SULPHUR RIVER ENVIRONMENTAL FLOW REGIME AND ANALYSIS RECOMMENDATION REPORT

Prepared By:

Trungale Engineering & Science
707 Rio Grande, Suite 200
Austin, Texas 78701

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INTRODUCTION

Texas' regional water planning process, SB1, currently in its fourth iteration, is charged with providing long-term water supply solutions to meet Texas' growing water demands. The plan is required to ensure protection of natural resources of the entire state. Protection of natural resources is achieved in part through the consideration of environmental water needs, including instream flows, and adjustments to water management strategies to provide for environmental water needs. For most of the state, analyses have recently been conducted under the SB3 environmental planning process to develop science-based environmental flow recommendations based on the best available data. The recommendations have been reviewed and commented on by basin stakeholders and have been considered by the Texas Commission on Environmental Quality (TCEQ) in the development of rules to be applied for the permitting of new water rights.

The SB3 process has not been performed in the Sulphur River Basin. Lacking state-of-the-science based flow recommendations, this basin has limited resources upon which to make planning decisions necessary to ensure the protection of natural resources as related to instream flows. For the purposes of evaluating available supply from a selected water management strategy, the SB1 Regional Water Planning Groups are to use environmental information in accordance with the Commission's adopted environmental flow standards under 30 TAC Chapter 298 (relating to Environmental Flow Standards for Surface Water) where applicable or, in basins where standards are not available or have not been adopted (such as the Red, Sulphur, and Cypress River Basins in the Region D planning area), information from existing site-specific studies or state consensus environmental planning criteria. The consensus criteria environmental flow recommendations were developed in the 1990's primarily as placeholders until more scientifically defensible approaches were developed. They are a simple desktop approach and do not consider site-specific flow needs. As will be discussed below, the continued use of these flows and especially their application to major reservoir projects such as the Region C proposed Marvin Nichols project is not appropriate and will not lead to the goal of ensuring protection of natural resources in the Sulphur basin.

This report presents an alternative recommendation based on the principles and methodologies developed as part of the SB3 process. Although there has been some variation among the different SB3 groups, particularly with respect to some of the technical details, as to how the flow recommendations were developed, for the sake of brevity and simplicity, the process can be summarized in two steps:

1. Calculation of preliminary flow recommendations by applying the Hydrology-based Environmental Flow Regime (HEFR) methodology to the appropriate historical gage data, and
2. Review and consideration best available science related to the water quality, aquatic biology, sediment transport and riparian ecology to refine the preliminary recommendations into the final recommendations.

1 PRELIMINARY FLOW RECOMMENDATIONS

A preliminary set of flow recommendations is generated based a statistical analysis of historical flows. This is accomplished through the application of HEFR, an excel software add-on developed by the Texas Parks and Wildlife Department specifically for the SB3 environmental flow program. The software reads in historical flow data for select gages, then parses and classifies levels of the flow regime into low and high flow categories. For the analysis presented in this report, the program has been applied to the historical flows recorded at the USGS gage 07343200 (Sulphur River near Talco, TX) for the period from 10/1/1956 to 9/30/1991. This period represents the entire unregulated period (prior to the construction of Jim Chapman Dam and Cooper Lake) and results in the preliminary flow recommendations shown in Figure 1. These results from HEFR provide flow recommendations for a full range of hydrologic conditions and are intended to protect and maintain the ecological functions described in Table 1.

Overbank Flows	Qp: 42,200 cfs with Average Frequency 1 per 5 years Regressed Volume is 308,212 to 688,796 (460,755) Regressed Duration is 19 to 50 (31)			
Overbank Flows	Qp: 28,300 cfs with Average Frequency 1 per 2 years Regressed Volume is 192,257 to 429,410 (287,327) Regressed Duration is 16 to 42 (26)			
High Flow Pulses	Qp: 24,300 cfs with Average Frequency 1 per year Regressed Volume is 160,586 to 358,599 (239,970) Regressed Duration is 15 to 39 (24)			
High Flow Pulses	Qp: 14,800 cfs with Average Frequency 2 per year Regressed Volume is 89,395 to 199,510 (133,548) Regressed Duration is 12 to 31 (20)			
High Flow Pulses	Qp: 10,800 cfs with Average Frequency 1 per season Regressed Volume is 62,379 to 135,586 (91,966) Regressed Duration is 10 to 27 (17)	Qp: 12,000 cfs with Average Frequency 1 per season Regressed Volume is 73,202 to 166,434 (110,378) Regressed Duration is 12 to 30 (19)	Qp: 1,790 cfs with Average Frequency 1 per season Regressed Volume is 7,345 to 16,249 (10,925) Regressed Duration is 5 to 12 (8)	Qp: 5,390 cfs with Average Frequency 1 per season Regressed Volume is 25,038 to 53,773 (36,693) Regressed Duration is 7 to 17 (11)
High Flow Pulses	Qp: 1,640 cfs with Average Frequency 2 per season Regressed Volume is 7,442 to 16,143 (10,960) Regressed Duration is 5 to 14 (8)	Qp: 1,690 cfs with Average Frequency 2 per season Regressed Volume is 7,195 to 16,320 (10,836) Regressed Duration is 5 to 13 (8)	Qp: 374 cfs with Average Frequency 2 per season Regressed Volume is 1,131 to 2,503 (1,683) Regressed Duration is 2 to 6 (4)	Qp: 1,010 cfs with Average Frequency 2 per season Regressed Volume is 3,331 to 7,144 (4,878) Regressed Duration is 3 to 8 (5)
Base Flows (cfs)	53(64.5%)	59(71.5%)	25(48.4%)	26(47.0%)
Base Flows (cfs)	24(76.0%)	33(81.3%)	8.4(62.3%)	9.1(60.2%)
Base Flows (cfs)	8(87.7%)	18(90.7%)	3.2(76.7%)	3.1(74.3%)
Subsistence Flows (cfs)	3(95.1%)	11(95.3%)	0.12(95.0%)	0.05(95.3%)
	Dec Jan Feb	Mar Apr May	Jun Jul Aug	Sep Oct Nov
	Winter	Spring	Summer	Fall

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:
1. Period of Record used : 10/1/1956 to 9/30/1991.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 0.4 cfs.

Figure 1 Preliminary Flow Recommendation

Table 1 Definitions and objectives for instream flow components (Table 10.1 from TIFP 2008)

Subsistence flows
Definition: Infrequent, seasonal periods of low flow
Objectives: Maintain water quality criteria

Base flows
Definition: Normal flow conditions between storm events
Objectives: Ensure adequate habitat conditions, including variability, to support the natural biological community

High flow pulses
Definition: Short-duration, in-channel, high flow events following storm events
Objectives: Maintain important physical habitat features
Provide longitudinal connectivity along the river channel

Overbank flows
Definition: Infrequent, high flow events that exceed the normal channel
Objectives: Maintain riparian areas
Provide lateral connectivity between the river channel and active floodplain

2 Application of Overlay Analysis

In step two of the SB3 process, BBEST teams applied overlay analysis related to water quality, aquatic biology, sediment transport and riparian ecology to produce the final flows recommendations needed to meet the objectives defined in Table 1.

For subsistence and low base flows, a water quality analysis was generally conducted and in some cases the reported minimum 7-day, 2-year discharge (7Q2) value was used as a minimum flow recommendation value. The 7Q2 for the Sulphur River near Talco is 7.8 cfs.

When available, instream habitat analyses were conducted to determine the flows necessary "to ensure adequate habitat conditions, including variability, to support the natural biological community of the specific river sub-basin. These habitat conditions are expected to vary from day to day, season to season, and year to year. This variability is essential in order to balance the distinct habitat requirements of various species, guilds, and assemblages." In the absence of site-specific data or some other compelling reason to select other values, the generally accepted theory is that habitat conditions which support natural biological communities are those that are produced by the natural hydrology of the stream. One reasonable estimate of the natural hydrology is the set of base flows produced by the HEFR program. Most of the BBEST have adopted, and not modified, the base flows produced by the HEFR program.

While subsistence and base flows produced by HERF have generally carried through to the flow standards adopted by TCEQ, the high flow and overbank flows have been subject to greater scrutiny and refinement. Thus, they will be the focus of greater attention in this report.

It is worth noting that the decision about how many and which high flow and overbank events would be included in the flow recommendation proposed by the various BBEST groups and in the flow standards adopted by TCEQ has varied widely between basins. In general, the BBEST groups have recognized the ecological benefits of overbank flow, but none of the standards adopted by TCEQ have included overbank recommendations, citing concern with the potential to cause flooding.

In its discussion of rules, TCEQ (2013) has in included the following language:

"The commission acknowledges that overbank flows are considered to be a component of a flow regime for a sound ecological environment. However, these flows result from naturally occurring large rainfall events, which will likely continue to occur. Therefore, the commission is not including overbank flows as a component of the proposed standards."

It is important to stress that the flows recommended as part of the recommendations contained that are being proposed in this report are in fact these naturally occurring flows. It is not the intent of this report to suggest that as a result of these recommendations that actions should be taken to artificially produce overbank flows (or maintain all naturally occurring overbank flows). It is also worth considering the geographic context is which these recommendations are to be applied. The middle Sulphur River in the vicinity of the proposed Marvin Nichols Reservoir sparsely populated and currently, regularly experiences overbank flows under existing conditions. The flow standards, rather than seeking to create floods, would seek to preserve the overbank flow regime that currently exists and is necessary for the maintenance and protections of bottomland hardwood forests that have been recognized to have high ecological value. The existing situation in the Sulphur is very different from some of the other rivers in Texas where large high flow pulse and overbank flow recommendations have been considered. For example, in the Cypress basin, scientists and stakeholders, while recognizing the importance of these high flow events, also recognized that even if these flows could be passed through the existing reservoir (Lake o' the Pines), doing so would present an unacceptable flood risk to the City of Jefferson. As a result, it was agreed that overbank flow recommendations at Lake O' the Pines would not be implementable under current conditions. This rational does not apply in the middle Sulphur River, which under existing conditions regularly experiences overbank flows. In fact, given the high ecological value of the wetland and bottomland hardwood forests in the area, it is precisely these overbank flows that will need to be maintained if the current ecological health of this system is to be maintained. As will be discussed later, the modeling of the proposed Marvin Nichols Reservoir Project demonstrates that if this project is implemented, most of these naturally occurring events are not likely to continue.

3 RIPARIAN AND WETLAND FORESTS CHARACTERIZATION

The first step in the overlay analysis to evaluate the relationship between overbank flow and riparian and wetland BLM forests is to characterize the existing biological condition and the ecological benefits that maintenance of a sound environment would be expected to produce. The ecological benefits derived from heathy riparian and wetland bottomland hardwood (BLH) forests are significant. Floodplains with BLH and other ecologically important habitats are one of most altered and imperiled ecosystems on Earth (Opperman et al. 2010). The bottomland hardwood forest habitat diversity within the Sulphur River basin is high (USFWS 1985 and 2000). Primarily due to environmental variability, these floodplain forest communities exhibit a high diversity of tree species, unlike upland forests, which are often dominated by one or two tree species (McKnight et al. 1981). The interaction of a changeable inundation regime with the geomorphologic patchwork of microtopography and soil types also leads to high between-habitat diversity (Junk et al. 1989). As a consequence of this ongoing interplay between hydrology and geomorphology, the biodiversity of BLH forests is usually double that of nearby upland forests (Gosselink et al. 1981).

Though tolerance to water saturation of an individual species will vary according to interspecies competition, soil texture, soil nutrients, and available light, the presence of a particular BLH community consisting of many dominant and co-dominant species is defined by the characteristics of the flow regime (Huffman and Forsythe 1981b). Incorporating east Texas BLH habitat types (TPWD 2009), Figure 2 is a schematic presentation of the interdependence of landscape context (relative elevation), tree species, and flow regime (adapted from Diamond 2009 and Huffman and Forsythe 1981a).

The major riparian forest types within the overall project area are summarized in terms of species composition, relative elevation context, and flow regime in Figure 2. Flood frequency and duration (adapted from Huffman and Forsythe, 1981a) are also tabulated for these forest types in Figure 2. In this manner, Figure 2 is a schematic presentation of the interdependence of landscape context (relative elevation), tree species, and flow regime (adapted from Diamond 2009 and Huffman and Forsythe 1981a), for East Texas riparian forest types.

Forested Wetland

Forested wetlands (swamps) are often dominated by monocultures of bald cypress. At relatively low surface elevations, these forests flood essentially every year and are only intermittently exposed. Slightly higher elevations support upper and backwater swamps, which are semi-permanently flooded (more than two months during the growing season) and receive flood inflows ranging from every year to every other year. In addition to bald cypress, upper swamps are characterized by admixtures of water elm, overcup oak, and sweetgum, while in backwater swamps, tupelo gum and green ash may become co-dominant with bald cypress.

Bottomland Hardwood Forest

Seasonally Flooded Forests

As depicted in Figure 2, the probability of seasonally flooded BLH forests being flooded in a given year is 51-100 percent. With the natural hydrologic regime relatively undisturbed, these forests are flooded a total of 1-2 months (12.5-25 percent) during the growing season. Species composition is diverse and dominated by various combinations of willow oak, water oak, sweetgum, and overcup oak, with water hickory, laurel oak, and green ash often as co-dominants.

Temporarily Flooded Forests

With an annual flood probability of 11-50 percent, these forests experience a total flood duration during the growing season of 5-30 days or 2-12.5 percent. Tree species diversity is high, and is currently characterized by water oak, sweetgum, loblolly pine, and cedar elm, along with sugarberry, ironwood, and other red oaks such as willow oak.

Though currently uncommon in northeast Texas and the study area, temporarily flooded forests that are undisturbed and approaching maturity are dominated by elms, ashes, and sugarberry, along with some red oaks (Hodges 1997). The now very uncommon, final successional stage for this community type is characterized by the addition of white oaks and hickories (Hodges 1997). Agriculture and altered hydrologic regimes have all contributed to the loss of this somewhat drier BLH forest type in East Texas. Such disturbances lead to invasion by sweetgum and red oaks in remaining forests.

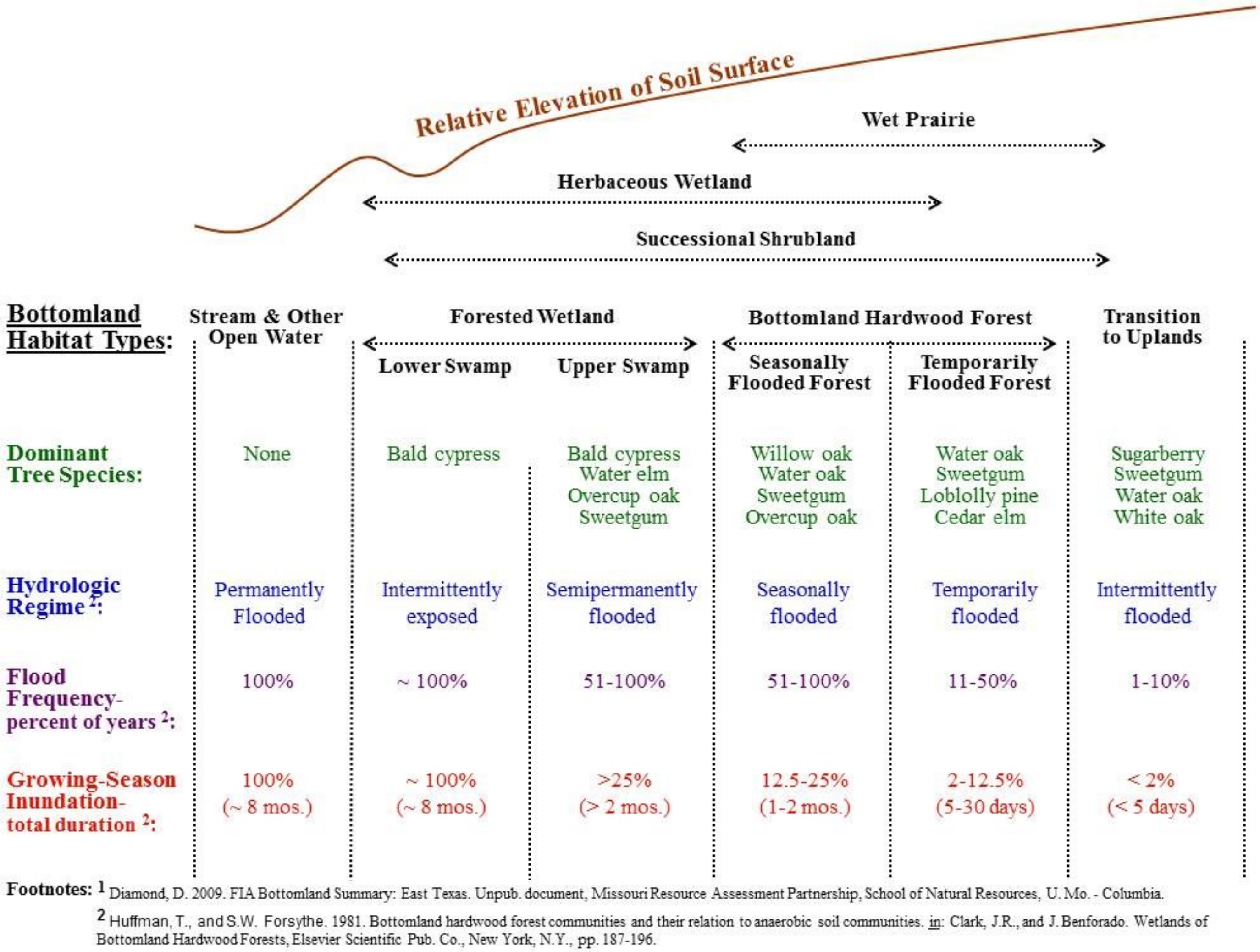

Figure 2 Bottomland Habitat Types in Northeast Texas: Landscape Context, Tree Species, and Hydrology

<u>USFWS Priority 1 Bottomland Hardwood Preservation Site</u>

The Sulphur River basin downstream of the proposed reservoir supports the largest, relatively undisturbed bottomland hardwood forest remaining in Texas (USFWS 1985 and 2000, see Figure 3)).

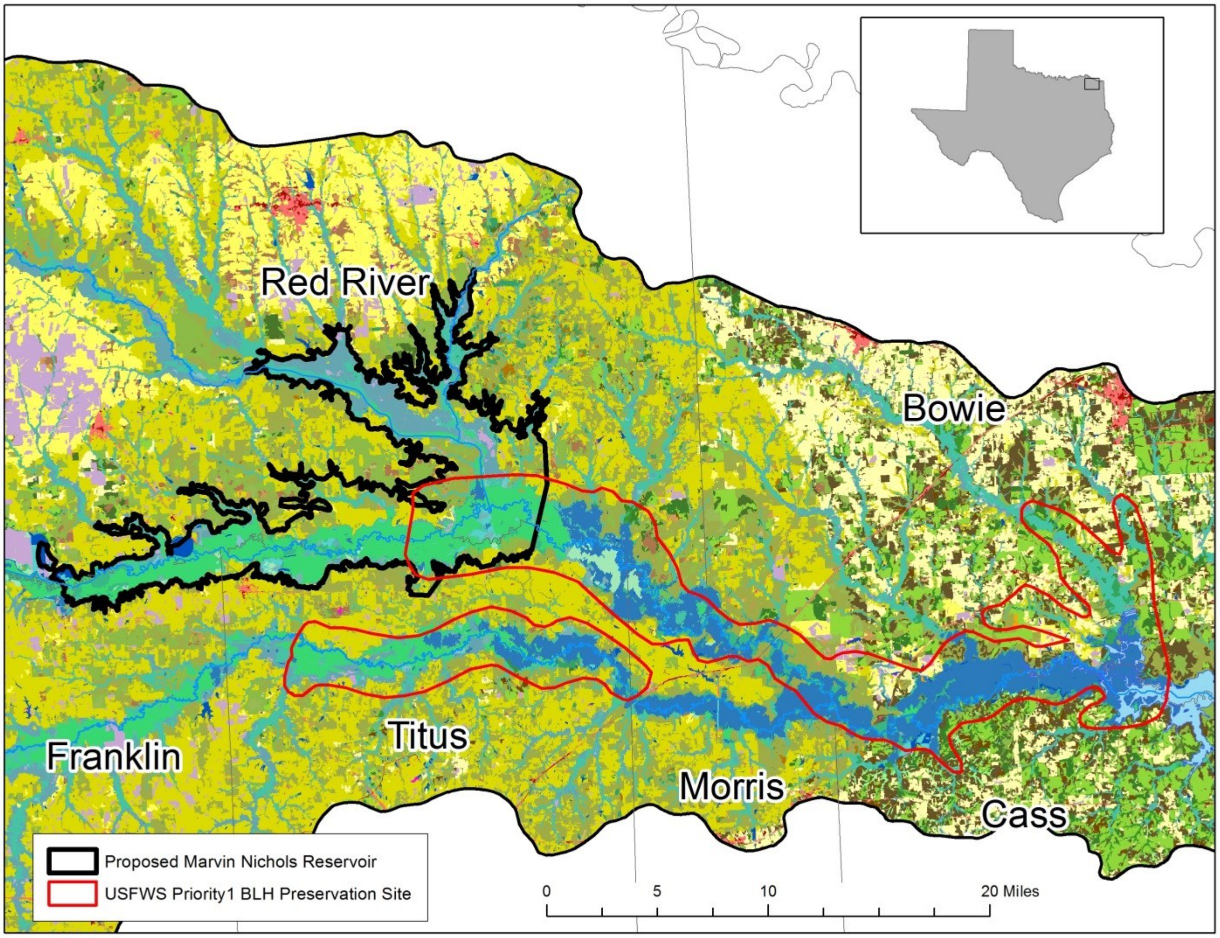

Figure 3 Location of proposed Marvin Nichols Reservoir in relation to USFWS designated Priority Bottomland Hardwood Preservations Site.

3.1 Ecological Services Provided by Bottomland Hardwood Forests

The Sulphur River basin covers a large area that produces highly significant benefits, largely due to relatively undisturbed high and overbank flows that perform many important ecosystem and societal functions. Many important BLH ecosystem services peak with annual flooding, including primary production, plant diversity, animal habitat use, and organic matter export (Gosselink et al. 1981, Hunter et al. 2008, Opperman et al. 2010). Spanning several counties, the Sulphur floodplain is large enough to provide substantial amounts of such services.

Examples of the ecological importance of hydrologic connections within floodplains abound. The reduction in overbank flows results in the loss of backwater areas that comprise a primary source of labile carbon, which forms an essential foundation of riverine and estuarine food chains (Thoms et al. 2005). Where river and floodplains remain connected, freshwater fishery yields are consistently higher (Bayley 1995).

In addition to ecosystem processes, hydrologically-intact floodplains provide important economic benefits, increased biodiversity, and stable environmental services (Bayley 1995). BLH forests function as the foundation of local and regional food chains; supply critical nesting microhabitats, spawning, rearing, and resting areas for aquatic and upland species; and reduce storm and flood damage within adjacent and downstream areas (Gosselink et al. 1981). Though highly vulnerable to flow reductions, temporarily flooded BLH forests near the upland edge of the floodplain offer supplemental water storage, which is especially important during extreme flood events. These forests also serve as buffer-traps for pollution.

3.1.1 Water Quality

One of the most important ecosystem functions of BLH forests to society is improving water quality through the removal of high N concentrations. The wet-dry fluctuations of floodplain soils create successive aerobic and anaerobic environments. Nitrification is an aerobic process, which through microbial oxidation basically converts ammonia compounds to nitrate compounds. During the succeeding wet period, anaerobic soil conditions are created, which promote denitrifying bacteria that, in turn, convert the nitrate compounds to N gases such as nitrous oxide. In this fashion, high N concentrations in river flows are reduced. Healthy BLH forests have high and long-term capacities to remove N and retain phosphorous (P) from floodwaters (Ardon et al. 2010).

3.1.2 Bottomland Forests

King and Allen (1996) showed that reductions in natural flow regimes harm BLH forests by: (1) reducing the growth and primary production of plant communities, (2) shifting plant species composition to that of drier communities, (3) preventing river-floodplain connections leading to reduced sedimentation and water quality, and (4) causing failures in fish and herpetological reproduction. To be most effective, both in terms of maintaining BLH tree species and discouraging invasive upland species, early spring floods following leaf emergence should last a total of two to four weeks (Rypel et al. 2009).

Kozlowski (2002) found that reductions in the variability of river flows reduced groundwater levels, which in turn lowered BLH ecosystem productivity and species diversity. In many areas of the southeastern United States, including east Texas, where high and overbank flows have been reduced due to dams and water extraction, the composition of BLH forests is shifting to species adapted to drier environments (Stallins et al. 2009). This widespread successional change of BLH forests to increased dominance by upland species is first apparent in the understory, including tree seedlings and saplings.

3.1.3 Primary Productivity

The enhancement of primary productivity due to overbank flows allows river floodplains to achieve the highest biomass per area of any temperate ecosystem (Gosselink et al. 1981). An extensive literature review by Conner et al. (1990) shows that primary production of BLH forests with natural hydrology is greater than 1000 g/m2/y, which ranks these forests among the most productive wetland ecosystems. Recent research in northeast Louisiana found the range of carbon storage in BLH forests to be 90-124 Mg C/ha (Hunter et al. 2008). The potential role of BLH forests in mitigating climate change is substantial.

Variable river levels trigger switches between biological production and transfer phases within floodplain habitats, which initiate the exchange of organic matter and nutrients among different terrestrial, aquatic, and estuarine habitats (Amoros and Bornette 2002). The temporal distribution of repeated overbank flows not only is the primary determinant of habitat types, but also drives biogeochemical processes in bottomland soils, such as decomposition, sedimentation, and N cycling (Hunter et al. 2008).

3.1.4 Fish and Wildlife Productivity

Decreased flood frequency reduces bird, mammal, and fish densities in riparian ecosystems (Gosselink et al. 1981). Access to floodplain resources during overbank flows is critical, since almost all animal biomass within riverine systems is produced within floodplains rather than rivers (Junk et al. 1989, Smock et al. 1992). Consequently, for animals the primary function of the main river channel is not production, but to act as an access route for fish and other biota to adjacent floodplain resources. A strongly positive relationship exists between fish production and the amount of accessible floodplain (Junk et al. 1989). Bayley (1995) documented that earlier and briefer overbank events disrupt the evolutionarily-synchronized timing of fish spawning and invertebrate prey availability.

4 Relationship Between Flow Regimes and Healthy BLH Forests

The heath of BLH forests is maintained by the regular occurrence of intermittent overbank pulse flow events. River-floodplain landscapes consist of continuously changing environments and habitats. In undisturbed floodplains, habitats are dominated by a diversity of bottomland hardwood forests, along with shrub and herbaceous wetlands, and both lentic (still) and lotic (flowing) aquatic habitats. The different habitat patches naturally connect with each other via water level fluctuations (Thoms et al. 2005). In this manner, a floodplain is a highly dynamic "aquatic-terrestrial transition zone” (Junk et al. 1989).

Through its effect on habitat availability, the flow regime is the strongest determinant of BLH species composition for both plant and animal populations (King and Allen 1996). This is due to the evolutionarily-tuned correspondence among species distributions and hydrologic cycles (Bedinger 1981). Wetland forests are maintained by episodic high flow events defined by the site-specific flow regimes.

The temporal distribution of repeated overbank flows is not only the primary determinant of habitat types, but also drives biogeochemical processes in floodplain soils, such as decomposition, sedimentation, and nitrogen (N) cycling (Hunter et al. 2008). Variable river levels trigger switches between biological production within floodplain habitats and the exchange of the resulting organic matter and nutrients among different terrestrial, aquatic, and estuarine habitats (Amoros and Bornette 2002). These inputs from productive floodplains are essential to the sustainability of downstream and other habitats linked by variable river flows. In east Texas floodplain forests, Dewey et al. (2006) pinpointed flood duration as the single most important component of the flow regime, in terms of influence on wetland vegetation and soil characteristics.

Hydrologic variability produces spatial and temporal variability of habitats that increases biodiversity. Hydrologic connectivity is multi-dimensional and encompasses longitudinal, lateral, vertical, and temporal variables (Amoros and Bornette 2002). Various species and life cycle stages depend upon the complementary habitats provided by this connectivity. For example, fish migration between spawning and nursery habitats is evolutionarily adapted to floodplain variability.

During their research in floodplain hardwood forests of the southeastern United States coastal plain, Burke and Chambers (2003) conducted regression analyses that compared the annual durations of surface flooding and soil saturation. The analysis indicated the swamp and temporarily flooded forest, on average, flooded 61% and 3% of the year, respectively, compared to soil saturation in the upper 30 cm of soil lasting 84% and 20% of the year, respectively. In the swamp, the depth to the water table normally remained within 30 cm of the surface, while in the temporarily flooded forest the water table receded to a depth of more than one meter every summer.

The depth to persistent soil saturation strongly influences which tree species are sustained within a floodplain. In their study of relationships among hydrology and soil variables in a floodplain forest, Bledsoe and Shear (2000) determined tree species distributions to be most significantly correlated with depth to mottling (r2 = 0.75), which is a measure of the average depth of soil saturation. This finding may be compared to their other significant correlations of tree species distributions to flooding frequency (r2 = 0.57) and surface elevation (r2 = 0.70).

Rood et al. (2005) describe the "flood pulse" as a natural disturbance that revitalizes floodplain habitats. For many BLH tree species, seed germination and seedling establishment must follow floods severe enough to remove existing vegetation and create new seedbeds from bare soil. In addition to providing new substrates in different configurations, floods distribute seeds and vegetative propagules to reestablish plants across the floodplain (Bendix and Hupp 2000). The timing of forest-regeneration floods is important, since not only do the flood-induced erosion and deposition of bare seedbeds need to occur before seed dispersal (Hughes and Rood 2003), but the timing of subsequent seed germination varies by tree species. The spatial configuration and timing of vegetation destruction and renewal during floods causes BLH forests to consist of mosaics of vegetation of different ages and species compositions.

Hughes and Rood (2003) list the most important considerations as: (1) timing inundation to coincide with the phenology (seed dispersal and germination) of target tree species, (2) varying the interannual timing of floods to increase plant diversity, (3) adjusting the rate of flood-water recession, and (4) promoting channel movement and new sedimentation sites to create regeneration sites. A distinctive characteristic of regeneration flows is their requirement for between-year variability of overbank events on a decadal scale, which are superimposed on annual "maintenance flows" that depend on within-year variability for seedling survival.

In addition to their importance in maintaining BLH species diversity, the frequency and duration of overbank flows need to be sufficient to exclude upland species. Extended flooding during extremely wet years has the strongest control on BLH species composition (Townsend 2001), largely due to its adverse impact on upland species. Figure 2 lists flood duration and frequency targets to maintain each BLH habitat type in the proposed project area.

The seasonal timing of flooding largely determines the tree species regenerating within floodplain forests. The high flow and overbank components of the flow regime are consequential determinants of the long-term survival of bottomland species and, thus, species dominance within mature floodplain forests (Townsend 2001). The species-specific effects of extreme flood events, in particular, maintain high species diversity. When flow variability is reduced, floodplain forests are degraded by artificially homogenous species composition with lower productivity.

Both terrestrial and aquatic species benefit from periodic inundation and nutrient exchange caused by floodwater. Proposed water development projects that have the potential to alter the flow regime also have the potential to alter the inundation frequency of low-lying flood-prone areas. Since native species could be affected by such an alteration to their regime, an analysis of inundation extent has been performed to quantify the flooded area for typically recurring floods. (See Section **Error! Reference source not found.** below)

5 Flow Regime Evaluation

Given the value of the BLH forests and their dependence on overbank flows, the next step in the overlay analysis appropriate for determining the flow necessary to protect these habitats is to quantify the areas of inundation that would be expected at different high flow pulse magnitudes.

One quantitative overlay analysis that can be performed using existing data, and thus would likely be employed by a group like a BBEST, would be to determine the area inundated under different high flow pulse event. Considered along with the above review of existing literature relating to the life history requirements of the various plant species that dominate existing wetland habitat types, this quantitative data can be considered in the refinement or modification of the preliminary values estimated by HEFR. An inundation analysis conducted as part of a TWDB study conducted for the USACE (2004) reported results based on an earlier configuration of the proposed reservoir, one which sited the dam about 10 miles further downstream. The data and methodology used by TWDB/USACE are used to estimate areas of inundation based on the currently proposed reservoir site. The following sections mimic the TWDB/USACE report.

The TWDB determined inundation areas for six frequently occurring flood events listed in Table 2, which includes a description of the recurrence frequency of each of these flows based on the HEFR outputs.

Table 2 Flow rates for flood inundation analysis in TWDB report (2004).

Flows (cfs)	Recurrence Description (HEFR)
362	Within bank, base flow condition
862	Transition from in bank to out of bank, occur multiple times in most years
3,000	Flows in these ranges occur on average once per season in each of the
7,130	winter, spring and fall seasons
18,300	Occurs once a year or once every two years on average
32,000	Occurs once every three or four years

Following the same approach and data used by TWDB, flood surfaces were developed for each of these flow rates and overlaid upon National Elevation Dataset (NED) digital elevation models to determine the area of inundation at each flow rate. Figure 4 shows the flood inundation areas produced by lowest (326 cfs) and highest (32,000) flow rates modeled.

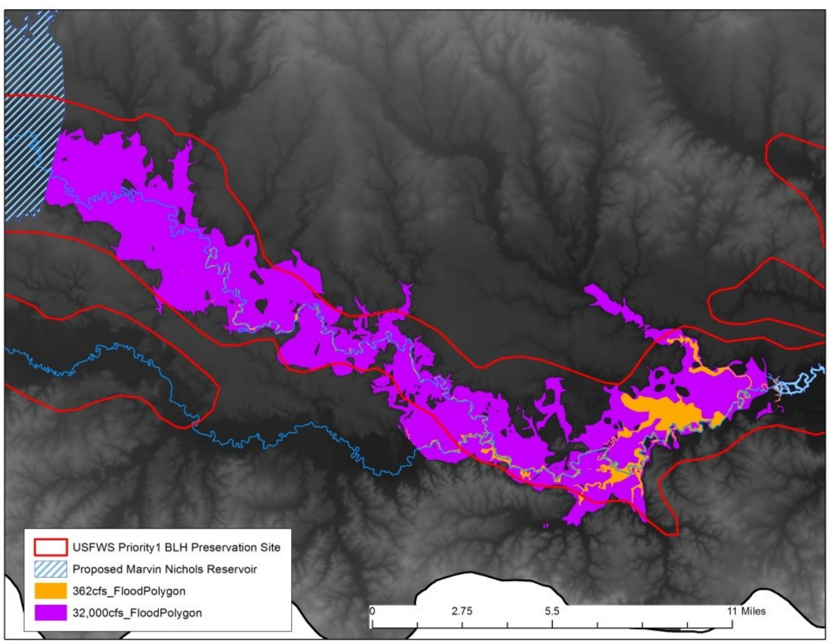

Figure 4 Flood inundation areas produced by lowest (326 cfs) and highest (32,000) flow rates modeled.

Consistent with the finding reported by TWDB, the lower flow rates are mostly confined to the river channel, while the highest flow rates inundate much of the BLH forest. These area polygons were used to determine the areas of inundation of the most flow dependent Texas Vegetation Classification Project Cover Types.

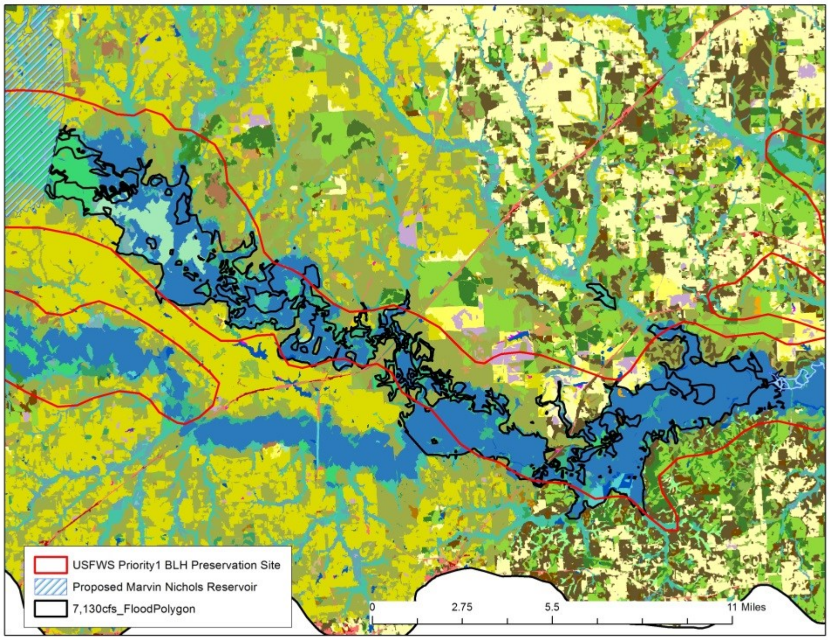

Figure 5 Inundated area and vegetation map for 7,130 cfs flows.

As can be seen in Figure 5, the 7,130 cfs inundation area closely tracks the outline of the Forested Wetland (Bald Cypress Swamp) vegetation type, which is such a critical factor in the USFWS determination to designate this area a Priority 1 Bottomland hardwood forest. This correlation is consistent with the scientific literature that identifies these overbank events as a primary factor in maintaining the health of these forests. As will be discussed in the next section, if the Marvin Nichols Reservoir Project is implemented, flows are predicted to exceed 7,000 cfs very rarely, if at all, and flow between 1,000 -7,000 cfs, which currently occurs several times in most years, would become a rare event, putting the ecological soundness of these forests at significant risk.

Figure 6 show the acres inundated at each flow rate for Forested Wetland and Bottomland Hardwood Forest types. Table 3 shows the total areas that would be impacted due to the loss of inundation by overbank flows.

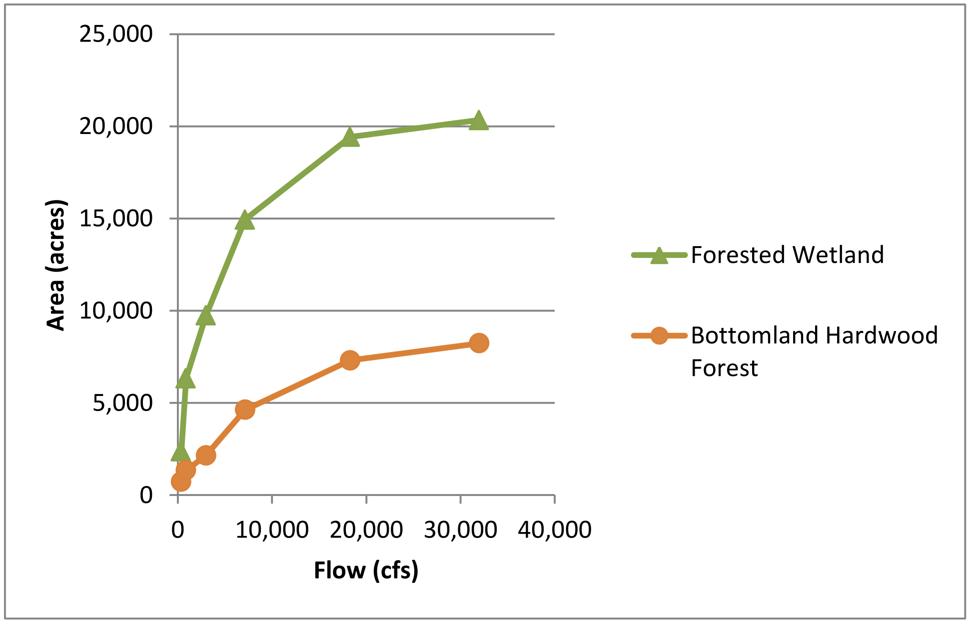

Figure 6 Vegetation areas downstream of the proposed Marvin Nichols project, main stem Sulphur River.

Table 3 Vegetation areas downstream of the proposed Marvin Nichols project, main stem Sulphur River.

				Flows (cfs)						Reservoir Foot Print Only		Reservoir Footprint plus loss of indudated area at 32,000 cfs	
	Sulphur	RegionD	Marvin Nichols	362	862	3,000	7,130	18,300	32,000	Sulphur	RegionD	Sulphur	RegionD
Bottomland Hardwood Forest	232,007	643,330	31,241	732	1,341	2,151	4,626	7,308	8,231	13%	5%	17%	6%
Forested Wetland	47,053	90,639	529	2,366	6,335	9,743	14,938	19,426	20,339	1%	1%	44%	23%

When the effect on flows and the loss of episodic inundation are added to the impacts resulting within the reservoir footprint, the impacts from the Proposed Marvin Nichols Reservoir Project are huge. In the Sulphur basin 44% of the Forested Wetland area and 17% of the Bottomland Hardwood Forests would be at significant risk.

5.1 Consensus Criteria in Region C Plan

The analysis above provides a framework to evaluate the impact of water management strategies on the heath of the BLH forests in the Sulphur basin. The environmental flow requirements used to evaluate the Marvin Nichols Reservoir Water Supply Project are based on an approach developed in the 1990's called the "Consensus Criteria". Under this approach, the flows passed through the reservoir for instream protections are dependent on reservoir levels. The specific target flows are based on statistics calculated based on daily-naturalized inflows. When the reservoir is greater than 80% full, the project is supposed to pass the median flows; when greater than 50% full, the project is supposed to pass the 25^{th} percentile flows, otherwise the project is supposed to pass the 7Q2 flows. Unlike the more recent environmental flow criteria developed as part of SB3, there are no requirements, under the consensus criteria, to pass any high flow pulse flows. The maximum pass through for the proposed Marvin Nichols Reservoir Project, as required by consensus criteria, would be 514 cfs in May and then only if the reservoir is greater than 80% full.

Table 4 Consensus Criteria for Environmental Flow Needs for Marvin Nichols I Reservoir.

Month	Median		25th Percentile		7Q2	
	acft/mo	cfs	acft/mo	cfs	acft/mo	cfs
Jan	13,621	221.5	3,351	54.5	79	1.3
Feb	20,928	373.5	6,192	110.5	72	1.3
Mar	30,522	496.4	8,753	142.4	79	1.3
Apr	17,947	301.6	5,712	96.0	76	1.3
May	31,613	514.1	6,019	97.9	79	1.3
Jun	11,488	193.1	2,748	46.2	76	1.3
Jul	2,524	41.1	530	8.6	79	1.3
Aug	906	14.7	211	3.4	79	1.3
Sep	943	15.8	111	1.9	76	1.3
Oct	1,550	25.2	242	3.9	79	1.3
Nov	4,687	78.8	943	15.9	76	1.3
Dec	11,488	186.8	2,173	35.3	79	1.3

Unless the reservoir is full and spilling, flows in the river downstream of Marvin Nichols will be less than 514 cfs. During most times, flows passed through the reservoir will be much lower. The impact on flows is evident from the flow frequency figure included in a report produced by Region to quantify the impact of the proposed reservoir project (Freese and Nichols 2014), which shows the significant differences in flows with and without the reservoir.

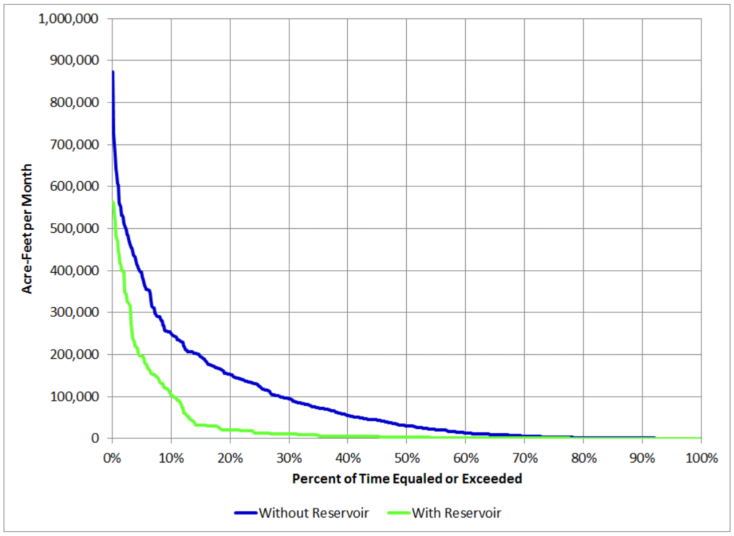

Figure 7 Flow-Frequency Relationship of Sulphur River at Marvin Nichols Dam Site with and without the Reservoir

While the Region C report presents this flow frequency curve and a table of monthly flow frequency relationship with and without Marvin Nichols I reservoir, the report provides no interpretation of these results or any context with which a reviewer might evaluate their importance.

The changes depicted in Figure 7 are massive. The entire flow regime is impacted and the resulting flows would be only a small fraction of the natural regime. Components of this natural flow regime are critical to the maintenance of a sound environment. As discussed above, the most important components of the flow regime for the protection of BLH forests are the occurrence and frequency of high flow pulse and overbank events.

Direct observations and technical evaluations reported in the USACE/TWDB study from 2004 indicate that flows in the range of 862 cfs (approximately 50,000 ACFT per month) are transitional between in-channel and overbank flow. Figure 7 suggests that the occurrence of these events would shift from happening close to 40-50% of the time to happening less than 15% of the time.

An analysis of the outputs from the water availability model, developed by Region C to evaluate the Marvin Nichols project, show that under existing conditions, there is only one year, out of the 57-year record, in which flows did not exceed this threshold volume in at least one month. When the proposed reservoir is included in the simulation, this number jumps to 29 years (more than half of the time) when no overbank events occur. The longest duration of time in which no overbank event occurs under the without-project scenario is 16 months; the flow regime resulting from the proposed reservoir indicates that at two separate times in the record, the river would go 80 months (almost 7 years) without overbank flow events. Figure 8 shows the 82-month period between 1961 – 1968, during which releases from the project would rarely have exceeded 2 acft per month (1 cfs) flows. These flow rates, based on the 7Q2 water quality target, are intended to sustain the river during brief, infrequent and severe droughts, but with the Marvin Nichols project as proposed and modeled by Region C, these extremely low flows would occur much more frequently.

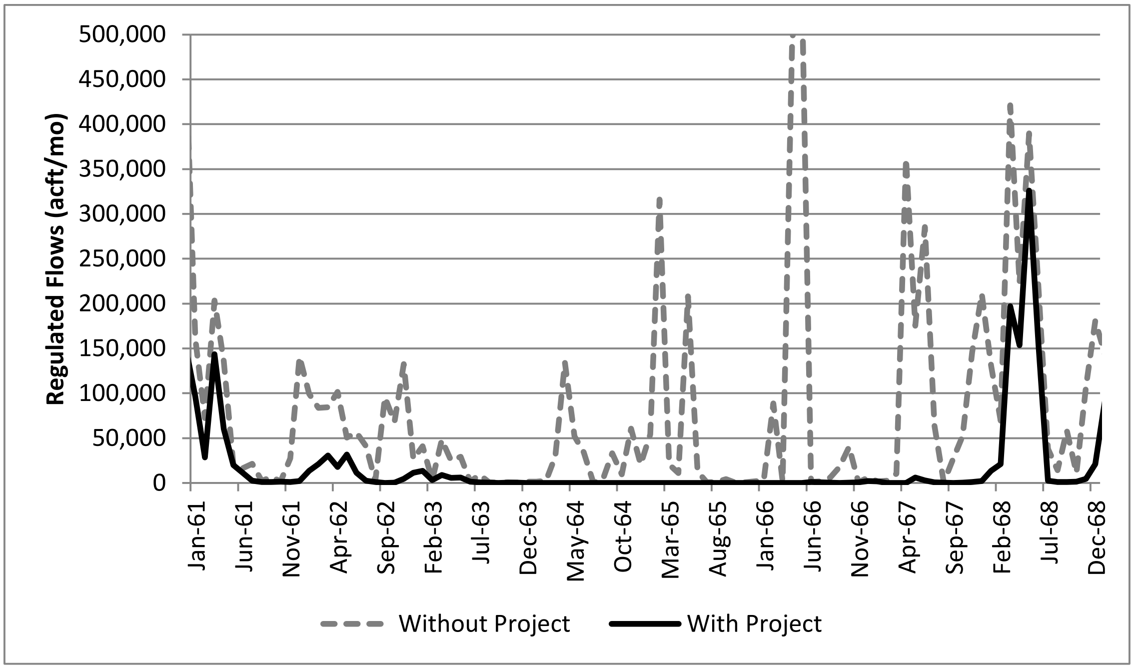

Figure 8 Regulated flows with and without the Marvin Nichols I Reservoir Project (1961-1968)

The flow regime resulting from the implementation of the proposed Marvin Nichols Reservoir water management strategy would have devastating effects on this valuable resource. If the Marvin Nichols project is constructed, downstream river flows, especially critical high flow events, will be significantly reduced. The lack of seasonal flooding identified in the water availability results indicates BLH forests cannot be maintained downstream of the proposed Marvin Nichols reservoir.

6 Flow Regime Recommendation

Had a full-scale SB3 process been conducted in the Sulphur River Basin, it is reasonable to expect that the BBEST would have developed recommendations following the approach described above. The results of the first of two steps, the development of preliminary flow recommendations based on application of the HERF software, are presented in Figure 1.

Although this study presents no overlay analysis to either support or suggest changes to the preliminary flow recommendations for subsistence and base flows, it would be consistent with many other SB3 studies to recommend increasing the subsistence levels to the 7Q2 flow levels and adopting the three base flow levels calculated by the HEFR program.

With respect to the high flow pulse and overbank components of the flow regime, the overlay analyses presented in this report demonstrate the high ecological value associated with the BLH forests in the Sulphur River Basin and the myriad of ecological services provided by the maintenance of healthy bottomland hardwood forests. Furthermore, inundation analysis demonstrates the need for the continued occurrence of regular high flow pulse and overbank flows to provide the levels of inundations necessary for the protection of the existing floodplain forests in the middle Sulphur basin. Results from these analyses clearly demonstrate the need to maintain the various season pulse targets included in HEFR outputs. Diminishing ecological benefits per unit of additional flows as portrayed in Figure 6 suggest that perhaps some of the highest flows may be less critical; however, considering the high resource value and the limited analysis presented in this report, this finding should be subjected to more detailed analysis. Based on these opinions, the flow recommendations for the Sulphur river at Talco are provided in Figure 9.

USGS Gage 07343200, Sulphur Rv nr Talco

	Winter	Spring	Summer	Fall
Subsistence	8 cfs	11 cfs	8 cfs	8 cfs
Base Low	8 cfs	18 cfs	8 cfs	8 cfs
Base Medium	24 cfs	33 cfs	8 cfs	9 cfs
Base High	53 cfs	59 cfs	25 cfs	26 cfs
2 per season	Trigger: 1,600 cfs Volume: 11,000 af Duration: 14 days	Trigger: 1,700 cfs Volume: 10,800 af Duration: 13 days	Trigger: 370 cfs Volume: 1,700 af Duration: 6 days	Trigger: 1,000 cfs Volume: 4,900 af Duration: 8 days
1 per season	Trigger: 10,800 cfs Volume: 92,000 af Duration: 27 days	Trigger: 12,000 cfs Volume: 110,400 af Duration: 30 days	Trigger: 1,800 cfs Volume: 10,900 af Duration: 12 days	Trigger: 5,400 cfs Volume: 36,700 af Duration: 17 days
2 per year	Trigger: 14,800 cfs Volume: 133,500 af Duration: 31 days			
1 per year	Trigger: 24,300 cfs Volume: 240,000 af Duration: 39 days			

cfs = cubic feet per second
af = acre-feet

Figure 9 Recommended Environmental Flow Regime

7 CONCLUSION

This report presents flow recommendations based on an SB3 type environmental flows analysis for one site in the Sulphur River Basin. At this site the ecosystem value Bottomland Hardwood Forests have led to a focus on the importance of considering the protection of high pulse and overbank flow components of the flow regime. A full-scale SB3 analysis would have considered the geographic scope of the Sulphur Basin and have identified additional sites for the development of SB3 monitoring points. Other locations would likely call for greater focus on other parts of the flow regime and the development of overlay analysis to refine or validate preliminary, hydrology-based flow recommendations. Nonetheless the information contained in this report should provide valuable site specific analysis to the Region D planning group to aid it in its consideration a water plan that ensures the protection of natural resources in the region.

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