently divert and reuse the flows, regardless of whether the original source water is groundwater (a private resource) or surface water (a state-owned resource).

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[1] An unmodified Run 3 WAM is the base model with which TCEQ determines the legal availability of water to individual water rights. Run 3 simulations typically do not include return flows and usually do not consider specific operational strategies, including subordination agreements and system operation of supplies, unless those are specified in individual water rights. The Run 3 WAM is the prescribed model for use in the RWPs; however, regional water planning groups, through requests for hydrologic variance, often employ modifications of the Run 3 WAM to provide capabilities more suitable for water planning. The Brazos G WAM used in this analysis includes modifications reflecting the hydrologic variances to the Run 3 Brazos Basin WAM requested by the Brazos G Regional Water Planning Group.

[2] https://www.twdb.texas.gov/innovativewater/index.asp

3.1.2 *Direct reuse*

As described above, direct reuse occurs when treated effluent is delivered directly from a wastewater treatment facility to a user without returning to a state watercourse. In general, water right holders in Texas can directly reuse all of their treated wastewater effluent. For effluent that originates as surface water, reuse is subject to any limitations on reuse contained in the underlying water right from which the effluent was derived, including limitations on the place or purpose of use.

Common types of direct reuse are agricultural or landscape irrigation and industrial and power plant cooling. Additional treatment requirements depend on the intended end use of the directly reused water (often referred to as reclaimed water) and potential for public exposure. Several of the larger cities in Texas (San Antonio, Austin, El Paso, Fort Worth, and others) have direct reuse systems that deliver treated effluent for non-potable use to multiple customers over a large area.

Direct reuse generally requires an authorization from TCEQ under 30 TAC 210. The authorization is granted to the holder of the TPDES wastewater discharge permit from TCEQ, and the requirements for authorization focus on water quality.

3.1.3 *Indirect reuse*

Indirect reuse, in which treated wastewater is returned to a state watercourse before being diverted downstream for reuse, requires a TCEQ water right permit. In this case, the bed and banks of the surface watercourse are used to transport the discharged water (return flows) from the discharge point to the diversion location. Existing water rights for indirect reuse may have measures to protect instream flows for senior water rights and the environment, including specific environmental flow levels that must be met before water can be diverted for indirect reuse. For basins with adopted environmental flow standards, these may be one or more of the base flow criteria. TCEQ will also only authorize indirect reuse up to the amount permitted in the TPDES permit of the discharging facilities. The indirect reuse permit can include multiple facilities.

3.2 Relevance of reuse to environmental flows

Although return flows are not included in Run 3 WAMs, which are often used to determine supplies in regional planning, return flows may contribute significantly to the total amount of flow in some streams, especially during drier seasons. As a result, the WAMs used for regional water planning typically do not provide an accurate assessment of actual stream flows. Assessment of the impacts of future reuse projects on stream flows is complex because there are multiple considerations during the permitting process that affect potential instream flow requirements:

- Direct reuse versus indirect reuse.
- Historical return flows versus future return flows.
- Location of indirect reuse project (*i.e.*, points of discharge and diversion).
- Source water of return flows.

3.2.1 *Direct reuse versus indirect reuse*

As previously discussed, TCEQ generally does not require diverted water to be returned to a stream. Because reclaimed water in direct reuse projects is not returned to a stream, no environmental flow protections apply to direct reuse authorizations. The impact to stream flow will depend on whether the direct reuse is for historically discharged return flows or future return flows. Direct reuse of future return flows would have no impact to stream flows beyond any impacts associated with an increase in surface water diversions for the source water. Direct reuse of historically discharged return flows will decrease stream flows.

Environmental flows typically are a consideration for TCEQ to issue permits for an indirect reuse project. Historically discharged return flows are subject to senior water rights granted based on these discharges, as well as adopted environmental flow standards (TCEQ). The senior water right provisions are included when a senior water right was granted based on an assumption that some level of return flows would be available to that right-holder. These protections may depend on the amount of return flows historically discharged at the time the senior water rights were granted. Additional return flows beyond the amount considered in senior rights typically are not subject to senior water rights but may be subject to environmental flow standards. Indirect reuse is only subject to base flow criteria for projects that use the bed and banks of a state watercourse. For indirect reuse projects that are discharged to and diverted from a reservoir, no environmental criteria are applied (although TCEQ requires additional water accounting).

3.2.2 *Historical return flows versus future return flows*

As previously discussed, historical versus future return flows have a direct effect on the impacts to stream flows for direct reuse projects. However, there is less of an impact on downstream flow conditions for indirect reuse projects because the return flows are allowed to remain in the stream between the discharge and diversion locations. The TCEQ commonly applies environmental base flow criteria to authorizations for the reuse of return flows. Therefore, indirect reuse projects should have a minimal impact on attainment of base flow standards since environmental flows are considered during permitting. However, a reduction in total stream flow downstream of the diversion point could occur when flows exceed the environmental criteria.

3.2.3 *Location of indirect reuse project (i.e., points of discharge and diversion)*

The locations of the discharge and diversion points for indirect reuse projects can affect whether a stream segment will experience increases or decreases in stream flow. Generally, indirect reuse projects to reservoirs will not cause changes in water elevation if the return flows are diverted shortly after being discharged.

3.2.4 *Source water of return flows*

In Texas, surface water is a state resource that requires authorization to use, while groundwater is a private property right. Imported water (surface water from outside the basin, or reuse) is considered developed water. These distinctions affect how indirect reuse is permitted. Developed water and groundwater are not subject to senior water rights but may be subject to environmental flow standards. Indirect reuse permitting provisions may also depend on whether the return flows were historically discharged or include return flows in excess of historical discharges.

Another consideration for environmental flows is water quality, which can be a factor associated with return flows and reuse. A TPDES wastewater discharge permit is used to regulate the discharge of specified pollutants into a water body. Some constituents, such as pharmaceuticals, currently are not assessed in a TPDES permit. Direct potable reuse has additional treatment requirements for authorizations. Often advanced water treatment, such as reverse osmosis, is needed to meet these requirements and water quality needs for the end user. Depending on the treatment systems, up to 20 to 30 percent of the source effluent could be discharged as waste. If this waste is returned to a stream, it could affect both stream flow and quality. However, discharge of this waste will require a TPDES permit that will consider these factors.

3.3 Special considerations

3.3.1 *Diversion and consumption permits*

Most water rights do not require a specific amount of diverted water to be returned to the stream. There may be cases where a water right limits the consumptive amount, but the right may or may not specify the location where the non-consumed water is returned to. Some water rights have special conditions that can include a wide range of conditions to use the water. Some of these conditions may include specific agreements to pass inflows or return a percentage of diverted water for environmental purposes.

3.3.2 *TCEQ ownership requirements*

TCEQ requires a reuse permit applicant to own either the source water or the TPDES permit. The owning entities are not necessarily the same, which means that two entities may apply for indirect reuse of the same return flows. Typically, there are agreements between entities where this may occur.

3.4 Conclusions

The regulatory framework for indirect reuse of water in Texas can be complicated, and unique conditions apply to each permit and application of reclaimed water. Interpretations of reuse permits may vary between permit holders, adding further complexity. Reuse is generally not included in the WAMs used for regional water planning, and inclusion in the cumulative impact analysis would likely require major modifications of the WAMs to include return flows. Because of the complexity required to model reuse projects and the uniqueness of each permit and permit application, we recommend that each RWPG be allowed to determine the extent and method by which to include reuse water management strategies (WMS) in its analysis of cumulative effects of recommended WMS on environmental flows.

4. Impacts of reuse strategies on streamflow in the Brazos Basin

4.1 Methodology

The Brazos Basin was selected for this study as the demonstration river basin for studying the impact of reuse on streamflow. The recommended reuse projects in the Brazos River basin are distributed across three applicable regional water planning areas (Regions O, G, and H). Recommended reuse water management strategies (WMS) in the 2021 regional water plans (RWPs) for Region O, Brazos G, and Region H were modeled in the Water Availability Model (WAM) for the Brazos River Basin to assess the cumulative effects of the 2021 regional water plans (RWPs) on streamflow in the basin. The assessment starts with an analysis of discharges occurring from 2015 through 2017 from wastewater treatment plants (WWTPs) permitted to discharge one million gallons per day (1 mgd) or more. Those discharge records were summarized to develop constant inflow records (CI records) that were added to the WAM to reflect current levels of return flows.

Three modeling scenarios were developed to assess the impacts of return flows and the impacts of reuse strategies in the Brazos Basin (Table 4-1). Reuse strategies from all three regions were included in the Reuse WMS model scenario to reflect the full cumulative impact of reuse in the 2021 RWPs on the basin. The Brazos WAM includes modeling of the San Jacinto-Brazos Coastal Basin; however, this study focused on strategies in, and impacts to, the Brazos River Basin, and no adjustments were made between scenarios in the San Jacinto-Brazos Coastal Basin. Cumulative effects were assessed in 2070, but this approach could be applied for any selected planning decade to assess RWP impacts. For this assessment, only recommended reuse water management strategies were modeled. These strategies included only direct reuse water management strategies.

Table 4-1. Modeling scenarios to assess impacts of reuse strategies.

Scenario name	Model files	Return flows	Modeled water management strategies
No Return Flows	Brazos_2070_NoReturnFlow	None	None
Current Return Flows	Brazos_2070_CurrentReturnFlows	Minimum annual return flow from 2015 through 2017	None
Reuse WMS	Brazos_2070_ReuseWMS	Minimum annual return flow from 2015 through 2017, adjusted to reflect reuse of return flows by WMS	All recommended strategies (2020 – 2070)

The Brazos G Supply WAM, with hydrologic variances from Run 3 approved by TWDB, was used as the baseline model for all scenarios. The Brazos G Supply WAM for the 2070 planning decade, which includes adjustments to reservoir area-capacity curves and maximum storage capacities to account for sedimentation occurring by 2070, was used in order to capture the impacts of the recommended reuse projects.

- No Return Flows – The Brazos G Supply WAM used to develop supplies in the 2021 RWPs included return flows, however those flows were removed to create a version of the model with no return flows against which the models with return flows could be compared.
- Current Return Flows – The Current Return Flows scenario uses CI records in the .DAT file to add return flows to the WAM. The return flows in this scenario are similar to those used to develop supplies in the RWPs but include a few additional discharge locations. Current levels of return flows were estimated as the minimum annual recorded discharge from each major wastewater treatment plant in the basin between 2015 and 2017.
- Reuse WMS – In the Reuse WMS scenario, current return flows were reduced where reuse strategies have been recommended. Strategies associated with wastewater treatment plants (WWTPs) that have not been built yet were excluded, as these strategies will utilize future return flows which are not currently in the river, thus not reducing instream flows. For recommended reuse strategies at existing WWTPs that rely on assumed increases in return flows as populations grow, it was assumed that increases in return flows that occur by the decade a strategy is first implemented would be utilized by that strategy. Then, any remaining volume required to meet the proposed reuse project yield would be allocated from the current return flows. Figure 4-1 describes an example of this allocation process.

The implementation of recommended reuse water management strategies in the WAM was achieved by reducing return flows input in CI records; no water rights were added, removed, or altered to model reuse.

Regulated flows were extracted from the output files of the WAM simulations for comparison between conditions with current return flows and with recommended reuse strategies[3]. Regulated flow is the total flow passing a given control point location after all water rights have appropriated the flows to which they are entitled.

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[3] Metrics selected for comparison in this analysis are limited to graphical and statistical comparisons of regulated flows between modeling conditions. Ecological health indicators were considered as additional metrics, but the evaluation of how reduced flow associated with reuse projects in the Brazos Basin affects these metrics is beyond the scope of the project.

Entity A has the following current return flows and projected water demand:
Current Return Flows = 100 acft/yr
2020 Projected Water Demand = 200 acft/yr
2030 Projected Water Demand = 260 acft/yr
Return flows are assumed to increase at the same rate of growth as water demands.
Growth in Water Demand, 2020 to 2030 = +30%
Expected Increase in Return Flows by 2030 = (100 acft/yr) x (30%) = +30 acft/yr

Entity A has a direct non-potable reuse strategy that will be implemented in 2030. The strategy is expected to yield 50 acft/yr of supply. 60 acft/yr will be diverted from the WWTP effluent for advanced treatment, but 10 acft/yr will be returned to the stream at the discharge location as waste from the advanced treatment process, while 50 acft/yr will be applied as irrigation. So, only 50 acft/yr of return flows will be removed from instream flows.

Increases in return flows due to growth will be applied first to meet the need for the strategy, with remaining yield met by current return flows if available.
Total reuse strategy yield = 50 acft/yr
Reuse yield from increases in return flows = 30 acft/yr
Reuse yield from current return flows = 50 – 30 = 20 acft/yr
Reduced return flows after WMS = 100 – 20 = 80 acft/yr

Therefore, the Current Return Flows model would include 100 acft/yr of discharge for Entity A, and the Reuse WMS model would include reduced discharge of 80 acft/yr.

Figure 4-1. Example of allocation of current return flows to reuse WMS

4.2 Selection of control point locations

The cumulative effects of the 2021 Plans reuse strategies on streamflow were evaluated at the nine locations listed in Table 4-2 and shown in Figure 4-2. The cumulative effects on regulated streamflow of implementing the reuse strategies recommended in the 2021 Region O, Brazos G, and Region H Plans were evaluated by comparing regulated streamflow statistics for the ‘Current Return Flows’ scenario and ‘Reuse WMS’ scenario at these locations, and the ‘No Return Flows’ and ‘Current Return Flows’ scenarios.

Locations were selected primarily to demonstrate the impacts on streamflow of upstream return flows and reuse of those return flows. The Texas Parks and Wildlife Department (TPWD) has identified several stream segments in the Brazos Basin as ecologically significant (TPWD). Five of the nine locations evaluated in this study are within or adjacent to those TPWD-designated stream segments. Similarly, the TCEQ has adopted environmental flow standards (e-flows) at multiple locations in the Brazos Basin, including six of the nine locations evaluated (TCEQ).

Table 4-2. Locations for evaluating the effects of recommended reuse strategies on streamflow and inflows to the Brazos River estuary.

Control point	**Description**	**Regional water planning area**	**TPWD[1] ecologically significant segment**	**TCEQ adopted e-flows**
DMAS09	Double Mountain Fork Brazos River near Aspermont	G	Yes	Yes
BRSB23	Brazos River at South Bend	G	No	Yes
BRGR30	Brazos River near Glen Rose	G	Yes	Yes
BOWA40	Bosque River near Waco	G	No	No
LRCA58	Little River near Cameron	G	Yes	Yes
NABR67	Navasota River near Bryan	G	No	No
BRHE68	Brazos River near Hempstead	H	No	Yes
BRRI70	Brazos River at Richmond	H	Yes	Yes
BRGM73	Brazos River at Gulf of Mexico	H	Yes	No

1. Texas Parks and Wildlife Department

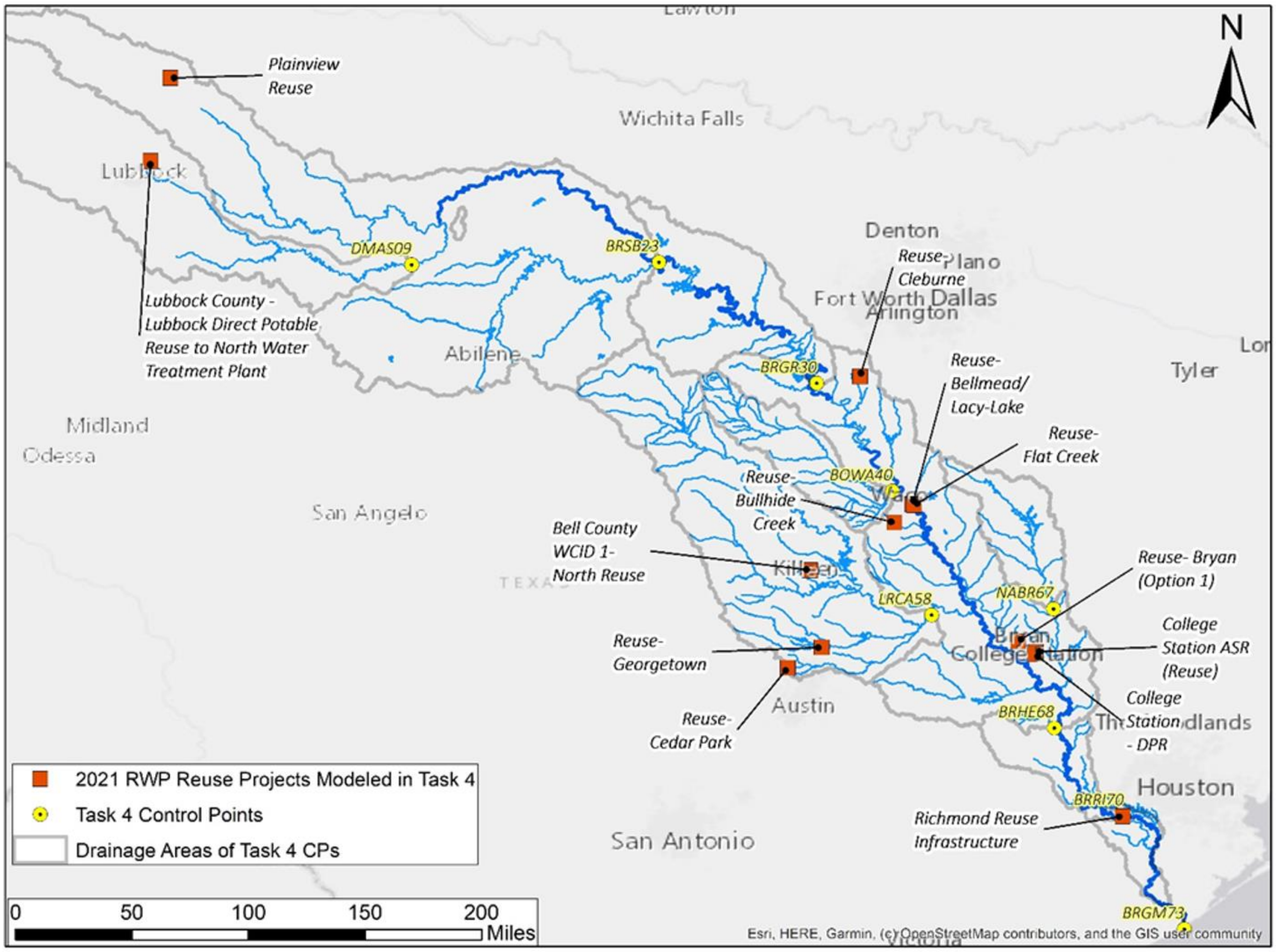

Figure 4-2. Location of reuse water management strategies and selected control points.

4.3 Current return flows in the Brazos Basin

Current WWTPs permitted to discharge 1 mgd (1,120 acft/yr) or greater were identified from TCEQ records. Discharges from those plants from 2015 through 2017 were analyzed and the minimum monthly discharges were determined and used to develop a series of 12 monthly return flow discharges at each location. These were used to develop the CI records input to the WAM .DAT input file to reflect current levels of return flows. The 58 WWTPs included in the analysis and annual return flows are summarized in Table 4-3.

Table 4-3. Wastewater treatment plants included in return flow analysis.

WWTP	County	Downstream analysis control point	Annual return flow (acft)
Southeast Water Reclamation Plant Outfall 001	Lubbock	DMAS09	3,455
Southeast Water Reclamation Plant Outfall 007	Lubbock	DMAS09	4,830
City of Plainview WWTF	Hale	BRSB23	1,366
City of Breckenridge WWTF	Stephens	BRSB23	354
City of Granbury WWTP	Hood	BRGR30	658
Pollard Creek WWTP	Palo Pinto	BRGR30	1,192
Willow Creek WWTP	Parker	BRGR30	117
City of Graham WWTF	Young	BRGR30	750
Stephenville WWTP	Erath	BOWA40	1,415
McGregor South WWTF	McLennan	BOWA40	462
City of Harker Heights WWTP	Bell	LRCA58	2,219
Bell County WCID 1 WWTP	Bell	LRCA58	588
Bell County WCID 1 WWTF	Bell	LRCA58	12,795
Temple Belton WWTP	Bell	LRCA58	6,737
Copperas Cove Northeast WWTP	Coryell	LRCA58	896
Leon Plant WWTP	Coryell	LRCA58	821
Stillhouse Branch WWTP	Coryell	LRCA58	2,013
Copperas Cove South WWTF	Coryell	LRCA58	642
City of Eastland WWTF	Eastland	LRCA58	116
Henderson WWTF	Lampasas	LRCA58	673
Cameron WWTP	Milam	LRCA58	744
San Gabriel WWTP	Williamson	LRCA58	1,623
Dove Springs WWTP	Williamson	LRCA58	1,538
Brushy West WWTP	Williamson	LRCA58	1,509
Brushy Creek Regional East WWTF	Williamson	LRCA58	17,136
Mustang Creek WWTP	Williamson	LRCA58	1,858
Water Reclamation WWTF (Cedar Park)	Williamson	LRCA58	2,505
City of Leander WWTF	Williamson	LRCA58	1,073
Bell Co WCID 1 WWTP 3	Bell	LRCA58	2,423
Hutto WWTP	Williamson	LRCA58	1,111

WWTP	**County**	**Downstream analysis control point**	**Annual return flow (acft)**
Copperas Cove Northwest WWTP	Coryell	LRCA58	1,684
Doshier Farm WWTP	Bell	BRHE68	4,134
Carter Creek WWTP	Brazos	BRHE68	6,883
Lick Creek WWTP	Brazos	BRHE68	1,363
Burton Creek WWTP	Brazos	BRHE68	5,072
Still Creek WWTP	Brazos	BRHE68	1,875
TAMU Main Campus WWTP	Brazos	BRHE68	1,810
TEEX Brayton Fire Training Field	Brazos	BRHE68	402
City of Marlin WWTP	Falls	BRHE68	1,136
City of Navasota Old WWTP	Grimes	BRHE68	682
City of Hillsboro WWTP	Hill	BRHE68	1,202
City of Cleburne WWTF	Johnson	BRHE68	5,013
Waco Metropolitan Area Regional Sewage System	McLennan	BRHE68	24,091
Bull Hide Creek WWTP	McLennan	BRHE68	781
City of Hearne WWTP 2	Robertson	BRHE68	574
City of Brenham WWTP	Washington	BRHE68	2,074
City of Bellville WWTP	Austin	BRRI70	436
Allens Creek WWTF	Austin	BRRI70	659
City of Rosenberg 1A WWTF	Fort Bend	BRRI70	1,337
Pecan Grove MUD WWTP	Fort Bend	BRRI70	929
Prairie View A&M WWTF	Waller	BRRI70	500
City of West Columbia WWTP	Brazoria	BRGM73	828
City of Freeport Central WWTF	Brazoria	BRGM73	1,018
City of Rosenberg WWTF 2	Fort Bend	BRGM73	2,011
Richmond Regional WWTP	Fort Bend	BRGM73	1,517
Sugar Land Greatwood WWTP	Fort Bend	BRGM73	1,122
City of Sugar Land New Territory North Regional WWTF	Fort Bend	BRGM73	1,587
Oyster Creek WWTP	Brazoria	n/a[1]	1,989
		Total	146,326

1. WWTP is in the San Jacinto-Brazos Coastal Basin.

The volume of annual current return flows included in the analysis from the 58 WWPTs totals 146,326 acft/yr. Figure 4-3 presents the distribution of the discharges graphically. All but 10 of the 58 WWTPs individually discharge less than about 2,500 acft/yr.

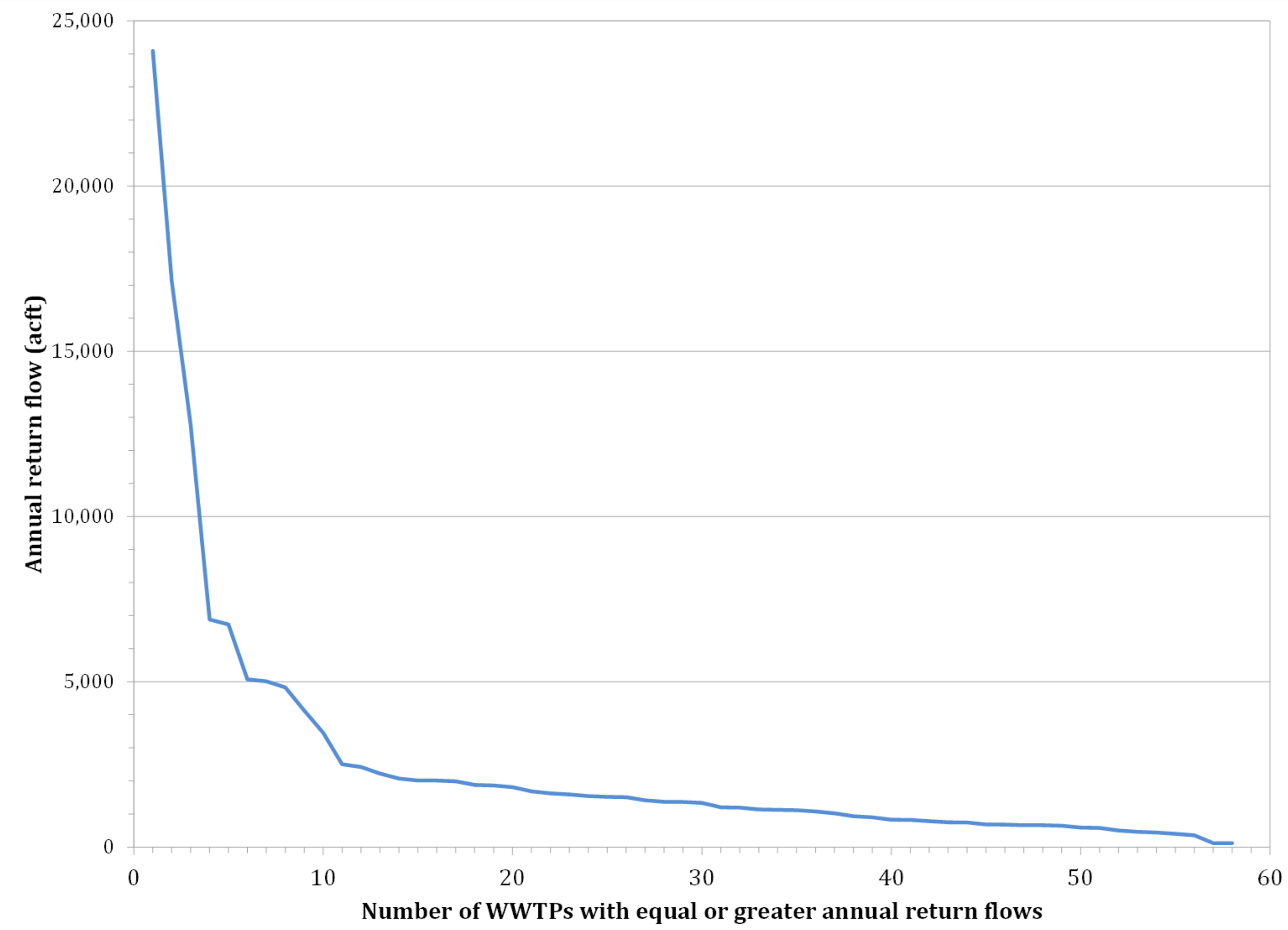

Figure 4-3. Distribution of return flows for WWTPS included in analysis.

Because the return flow discharges generally are small compared to naturalized flows in the Brazos Basin, return flows are expected to influence only the smallest regulated flows.

Table 4-4 presents annual naturalized flows at the analysis control points both with and without the current return flows added into the basin. For small annual flows that are equaled or exceeded 95 percent of the time, the current return flows represent a measurable portion of low streamflow, with the exception of the Navasota River at Bryan (NABR67), which has no return flows discharged upstream that are permitted for 1 mgd or greater.

Table 4-4. Effects of current return flows on 95th percentile exceedance flows.

Control point	Annual naturalized flow (acft)	Annual naturalized flow with current return flows (acft)	Change in annual flow (acft)	Percent change in annual flow
DMAS09	16,724	25,009	8,285	49.5%
BRSB23	80,218	90,222	10,004	12.5%
BRGR30	179,449	192,171	12,722	7.1%
BOWA40	52,160	54,036	1,876	3.6%
LRCA58	199,946	258,637	58,691	29.4%
NABR67	60,236	60,236	0	0.0%
BRHE68	1,184,077	1,314,456	130,379	11.0%
BRRI70	1,401,297	1,535,537	134,240	9.6%
BRGM73	1,495,888	1,638,212	142,324	9.5%

4.4 Selected reuse strategies

Direct reuse projects identified as recommended water management strategies in the 2021 RWPs that were modeled in the Reuse WMS scenario are listed in Table 4-5 and shown in Figure 4-2. The total supply from these strategies amounts to 45,569 acft/yr.

Other recommended reuse water management strategies were reviewed but were excluded from this analysis for the following reasons:

- Bell County WCID 1 – South Reuse (Region G)

  No return flow data could be found for the South WWTP associated with this project.

- Reuse – WMARSS China Spring (Region G)

  This project utilizes flows from a planned future WWTP.

- Reuse – WMARSS I-84 (Region G)

  This project utilizes flows from a planned future WWTP.

- Municipal Irrigation Reuse Development, Fort Bend County (Region H)

  Strategy is intended to utilize future return flows only.

- Fort Bend MUD 25 GRP Infrastructure (Region H)

  WWTP discharges to the San Jacinto-Brazos Coastal Basin; discharge stream is no longer connected to the Brazos River.

- Sugar Land Integrated Water Reuse Plan (IWRP) Reuse Infrastructure – Phase 1 (Region H)

  WWTP discharges to the San Jacinto-Brazos Coastal Basin; discharge stream is no longer connected to the Brazos River.

- Sugar Land IWRP Reuse Infrastructure – Phase 2 (Region H)

  WWTP discharges to the San Jacinto-Brazos Coastal Basin; discharge stream is no longer connected to the Brazos River.

Table 4-5. Reuse water management strategies included in analysis of reuse impacts.

Year online	WMS name	Associated WWTP	Annual supply from reuse strategy (acre-feet)
		Region O	
2040	Plainview Reuse	City of Plainview WWTF	683
2070	Lubbock County- Lubbock Direct Potable Reuse to North WTP	South East Water Reclamation Plant	8,064
		Brazos G	
2020	Waco Reuse- Bellmead/ Lacy-Lakeview	WMARSS[1] Central WWTP	2,242
2020	Reuse- Bryan (Option 1)	Still Creek WWTP	605
2020	Reuse- Cleburne	City of Cleburne WWTF	7,616
2020	Waco Reuse- Flat Creek	WMARSS Central WWTP	7,847
2020	Reuse- Cedar Park	Water Reclamation WWTF	1,120
2030	Bell County WCID 1- North Reuse	Bell County WCID #1 WWTF	1,925
2030	College Station ASR (Reuse)	Carters Creek WWTP and Lick Creek WWTP	3,640
2030	College Station- Direct Potable Reuse	Carters Creek WWTP and Lick Creek WWTP	8,232
2030	Waco Reuse- Bull Hide Creek	WMARSS Bull Hide Creek WWTP	1,681
2030	Reuse- Georgetown	Dove Springs WWTP	1,456
		Region H	
2020	Richmond Reuse Infrastructure	Regional WWTP	458
		Total	**45,569**

1. Waco Metropolitan Area Regional Sewerage System

Each reuse strategy included in the analysis will impact return flows currently discharged by their respective WWTP facilities. These effects are summarized on an annual basis in Table 4-6 and Figure 4-4. Some strategies are anticipated to utilize all return flows currently discharged and some only a portion.

Table 4-6. Effects of reuse strategies on current return flows.

Project name	**Associated WWTP**	**Annual return flow (acre-feet)**	**Annual return flow reduction (acre-feet)**
	Region O		
Plainview Reuse[1]	City of Plainview WWTF	1,366	683
Lubbock County- Lubbock Direct Potable Reuse to North WTP[2]	South East Water Reclamation Plant	8,285	4,236
	Brazos G		
Reuse- Bellmead/ Lacy-Lakeview[3]; Flat Creek[3]	WMARSS Central WWTP	24,091	10,089
Reuse- Bull Hide Creek4	WMARSS Bull Hide Creek WWTP	781	781
Reuse- Bryan (Option 1)[5]	Still Creek WWTP	1,875	453
Reuse- Cleburne[6]	City of Cleburne WWTF	5,013	5,013
Reuse- Cedar Park[3]	Water Reclamation WWTF	2,505	1,120
Bell County WCID 1- North Reuse[7]	Bell County WCID #1 WWTF	12,795	991
College Station DPR and ASR (Reuse)[8]	Carters Creek WWTP and Lick Creek WWTP	8,246	8,246
Reuse- Georgetown[9]	Dove Springs WWTP	1,538	991
	Region H		
Richmond Reuse Infrastructure[3]	Regional WWTP	1,517	458
	Total	**68,012**	**33,061**

1. Project defined as using up to 50% of return flow. Fifty percent of current return flows equals 683 acft/yr.
2. 4,236 acft/yr is the portion of the WMS supply estimated to come from current return flows rather than future growth.
3. WMS supply limited to current level of return flows. Current return flows are sufficient to meet planned supply.
4. WMS supply is expected to fully utilize current return flows and future growth. Current return flows are 781 acft/yr.
5. WMS supply limited to current level of return flows. WMS will use return flows from June-August only. June-August current return flows total 453 acft.
6. WMS supply limited to current level of return flows.
7. 991 acft/yr is the portion of WMS supply estimated to come from current return flows rather than future growth.
8. WMS supply is expected to fully utilize current return flows and future growth. Combined current return flows at Carters Creek WWTP and Lick Creek WWTP are 8,246 acft/yr.
9. 991 acft/yr is the portion of the WMS supply estimated to come from current return flows rather than future growth.

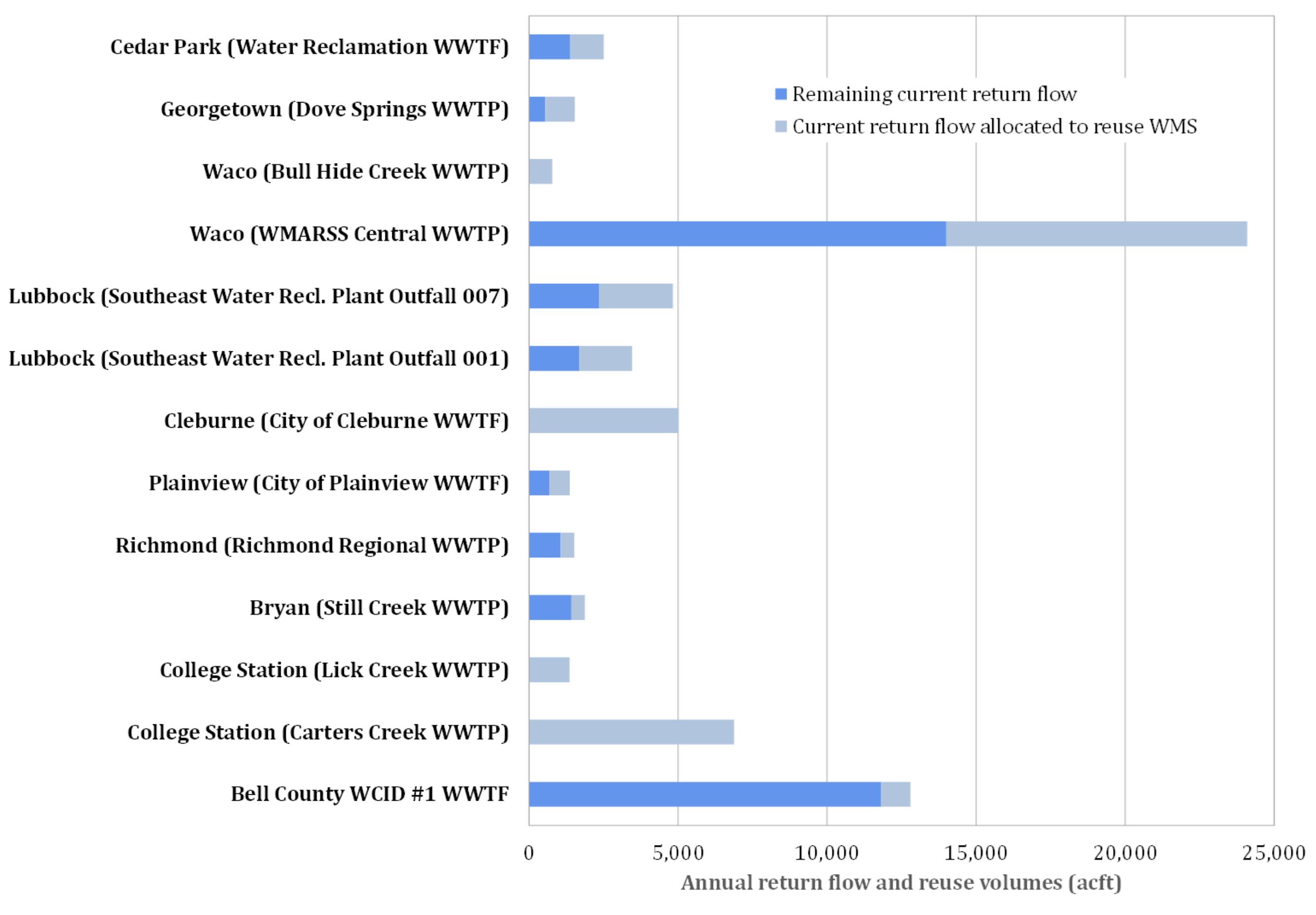

Figure 4-4. Effect of reuse strategies on current return flows.

4.5 Impacts of reuse strategies on streamflow in the Brazos Basin

Overall, the analysis results reveal that the recommended Reuse WMSs in the Brazos Basin from the 2021 RWPs have varying impacts on the monthly median flows for different months of the year at each control point and generally decrease the monthly [median] flow volumes by 1% to 3%.

Most locations exhibit lower median monthly flows with the implementation of the reuse strategies recommended in the 2021 Plans compared to the current return flows condition. This is because the reuse strategies modeled in the 'Reuse WMS' scenario utilize return flows that are currently being discharged to the basin. Figure 4-2 shows the approximate locations of the reuse strategies relative to the nine control points that were evaluated.

4.5.1 *Double Mountain Fork of the Brazos River near Aspermont*

The only recommended reuse strategy upstream of the Double Mountain Fork of the Brazos River near Aspermont (DMAS09) is Lubbock's Direct Potable Reuse to North Water Treatment Plant. The median (50% exceedance frequency) regulated flow at DMAS09 decreased for all months when reuse strategies are implemented compared to current return flows, as shown in Figure 4-5 and Table 4-7. The decrease in median monthly streamflow relative to current return flow conditions ranged between 105 acft per month (in July) and 154 acft per month (in May), with an average of 132 acft per month. Spring, summer, and winter median flows also decreased at DMAS09.

The flow frequency plots in Figure 4-6 indicate that while flows greater than the median flow are largely unchanged compared to current return flow conditions, lower flows are reduced. For example, the flows that are exceeded 95 percent of time (*i.e.*, very low flows) are reduced by around 9 percent on an annual basis (see Table 4-7). The month-to-month comparisons presented in the scatterplots in Figure 4-7 show that in each month the lower flows decrease with the Reuse WMS scenario compared to the current return flows scenario.

Return flows discharged upstream of this location (from the City of Lubbock) have a substantial impact on low streamflow, as illustrated in Table 4-4, and in the flow frequency plots in Figure 4-8 and in Figure 4-9.

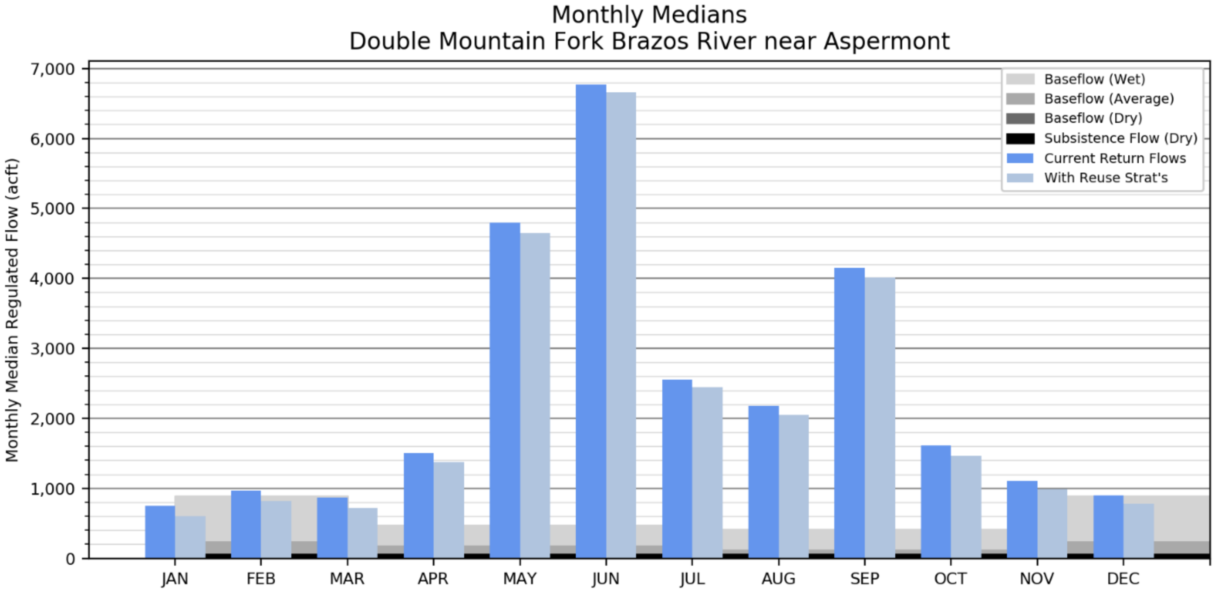

Figure 4-5. Monthly median flows at the Double Mountain Fork of the Brazos River near Aspermont with current return flows and with reuse strategies.[4]

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[4] Some figures presented in this section include comparison of regulated flows to environmental flow standards adopted by the TCEQ. These graphics were developed using the TWDB Cumulative Effects of Recommended Strategies Tool (TWDB CERST), which automatically includes environmental flow standards in the graphics if standards have been adopted for a specific location. These standards define seasonal daily subsistence and base flow quantities that often vary by current hydrologic conditions (wet, dry, or average), depending on the river basin and location within the river basin. For these plots, the standards are converted from daily to monthly quantities for comparison to WAM regulated flows. It can be informative to compare WAM regulated flows with these standards, recognizing the limitation that the standards are based on daily flows and the regulated flows output by the WAM are monthly quantities.

Table 4-7. Streamflow frequencies at the Double Mountain Fork of the Brazos River near Aspermont with current return flows and with reuse strategies (acre-feet).

Period	Current Return Flows - Exceedance Frequency					With Reuse Strategies - Exceedance Frequency				
	95%	75%	50%	25%	5%	95%	75%	50%	25%	5%
Jan	221	365	747	1,513	3,612	108	252	601	1,399	3,499
Feb	292	513	966	1,561	6,536	143	364	817	1,412	6,387
Mar	295	432	872	2,017	10,910	144	281	721	1,866	10,759
Apr	302	658	1,508	4,928	18,153	163	519	1,373	4,737	18,014
May	609	2,494	4,800	15,265	67,840	455	2,340	4,646	15,111	67,685
Jun	761	3,166	6,769	19,798	58,905	648	3,054	6,657	19,591	58,789
Jul	251	740	2,552	8,960	48,197	146	635	2,447	8,855	48,063
Aug	241	1,019	2,175	7,822	24,745	119	897	2,053	7,775	24,623
Sep	261	698	4,146	10,113	41,054	127	564	4,013	9,979	40,921
Oct	293	646	1,612	12,801	39,788	143	496	1,461	12,651	39,638
Nov	231	438	1,102	3,012	8,063	113	339	984	2,893	7,945
Dec	220	344	894	1,926	5,938	107	232	782	1,814	5,826
Winter	1,298	2,684	5,357	9,447	23,276	889	2,221	4,900	8,954	22,784
Spring	6,414	10,795	24,921	53,301	101,030	5,857	10,243	24,364	52,744	100,474
Summer	2,532	10,806	24,031	48,044	129,540	2,022	10,296	23,486	47,506	129,087
Annual	16,617	33,175	67,411	114,939	195,208	15,058	31,615	65,852	113,397	193,700

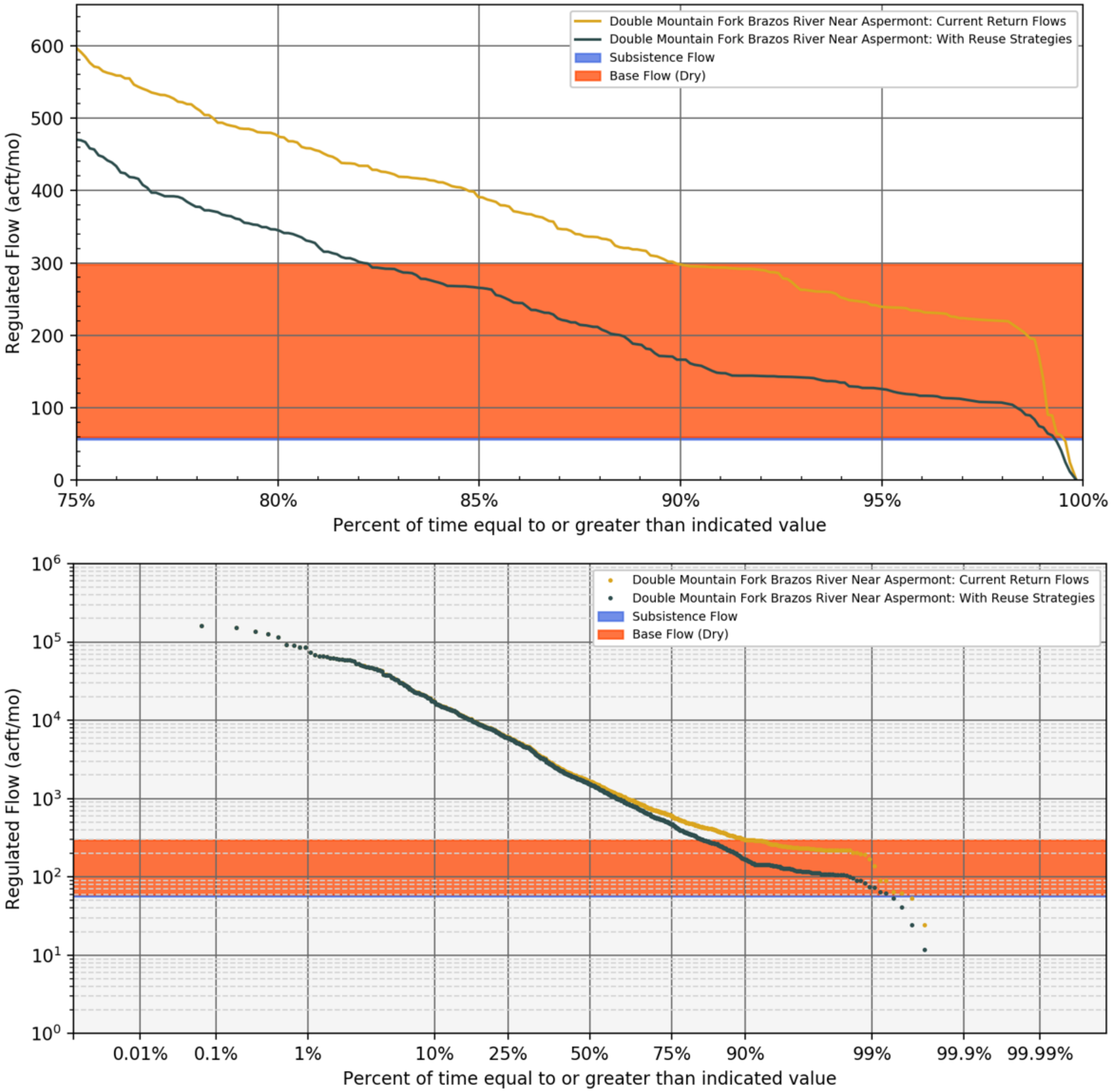

Figure 4-6. Streamflow frequencies at the Double Mountain Fork of the Brazos River near Aspermont with current return flows and with reuse strategies.

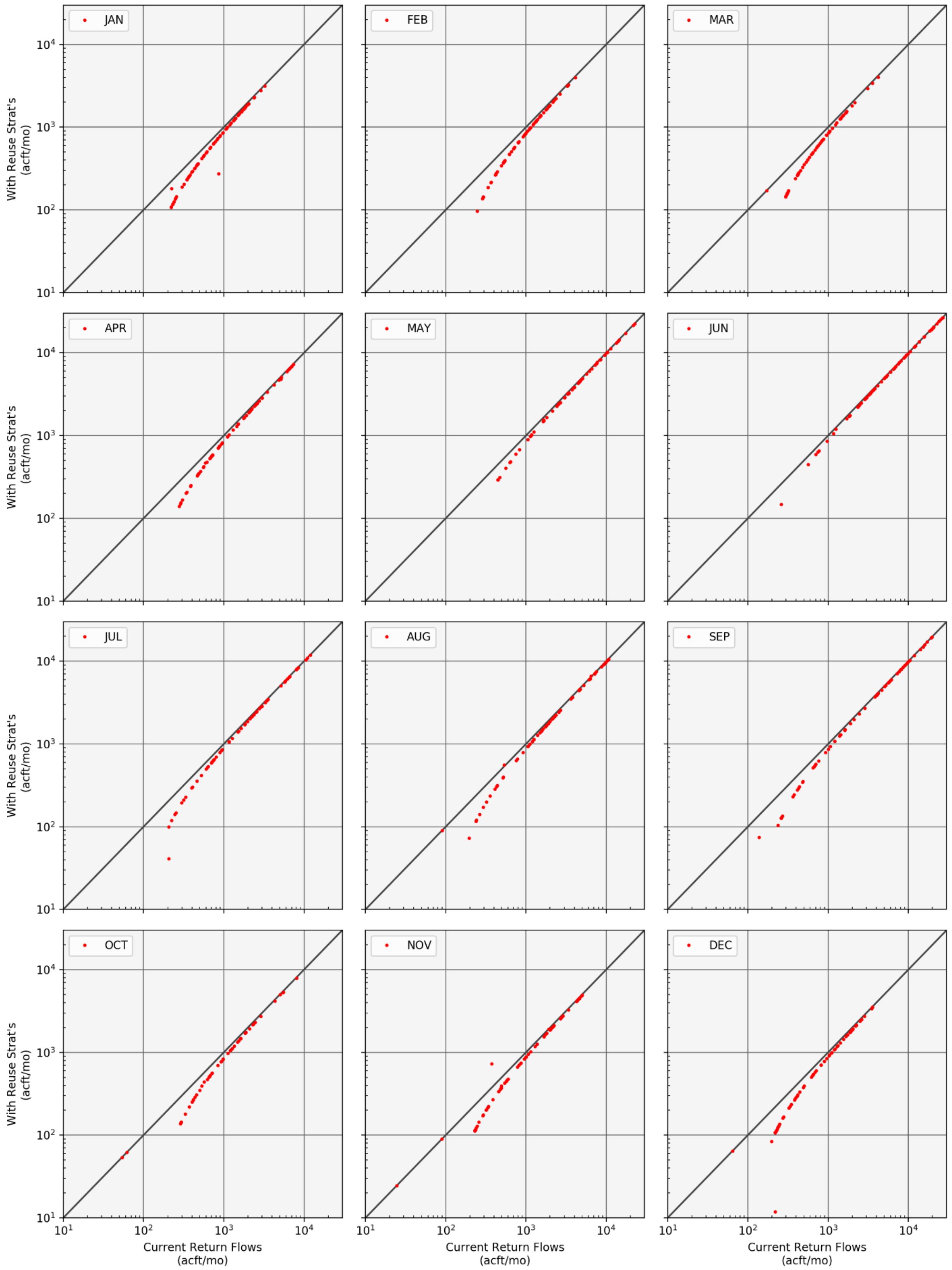

Figure 4-7. Monthly flows at the Double Mountain Fork of the Brazos River near Aspermont with current return flows and with reuse strategies.

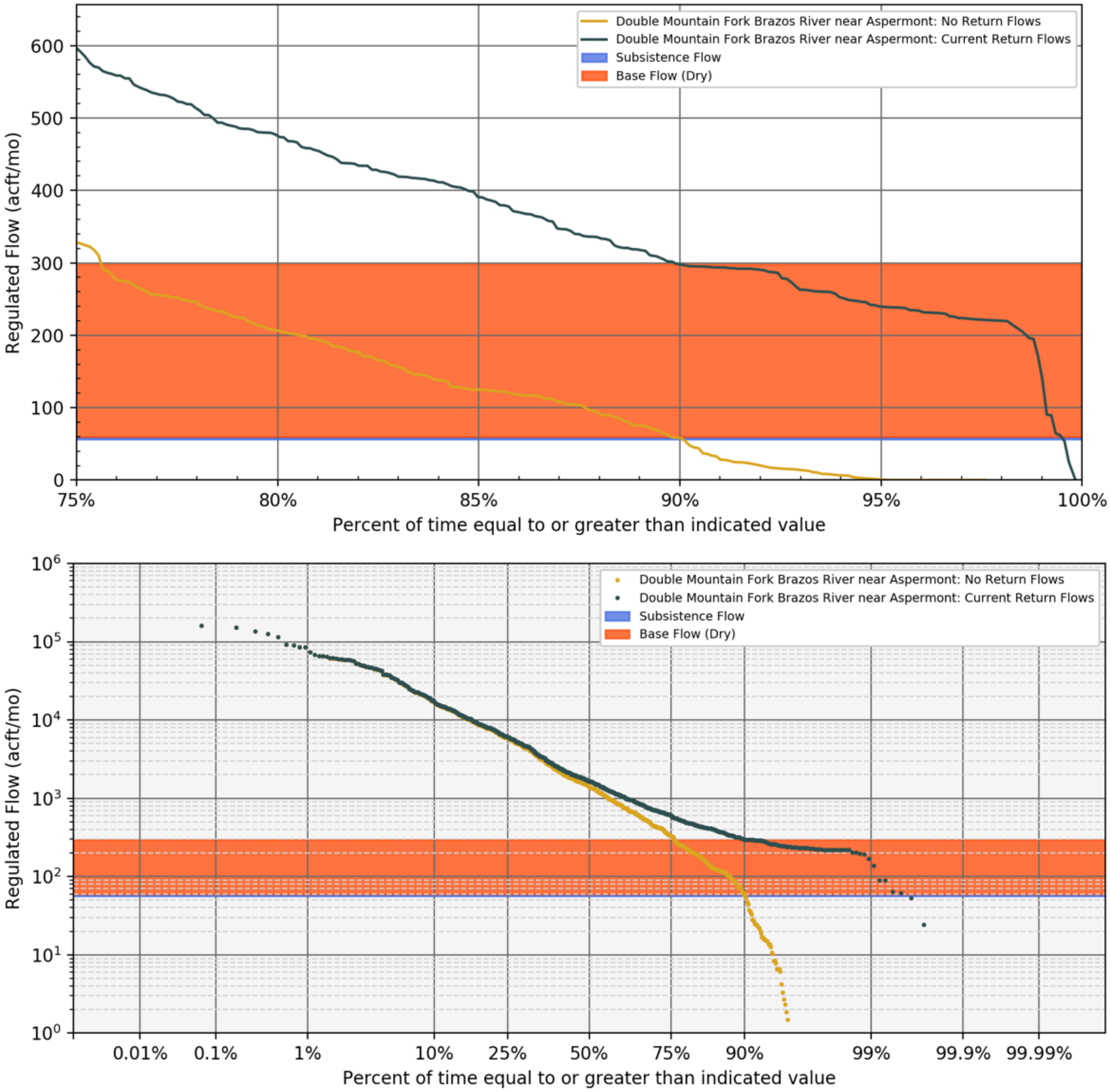

Figure 4-8. Streamflow frequencies at the Double Mountain Fork of the Brazos River near Aspermont with no return flows and with current return flows,, but no WMSs.

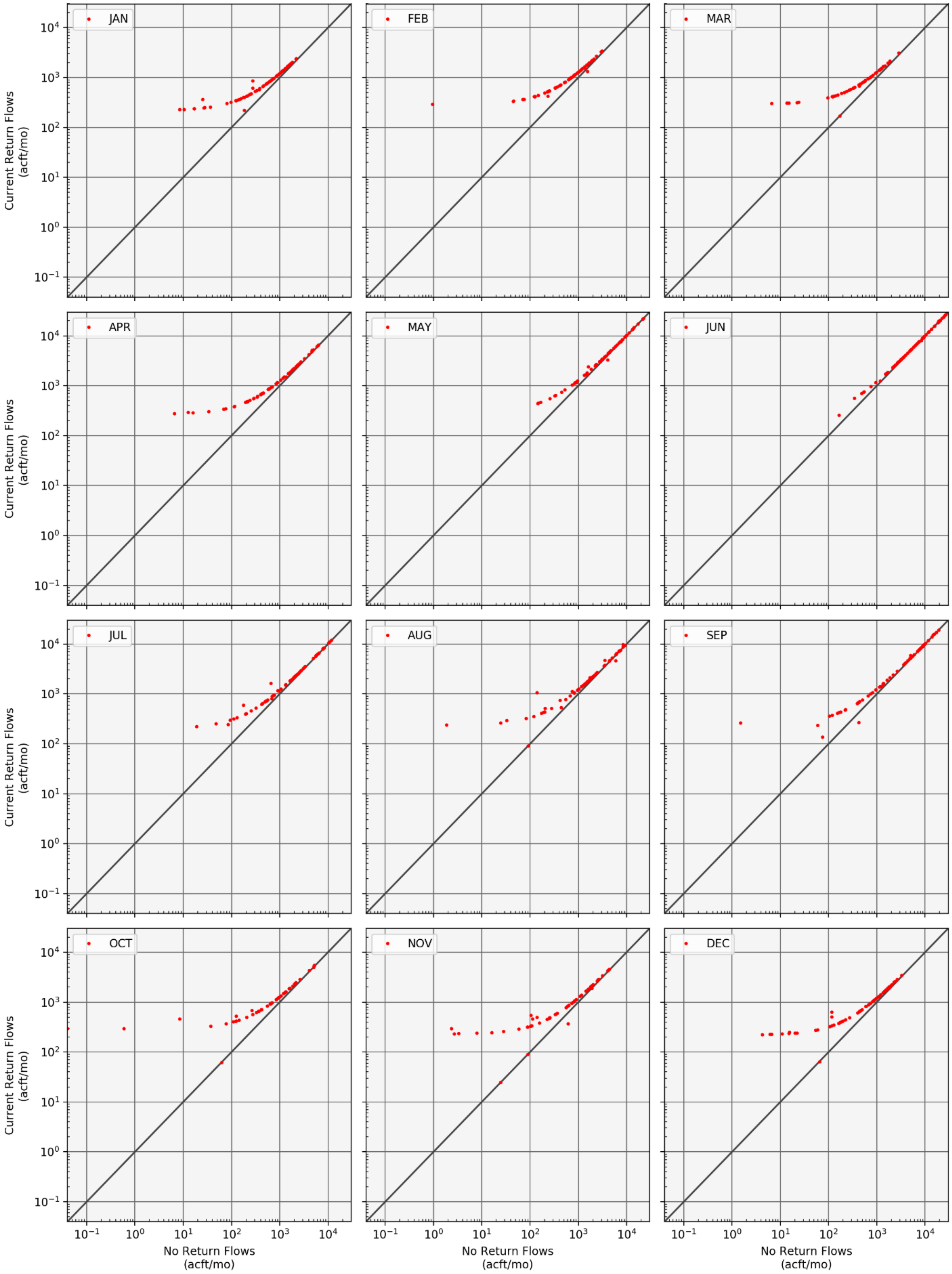

Figure 4-9. Monthly flows at the Double Mountain Fork of the Brazos River near Aspermont without return flows and with current return flows, but no WMSs.

4.5.2 *Brazos River at South Bend*

Lubbock's Direct Potable Reuse to North Water Treatment Plant and the Plainview Reuse project are both upstream of the Brazos River at South Bend (BRSB23) location. At BRSB23, the median streamflow would decrease in every month with the recommended reuse strategies compared to the current return flow conditions as shown in Figure 4-10. The decrease in streamflow relative to current return flow conditions ranged from 31 acft per month to 46 acft per month, with an average of 39 acft per month. The reductions in return flows are minor and account for between 0 and 1 percent of the flow compared to current return flow conditions. The flow frequency plots in Figure 4-11 indicate that while flows greater than the flow exceeded 75 percent of the time are largely unchanged compared to current return flow conditions, the lowest 25 percent of flows are reduced slightly.

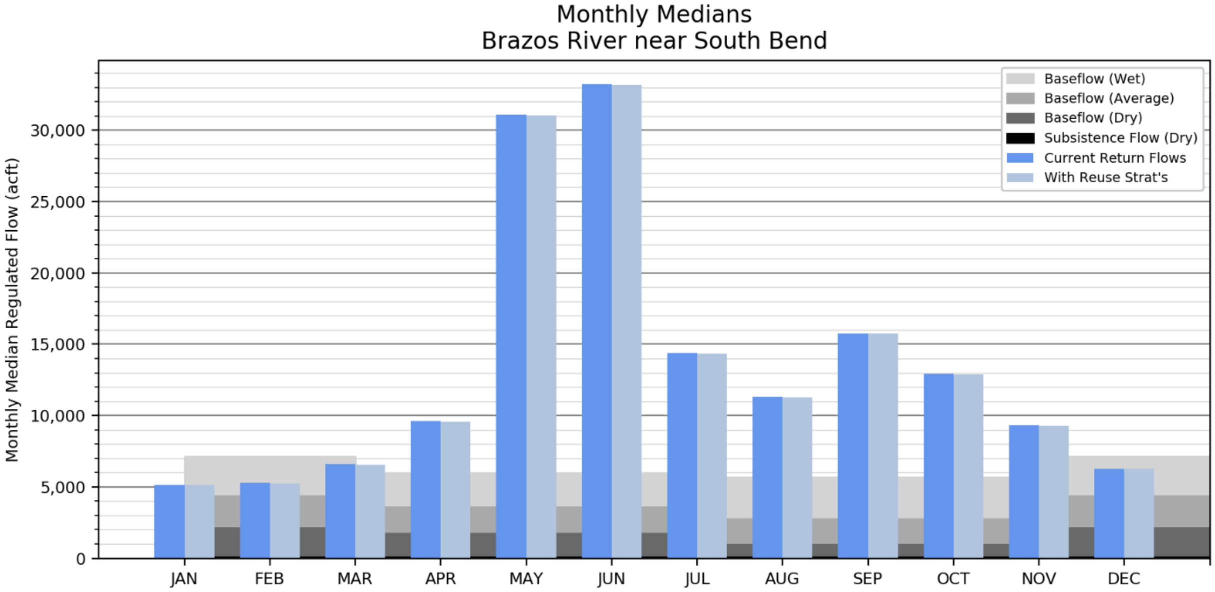

Figure 4-10. Monthly median flows at the Brazos River near South Bend with current return flows and with reuse strategies.

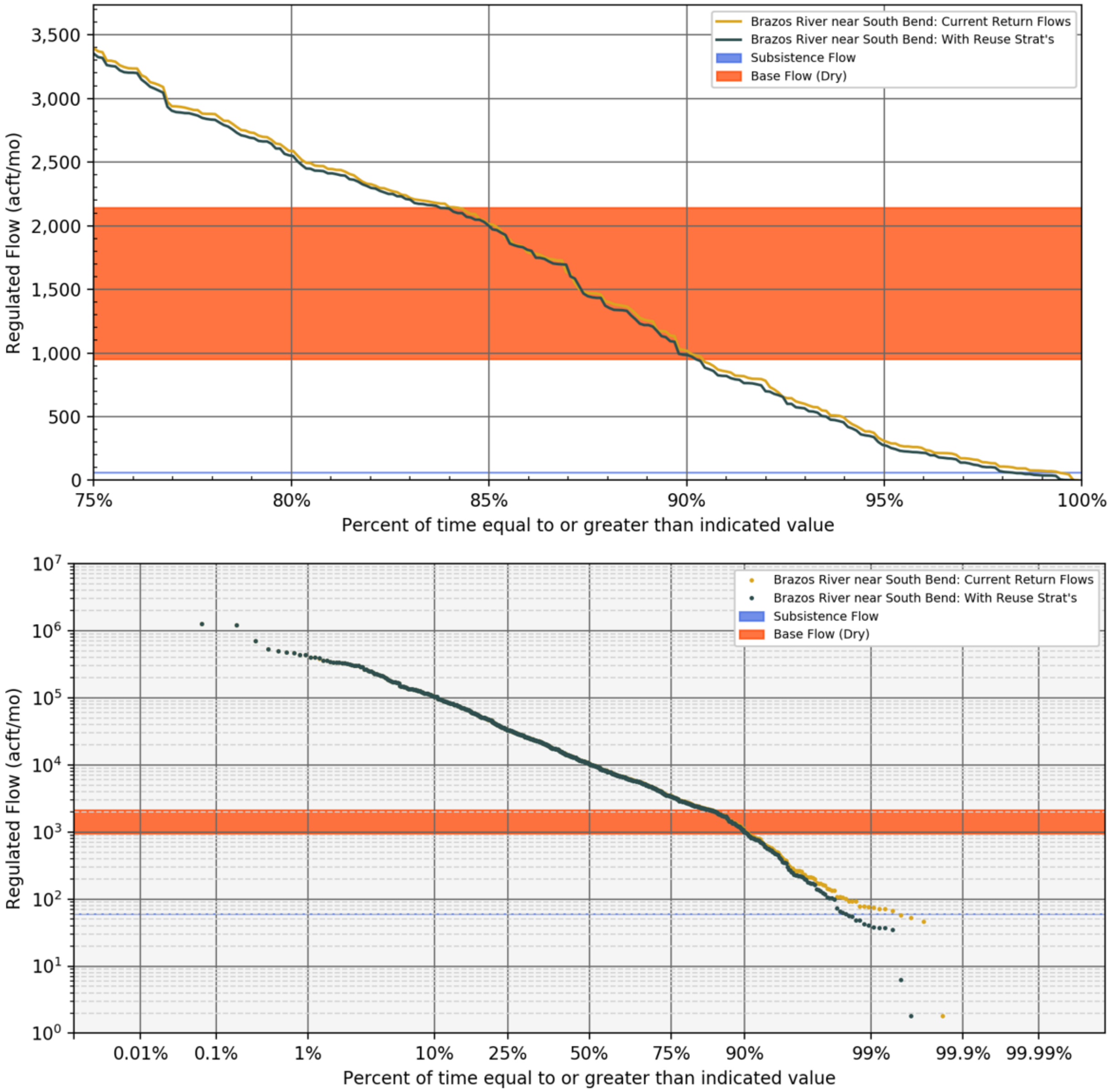

Figure 4-11. Flow frequencies at the Brazos River near South Bend with current return flows and with reuse strategies.

4.5.3 *Brazos River near Glen Rose*

The Brazos River near Glen Rose (BRGR30) location is impacted by the same reuse strategies as the South Bend site, which is upstream. BRGR30 shows median monthly streamflow both increasing and decreasing relative to the current return flows condition (see Figure 4-12). Simulated monthly median streamflow decrease in January, February, May, June, and October, and increase the other months. The average decrease is 850 acft per month during the five months, with the largest decrease in monthly median flows occurring in May (-2,011 acft per month). The average increase for the other seven months was 956 acft per month with the largest increase occurring in November (1,707 acft per month). Spring and summer median flows decreased relative to current return flow conditions and winter median flows increased slightly as shown in Table 4-8.

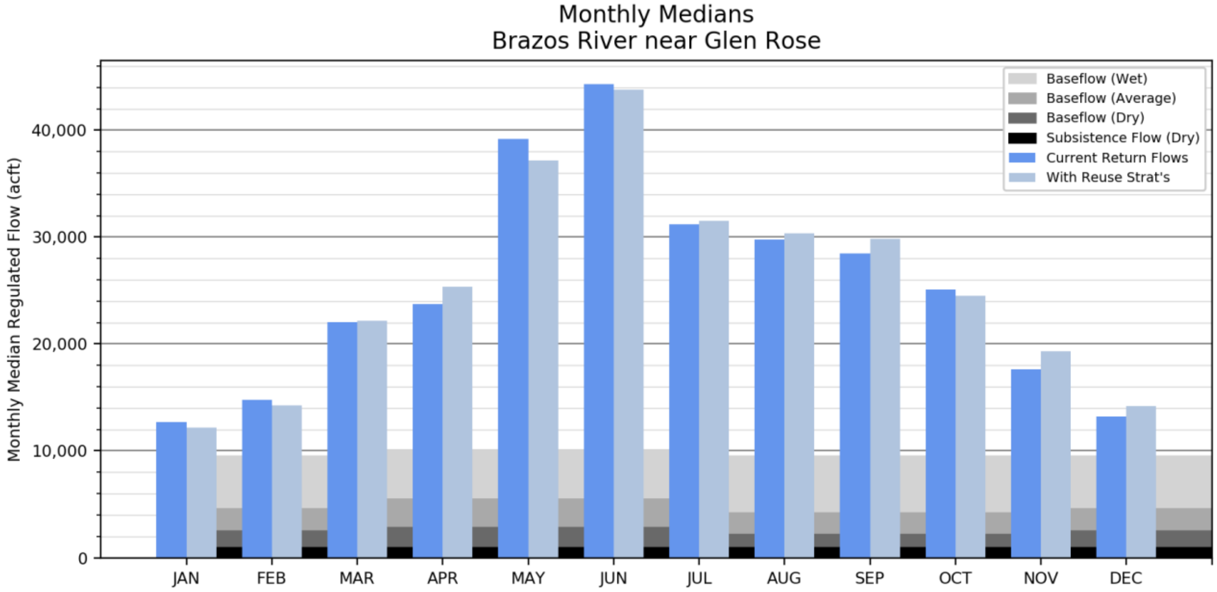

Figure 4-12. Monthly median flows at the Brazos River near Glen Rose with current return flows and with reuse strategies.

Table 4-8. Flow frequencies at the Brazos River near Glen Rose with current return flows and with reuse strategies (acre-feet).

Period	Current Return Flows - Exceedance Frequency					With Reuse Strategies - Exceedance Frequency				
	95%	75%	50%	25%	5%	95%	75%	50%	25%	5%
Jan	134	1,542	12,719	22,205	45,066	134	1,542	12,170	20,870	45,157
Feb	155	2,113	14,786	35,681	128,852	111	1,448	14,231	33,454	126,119
Mar	396	3,504	22,029	42,750	212,544	396	4,180	22,188	43,873	212,459
Apr	296	3,001	23,719	49,615	149,228	345	3,397	25,327	49,750	149,218
May	284	13,682	39,193	122,231	558,910	448	13,928	37,182	120,356	558,836
Jun	614	8,484	44,305	90,171	463,415	614	8,461	43,787	90,140	463,383
Jul	0	5,468	31,203	60,173	189,195	0	4,270	31,525	59,502	189,133
Aug	87	5,779	29,753	51,831	129,657	162	5,994	30,338	51,831	129,623
Sep	374	7,386	28,481	49,185	96,984	596	7,764	29,861	50,643	90,195
Oct	36	3,576	25,115	54,632	377,111	36	3,258	24,497	54,171	363,043
Nov	283	1,292	17,601	35,088	160,440	275	1,296	19,308	35,666	160,407
Dec	229	1,205	13,242	30,426	89,861	229	1,812	14,174	30,502	89,861
Winter	3,997	51,339	74,822	119,264	390,080	4,179	49,695	75,818	119,192	389,932
Spring	8,698	94,918	169,455	346,647	1,356,723	15,151	90,574	161,721	347,513	1,356,522
Summer	14,889	79,351	129,697	241,605	635,954	12,960	79,415	127,369	239,649	636,897
Annual	105,937	329,076	488,631	747,314	1,861,044	99,333	325,590	488,122	748,909	1,860,718

4.5.4 *Bosque River near Waco*

The Bosque River near Waco (BOWA40) location measures flow from the Bosque River watershed. There are no recommended reuse WMSs in the Bosque River watershed that are projected to utilize current return flows. The WMARSS I-84 reuse project recommended in the Brazos G Plan is upstream of BOWA40 but utilizes flows from a planned future WWTP and so is not expected to reduce existing return flow discharges. Increases in monthly median flows at this location in May and February are due to changes in priority calls by downstream senior water rights causing existing junior rights along the Bosque River to pass additional flows, slightly increasing regulated flows at this location (Figure 4-13).

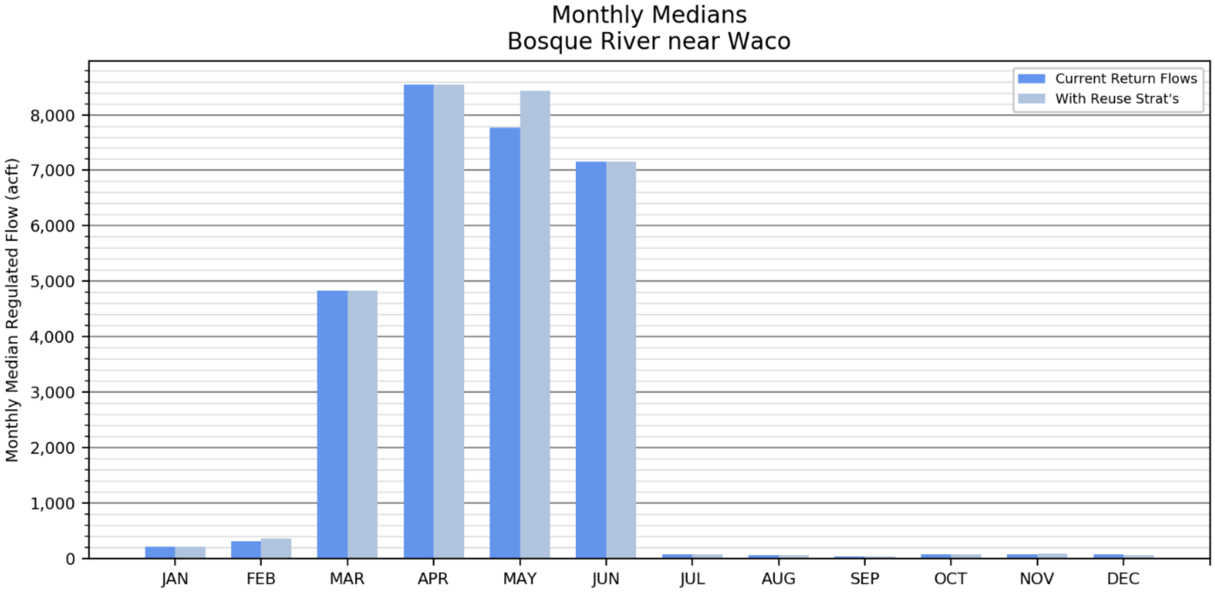

Figure 4-13. Monthly median flows at the Bosque River near Waco with current return flows and reuse strategies.

4.5.5 *Little River near Cameron*

The Little River near Cameron (LRCA58) location reflects changes from reuse water management strategies recommended for the Little River watershed, specifically the Bell County WCID 1 North reuse project (no return flow data could be found for the Bell County WCID 1 South project), the Georgetown reuse project, and the Cedar Park reuse project. Relative to current return flow conditions, median streamflow decreases in 10 of the 12 months, but most notably in May, as shown in Figure 4-14. Median streamflow increases in August and December by 5 percent and 2 percent, respectively. At LRCA58, spring median flows increases by 2 percent relative to current return flow conditions, the median flow during summer decreases by 3 percent, and the winter median decreases by less than 1 percent, as show in Table 4-9.

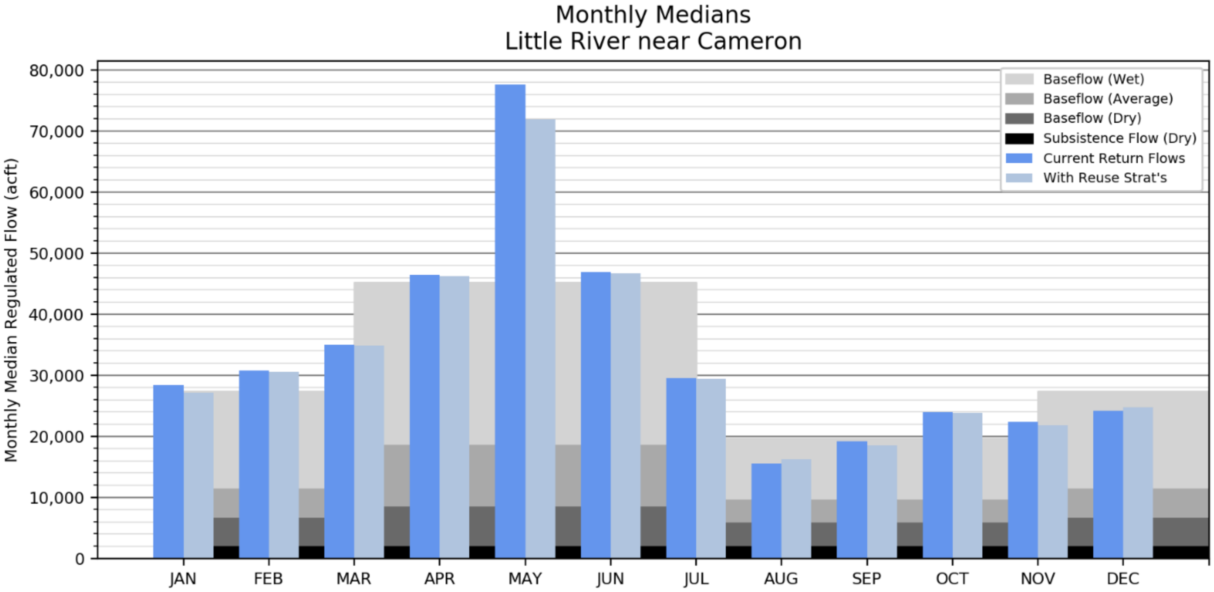

Figure 4-14. Monthly median flows at the Little River near Cameron with current return flows and with reuse strategies.

Table 4-9. Flow frequencies at the Little River near Cameron with current return flows and with reuse strategies (acre-feet).

Period	Current Return Flows - Exceedance Frequency					With Reuse Strategies - Exceedance Frequency				
	95%	75%	50%	25%	5%	95%	75%	50%	25%	5%
Jan	4,702	10,182	28,313	79,392	316,910	4,711	10,512	27,161	80,017	311,294
Feb	5,098	13,936	30,760	122,553	451,470	4,941	13,797	30,530	122,136	451,216
Mar	6,020	15,751	35,010	176,905	453,803	5,923	15,130	34,874	176,634	453,532
Apr	4,405	22,227	46,387	143,514	362,154	4,272	21,990	46,170	143,258	361,794
May	12,870	36,626	77,574	219,150	707,187	12,607	35,992	71,933	218,861	706,882
Jun	5,215	21,561	46,944	161,907	451,094	4,994	21,349	46,688	161,647	449,524
Jul	3,173	10,109	29,521	45,123	183,903	2,954	10,069	29,438	44,887	183,667
Aug	1,939	5,658	15,473	33,713	77,256	1,768	5,408	16,210	36,331	78,757
Sep	3,574	9,583	19,151	32,624	127,655	3,396	9,331	18,526	32,393	116,025
Oct	2,370	8,249	23,953	57,006	213,019	2,204	8,072	23,786	56,817	212,659
Nov	2,915	9,483	22,362	68,405	245,341	2,753	9,427	21,736	69,138	245,086
Dec	3,649	11,888	24,121	96,771	343,964	3,773	11,626	24,689	96,508	343,704
Winter	28,284	75,624	190,748	551,228	1,068,654	28,167	74,787	189,901	553,435	1,067,688
Spring	57,110	117,567	290,734	769,471	1,700,279	49,981	113,922	297,100	767,972	1,698,852
Summer	17,666	48,381	121,122	233,941	422,464	17,014	47,622	118,042	233,280	421,496
Annual	132,295	335,172	809,351	1,552,553	2,660,582	123,571	332,850	807,014	1,547,710	2,655,056

4.5.6 *Navasota River near Bryan*

The Navasota River near Bryan (NABR67) location measures streamflow in the Navasota River watershed, a tributary to the Brazos River. There are no recommended reuse strategies affecting streamflow upstream of NABR67. The College Station reuse strategies are downstream of NABR67. Relative to current return flow conditions, median streamflow at NABR67 increased in 7 of the 12 months (most notably in May), did not change in 2 months (June and August), and decreased in January, March, and December as show in Table 4-10. Spring and summer median flows decrease by about 1 percent relative to current return flow conditions, and the winter median flow increases by less than 1 percent.

Table 4-10. Flow frequencies at the Navasota River near Bryan with current return flows and with reuse strategies (acre-feet).

Period	Current Return Flows - Exceedance Frequency					With Reuse Strategies - Exceedance Frequency				
	95%	75%	50%	25%	5%	95%	75%	50%	25%	5%
Jan	1,424	5,801	18,700	34,982	150,405	1,424	5,927	18,124	34,982	150,407
Feb	2,462	9,064	22,615	56,216	140,646	2,440	8,603	23,098	56,610	140,646
Mar	2,166	8,553	23,409	57,037	147,585	2,166	8,645	23,250	57,037	147,984
Apr	2,493	4,467	13,797	38,711	162,287	2,534	5,361	14,150	38,711	162,134
May	2,172	6,006	18,057	68,856	222,241	1,873	6,042	19,872	68,856	222,241
Jun	1,063	2,132	9,159	43,170	127,070	1,068	2,283	9,159	43,170	126,883
Jul	416	957	2,067	9,932	30,812	416	961	2,149	9,209	30,812
Aug	106	778	1,386	11,346	35,552	106	748	1,386	11,540	32,002
Sep	28	772	1,573	8,236	23,719	28	802	1,720	9,655	26,376
Oct	193	782	3,689	12,258	77,006	193	782	4,214	12,253	74,089
Nov	605	1,485	5,412	18,293	112,820	628	1,675	5,959	19,330	112,788
Dec	1,025	2,427	10,334	41,947	161,653	968	2,527	9,421	41,951	161,653
Winter	20,666	38,750	84,249	189,310	445,502	17,289	43,356	84,516	189,309	444,908
Spring	15,094	50,756	114,680	234,541	436,462	16,116	49,941	113,867	235,180	436,426
Summer	2,881	7,638	25,626	51,762	123,133	2,881	8,225	25,283	55,314	123,133
Annual	51,987	138,056	318,878	472,548	743,222	54,560	139,309	318,878	469,728	743,229

4.5.7 *Lower Basin Main Stem Locations*

The three most downstream locations (Brazos River near Hempstead (BRHE68), Brazos River at Richmond (BRRI70), and Brazos River at the Gulf of Mexico (BRGM73)) are all located in the lower basin on the main stem of the Brazos River, and the changes in streamflow at these locations show similar patterns. All recommended reuse strategies that are expected to reduce flows below the current level are upstream of Hempstead, with the exception of the Richmond reuse strategy recommended in the Region H Plan, which is downstream of the Richmond location. The flow frequency plots in Figure 4-15, Figure 4-16, and Figure 4-17 indicate that there are modest changes in low-flow frequencies with implementation of the recommended reuse strategies.

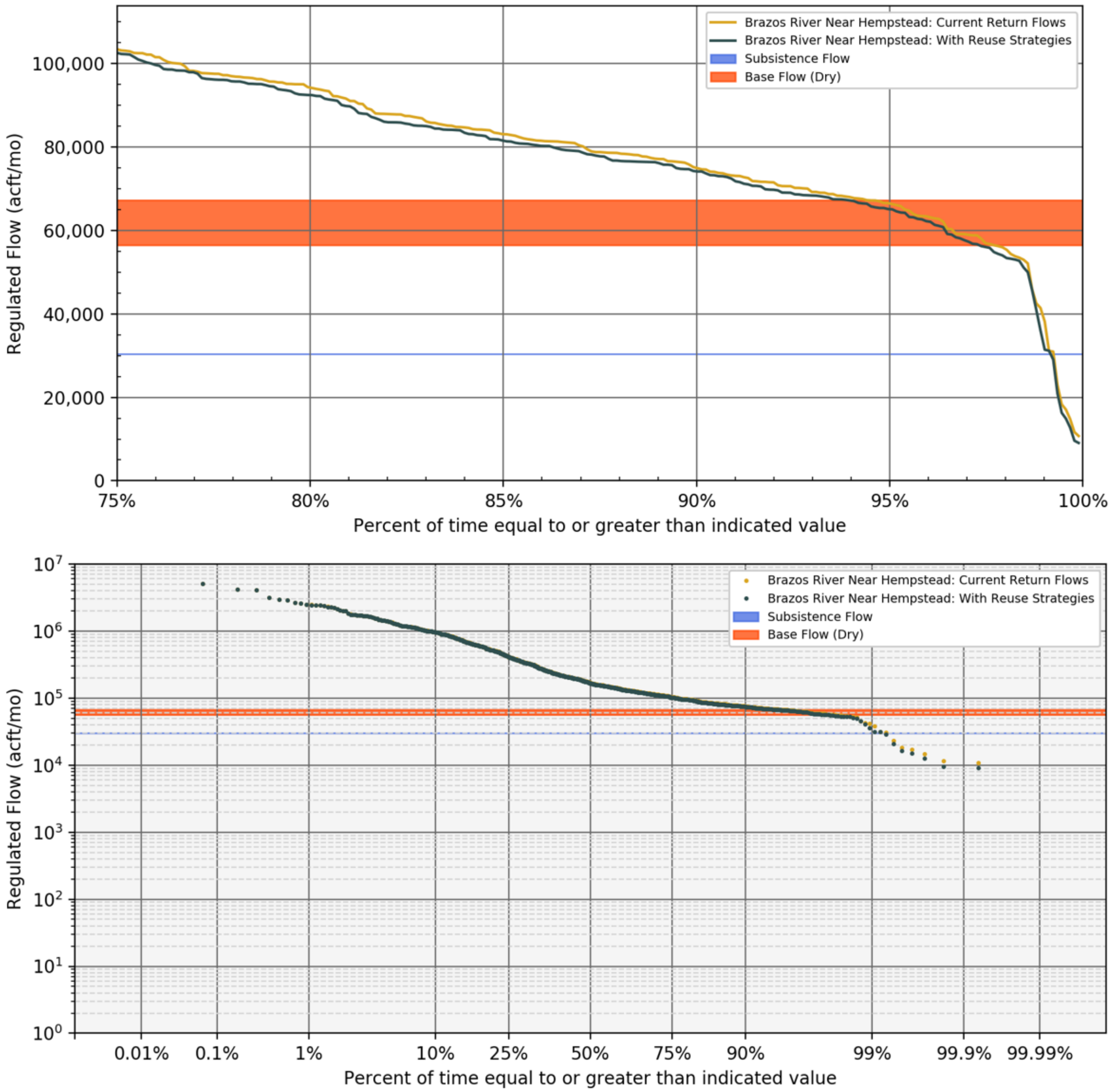

Figure 4-15. Flow frequencies at the Brazos River near Hempstead with current return flows and with reuse strategies.

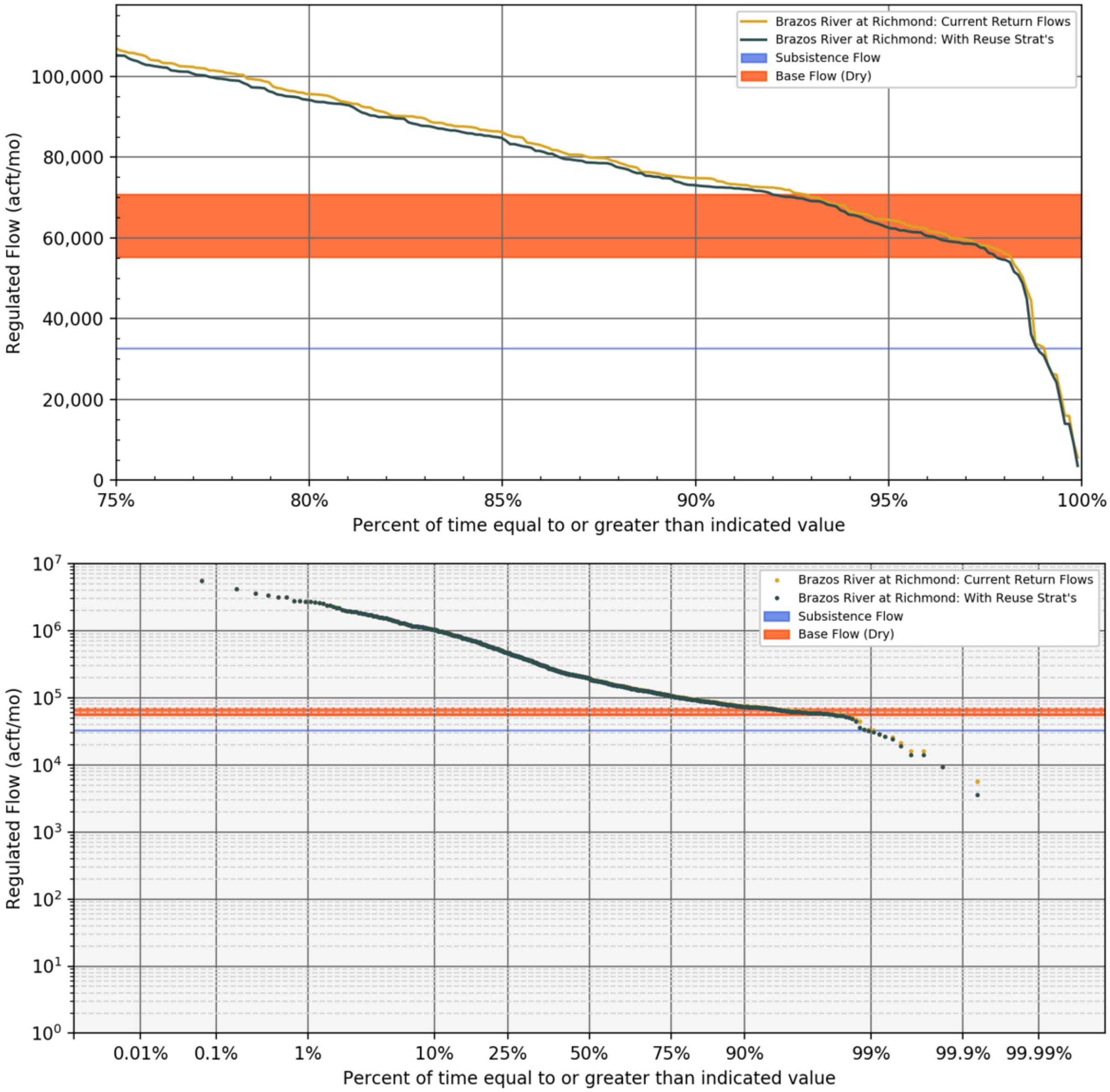

Figure 4-16. Flow frequencies at the Brazos River at Richmond with current return flows and with reuse strategies.

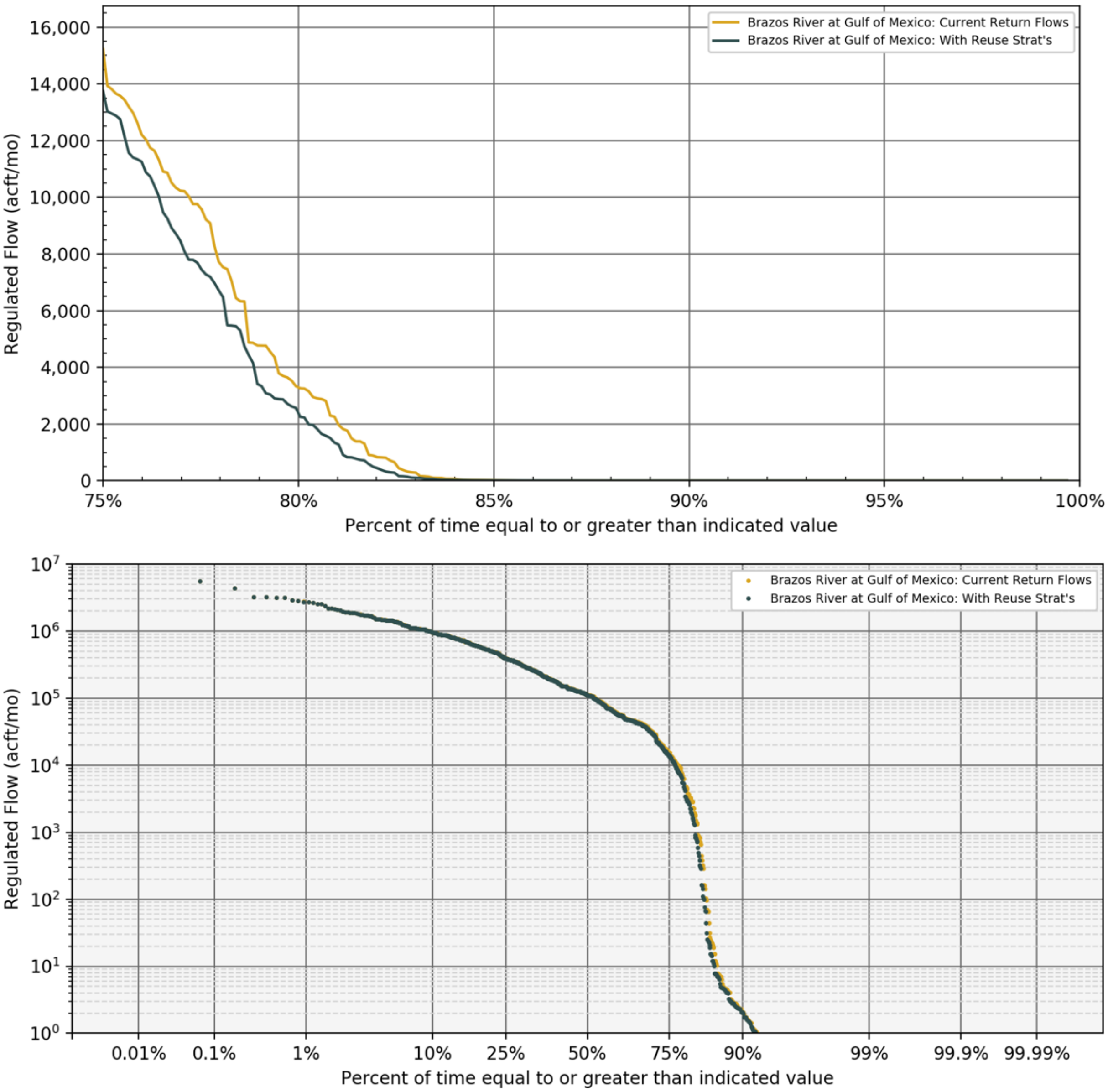

Figure 4-17. Flow frequencies at the Brazos River at Gulf of Mexico with current return flows and with reuse strategies.

Flow frequencies for each of the three lower basin locations are tabulated in Table 4-11. Monthly median streamflow at BRHE68 decreases during 11 of 12 months, but the changes are relatively minor (*i.e.*, between 0 and 2 percent). The changes range from -2,357 acft in October to +31 acft in July, with the average change per month being -1,415 acft. Median flows during spring, summer, and winter decrease by around 1 percent at BRHE68 relative to current return flow conditions.

Monthly median streamflow at BRRI70 decrease during 10 of 12 months, but the changes are relatively minor (*i.e.*, between 0 and 1 percent of current return flows). The changes range from -4,071 acft in October to +1,220 acft in January, with the average change per month being -1,233 acft. Changes in seasonal median flows at BRRI70 are within 1 percent of the current return flow conditions.

BRGM73 is located at the mouth of the Brazos River where it discharges into the Gulf of Mexico. Monthly median streamflow decreases during 10 of 12 months, but the changes are between 1 and 2 percent for all months except July (4 percent decrease) and August (9 percent decrease). The changes range from 3,186 acft in May to +1,506 acft in January. Decreases in seasonal median flows at BRGM73 are within 1 percent of the current return flow conditions.

4.5.8 ***Summary***

The cumulative effects of implementing the reuse water management strategies recommended in the 2021 Regional Water Plans for Region O, Brazos G, and Region H will tend to decrease streamflow slightly in all months, with occasional increases, <u>relative to conditions under current return flows</u>. Overall, the flow regimes, as characterized by flow frequency curves, show little change due to plan implementation relative to current return flow conditions, with changes occurring mostly to low flows exceeded 75 percent of the time. Locations directly downstream of proposed reuse projects would experience the most pronounced reductions in streamflow.

In summary, while most locations are not expected to experience significantly different streamflow with the implementation of reuse water management strategies that are recommended in the 2021 regional water plans, this study clearly identifies at least one site (i.e., Double Mountain Fork near Aspermont) where implementation of recommended reuse water management strategies will significantly affect low flow hydrology, which has already been affected by the return flows themselves. Both the return flows and reductions in return flows caused by implementation of the reuse strategies will potentially affect the aquatic environment.

As the methodology used in this analysis includes only <u>current</u> return flows and reuse of those return flows, the analysis does not account for <u>future</u> increases in return flows discharged or reused. Future streamflow could increase with increased return flows despite implementation of the reuse strategies recommended in the regional water plans.

This method could be applied to other basins and regional water planning areas, with appropriate modifications for the specific situations in other basins that should be considered given the widely varied nature of return flow discharges, reuse projects, and management of return flows between river basins and regional water planning areas.

The approach used in this analysis is limited in application due to differences between the time bases of the WAMs and of e-flow standards. Regulated flows obtained from a WAM are monthly while e-flows standards (subsistence and base flows) are based on daily flow values. Therefore, comparison of regulated flows from a WAM to e-flows can be misleading. In many instances, monthly flows during low-flow periods approximate long sequences of subsistence or base flows. However, even during relatively dry periods, small, intermittent storm events might cause a number of days during a month to exceed a given subsistence or base flow standard and the monthly evaluation will fail to capture those days. When averaged over a month the flows might not exceed the e-flow standard of interest even though some days within the month have exceeded the standard. Similarly, a mid-month storm event may increase the average monthly flow to be above the e-flow standard when for most days in the month the flows were less than the standard. Comparison of monthly regulated flows from a WAM to e-flows (subsistence and base flows) can be misleading and interpretations should be made with these differences in mind.

Table 4-11. Flow frequencies at the lower basin locations with current return flows and with reuse strategies (acre-feet).

Period	Current Return Flows - Exceedance Frequency					With Reuse Strategies - Exceedance Frequency				
	95%	75%	50%	25%	5%	95%	75%	50%	25%	5%
Brazos River near Hempstead										
Jan	60,012	93,880	187,878	422,256	1,096,727	58,848	92,017	186,128	420,147	1,095,088
Feb	73,286	97,507	229,781	543,188	1,293,663	71,482	96,126	228,321	544,240	1,291,301
Mar	76,117	114,044	221,661	673,627	1,316,115	75,942	112,378	220,828	670,987	1,308,995
Apr	91,483	128,061	239,129	539,059	1,321,163	89,637	126,833	237,485	536,938	1,317,647
May	111,012	196,668	363,665	1,043,954	2,479,935	108,177	194,164	361,423	1,040,142	2,476,739
Jun	101,111	142,864	250,967	726,093	1,676,749	98,601	142,246	248,826	723,380	1,673,848
Jul	76,214	115,915	152,293	215,048	851,821	76,258	115,051	152,324	214,125	850,033
Aug	71,209	95,367	131,839	176,089	261,911	67,416	93,392	130,512	174,358	260,280
Sep	68,279	94,374	121,497	162,042	461,063	66,149	94,413	121,278	162,038	459,533
Oct	61,867	80,400	132,578	245,750	1,090,682	59,922	78,779	130,221	241,191	1,089,207
Nov	57,709	80,745	133,178	336,111	1,216,845	56,482	78,793	131,210	334,040	1,206,700
Dec	56,688	78,028	154,759	410,423	1,286,206	55,730	76,029	153,684	407,863	1,283,901
Winter	334,355	602,175	967,350	1,810,832	3,986,158	328,332	599,060	961,878	1,804,982	3,977,301
Spring	419,202	663,211	1,683,456	3,401,980	5,674,390	415,173	659,845	1,677,787	3,387,916	5,663,321
Summer	304,566	440,579	654,350	1,017,970	1,643,071	296,551	435,280	648,224	1,012,249	1,635,312
Annual	1,214,264	1,922,540	3,995,981	6,119,754	10,518,586	1,193,829	1,903,507	3,965,756	6,090,137	10,490,909
Brazos River at Richmond										
Jan	61,148	107,395	212,433	519,155	1,164,049	60,789	105,409	213,653	517,102	1,162,429
Feb	70,716	110,893	262,604	578,914	1,346,479	70,168	110,033	260,841	579,101	1,342,167
Mar	75,329	132,206	250,959	739,592	1,417,398	75,321	130,290	250,652	737,135	1,410,446
Apr	86,985	128,557	276,806	550,789	1,325,127	84,886	126,557	274,214	548,422	1,322,327
May	99,678	196,460	434,028	1,092,015	2,599,073	98,278	193,613	429,957	1,088,293	2,595,198
Jun	87,835	146,604	299,136	875,846	1,844,749	85,619	146,194	297,024	871,899	1,842,554
Jul	66,796	114,270	154,006	288,495	888,795	70,060	113,231	152,802	286,699	875,099
Aug	61,049	88,699	129,654	193,942	282,066	58,884	86,604	128,274	193,527	280,373
Sep	60,721	93,784	136,434	179,436	501,665	56,826	93,122	135,500	179,062	491,312
Oct	60,545	86,006	146,371	296,415	1,147,932	61,286	84,380	145,324	294,079	1,133,393
Nov	58,263	96,765	160,429	384,689	1,233,383	57,299	94,560	159,779	383,235	1,230,963

Dec	60,544	90,122	195,871	443,096	1,419,081	58,919	88,077	195,912	441,172	1,416,830
Winter	331,938	609,526	1,155,000	1,966,070	4,392,306	325,688	605,800	1,151,129	1,958,219	4,368,295
Spring	371,168	736,767	1,894,331	3,592,462	5,970,819	366,539	743,507	1,900,158	3,581,884	5,959,258
Summer	290,400	451,464	718,056	1,072,733	1,911,055	282,312	446,458	707,863	1,064,169	1,894,090
Annual	1,224,635	2,066,128	4,340,444	6,601,529	11,533,446	1,206,523	2,043,573	4,302,203	6,574,418	11,506,424

Brazos River at Gulf of Mexico

Period	**Current Return Flows - Exceedance Frequency**					**With Reuse Strategies - Exceedance Frequency**				
	95%	**75%**	**50%**	**25%**	**5%**	**95%**	**75%**	**50%**	**25%**	**5%**
Jan	4	35,545	159,737	465,481	1,141,101	1	33,574	161,243	463,445	1,139,485
Feb	4	35,915	187,994	538,254	1,279,490	3	35,466	186,366	539,433	1,277,215
Mar	1	45,025	168,205	746,360	1,438,896	1	42,696	166,910	744,772	1,436,568
Apr	1	37,557	222,353	471,376	1,344,741	1	35,269	219,365	469,033	1,341,811
May	3,573	87,231	343,763	1,062,961	2,565,321	3,557	85,141	340,577	1,059,299	2,561,511
Jun	3	39,175	190,766	769,650	1,883,059	3	37,377	187,763	765,771	1,882,348
Jul	0	8	36,851	187,517	818,267	0	8	35,556	185,874	816,541
Aug	0	3	7,497	80,272	193,450	0	3	6,834	78,696	191,314
Sep	0	1,924	52,100	127,894	443,787	0	809	52,399	127,780	433,681
Oct	0	5,692	71,537	246,847	1,151,712	0	4,050	69,981	245,197	1,137,542
Nov	0	32,702	109,729	332,801	1,208,561	0	31,196	108,068	331,352	1,206,174
Dec	0	25,745	153,507	402,130	1,413,328	0	24,874	151,957	400,703	1,411,099
Winter	77,446	390,715	944,893	1,755,385	4,330,464	75,960	385,072	942,321	1,762,814	4,281,508
Spring	7,405	342,938	1,533,674	3,295,866	5,942,380	6,424	346,173	1,520,917	3,285,815	5,929,307
Summer	18	78,652	343,304	692,065	1,681,274	18	74,897	339,113	678,551	1,650,525
Annual	382,164	1,087,745	3,577,786	5,658,669	10,998,619	374,729	1,079,684	3,547,757	5,632,670	10,972,396

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Appendix – TWDB Comments Received on the Draft Report and Responses

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REQUIRED CHANGES

General Draft Final Report Comments:

1. Page 1: Please add the following statement to the cover page of the final report:
   Pursuant to House Bill 1, as approved by the 86th Texas Legislature, this study report was funded for the purpose of studying environmental flow needs for Texas rivers and estuaries as part of the adaptive management phase of the Senate Bill 3 process for environmental flows established by the 80th Texas Legislature. The views and conclusions expressed herein are those of the author(s) and do not necessarily reflect the views of the Texas Water Development Board.

Response: The requested statement has been added to the inside title page.

2. Title and throughout the report: please change "streamflows" to "streamflow".

Response: The requested change has been incorporated.

3. Executive Summary:
   a. Please remove all figures and tables in the Executive Summary.

Response: All figures and tables have been removed from the Executive Summary.

   b. Please summarize the text where details on methodology (e.g., details on how return flow discharges were developed can be omitted from the executive summary).

Response: The text in the Executive Summary related to methodology has been summarized and reduced in length.

   c. Please include in the text by how much the monthly medians and low flows are reduced at Double Mountain Fork.

Response: The text in the Executive Summary has been modified to discuss changes in flow at the Double Mountain Fork near Aspermont.

   d. Please consider adding a sentence or two that summarizes why using the WAMs are not ideal for assessing the impact of reuse strategies on environmental flows.

Response: Text has been added to both the summary section in Chapter 6 and to the Executive Summary discussing the limitations of comparing monthly WAM regulated flows to e-flows standards that are based on daily flows.

4. Page 8 (please replace the last paragraph with the requested wording below):
   Current wording: Overall, the flow regimes, as characterized by flow frequency curves, show little change due to plan implementation relative

to current return flow conditions, with changes occurring mostly to low flows that are exceeded 75 percent of the time. Locations directly downstream of proposed reuse projects would experience the most noticeable reductions in streamflow. In summary, none of the locations is expected to experience significantly different streamflow with implementation of the reuse water management strategies that are recommended in the 2021 regional water plans.

Requested wording: Overall, the flow regimes, as characterized by flow frequency curves, show that change due to plan implementation relative to current return flow conditions occur mostly to low flows that are exceeded 75 percent of the time. Locations directly downstream of proposed reuse projects would experience the most noticeable reductions in streamflow. This study clearly identifies at least one site (i.e., Double Mountain Fork near Aspermont) where implementation of reuse water management strategies that are recommended in the 2021 regional water plan will significantly impact low flow hydrology with potentially significant impacts on the aquatic environment.

Response: The requested text has been added with the following change:

> The requested text: *"...will significantly impact low flow hydrology with potentially significant impacts on the aquatic environment."*
>
> has been changed to: "*...will significantly affect low flow hydrology, which has already been affected by the return flows themselves. Both the return flows and reductions in return flows caused by implementation of the reuse strategies will potentially affect the aquatic environment.*"

5. Figures 4-5, 4-9, 4-11, and 4-13: Please show the base and subsistence flows for December. Currently they only appear for the first 11 months.

Response: This has been corrected. This resulted from using an earlier version of the CERST to generate the plots which has since been corrected.

6. Page 46, Section 4.5.8, Summary (please replace the fourth sentence with the requested wording below):

Current wording: In summary, none of the locations is expected to experience significantly different streamflow with implementation of the reuse water management strategies that are recommended in the 2021 regional water plans.

Requested wording: In summary, while most locations are not expected to experience significantly different streamflow with the implementation of reuse water management strategies that are recommended in the 2021 regional water plans, this study clearly identifies at least one site (i.e., Double Mountain Fork near Aspermont) where implementation of recommended reuse water management strategies will significantly impact low flow hydrology with potentially significant impacts on the aquatic environment.

Response: The requested text has been added with the following change:

The requested text: *"…will significantly impact low flow hydrology with potentially significant impacts on the aquatic environment."*

has been changed to: *"…will significantly affect low flow hydrology, which has already been affected by the return flows themselves. Both the return flows and reductions in return flows caused by implementation of the reuse strategies will potentially affect the aquatic environment."*

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