A REVIEW OF FLOW RELATED BENEFITS AND USES OF THE OCONEE BASIN

Report prepared as part of the project: Flow-Dependent Benefits and Values of Water Resources in the Upper Oconee Region

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Executive Summary

The Oconee River basin provides numerous benefits and uses for the residents of the basin and people in Georgia. These benefits and uses depend to various degrees on the amount of water flowing in the basin's streams and rivers and the reservoirs over time, i.e., the benefits and uses are "flow-dependent". This report aims to expand the information available to support water planning and management in the Oconee basin by summarizing flow-dependent benefits and uses, including supporting services (flow-dependent processes that support or enhance other uses), biodiversity, recreation, and the direct uses such as water supply, discharge of treated wastewater, and hydroelectric power production.

Supporting services provided by the Oconee River are flow-dependent processes that support other uses and benefits and include maintenance of (1) river channel form and aquatic habitats, (2) floodplain and wetland habitats, and (3) assimilative capacity and water quality. A "functional flows" framework was used to identify flow components, and specific flow levels, durations and timing, needed to sustain supporting services. High-flow events that mobilize and transport sediment are generally needed to maintain river channels and aquatic habitats and flows sufficiently high to inundate and connect to riparian floodplains, including wetlands and oxbows, are essential for maintaining ecological function of those habitats. Flow magnitudes that support channel maintenance and floodplain habitat functions have been identified for the mainstem Oconee River downstream from Sinclair Dam; channel-maintenance and floodplain habitat flows needed in the more upstream portion of the basin represent an information gap. Low flows, which occur during periods of reduced rainfall and seasonally during summertime, may limit a third supporting service – maintenance of assimilative capacity and water quality. In addition to waste-water assimilation, these flow-dependent supporting services enable and enhance other basin uses and benefits including riverine and riparian biodiversity and recreation.

The Oconee basin is home to biologically diverse aquatic ecosystems that support multiple species of conservation concern (including fishes, mussels, and crayfishes), as well as sport-fishing, bird-watching, and general nature enjoyment. Habitats for biodiversity in the upper, Piedmont portion of the basin include headwater streams, rocky shoals in larger streams and rivers, human-made reservoirs (Lakes Oconee and Sinclair), and bottomland hardwood communities in river floodplains. Habitats in the lower, Coastal Plain portion of the basin include oxbow lakes, sand and gravel bars, pools, complexes of large wood (snags), and seasonally inundated floodplain forests and wetlands. The variety of plants and animals – representing diverse modes of living and reproducing – associated with the basin's riverine and floodplain habitats potentially complicates identifying flows needed to support this biodiversity. One approach to this challenge entails using the functional flow framework to identify flow levels, durations and timing needed for processes key to supporting biodiversity generally. This report identifies five "functional flows" that together address supporting services and biodiversity: (1) Channel maintenance flows, (2) floodplain habitat connectivity flows, (3) Spring pulse flows, (4) Spring and early summer ('reproductive season') baseflows, and (5) Summer and fall (dry season) baseflows. Site-specific flow levels associated with particular functional flows are provided where available from previous studies. The relative emphasis placed on a functional flow may differ between the Piedmont and Coastal Plain. For example, there is greater floodplain and wetland connectivity in the Coastal Plain, and the wetland community present in the lower basin may be more reliant on maintaining the connections between the river and floodplain overtime than some sites along Piedmont floodplain. The context within functional flows also differs between the upper and lower basin (e.g., Piedmont and Coastal Plain provinces). In the Piedmont, extreme low flows can dry out shoal habitats and impair connectivity within and between shoals, while in the Coastal Plain connectivity within the channels and access to oxbow lakes may be lost during extreme low flows.

Recreation includes a wide range of activities in Oconee basin rivers and lakes, and along the riparian lands beside the rivers. Recreational opportunities available throughout the basin include hunting, fishing, paddling (kayaking and canoeing), and motorized boating, as well as enjoyment of parks and natural areas located along the basin's tributary streams, rivers, and reservoirs. Recreation activities in the basin are enabled by flows that maintain the river channels, habitats, and water quality (i.e., supporting services) provided by the river systems. Some recreational activities may be directly limited or enhanced by specific streamflow or lake levels. Some thresholds for paddling were identified in the literature, and summarized in the report, however, information relating to seasonal use and flow levels were not available in the literature across many of the recreational activities and was identified as a gap for this report. Historical and environmental education activities and opportunities associated with Oconee basin rivers, streams and floodplains are also noted.

Direct, flow-dependent uses include water supply, discharge of treated wastewater, and hydroelectric power production. Water-supply uses support municipal, industrial, and agricultural sectors, which vary geographically in water-demand and may be limited by low river flows that preclude operation of water withdrawal systems or that do not meet low-flow requirements associated with site-specific permits. Municipal and industrial water demands generally are higher in the upper basin where there is more urbanization. As of 2020, there were 34 permitted surface water withdrawals for municipal and industrial use in the Oconee Basin, with 16 on the mainstem of the North, Middle, and Oconee Rivers and in Lakes Oconee and Sinclair. Treated wastewater is discharged along the North, Middle, and Oconee mainstems as well as multiple locations on tributary streams and can also be limited by low flows. Three active hydropower dams, all located in the upper portion of the basin, have project-specific minimum flows or lake levels required for operations. Information on the flow requirements for these direct water uses in the Oconee basin (summarized in the final sections of the report) have improved over time and are currently used in the water planning process.

The information presented in this report was developed from available literature, including scientific studies, reports, and government documents that provide information on flow-related benefits and uses in the Oconee basin or from similar river basins. The information has provided a strong foundation to develop linkages, both qualitative and quantitative, between flow and these benefits and uses. There are, however, many areas that would be strengthened through additional information, with gaps identified with respect to specific benefits or uses. In many cases, site-specific studies could be used to inform understanding while also providing information useful for estimating flow needs at other, similar sites. Flow indicators presented in this report may be viewed a starting point for incorporating relations between flows and valued uses and benefits in water planning for the Oconee basin.

Introduction

Georgia's comprehensive State Water Plan, adopted in 2008, created ten water planning regions across the state. A council appointed for each region develops a Regional Water Plan, which is then approved by the Director of the Georgia Environmental Protection Division (GAEPD). Plans are revised or updated every 5 years, drawing projections of demand for water withdrawal and wastewater discharge as well as assessments of current and projected water availability (Council 2017, CDM Smith 2017). The plans specify goals for the region's water resources; identify resources with potential shortfalls, given projected demands; and recommend practices to address potential shortfalls and meet regional goals. The Upper Oconee Regional Water plan was last revised in 2017 and one of the stated goals of the plan is to "Identify and plan measures to ensure sustainable, adequate water supply to meet current and predicted long-term population, environmental, and economic needs" (Council 2017).

The regional water planning process depends on information about the freshwater uses and benefits in the basin and the streamflow levels ("flow") needed to support those. Detailed information on current and projected withdrawals to meet demands for water and wastewater discharge across multiple sectors (municipal, industrial, agricultural, power generation) has been incorporated in regional water plans. Information on other uses, such as recreation and natural resource conservation, have been incorporated to various degrees, however gaps in the types and extent of information available have limited planning for some uses. In particular, information on site-specific flows needed to support recreation and the environment (including ecological functions that maintain or enhance other uses) have not readily been available for use in water planning.

This literature review is part of a larger project drawing on the knowledge of Oconee basin water users and on currently available research to develop basin-specific information on water uses important to stakeholders, with a focus on flow-dependence. The review summarizes information from scientific and technical sources on the flow-dependent benefits and uses in the Oconee basin. Site-specific flow relationships are identified where possible. Sources include relevant empirical and modeling studies and provide information on how these uses, and benefits vary with water levels (streamflow or lake level). One specific aim is to expand the information available to support water planning and management in the Oconee basin. A second objective is to provide a framework for examining how flows relate to the uses and benefits of water resources.

The sections below provide examples, and quantitative relationships where possible, of how flow relates to different types of benefits, uses, and activities in the basin. Each section explicitly defines the relationship between the use or benefit and water levels or flows. In addition to direct uses such as water supply withdrawal, hydropower generation, and wastewater discharge, river systems also provide supporting services that maintain or enhance those direct uses and benefits that people derive from the river. Supporting services also maintain ecological functions that enhance other valued uses including recreation (e.g., fishing), water quality, and biodiversity. Analogous flow relationships are identified across uses to provide indicators that may be suitable for assessing future water use scenarios.

Flow Related Benefits and Uses

The area covered under the Upper Oconee Regional Water Planning Council encompasses much of the Oconee basin and in this report, we focus on the mainstem Oconee and major tributaries. The Oconee basin comprises two catchments defined by 8-digit Hydrologic Units Codes as delineated by the U.S. Geological Survey (Seaber et al. 1987). The upper Oconee River basin (HUC 03070101) has the North and Middle Oconee rivers and their major tributaries (e.g., Mulberry River). The North and Middle Oconee rivers join to form the Oconee River in the Piedmont physiographic province. The upper Oconee basin also covers the majority of the two reservoirs in the middle part of the basin, with inflow from the major tributaries in this section (e.g., Apalachee River, Hard Labor Creek). The lower Oconee River basin (HUC 03070102) is bounded upstream by Sinclair Dam (which impounds Lake Sinclair, the downstream-most mainstem reservoir) and is where the Oconee River enters the Coastal Plain physiographic province. The lower Oconee River basin extends downstream across the Coastal Plain to the Oconee's confluence with the Ocmulgee River. The Piedmont and the Coastal Plain portions of the Oconee basin each encompass several ecoregions, however these two physiographic provinces define general differences in the form of the rivers and surrounding landscape. These differences result, for example, in differing flow-dependent environmental relations, as highlighted below. Overall, the flow-related benefits and uses discussed in this report make the entire Oconee basin a valuable economic resource through the direct uses, recreation opportunities that bring people to the basin, and the property values along lakes and rivers (Sklarz and Miller 2018), which are enhanced by a functioning river system that sustains good water quality and wildlife habitat.

The supporting services for the Oconee basin are discussed first, including the maintenance of river channel form and aquatic habitat, floodplain and wetland habitat, and assimilative capacity and water quality. Next, aquatic biodiversity in the Oconee basin is introduced with information on the functional flows that support biota and the supporting services. Flows that support different types of recreation are discussed in the recreation section, followed by historical flow relationships and watershed connections to education (historical and environmental education section). The finals sections cover water supply, discharge of treated wastewater, and hydroelectric power production, which are currently used for water planning and have the most robust information already developed. All sections start by giving an overview of the use and/or benefit in the Oconee basin and then discuss the qualitative, and where possible the quantitative, relations to flow.

Supporting Services

This section introduces three supporting services that are not considered direct uses of the river, but that relate to and support many of the benefits and uses in the Oconee basin discussed in the following sections. These three supporting services are maintenance of (1) river channel form and aquatic habitats, (2) floodplain and wetland habitats, and (3) assimilative capacity and water quality. As a starting point to develop site-specific environmental flow relationships for the Oconee basin (i.e., flows needed to maintain supporting services and biodiversity), we present a "functional flows" framework (Yarnell et al. 2015). Functional flows aim to identify flow components necessary to maintain and provide key habitats, including in-channel and floodplain habitats, and ecological processes such as aquatic organism reproduction, growth and survival in differing seasons (Dephilip and Moberg 2010, Grantham et al. 2020). Each functional flow can be described by one or more indicators (e.g., seasonal flow levels) with site-specific thresholds identified as appropriate to achieve stakeholder objectives. Table 1 presents functional flows and indicators for maintenance of river channel form, aquatic habitat, floodplain and wetland habitat, assimilative capacity, water quality and biodiversity in the Oconee River basin (Table 1).

Maintenance of river channel form and aquatic habitats

Rivers are dynamic systems shaped by climate, physiography, and biogeography (Lubinski and Barko 2003, Jacobson and Galat 2008), and high flows (i.e., capable of mobilizing and transporting sediment) are the main driver of channel form. The balance between the slope and discharge of a river and the sediment load and characteristics of bed and bank material are the physical processes driving the shape and movement of the channel (Alvarez 2005, Robert 2014). The river channels in the Piedmont portion of the basin are more confined (i.e., within narrower valleys) than in the Coastal Plain and tend to have less lateral movement within the floodplain compared to the portion in the Coastal Plain (Yearwood 2010). The two physiographic provinces also produce different types of aquatic habitats. The Piedmont sections of the rivers have reaches with rocky shoal habitat. The Coastal Plain sections of the river have greater connectivity with the floodplain and lateral channel movement, with meanders and bends that result in oxbow lakes and sloughs as the channel shifts (Yearwood 2010). The two reservoirs near the middle of the basin are in the lower portion of the Piedmont and act as a sediment trap between the upstream and downstream portions of the river, and have altered the magnitude and timing of flows downstream of Sinclair Dam through hydropeaking operations and channel movement downstream of the reservoirs (Evans 1994, Yearwood 2010).

Historical land use has also significantly affected the river channel in the Piedmont. Farming practices during the 19th and 20th centuries resulted in significant sediment buildup in rivers and along the floodplain, which has led to high sediment yields in many Piedmont rivers, including the Oconee (Trimble 1969, Ruhlman and Nutter 1999, Mukundan et al. 2011). Based on studies in other Georgia Piedmont rivers, these changes to sediment dynamics have been shown to have significant and long-term impacts on the river channels and dynamics in terms of sediment movement and channel stability (Jackson et al. 2005, Mukundan et al. 2011). Many stream and river channels in the Piedmont are likely unstable, based on sediment yield and a channel stability index, with greater sediment entering stream channels during high flows, through erosion of the historically deposited bank sediment, and with accretion occurring downstream (Mukundan et al. 2011). The headwaters and tributaries of the Oconee River, which received the greatest amount of sediment, have experienced severe channel erosion and subsequent expansion due to the process described above (Trimble 1969, Ruhlman and Nutter 1999). The most recent surveys of channel morphology and evolution in the upper Oconee were conducted in 1994 by (Ruhlman and Nutter 1999).

Relation to Flow

Flows high enough to mobilize and transport sediment, which may occur during winter and early spring or may be associated with rainfall from hurricanes in late summer and fall, are important generally for the maintenance of channel form and for shaping riverine habitat. However, the effects of historic land-clearing and farming may dominate present-day sediment and channel dynamics in the Piedmont portion of the basin where there is also less lateral channel movement along the floodplain compared to the Coastal Plain. Flow magnitudes needed to maintain channel dynamics in the Piedmont portion of the Oconee basin have not been identified and are a notable information gap, both in the context of the range of flows for channel maintenance and in how it interacts with the impacts of historical sedimentation in the Piedmont.

In the Coastal Plain, river flows control the movement of the channel within a broader floodplain than in the Piedmont. The channel becomes more sinuous and meanders across the floodplain, with more erodible bank sediments, maintaining a number of habitats and features including sandbars, snags (i.e., trees and wood that become entrained within the channel), and oxbow lakes (Evans 1994). The transition from the Piedmont to the Coastal Plain is known as the Fall Line Hills District. In this area (approximately Milledgeville to above Dublin) the river has a steeper gradient than the lower Coastal Plain (USSC 1963, Evans 1994). Channel movement and dynamics below Sinclair Dam were assessed by Yearwood (2010) to evaluate changes before (1937) and after the dam was in place (2005). They found reduced lateral movement of the river but relatively small changes in the average daily discharge and average annual peak discharge compared to changes observed in other dammed rivers. Flow values associated with channel maintenance in the Coastal Plain (Table 1) reportedly occur annually despite operation of Sinclair Dam (EA Engineering 1994).

Maintenance of floodplain and wetland habitats

Floodplains are productive ecosystems at the interface of terrestrial and aquatic systems (Naiman and Decamps 1997), and support river health through the exchange of sediment and nutrients, trapping pollutants before they enter a river or stream, stabilizing stream banks, slowing and absorbing rainfall and runoff, and providing wildlife habitat (DCA 2004, Feld et al. 2018). The floodplain and river channel are a balance of erosive and depositional forces, closely connected through hydrologic and geomorphic processes. The dynamics between the floodplain and river channel differ in the Piedmont and Coastal Plain, with greater floodplain connectivity, wetland extent, and channel meandering in the Coastal Plain (Hupp et al. 2010, Yearwood 2010). Throughout the Oconee Basin, floodplains and wetlands support biodiversity and are important sites for recreation, cultural resources, and educational activities (see the Historical and Environmental Education and Recreation sections for more information).

Floodplain functions depend on flow dynamics (discussed below) and also on the land-use and vegetative cover in these riparian lands. In Georgia, a 25-foot, vegetated buffer generally is required along rivers and streams by the Georgia Erosion and Sedimentation Control Act (OCGA 12-7-1) to maintain some of the functions of the floodplain listed above. Wider buffer zones are required on state-designated trout streams (50-foot buffers are required, however there are no designated trout stream in the Oconee basin) and by some local ordinances (DCA 2004); e.g., Athens Clarke County protects a 75-foot buffer along streams. Land-disturbing activities (excepting agricultural operations) within the protected buffer zone generally require a variance. The natural riparian zone is typically wider than 25 ft and protecting wider buffers can benefit multiple functions including biodiversity. For example, a Candidate Conservation Agreement between the Georgia Power Company (GPC) and US Fish and Wildlife Service in cooperation with the GA Department of Natural Resources specifies protection of 100-foot buffers on selected GPC properties in the Oconee basin to mitigate threats to imperiled mussels (Georgia Power Company 2017).

The floodplains in the Piedmont are typically dominated by bottomland hardwood communities, with indicator species including box elder (*Acer negundo*), river birch (*Betula nigra*), green ash (*Fraxinus pennsylvanica*), sycamore (*Platanus occidentalis*), overcup oak (*Quercus lyrata*), and black willow (*Salix nigra*) (Brinson et al. 1996, Edwards et al. 2013). Tallassee Forest on the floodplain of the Middle Oconee River near Athens is one well surveyed example of an intact Piedmont old growth floodplain forest. Athens Clarke County purchased the 310-acre parcel in 2012 and it has 7 GADNR High Priority Habitats represented (Porter 2014). It also has high species diversity with at least 65 bird species, 58 butterfly species, 22 reptile and amphibian species, 13 aquatic invertebrate families, and 137 spring wildflowers and plants (Porter 2014).

Floodplains in the Coastal Plain portion of the Oconee Basin include hickory-gum bottomland hardwood and cypress-tupelo swamp forests and experience more frequent and prolonged inundation than the Piedmont floodplains (GADNR 1976, Evans 1994). The floodplain extent broadens between Milledgeville and Dublin and provides diverse habitat types for forest and wildlife communities. Cypress and cypress-tupelo swamps are two types of floodplain communities found primarily in the lower Oconee basin. Georgia has the 3rd greatest extend of cypress timberland in the South (Greis et al. 2012). Bald cypress (*Taxodium distichum*) are large, long-lived trees that provide nesting habitat for birds, and the broader community provides habitat for wildlife, floodplain functions (nutrient exchange, filtration, flood attenuation), and are an important tourism destination and popular for wildlife viewing (Meyer et al. 2003, Fabrizio et al. 2012).

Throughout the Oconee basin, lands that are under conservation easements, Wildlife Management Areas (WMAs), and floodplain lands that are protected from development help to maintain forested areas along the river. Specific flow relationships depend on the location in the basin and the type of habitat on those lands.

Relation to Flow

High flow events (i.e., that overtop riverbanks or otherwise push water into riparian areas) maintain connectivity between a river and the floodplain. In the Piedmont, the legacy of culturally accelerated sedimentation from the 1800's and 1900's, damming and diversions, and channelization have generally reduced floodplain connectivity (Trimble 1969, Brinson et al. 1996). Altered river dynamics resulting from increased sedimentation are largely responsible for incised channels within steep banks and lowered floodplain connectivity (Trimble 1969, Ruhlman and Nutter 1999, Mukundan et al. 2011). Although overbanks flows have been reduced, the presence of tributaries and creeks, rainfall and runoff, or beaver-dams that create wetlands also support floodplain communities in the Piedmont (Brinson et al. 1996). One study of floodplains near Athens found that a North Oconee floodplain maintained overbank flow connections from the river to the floodplain (Table 1), whereas a Middle Oconee floodplain connected to the river during rain events that filled the floodplain which then connected to the river through low spots in the bank (Galatowitsch and Batzer 2011). Connections between river and floodplain in the Oconee basin have been documented for Tallassee Forest Nature Preserve. Based on reported flooding in the area in early 2014, we know that this area maintains some connection to the river during high flow events (Porter 2014). During the flood event (maximum flow above 5000 cfs) there was about 2 feet of standing water in the area (Porter 2014). In Piedmont areas with valued floodplain resources, identifying the specific flow levels that connect the river and floodplain, and determining the frequency of these flooding events in the past would allow assessment of changes over time or those projected to change with water demand, improving the information available for water planning.

In the Coastal Plain, floodplain inundation ranges from days to months and depend both on river flows and seasonal evapotranspiration in floodplain forests, with the extent of flooding depending on flow magnitude (Benke et al. 2000, Meyer et al. 2003). High flow periods that connect the river to the floodplain also provide for sediment and nutrient exchange, and the timing has been shown to be important in maintaining or shaping the floodplain forest community (Junk et al. 1989, Meyer et al. 2003, Hupp et al. 2010). Bald cypress trees (*Taxodium distichum*) rely on hydrochory (passive dispersal by water) for seed dispersal. A study from the Roanoke River floodplain in North Carolina found that the median annual flood duration was 198 days (Townsend 2001, Meyer et al. 2003), with seed fall typically from September to November (Sharitz et al. 1990) and germination in the spring. Although bald cypress requires dry periods for development, the seedlings are tolerant to inundation (Souther and Shaffer 2000). Flows that connect the Oconee River in the Coastal Plain to the floodplain have been estimated (Table 1), however the inundation times needed to support floodplain functions are not currently known. For both the Piedmont and Coastal Plain, inundation time will depend on the season and hydrologic processes within the floodplain, such as evaporation and transpiration ranges, rainfall, runoff, and river flooding. The information about river and floodplain connections provided from the re-licensing study for Sinclair Dam (EA Engineering) provides a baseline for measuring floodplain connectivity in the lower Oconee (Table 1). However, developing relations between flow magnitude and the extent and duration of floodplain connectivity at specific locations (e.g., WMAs) where floodplain functions are particularly valued would refine the information available for water planning.

Assimilative capacity and water quality

Georgia EPD defines assimilative capacity as “the amount of pollutant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria” (GAEPD 2017). River ecosystems require nutrients to function; however, excessive loading from nonpoint or point sources can lead to a decline in water quality, loss of aquatic organisms, algal build up, and other deleterious effects (McClain et al. 1998). There are costs involved in the treatment of wastewater but also costs of poor water quality associated with impacts to other uses and benefits in the river, such as recreation and water supply. In the Oconee basin, treated wastewater is discharged along the North, Middle, and Oconee mainstems as well as multiple locations on tributary streams. Physical processes like dilution, chemical processes like adsorption, and biological processes like decomposition all contribute to the capacity of a river or stream to assimilate pollution. A range of pollutants reduce water quality, including oxygen-demanding compounds, nutrients, heavy metals, pharmaceuticals, and other chemicals, and assimilative capacity varies for each pollutant. Here we focus on nutrients themselves, particularly nitrogen and phosphorus, as well as fecal coliform.

In the Oconee Basin, urban and agricultural areas are the primary sources of nutrient and fecal coliform loading. In the upper basin, poultry, dairy, and beef operations as well as a growing urban population have contributed to point and non-point sources of nutrient and fecal coliform pollution (Fisher et al. 2000, Cho et al. 2018). From the 2018-2019 monitoring results by EPD, many of the locations sampled in the upper basin were not meeting designated uses due to fecal coliform levels (GAEPD 2020a). Around Athens, heavy rainfall events were shown to cause short-term increases in sediment and fecal coliform or *E. coli* concentrations (Eggert et al. 2005, Purvis and Wenner 2005).

Land uses around Lake Oconee and Lake Sinclair are also a source of nutrients and fecal coliform loading into waterbodies. The water quality for Lake Oconee is meeting its designated use. The assessment for Lake Sinclair is pending due to the need to finalize pH standards for fishing in the lake, but all other standards were met under the current criteria (GAEPD 2020a). Agricultural land use around Lake Oconee and its tributaries, in particular dairy, beef, and poultry, contribute to nutrient pollution that can lead to increased algal growth and is also a source of fecal pollution (Fisher et al. 2000, Bachoon et al. 2009, Burt et al. 2013). Urban and suburban areas are also sources of pollution in both lakes, primarily due to runoff (Bachoon et al. 2009, Booth and Adams 2018). While the lakes largely meet the water quality standards for their designated use, excess algal growth has been problematic in localized areas, including water supply infrastructure in Lake Sinclair (Booth and Adams 2018). Nutrient pollution from wastewater discharges and land use changes has been recognized for its potential to lead to future water quality problems in Lakes Oconee and Sinclair (Council 2017).

There is less urban development in the lower Oconee basin compared to the upper basin, with common land types being forest, row crop or pasture, clear-cut or sparse vegetation, and forested wetlands. There are also quarries and mining that are concentrated in Wilkinson and Washington Counties (Council 2017). Parts of the middle and lower basin have been flagged in the Regional Water Plan as areas where assimilative capacity may be limited due to low dissolved oxygen levels (GAEPD 2020a). Water quality in the mainstem Oconee has been within the water quality standards, however, many of the tributaries into the Oconee River are not meeting their designated use (GAEPD 2020a). Samples at Fishing Creek tributary and wastewater sites had high concentrations of iron, nitrate, and nitrite (Brittian et al. 2012). Generally, the primary causes for not meeting designated uses in the tributaries of the Oconee are fecal coliform and impacted fish communities (which frequently results from sedimentation or other changes in habitat conditions) (GAEPD 2007, GAEPD 2020a).

Relation to flow

Complex processes control surface water quality in rivers. Water quality at different sites along a river will be influenced by a combination of site-specific factors (i.e., land use, proximity to discharge points, urbanization, river size, etc.) and various biotic and abiotic processes, including flow seasonality and primary production (Nilsson and Renöfält 2008). Elevated flows follow periods of rainfall, which can increase non-point source loading of bacteria and other pollutants (see Eggert et al. (2005) and Purvis and Wenner (2005) for examples from the North and Middle Oconee Rivers). However, relevant to water management and water quality, low flows (e.g., lower than median flows during periods of limited rainfall; Table 1) typically are of greatest concern because of reduced dilution capacity and, at times, reduced dissolved oxygen and higher temperatures (Nilsson and Renöfält 2008). Low-flows coupled with high nutrient concentrations, for example, can cause algal blooms that lead to increased turbidity, reduced habitat suitability for other aquatic species, and impaired recreational value (Nilsson and Renöfält 2008). Sufficient amounts of water during the seasonally low summer flows to support intact biological communities including primary producers (i.e., algal and aquatic plant communities) may also enhance nutrient uptake and assimilation (Clarke 2002, Keitel et al. 2016, Vila-Costa et al. 2016). A functional biotic community is an important part of the nutrient cycling process, and the impacts of flow on the biotic community are discussed in greater detail in the biodiversity section.

The water quality of the two reservoirs in the middle of the basin is influenced by the upstream water quality and land use around the lakes, as well as by nutrient cycling within the lakes. Rainfall events that produce elevated surface runoff into the lakes and tributaries have been identified as a challenge for water quality when runoff carries nutrients that cause increased algal growth (Fisher et al. 2000, Booth and Adams 2018). Downstream from Lake Sinclair, releases from the dam appear to have less effects on water quality compared to hydropower operations at other dams where the upstream reservoir is significantly stratified. The pump-back operations between Lakes Oconee and Sinclair result in water column mixing, and while there are some seasonal differences in the temperature and dissolved oxygen released in the tailrace, they do not appear to limit the sport fishery (Evans 1994).

Biodiversity

Rivers and streams in the southeastern US, including Georgia, support globally exceptional diversity of freshwater fishes, mussels, snails, crayfishes, turtles, salamanders and multiple kinds of aquatic insects (Benz and Collins 1997, Abell et al. 2000, Elkins et al. 2019). The Oconee River basin is home to a portion of this diversity, including at least 65 species of native fishes, 16 native mussel species, and 11 native crayfish species (Wildlife Resources Division 2021a, Georgia Museum of Natural History 2021). These and other aquatic species form interdependent communities of plants and animals that extend into the surrounding riparian area. Insects emerging from the river are food for birds, frogs, bats, spiders; conversely, fishes may feed extensively on caterpillars and other insects that fall from riparian vegetation into the river.

The local species composition of these inter-connected, river-riparian communities depends in part on habitat characteristics. The Piedmont portion of the basin has headwater stream habitats, rocky shoal habitats in the larger rivers, and deeper-water habitats between shoals that each support distinct communities of aquatic species. Coastal Plain river communities similarly vary among habitats including oxbow lakes, seasonally inundated floodplain forests and wetlands, sand and gravel bars, deeper pools, and complexes of large wood (snags) in the river. Reservoirs are human-made habitat features that support a variety of fish species, many of which also depend on rivers at different points of their life cycles. Biodiversity across all of these river-associated habitats supports recreational and educational activities including sport-fishing, birding, and enjoyment of nature.

The Oconee system also supports aquatic species that the GA DNR Wildlife Resources Division tracks as species of Special Concern. Statewide, Special Concern species include those listed as Threatened or Endangered under the U.S. Endangered Species Act or protected under Georgia's Endangered Wildlife Act or Wildflower Preservation Act. DNR additionally tracks the status of species that stakeholders and partners have identified in the 2015 State Wildlife Action Plan as high priorities for conservation (i.e., "Species of Greatest Conservation Need"; (Wildlife

Resources Division undated). These conservation-priority species face a variety of threats to continued existence, including habitat alteration and in some cases displacement by non-native, introduced species. Aquatic species of Special Concern in the Oconee basin comprise 9 fish species, 2 crayfish species, and 3 mollusks species (Appendix). These include two federally-listed fish species, Atlantic Sturgeon and Shortnose Sturgeon, that occur in the downstream portion of the lower Oconee River. Five Oconee basin species are protected under Georgia's Wildlife Protection Act: Altamaha Shiner (known from the upper Oconee basin); Robust Redhorse (known from the lower Oconee River); Chattahoochee crayfish (known from the Mulberry River system in the upper Oconee basin); Oconee burrowing crayfish (known from the lower Oconee basin); and Altamaha arcmussel (also known from the lower Oconee basin). The Altamaha Bass is another species of Special Concern and also a potential sportfish (Wildlife Resources Division 2021e); this riverine bass species only occurs in the Oconee, Ocmulgee and Ogeechee river systems, primarily in the Piedmont portions of these basins.

Relation to flow

Flows support aquatic communities in three general ways (Bunn and Arthington 2002): by providing habitats needed in different seasons for various species to reproduce, survive, and grow; by cueing reproduction and promoting migration and dispersal; and by allowing access to floodplain and off-channel habitats (such as oxbow lakes and backwaters). Habitat is both maintained and defined by flow levels. Peak flows scour sediments and bring wood into the river channel - processes that provide a supporting service by maintaining habitat. Flow levels that occur between flood events (baseflows) determine the availability of differing habitats that organisms require to reproduce, usually in the spring and summer, and to feed, grow and survive in all seasons. Although aquatic species differ in habitat affinities, there are some general flow-dependent processes that apply to many organisms. These include channel scour (as noted above), sediment deposition, material transport, and movement among habitats. For example, the Altamaha Shiner belongs to a group of minnows that spawn in crevices in rocks or logs; if flows are too low during the spawning season, crevices may fill with silt, smothering the eggs. Similarly, Robust Redhorse (and many other fishes) spawn in gravel, where eggs are be deprived of oxygen if excessive silt clogs the spaces between gravel and blocks water exchange (Jennings et al. 2010). Redhorse suckers and other gravel-spawning fishes may require periodic high flows to clean deposited silt from gravel substrates, as well as sufficient flows when eggs are incubating to maintain inter-gravel water exchange. A study of reproductive success of fishes in relation to flow in three eastern US rivers similarly illustrates a positive effect of short-term high flows during the spawning season on subsequent production of juvenile fish (Craven et al. 2010). Higher flows also are generally necessary for inundating and connecting floodplain habitats, which facilitate seed dispersal, support reproduction and growth of a variety of fishes and invertebrates, protect nesting birds from terrestrial predators, and replenish floodplain soils (Meyer et al. 2003, Batzer et al. 2016).

Low flow conditions during appropriate seasons are also essential to supporting biodiversity. Craven et al. (2010) found that fishes that broadcast eggs into the water-column have better reproductive success in years with lower short-term peaks during the spawning season, and periods of more stable flows during summer improved juvenile survival of many fishes. Reduced suspended sediment (i.e., clearer water), as occurs during lower flow conditions under present-day conditions, appears to improve spawning success of crevice-spawning fishes such as the Altamaha Shiner (Burkhead and Jelks 2001, Sutherland 2007). At least one fish native to the Middle Oconee River (Turquoise Darter) produced more juveniles in the mainstem during relatively low-flow years (Katz and Freeman 2015). Many of Georgia's native darters (including the Turquoise Darter) and minnows display bright spawning colors to attract mates, and high turbidity caused by suspended sediment may interfere with reproduction (Burkhead and Jelks 2001). In floodplain habitats, periodic sequences of dry years with limited inundation are important for seed germination and tree recruitment (Meyer et al. 2003, Palta et al. 2011).

Flow alteration can compromise habitats that organisms need to persist. Pulsed flow-releases for hydropower generation, for example, create unstable habitat for larval fishes downstream from Sinclair Dam (Evans 1994, Ruetz III and Jennings 2000). Flow depletion may occur downstream of large water withdrawals or flow diversions (for example, when flow is diverted out of the river channel to pass through turbines, as occurs at the Tallassee Shoals dam), modifying aquatic habitats in ways that reduce occurrences of flow-dependent fishes including rare species such as the Altamaha Shiner (Freeman and Marcinek 2006).

If planning objectives include maintenance of biodiversity and supporting services, assessments of water availability under future water-use scenarios would be enhanced by identifying specific components of the flow regime that support functions critical to those services. Such flow components have been called "functional flows" (Yarnell et al. 2019), which we also refer to as "flows for species and habitats." Table 1 proposes five functional flows (flows for species and habitats) for the Oconee basin: (1) High flow levels that maintain the river channel; (2) High flows that connect the river and floodplain; (3) High flow pulses in early spring that clean fish-spawning substrates; (4) Flow levels that sustain successful fish spawning in spring and early summer; and (5) Flow levels that sustain organism survival and growth during low-flow seasons, typically summer and fall. Indicators and location-specific values are included in Table 1 where available. These or similar relations between flow components and functions are supported by diverse studies and observations, highlighting the ecological importance of components of naturally occurring flow regimes (Poff et al. 1997, 2010). Identifying functional flows (flows for species and habitats) may be a practical way for stakeholders and managers to assess whether future flow conditions are likely to sustain desired environmental or ecological conditions. As illustrated in Table 1 and the examples in Box 1 and Box 2, each functional flow component is associated with one or more indicators that are, in turn, associated with site-specific metrics. Thresholds are not targets, but rather benchmarks that can be used to compare future flow scenarios with historical flows to identify changes that could compromise critical functions.

Table 1. Functional flows (flows for species and habitats) proposed for the Oconee River basin. Five components of the flow regime and the associated indicators of ecological function and maintenance of supporting services have been identified for use in analysis of water availability at locations in the Oconee River basin. Example metrics allow comparison with historical values to assess changes that could compromise ecological functions or supporting services. The gage associated with location of metrics is in parentheses.

Functional Flow Component	***Function(s)***	***Indicator***	***Location-specific metrics***
Channel maintenance	Sediment transport and channel dynamics that maintain and create diversity of in-channel habitats	# years > *channel threshold level* Objective: The channel maintenance flow is met with similar frequency to historical record	Oconee R downstream of Milledgeville (02223056): flows ≥ *12,000 cfs* sufficient for maintaining channel migration, bank erosion processes.[1]
Floodplain habitat connectivity	Inundate and connect habitat for wetland dependent species (amphibians, aquatic insects, fishes, birds) Support seed dispersal for floodplain tree species, e.g. bald cypress and water tupelo Nutrient exchange between channel and floodplain	# days during November-March with flows > *floodplain threshold level* Objective: The # of days the floodplain is inundated is similar to historical record.	North Oconee R at Athens (02217770): flows ≥ *800 cfs* allow invertebrate (mayflies) movement onto floodplain.[2] Middle Oconee R at Tallassee Forest (02217500): *flow to connect floodplain wetlands to river*[3] Oconee R downstream of Milledgeville (02223056): flows of *5,000 cfs* inundate most of the low and moderate elevation floodplain habitats, with greater amount of deep habitat in oxbows. Oconee R downstream of Milledgeville (02223056): Flows of *10,000 cfs* inundate the entire floodplain and fill oxbow lakes.[4] Oconee R near Dublin (02223500): Flows of *15,000 cfs* inundate the floodplain.[5]

Spring pulse flows	Flush fine sediment from fish spawning substrates (e.g., gravel, crevices, cavities)	# years with the maximum 10-day high flow in March-May > *spring pulse flow* Objective: Spring flow pulse frequency is similar to historical record	Middle Oconee R at Athens (02217500): *≥ 1200 cfs* spring flow pulses maximize potential reproductive output for gravel-spawning fishes.[6]
Spring and early summer ('reproductive season') baseflow	Create and maintain conditions needed for animals to successfully reproduce, including habitat availability preventing settling (broadcast- spawned) and siltation (gravel- and crevice-spawned) of eggs and larvae providing oxygen to deposited eggs and larvae	# days during March-May with flow < *reproductive season threshold* Objective: # of days of reduced habitat availability during the fish reproductive season is similar to historical record. More days means longer periods of stressful conditions for fishes.	Middle Oconee R at Athens (02217500): flows *< 500 cfs* sharply decrease swift-water habitat (> 45cm/s) required by fishes.[7] Oconee R downstream of Milledgeville (02223056): # of consecutive days in May with flow between *1000-2000 cfs* to provide maximum habitat area for Robust Redhorse spawning.[8] Oconee R downstream of Milledgeville (02223056): Flows < *3000 cfs* reduce oxbow (e.g. spawning and rearing) habitat for fishes.
Summer and fall (dry season) baseflow	Support growth and survival of aquatic organisms Sustain higher velocity habitats Maintain habitat connectivity	# days during June-October with flow < *dry season threshold* Objective: # of days of low and extreme low flows similar to historical record, more days mean longer severe low flow conditions or reduced habitat availability for aquatic organisms.	Oconee R near Athens: flow < *265 cfs* is associated with severe reduction in deeper (i.e., >35cm) swift water (i.e., velocity ≥ 45 cm/s) habitat.[9] Oconee R near Athens ((02217500): flows < *100 cfs* associated with loss of riverweed, caddisflies in shoal habitats[10] Oconee R downstream of Milledgeville (02223056): flows < *750 cfs* block small fish passage between channel and oxbows, 1450 cfs needed for large fish passage.[11] Oconee R downstream of Milledgeville (02223056): flows < *500 cfs* sharply decrease the area of submerged woody debris[12]

[1] EA Engineering 1994

[2] Variety of invertebrates colonize floodplain habitats (Tronstad et al. 2007). (Galatowitsch and Batzer 2011) documented movement of mayflies in two floodplain locations in the North and Middle Oconee Rivers near Athens. Movement occurred during high flow periods early in the flood season (December-January). The North Oconee floodplain was inundated by rainfall and high river flows overtopping the banks. The Middle Oconee floodplain was inundated through rainfall and surface water runoff, with connections to the river occurring when wetlands filled and overflowed into the river.

[3] Tallassee Forest supports 3 high priority wetland habitat types; flows to connect these to the channel are not specified (Porter 2014).

[4] EA Engineering 1994

[5] EA Engineering 1994

[6] Spring flow pulses can improve reproductive outcomes for fishes (Cattaneo et al. 2001, Craven et al. 2010, Jennings et al. 2010, Jones and Petreman 2012), in part by cleansing fine sediment from spawning substrates. Jennings et al. (2010) showed detrimental effects of fine sediment on Robust Redhorse reproduction. Craven et al. (2010) found higher 10-day high flow pulses from April to June improved reproductive success in a variety of fishes. Estimates for the Middle Oconee were based on (McKay et al. 2016).

[7] Instream habitat model for the Middle Oconee River at Ben Burton Park (Bhattacharjee et al. 2019); fishes that deposit eggs in gravel (Oconee examples include Redhorse suckers, darters) or in crevices (ex. Altamaha Shiner) may require sufficient velocities to keep spawning substrates free of silt and eggs oxygenated. Fishes that broadcast eggs into the water column (ex. Spottail Shiner) may require sufficient velocity to keep eggs and larvae suspended in the water column (Perkin et al. 2019).

[8] EA Engineering (1994)

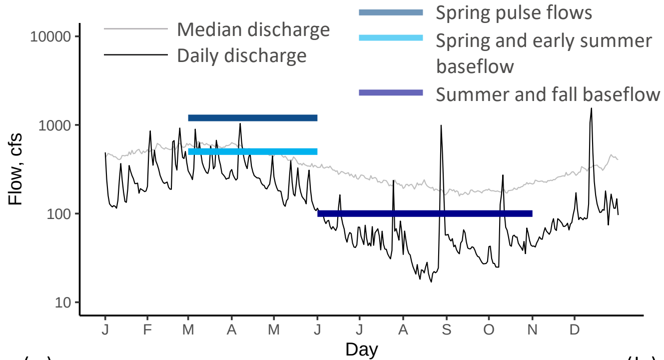
[9] Instream habitat model for the Middle Oconee River at Ben Burton Park (Bhattacharjee et al. 2019); invertebrates such as net-spinning caddisflies are more abundant in high velocity areas (Katz 2009); grazing reduces riverweed biomass at velocities <40cm/s (Wood et al. 2019) and can result in a loss of habitat for a variety of aquatic invertebrates (Grubaugh and Wallace 1995).

[10] Reduced Riverweed biomass in the Middle Oconee River shoals during the 2007-2008 drought was attributed in part to stress and possible plant emersion when low river flows, in combination with an upstream water withdrawal, reduced water depth to <5 cm over the plant for multiple days in the month prior to sample collection (Pahl 2009). Larval net-spinning caddisfly production was reduced by 84% during the drought compared to an earlier study in the Middle Oconee River (Grubaugh and Wallace 1995). During the drought conditions of 2007-2008, caddisfly densities were greater in locations with higher water velocities and with greater amounts of Riverweed (Katz 2009), illustrating the potential multiple effects of reduced water velocity during low-flow periods on riverweed and insects (in this case, filter-feeding caddisfly larvae).

[11] (EA Engineering 1994) - higher flow levels needed for larger fish

[12] Submerged woody debris supports substantial invertebrate production in Coastal Plain rivers (Benke et al. 1985, Benke and Bruce Wallace 2015); flows of ~500-2000 cfs are needed to submerge at least half of the volume of wood present in the lower Oconee (EA Engineering 1994).

Box 1. Flows for species and habitat in a Piedmont shoal. Evidence and rationale for application of functional flows for shoals in the upper Oconee River, with a drought example.



(a)


(b)

Photo: M. Freeman

Figure (a) is a hydrograph of the daily discharge at USGS gage near Athens (02217500) for the summer of 2008 (black), with the long-term median daily discharge (grey) and functional flow metrics (blues) and (b) shows a shoal near Ben Burton Park during the 2008 drought.

The shoal areas in the Piedmont portion of the Oconee are highly productive habitats (Nelson and Scott 1962, Grubaugh and Wallace 1995). Droughts that lead to infrequent, extreme low-flow conditions occur naturally, but can be exacerbated by climate and human demand. In the shoals near Ben Burton Park in the upper Oconee, studies during the 2006-2008 drought (Fig. a & b) found a severe decline in productivity of riverweed and net -spinning caddisflies at flows around 100 cfs, and that water withdrawals can exacerbate drought conditions for biota (Katz 2009, Pahl 2009). Riverweed loss reduces habitat structure for many macroinvertebrates and fishes (Nelson and Scott 1962, Grubaugh and Wallace 1995, Argentina et al. 2010). The summer and fall baseflow metric for the Middle Oconee is 100 cfs, to represent when we expect low flows to lead to a decline in shoal productivity.

Another study from the same location focused on Turquoise Darters (*Etheostoma inscriptum*) from 2008-2012 and found that these fish reproduced well during drought conditions but also that the darters took refuge in the portions of the shoal that maintained flowing water (Katz and Freeman 2015). The resulting high fish densities in the shoals during dry years likely increase predation on invertebrates, which can reduce emergence of aquatic insects that provide for birds, bats and other terrestrial animals.

Bhattacharjee et al. (2019) modeled how the availability of different habitat types (shallow-fast, shallow-slow, deep-fast, deep-slow) changed across a range of flow conditions for a section of the shoals at Ben Burton Park. The model shows a loss of the deep-fast habitat as flows decrease below 500 cfs, with almost complete disappearance by 100 cfs. Most fishes reproduce in the spring and need adequate flow for spawning and to keep developing eggs oxygenated. The spring and early summer reproductive flow, 500 cfs, maintains the range of habitat available and adequate flows for reproduction of fish species in the shoals. Spring flow pulses, above 12,000 cfs, are also important for fish spawning and may act as a spawning cue or to maintain spawning habitat, such as by flushing fine sediment.

A large change in the frequency (# of days or # of years) of these functional flows would indicate potential impacts to the survival or growth of aquatic organisms.

Box 2. Coastal Plain flows for species and floodplain, oxbow lakes, and in-channel habitat. Evidence and rationale for application of functional flows for the lower Oconee River.

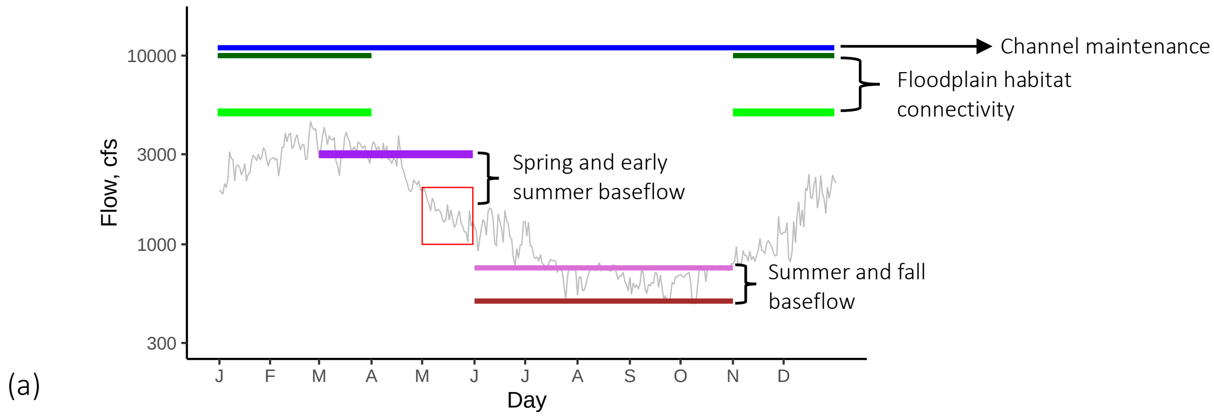


Figure (a) is a hydrograph of the long-term median daily discharge (grey) and functional flows at the Oconee River at Avant Mine USGS gage (02223056).

Habitats in the lower Oconee Basin include oxbow lakes, seasonally inundated floodplain forests and wetlands, sand and gravel bars, deeper pools, and complexes of large wood (snags) in the river. During the relicensing of Sinclair dam in the 1990's, EA Engineering (1994) conducted an in-depth survey of the Oconee River from below Sinclair Dam to just above Dublin, GA. Using data from this report, we developed metrics for four of the species and habitat functional flows for this part of the basin: channel maintenance, floodplain habitat connectivity, spring and early summer baseflow, summer and fall baseflow.

The highest functional flow, "channel maintenance", supports sediment movement needed to maintain channel form, instream habitats and oxbows lakes. Flows at and above this level are relatively less affected than lower flows by Sinclair Dam operations.

We developed two indicators for floodplain habitat connectivity, which is important for nutrient exchange between the river and floodplain, allowing access for fishes to floodplain habitats, and supporting floodplain communities (e.g, tupelo and bald cypress). The higher metric is an indicator for full inundation of the floodplain, while the lower metric indicates when low-lying floodplain habitats are inundated. The extent of inundation at these and higher flows will depend on site-specific characteristics of the river and floodplain.

Spring and early summer baseflows support fish reproduction and line up with the typical fish spawning and rearing window (March-May). We developed two metrics that are related to habitat availability. The upper metric indicates when habitat diversity is maximized in oxbow habitats. The second metric is specific to Robust Redhorse spawning, which occurs in May; this range of flow levels maximizes spawning habitat.

The summer and fall baseflow flows are low-flow metrics meant to support survival of aquatic biota during the dry season. The upper metric represents when small fishes can pass between the river and oxbow habitats; large fishes require higher river levels. The lower metric indicates flows that keep woody debris inundated. In the lower basin, woody debris can act as important refugia for aquatic organisms during droughts.

As with the example from the Upper Basin, evaluating changes in the frequency of meeting these flows can provide information on the potential for loss of ecological function under future conditions.

Recreation

Recreation is economically important for the state of Georgia, with an estimated 1 million paddlers in Georgia and 1.8 billion dollars generated in state and local tax revenue by the outdoor recreation industry. An estimated 11.3 billion is spent annually in the state on kayaking, canoeing, and rafting (Georgia River Network 2018b). Fishing, hunting, and wildlife viewing also contribute to the Georgia economy. There are over a million resident anglers that fish in Georgia and generate about 1.3 billion dollars in retails sales and maintain 15,644 jobs. The ripple effect of hunting is 1.6 billion dollars, with 977 million dollars in retail sales. Peoples who participate in wildlife viewing activities spend about 639 dollars per person on average for food, lodging, transportation, and other supplies (Wildlife Resources Division 2020). Residents and visitors engage in these types of activities throughout the Oconee basin, contributing to the economic value of water-based activities. While we did not find specific analyses of the value of recreation in the Oconee, there are studies conducted for the dam relicensing process that reported on recreation use at Tallassee Shoals and in Lakes Oconee and Sinclair (FERC 2019, Kleinschmidt Associates 2021).

Recreation in the Oconee Basin includes river and lake-based activities. In general, the basin supports a vibrant sport fishery, paddling opportunities, swimming, camping, birdwatching, hunting and similar water-associated activities. Many of the riparian lands managed for conservation or hunting can be ecologically significant both in their habitat types as well as supporting the hydrology of the river through slowing surface water flows, supporting recharge, and protecting creek and spring connections to the river (DCA 2004). There are many areas within the Oconee Basin that provide multiple types of recreation opportunities in or along the rivers and lakes (see, for example, the Oconee River User's Guide, Georgia River Network).

Relation to flow

Flow directly supports recreation in two general ways, either by allowing activities to occur or by enhancing recreational experiences (Whittaker et al. 1993). Flow-dependent activities are directly impacted by the instantaneous flow conditions, and these typically take place in the river. Flow-enhanced activities occur where the instantaneous flow conditions contribute to the aesthetic aspects of the activity, such as those that take place along the river. Flows at the low and high ends of the usual flow range are generally the most directly limiting for recreational activities, and assessing the change in quality of the recreational activity across flow levels can help to differentiate between preferential flow levels for an activity versus thresholds that make an activity inaccessible (Brown et al. 1991). Below is a brief description of identified flow relationships for different types of recreation activities, including location- or season-specific flow relationships.

Boating and paddling

Motorized and non-motorized (e.g., kayaking, canoeing, referred to as paddling) boating take place throughout the basin as well as other activities such as paddle boarding. Motorized boating is popular on Lakes Oconee and Sinclair and on the Oconee River. Lake levels that limit motorized boating in Lakes Oconee and Sinclair have not been identified. There are also low-flow levels in the river that preclude motor boating, however specific levels are not identified in the literature. There are two water trails (blue trails) in development meant to provide access points along rivers to launch and retrieve boats for paddling. The Upper Oconee Water Trail currently includes six public access points, with plans for the trail to extend ~98 river miles from the North and Middle Oconee headwaters to their confluence and downstream into Lake Oconee (Upper Oconee Water Trail 2017). There are plans for additional access points to connect the full length of the river to the lakes. The Lower Oconee River Water Trail begins just below Sinclair Dam and ends just downstream from Milledgeville and is planned to extend to the confluence of the Oconee and Ocmulgee Rivers. Three public access points are currently available for the lower water trail (Georgia River Network 2018b). There are many other launches and access points to the rivers, including in parks and greenways and sites on private lands. Three outfitters run paddling trips in the river portion of the Oconee basin and offer shuttle trips for kayaking and canoeing (Georgia River Network 2018a). There are also numerous outfitters on both Lakes Oconee and Sinclair that offer a range of rental options for motorized boats, jet skis, kayaks, canoes, and paddle boards. Available information on flow levels related to paddling throughout the Basin is presented in Table 2. Flow relationships for paddling (kayaking and canoeing) and motor boating that could be used as indicators under scenarios of future flows at locations in the Oconee River basin. Activities and locations without specific flow levels identified in the literature are noted as Not Identified.. More information on location-specific flow levels that support paddling and motor-boating opportunities for both novice and expert users could be developed to assess how often those paddling opportunities are available throughout the year in different parts of the basin and better understand tradeoffs between recreation with its local economic impacts and other water uses.

Table 2. Flow relationships for paddling (kayaking and canoeing) and motor boating that could be used as indicators under scenarios of future flows at locations in the Oconee River basin. Activities and locations without specific flow levels identified in the literature are noted as Not Identified.

Activity	***Indicator***	***Site specific value***
Paddling	# of days with flows < *low-flow paddling threshold*, April-October	North Oconee River - *60 cfs, 2 ft*[1] [USGS 02217615, North Oconee River at Woodbridge Rd, near Commerce, GA] Headwaters to Ga. 330 - *250 cfs, 3 ft*[2] [USGS 02217475, Middle Oconee R near Arcade, GA] Middle Oconee River, Ga. 330 to Barnett Shoals Road *300 cfs, 1.5 ft*[3] [USGS 02217500, Middle Oconee R near Athens, GA] Middle Oconee River, Tallassee Dam *900-1100 cfs*[4] [USGS 02217475, Middle Oconee R near Arcade, GA]
	# of days with flows < *high-quality freestyle paddling threshold*	Lakes Oconee and Sinclair: Unknown Middle Oconee River, Tallassee Dam

[1] Cook, J. 2019. Oconee River User's Guide. University of Georgia Press, Athens, GA.
[2] Cook, J. 2019. Oconee River User's Guide. University of Georgia Press, Athens, GA.
[3] Cook, J. 2019. Oconee River User's Guide. University of Georgia Press, Athens, GA.
[4] American Whitewater. 2018. COMMENTS OF AMERICAN WHITEWATER REGARDING THE PRELIMINARY APPLICATION DOCUMENT AND REQUEST TO USE THE TRADITIONAL LICENSING PROCESS FOR THE TALLASSEE SHOALS HYDROELECTRIC PROJECT, FERC PROJECT 6951.

	# of days with flow > *high-flow paddling threshold*	*1300-3000 cfs*[5] [USGS 02217475, Middle Oconee R near Arcade, GA] Upper Oconee River: *Not Identified* Lower Oconee River: *Not Identified*
Motor boating	# of days with flows < *low-flow motor boating threshold* # of days with lake levels < *threshold for boat launch or dock access*	Upper Oconee River: *Not Identified* Lower Oconee River: *Not Identified* Lakes Oconee and Sinclair: *Not Identified*

Fishing

In the riverine areas of the Oconee Basin, flows interact with fishing by (1) supporting a healthy fishery, and (2) providing preferred seasonal conditions for fishing. The preferred flow for fishing likely varies with how one accesses the fishery, for example from a boat, from the bank, or wading in the river. Few specific flow criteria were identified for fishing in the literature, but below are some common recreational fishes and seasonal information about the riverine fishery in the basin (Table 3).

Table 3. Season and location specific information on popular riverine sport fishes (Wildlife Resources Division 2021d).

Fish	***Seasons***	***Locations***
Black Bass (Largemouth, Altamaha, Spotted, Shoal, hybrid)	Year-round	Altamaha bass – bedrock outcroppings and pools in the Piedmont portion of the basin Largemouth bass- basin wide, rivers and lakes, shorelines

[5] American Whitewater. 2018. COMMENTS OF AMERICAN WHITEWATER REGARDING THE PRELIMINARY APPLICATION DOCUMENT AND REQUEST TO USE THE TRADITIONAL LICENSING PROCESS FOR THE TALLASSEE SHOALS HYDROELECTRIC PROJECT, FERC PROJECT 6951

White Bass	March-April spawning runs	Barnett Shoals Dam Creek mouths – between Barnett Shoals Dam and Lake Oconee
Catfish (Channel, White, Bullhead) (Blue, Flathead – introduced, impacting native populations)	Summer months	Throughout rivers
Bream (Bluegill)	Year-round	Basin wide, rivers and lakes. Common in pools associated with bedrock shoals in the upper Oconee Creek mouths or eddy pools in lower Oconee
Crappie	February-April	Target locations vary by season; Barnett Shoals Dam in early spring, e.g.,

Lakes Oconee and Sinclair are popular fishing spots and support an economically important fishery in the basin. Fishing tournaments are hosted between March and November (FERC 2019) and there are many access points, public and private, on both lakes for bank fishing and boat launches for boat fishing. Based on information collected in FERC (2019), it appears that the quantity and condition of the infrastructure used to access the fishery is typically a more limiting factor than specific lake levels, although it could be useful to identify if there are lake levels that impact bank or boat fishing. Common recreational fishes and seasonal information about the lake fisheries are listed Table 4 and Table 5. We did not find specific information on lake levels associated with fishing spots, however see tables 10 and 11 in FERC (2019), for specific location used to access the fishery.

Table 4. Season and location specific information on popular Lake Oconee sport fishes (Wildlife Resources Division 2021b).

Fish	***Seasons***	***Locations***
Largemouth bass	Year-round	Target locations vary by season
Hybrid bass	Year-round	Target locations vary by season
White bass	March and April spawning runs	Not listed
Striped bass	Winter and spring	Oconee River arm to dam (winter)

		Middle and upper reservoir (spring)
Catfish (channel, blue, flathead)	Summer months	Not listed
Crappie	Year-round	Target locations vary by season

Table 5. Season and location specific information on popular Lake Sinclair sport fishes (Wildlife Resources Division 2021c).

Fish	***Seasons***	***Locations***
Largemouth bass	Year-round	Wallace dam generation or pump back phase
Hybrid bass	Year-round	Target locations vary by season
Striped bass	Year-round	Target locations vary by season
Catfish (channel, white, bullhead, blue, flathead)	Year-round	Old creek channels, docks with brush, below Wallace Dam during generation
Bream (bluegill, redbreast, shellcrackers)	Spring and summer spawning, year-round	Near cover (weed beds, brush piles, docks with brush)
Crappie	Year-round	Target locations vary by season

Hunting

Hunting lands are found throughout the basin on private property and public lands. The Oconee National Forest and state Wildlife Management Areas (WMAs) provide extensive hunting opportunities. Many floodplains throughout the Oconee Basin are managed for hunting, including the Dan Denton Waterfowl area in the Oconee WMA, Beaverdam WMA, and Riverbend WMA. Water levels in these areas are controlled to provide seasonal habitat availability for waterfowl (Balkcom et al. undated). Hunting in these areas benefit from proximity to the supporting services of the adjacent waterbody, which can also enhance the hunting experience. The river can be used for navigation to access other hunting sites on the floodplain. Relationships between hunting and river levels were not identified in the literature, however many game animals have a designated hunting season and stakeholders may be aware of flow levels that impact hunting.

Other Recreation

Other types of recreation include visiting lands along the river to walk, picnic, swim, view nature or spend time near the river. These typically occur at parks or other publicly managed lands such Balls Ferry State Park, the Oconee National Forest, or the various WMAs in the basin. At Dyar Pasture, there is a wetland that is managed specifically for bird habitat and viewing; hunting is not allowed. Water levels in these areas are controlled to provide seasonal habitat availability for waterfowl, wetland birds, and other migratory birds (Balkcom et al. undated). While water levels in these wetlands are specifically managed for bird habitat, these habitat types also occur naturally along the river and are maintained through seasonally elevated flows that inundate floodplain habitats (floodplain habitat connectivity functional flow) and flow recessions (spring and summer baseflow functional flow), as noted in the Supporting Services section. Other recreation activities, such as walking, birdwatching, or picnicking in river-associated parks may be enhanced when rivers are at levels tied to the aesthetic preferences of park users. Information could be developed (or may be available at request from parks) on seasonal usage and preferred flows for park visits.

Historical and environmental education

There are many environmental and historical education sites along the North, Middle, and Oconee Rivers and this section presents examples of different types of flow relationships between historical and education sites and river flows. Many environmental and historical education sites are located where they are due to their proximity and relationship to a river. In some cases, there are strong historical ties to river flows, but less of a contemporary relationship to flow. In other cases, there are specific flow levels that maintain linkages between the river and floodplain habitats.

Historical

Indigenous people have lived throughout the Oconee Basin and along the Oconee River for upwards of 12,000 years and have used the river for food and other resources. Scull Shoals Archaeological Site in Green County and the Mississippian Mounds in Laurens County are two examples of Native American mound sites that date back to about 1250 AD (Williams 1992, 1996). Excavations at these sites have documented the village structure and catalogued numerous artifacts of life at this time. The Scull Shoals site appears to have been occupied at different time periods, and it is likely that the inhabitants of the sites interacted with other tribes in the basin and in surrounding basins (Williams 1992). These historic and cultural resources provide examples of early connections and reliance on the river. Forced removal of Native Americans through the Indian Removal Act and a long history of land dispossession have resulted in no federally recognized tribal lands in Georgia, however Native Americans still live in Georgia today. The state recognizes three tribes, Cherokee of Georgia Tribal Council, Lower Muskogee Creek Tribe, Cherokee of Georgia Tribal Council (Georgia Council on American Indian Concerns 2021). More historical and contemporary information on Native Americans in Georgia can be found through the Georgia Council on American Indian Concerns or the Institute of Native American Studies at the University of Georgia.

Mill villages were constructed along rivers in the mid-19th and early 20th century. Two examples of mill villages that are currently recognized as a historical and cultural resource are Healan's

Head Mill in Hall County and the mill village at Scull Shoals Historic Site. Healan's Head Mill relied on flows from the North Oconee River to power the mill. Part of the river was dammed upstream of the mill and diverted to power the water wheel. This technology was innovative for the time and an important economic resource for the village (Hall County 2021). There are still a number of historical buildings on site that have been restored and the master plan for the sites recommends a number of land use districts to represent and display the multiple values the site holds, including a trails district, historic district, conservation district, education district, and administrative district (Hall County 2021). The mill village at Scull Shoals Historical Site had the largest mill on the Oconee, and the site now depicts the remnants of life in the mill village (Ferguson 1999). The first mill was built in the early 1800's and multiple dams were built over the years to help power the mill; the last and largest dam was built in 1860. However, by the 1880's sedimentation in the river, due agricultural land practices in the cotton farming era, resulted in the mill failing. Sedimentation decreased the waterpower available to the mill and exacerbated periodic flooding. A large flood in the late 1880's devastated the village and the town was eventually abandoned by the early 1900's (Ferguson 1999).

Beech Haven Park is situated in the floodplain of the Middle Oconee, near Athens, and includes 149 acres and 7 GADNR "High Priority Habitats". The property is not currently open to public, but a plan is underway to open it up to the public. The property includes opportunities for environmental education, but the primary emphasis is on the historical and cultural values (Athens-Clarke Heritage Foundation 2018). The home and other structures on the property are in the process of being restored and are an example of the Arts and Crafts style, with Asian influences on landscape and structures (Morales 2014, Athens-Clarke Heritage Foundation 2018). The house was built by Ike Osborn, a local African American Master Stonemason and Jim Glen, Master Carpenter, and the Rowland family who owned the property. In a project proposal for the park, the Athens Clarke County Heritage Foundation say that:
"In the context of the park setting, these constructions allow the park to introduce visitors to a unique and complex history of the racial and social relationship in Athens over our history, the

history of class and race in Athens, as well as the impact of African-American entrepreneurs and craftsman on our community." (Athens-Clarke Heritage Foundation 2018)

Beech Haven Park offers historical, cultural, and educational resources for the surrounding community and wider tourism opportunities in the future.

Educational

Lands along the North, Middle, and Oconee rivers provide opportunities for education about the water resources in the basin. Two examples of education centers along the Oconee are the BioS.T.E.A.M. Outdoor Learning Center and Sandy Creek Nature Reserve. The BioS.T.E.A.M. center offers educational field trips to a wetland along the Middle Oconee River for Jefferson City Schools. The center is a partnership between the Jefferson City Schools System and Oconee River Land Trust, with land donated by the Jeffco Boys, LLC who previously managed the wetland for waterfowl through a constructed levee (BioS.T.E.A.M. 2021). The wetland is now used as a site for students to learn about water resources and watersheds, including wetlands and rivers. Sandy Creek Nature Reserve includes 225 acres of woodlands and wetlands, with a Visitor and Education Center and trails with interpretive signage. Sandy Creek Nature Center hosts a number of education and nature programs, including trainings for Adopt-A-Stream sampling (Sandy Creek Nature Center). Trails in the park offer visitors an opportunity to walk through the floodplain of the North Oconee River and learn about wildlife in and around the river and connections between the river and floodplain. There are also other organizations, such as the Upper Oconee Watershed Network (UOWN) that provide educational training and experience through water quality and biotic sampling in various portions of the basin (UOWN 2017). The data collected by UOWN has been used in a few scientific publications as well as an informational resource and tool that can help address local water quality concerns.

Water supply

The Oconee River basin supports water withdrawals primarily for municipal, industrial, and agricultural uses, with small quantities permitted for energy production (Council 2017, CDM Smith 2020). Users depend on enough water to meet demand at an acceptable level of reliability (i.e., the percent of time that supply meets demand without necessitating reductions in usage) and on the water being clean enough that it can be treated for the use at hand at a reasonable cost. Withdrawals for water supply in Georgia are regulated under two state laws that require permits for withdrawals that exceed 100,000 gallons per day. Surface water withdrawals may be subject to low flow requirements, depending on the date when the withdrawal was first permitted and specifics of the source water body. It is important to note that existing downstream water withdrawals and wastewater discharges are taken into consideration when permitting a new or expanded municipal or industrial withdrawal upstream. EPD generally determines the pro-rata share of water needed for downstream withdrawal(s) or wastewater discharge(s), using the drainage area ratio method. Low flow requirements in water withdrawal permits generally specify flow threshold(s) below which the permit holder may not withdraw, allowing whatever flow is there to pass the intake. State regulations that require flow thresholds give the permitting agency, Georgia EPD, discretion in how thresholds are set. As a result, flow requirements in permits have been established in different ways in different time periods and at different sites. As of 2020, there were 34 permitted surface water withdrawals for municipal and industrial use in the Oconee Basin, with 16[6] on the mainstem of the North, Middle, and Oconee Rivers and in Lakes Oconee and Sinclair (Table 6). There were also 366 permitted agricultural withdrawals from rivers and streams in the basin (GAEPD 2020c).

Public water supply is also regulated under the federal Safe Drinking Water Act and the Georgia Safe Drinking Water Act. The federal law establishes maximum contaminant levels for drinking water, among other provisions, and the state law provides for Georgia-specific implementation of the federal requirements. The focus of these acts is safety of drinking water delivered

[6] As of February 2021, City of Milledgeville Permit #005-0391-03 was no longer active and is not listed in Table 6

through public and community water systems (defined in the Act based on number of connections). Public water suppliers may or may not have a municipal water withdrawal permit for their water system; withdrawal permits are not necessary for those that only purchase water from another system.

It is difficult to overestimate the value of access to freshwater resources. However, there are tangible costs of water treatment required to meet drinking water standards and these costs can increase based on poor water quality, which can decline during low and high flow events. While we did not identify studies conducted within the Oconee Basin that evaluate the cost of drinking water treatment and water quality, studies have shown increased treatment cost associated with higher turbidity. With increased turbidity levels there is also is a greater chance for the presence of disease-causing microorganisms (Dearmont et al. 1998, Saha et al. 2018). In a study by Dearmont et al. (1998) of Texas water treatment plants, authors estimated that with a 1% decrease in turbidity, treatment cost could decrease by 0.27%, highlighting potential costs associated with declining water quality.

Changing land use patterns impact water quality, with better water quality in areas with natural buffer areas around streams and water sources (Lee et al. 2009, Tran et al. 2010). The upper Oconee is impacted by historical sedimentation, and in combination with other land use practices can have very high turbidity levels during high flow events (Cox and Rasmussen 1999). The cost of protecting forested areas to improve water quality in source watersheds is another mechanism that has been compared with the cost of drinking water treatment. In some locations, the tradeoff in protecting or restoring land is more cost effective than water treatment costs (Price and Heberling 2018), however this is not always the case (Heberling et al. 2015). There is an ongoing project that is focused on source water protection in the upper Oconee to support water quality (Oconee River Watershed Partnership undated). In Lake Sinclair, the Sinclair Water Authority has had issues with algae during warm summer months. For example, in 2017 algal concerns resulted in increased treatment costs due to the testing required for cyanotoxins, purchase of algicide, ongoing cleaning costs of intake equipment, and increased treatment costs due to color, taste, and odor issues (Booth and Adams 2018).

Table 6. Permitted maximum withdrawal and low flow limit for municipal and industrial water withdrawals from the mainstem North Oconee, Middle Oconee, Oconee Rivers, and Lakes Oconee and Sinclair.

Source	Permit Holder	Permit Number	Max daily withdrawal mgd (cfs)	Low-flow limit cfs
North Oconee River	Hall County Government[7]	069-0301-04	2 (3.09)	11.06
North Oconee River	City of Jefferson[8]	078-0301-06	4 (6.19)	26.9
North Oconee River	Athens-Clarke County	029-0301-03	34.75 (53.77)	31.6
Middle Oconee River	Upper Oconee Basin Water Authority	078-0304-05	60 (92.83)	60.4
Middle Oconee River	Tallassee Shoals, Inc.	029-0304-03	533.25 (825.06)	53 cfs*
Middle Oconee River	Athens-Clarke County	029-0304-02	16 (24.76)	44.4
Lake Oconee	City of Madison	104-0307-02	2 (3.09)	None
Lake Oconee	City of Greensboro	066-0390-03	3.31(5.12)	None
Lake Oconee	Piedmont Water Resources[9]	066-0390-05	2 (3.09)	None
Lake Sinclair	City of Sparta	070-0390-04	2 (3.09)	None
Lake Sinclair	Sinclair Water Authority	117-0390-06	9.5 (14.70)	None
Lake Sinclair	Georgia Power Company - Plant Branch	117-0390-01	6 (9.28)	None
Oconee River	City of Milledgeville	005-0391-02	12.44 (19.25)	None
Oconee River	City of Dublin	087-0391-01	5 (7.74)	606[10]
Oconee River	WestRock Southeast, LLC	087-0392-01	19 (29.40)	569[11]

[7] No withdrawals were reported in 2020 for this permit
[8] No withdrawals were reported in 2020 for this permit
[9] No withdrawals were reported in 2020 for this permit but the withdrawal became active in 2021
[10] No withdrawals in excess of 3.3 mgd (24hr) or 3.0 mgd (monthly) average at or below 606 cfs
[11] At or below 569 cfs, withdrawal quantity must be less than or equal to wastewater discharge quantity to maintain 7Q10

Relation to flow

Water supply may be limited by low river flows, which typically coincide with seasonal low flow and the potential for increased water demand in summer. Water storage in the reservoirs throughout the basin is one mechanism used to increase water supply reliability during low-flow periods. There are flow levels that physically limit water supply in the river, at which water withdrawal systems no longer function (i.e., flows or levels are too low for intakes to operate). Many water withdrawal permits also set low-flow limits, below which permitted withdrawals should be curtailed, to protect water quality and aspects of the aquatic environment (Board of Natural Resources 2001). The lake levels in Lakes Oconee and Sinclair are highly regulated and buffered from significant variation in water levels, although during severe drought lower lake levels may raise concerns about intake function. Water quality in the rivers and lakes can also impact water supply through treatment costs. Water quality tends to be of greatest concern for management during summer months or when water levels are lower for a given time of year. The maintenance of water quality at all flow levels is a supporting service provided by the river and is discussed in greater detail in the Supporting Services section.

Discharge of treated wastewater

Discharge of treated wastewater is regulated under the federal Clean Water Act (CWA) and the Georgia Water Quality Control Act. The regulatory sections of these acts[12] focus on monitoring and assessment of ambient water quality as well as management of various sources of water pollution to protect public health and aquatic life. The state act provides for Georgia-specific implementation of the federal act. The CWA establishes a process for setting and revising ambient water quality standards, which include designated uses for specific water bodies and numeric and narrative criteria for multiple parameters that measure water quality. The CWA also establishes a process for permitting discharges of treated wastewater with facility-specific effluent limits. The parameters for which effluent limits are established is determined by the characteristics of the wastewater and the potential for impacts to public health or aquatic life.

The Oconee Basin supports 90 NPDES permitted discharges (GAEPD 2020b). The discharge of treated wastewater relies on assimilative capacity, a supporting service, and can reduce water quality if those inputs lead to higher levels of nutrients, organic matter or other pollutants in the river or lake than can be processed or stored through biotic or abiotic processes. However, if river or lake systems are not already stressed by nutrient additions, direct discharge of treated wastewater is a feasible means of waste disposal and is less expensive than the cost treating wastewater to a higher standard. There are, however, benefits associated with treating wastewater to a higher standard, particularly to other uses such as water supply and recreation. A few potential impacts of discharging treated wastewater include higher fecal coliform levels and increased nutrient levels that can lead to algal accumulation.

Relation to flow

Low flow is typically the limiting factor for assimilative capacity (Nilsson and Renöfält 2008, GAEPD 2017). This occurs both due to the reduced dilution capacity of the river and complex dynamics between flow and the chemical and biological processes that can impact pollutant

[12] This document does not address the CWA's non-regulatory sections (e.g., Section 319) nor does it address all of the regulatory sections (e.g., Section 404).

uptake. The dynamics between uptake and flow for nutrients are discussed in the Supporting Services section. The discharge of treated wastewater returns flow to the river system, although often at a location that is remote from the point of water withdrawal. Thus, although discharge of treated wastewater lessens the net effect of water withdrawals on basin-wide flow, river reaches directly downstream of withdrawal locations typically do not benefit (unless, e.g., wastewater returns are at or upstream of withdrawals).

While flow levels directly affect ambient water quality and are one factor that determines assimilative capacity, the implications of the CWA for flow management are largely indirect, as shown by two examples. First, under provisions for permitting of wastewater discharges, effluent limits in a permit are set at levels expected to maintain ambient water quality standards at flows above a site-specific annual 7Q10. That is, flow is a consideration in the permitting and changes in flows are reflected in calculations of annual 7Q10 made when permits are renewed every 5 years. Second, flow is also an important parameter in the water quality modeling that supports the state's implementation of the Clean Water Act. Flow affects the loading of nonpoint source pollution, in particular. Nonpoint sources of pollution will often have a greater impact in wet years than in dry years. While these examples illustrate indirect, flow-related implications under the CWA, they also illustrate that the CWA has limited direct management impact on flows.

Hydroelectric power production

Hydroelectric production in the Oconee River basin only occurs at non-Federal facilities, which are regulated by the Federal Energy Regulatory Commission under the Federal Power Act of 1920 and subsequent legislation. FERC jurisdiction covers the Tallassee Shoals dam (privately owned), Wallace Dam (Georgia Power), and Sinclair Dam (Georgia Power). The privately-owned Barnett Shoals Dam is not licensed by FERC and may be among the dams exempted from the Federal Power Act by specific Congressional action. Tallassee Shoals Hydroelectric Project operates as run-of-river (McIlvaine 2019) and Wallace and Sinclair Dams are part of a pumped-storage project. Wallace Dam creates Lake Oconee, which is the upper reservoir for the pumped-storage project. Sinclair Dam forms Lake Sinclair just below Lake Oconee. To our knowledge, the Barnett Shoals Dam located on the Oconee River a few miles south of the confluence of the North and Middle Oconee is not currently operational, but was operated a as a run-of-river hydropower operation until mid-2010 (Giles 2010).

The hydropower operations in the basin generate power that can be sold to surrounding areas. The pumped-storage operation of Wallace and Sinclair dams is the largest in the basin and while pumped-storage reservoirs typically use more power than they generate, they are economically valuable in that they produce power during high demand times and can use power when costs are lower for pump-back operations (U.S. Energy Information Administration 2020). The lakes created through the hydropower project also have tangential and often substantial benefits for water supply, recreation, and economic development. Property value can increase on the lands surrounding lakes (Sklarz and Miller 2018), as has been seen around Lakes Oconee and Sinclair. However, there may also be adverse impacts to downstream property owners due to hydropeaking operations below the dam.

Table 7. Active hydropower operations on the mainstems of the Middle Oconee and Oconee Rivers.

Hydropower Project	Minimum flow or lake levels for generation or pump operation	Required minimum outflow	Source(s)
Tallassee Shoals Hydroelectric	200 cfs	70 cfs, 138 cfs in May[13]	(LIHI , McIlvaine 2019)
Wallace Dam	337.2 ft, 335.5 ft, 334.5 ft, and 333.8 ft	NA	(Booth and Adams 2018)
Sinclair Dam	298.66 ft; 337.2 ft for pump back operations	Decision rules based on time of year and inflows	(Booth and Adams 2018, FERC 2019)

Relation to flow

Constructing a dam on a river creates an impoundment, with a transition from flowing water (lotic) to a lake-like state (lentic). The water that is released from the dams downstream alters the magnitude, timing, and variability of flows. FERC license applications must be supported by an environmental report that describes the project's cumulative effects. Required details include streamflow records and flow regime characteristics, current and proposed dam operations, and minimum flow releases. Individual sections address project effects and actions to address impacts on various resources: water use and water quality; fish and aquatic resources; wetlands, riparian, and littoral habitat; rare, threatened and endangered species; recreation resources; and cultural resources. In the case of Tallassee Hydroelectric Project, a run-of-river operation, water is diverted around a section of the river channel (750 ft), referred to as the bypass section, and results in more stable and artificially low flows in that section of the river (McIlvaine 2019). Wallace and Sinclair Dams are both hydropeaking operations. Wallace Dam releases water into Lake Sinclair and then water is pumped back into Lake Oconee during off peak demand hours, which also results in relatively constant lake levels in Lake Oconee (between 435 ft. and 433.5 ft). The hydropeaking operations of Sinclair Dam release into the Oconee River, with a minimum flow requirements depending on the time of year and inflows to the project (FERC 2001). The minimum flows below Tallassee and Sinclair are established to maintain aspects of habitat for aquatic organisms, primarily fishes, during

[13] Tallassee operation range is between 200-800cfs (LIHI , McIlvaine 2019)

periods of water diversion (Tallassee Dam) or when water is not being released for power generation (Sinclair Dam). Each of the hydropower projects also have minimum flow (Tallassee) or lake (Wallace and Sinclair) levels that are required to generate electricity (Table 8).

Table 8. The minimum flow or lake levels for operation and the minimum outflow requirements for the three active hydropower projects in the Middle Oconee and Oconee Rivers.

Hydropower Project	***Minimum flow or lake levels for generation or pump operation***	***Required minimum outflow***	***Source(s)***
Tallassee Shoals Hydroelectric	200 cfs	70 cfs, 138 cfs in May[14]	(LIHI , McIlvaine 2019)
Wallace Dam	337.2 ft, 335.5 ft, 334.5 ft, and 333.8 ft	NA	(Booth and Adams 2018)
Sinclair Dam	298.66 ft; 337.2 ft for pump back operations	Decision rules based on time of year and inflows	(Booth and Adams 2018, FERC 2019)

[14] Tallassee operation range is between 200-800cfs (LIHI , McIlvaine 2019)

Conclusions

The Oconee basin is a valuable resource, providing many benefits and uses which range from direct uses such as water supply and recreation to the supporting services that help to maintain or enhance other uses. In each section of the report, the relationship to flow was presented for each use, which allowed for the development of analogous flow relationships across uses to provide indicators suitable for assessing future water use scenarios. The functional flows (flows for species and habitat) presented for supporting services and biodiversity indicate some specific flow levels, as well as qualitative relationships where quantitative information was not available, that may be applicable to examine as benchmarks for change in flows over time or with changing demand in different parts of the basin. Similarly, the recreation section provides flow levels that have been identified for kayaking and canoeing in the upper portion of the basin, that may be deemed important to consider for planning if maintaining paddling opportunities is a priority. For recreation activities that are less directly dependent on flow, opportunities for types of flow-related data collection are presented. For the direct uses that currently have the most information available for planning purposes, water supply, wastewater discharge, and hydroelectric power production, some of the current flow levels used for planning have been included, such as the permitted low-flow limit for water withdrawals in the mainstems portion of the basin.

Basin-specific information from scientific papers and other reports have informed the understanding of flow relationships for specific uses. In some cases, sources helped to identify site-specific flows related to a use or benefit (Table 1, Table 2, Table 6, Table 8). The report also highlights areas where we do not have information, either broadly for a use or site-specific relationships. Given some of the gaps identified within sections and recognizing that some sites have been the focus of numerous studies while many others have not been studied directly, the information in this report should be viewed as a starting point and not an endpoint for understanding how flow relates to the uses and benefits in the Oconee basin. The information in the report and information gaps identified may be a useful starting point for future data collection to address areas of interest (both topically and locations) for future study and the types of data collection that could support or refine understanding for that area.

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Appendix

Aquatic species of Special Concern in the Oconee River basin. All information is from the GA DNR Wildlife Resources Division, http://georgiabiodiversityportal.org/) except as noted. Species with federal ("**US:E**", Endangered; federal Endangered Species Act) or state ("**GA:E**", Endangered, "**GA:T**", Threatened; or **"GA:R"**, Rare; Georgia's Wildlife Protection Act) level protection are so designated.

Name	***Description***	***Habitat***	***Global Distribution***	***Oconee Basin Occurrences***	***Threats***
Shortnose Sturgeon * *Acipenser brevirostrum* US:E GA:E	A relatively small (<5' total length) sturgeon (family Acipenseridae); adults mostly live near saltwater in coastal rivers, but migrate upstream to spawn in rocky habitats during winter and early spring. After hatching, larvae drift downstream, and juveniles live and grow in estuaries.	Large coastal rivers and nearshore coastal waters.	Historically occurred widely in coastal rivers of eastern North America, from Canada to Florida.	Known only from the downstream-most reaches of the lower Oconee River.	Habitat alteration by sedimentation, pollution; changes in water temperature and river flow regimes that lower reproductive success. Boat strikes, by-catch.
Atlantic Sturgeon * *Acipenser oxyrinchus* US:E GA:E	A relatively large (>8' total length) sturgeon (family Acipenseridae); adults live in the Atlantic Ocean but return to their natal rivers to spawn in rocky habitat near the fall line. Larvae drift downstream and juveniles live in estuaries, lower rivers and coastal waters.	Atlantic Ocean, large coastal rivers and nearshore coastal waters.	Historically occurred widely in coastal rivers of eastern North America, from Canada to Florida.	Known throughout the lower Oconee River upstream to Sinclair Dam.	Habitat alteration by sedimentation, pollution; changes in water temperature and river flow regimes that lower reproductive success. Boat strikes, by-catch.
American Eel *Anguilla rostrata*	A fish in the eel family Angullidae; lives in freshwaters until maturity; adults migrate to the Atlantic	Pools, undercut banks in	Historically occurred widely in North American rivers that empty into the	Potentially widespread downstream of Sinclair Dam. Not	Dams that block upstream and downstream

	ocean to spawn; juveniles return to freshwater.	streams and rivers	Atlantic Ocean and Gulf of Mexico.	expected upstream of Sinclair Dam (a barrier to movement from the ocean).	movements and restrict range.
Altamaha Shiner *Cyprinella xaenura* GA:T	A fish belonging to a minnow family (Leuciscidae); lives entirely in freshwater.	Pools and shoals in rivers and larger tributaries	Only occurs in the Piedmont portions of the Oconee and Ocmulgee river systems.	Multiple stream and river locations upstream from Lake Oconee	Habitat replacement by impoundments; stream sedimentation, pollution
Ironcolor Shiner *Notropis chalybeus*	A fish belonging to a minnow family (Leuciscidae); lives entirely in freshwater.	Low-gradient streams and floodplain swamps	Lowland river systems in eastern North America and the Mississippi basin.[1]	Known from historic records in the lower basin and from the Murder Creek watershed.	Habitat alteration
Robust Redhorse *Moxostoma robustum* GA:E	A large (>2' total length) fish belonging to the sucker family (Catostomidae); lives entirely in freshwater. Adults migrate to gravel shoals to spawn, sometimes moving long distances.	Mainstem rivers; adults and juveniles may occur in reservoirs, but requires rivers to spawn.	Historically occurred in Atlantic slope rivers from the Altamaha River system (GA) to the Pee Dee River system (NC and SC).	Known from the lower Oconee River downstream from Sinclair Dam; may occur in the Little River upstream from Lake Sinclair.	Habitat fragmentation by dams; stream sedimentation, pollution. Changes in water temperature and river flow regimes that lower reproductive success
Brassy Jumprock *Moxostoma sp.*	A fish belonging to the sucker family (Catostomidae); lives entirely in freshwater. Adults migrate to gravel shoals to spawn.	Medium-sized tributaries and mainstem rivers with rocky shoals	Historically occurred in Atlantic slope rivers from the Altamaha River system (GA) to the Pee Dee River system (NC and SC).	Known from the upper Oconee River system.	Habitat fragmentation by dams; stream sedimentation, pollution.

Altamaha Bass *Micropterus sp.*	A fish in the bass and sunfish family (Centrarchidae); lives entirely in freshwater.	Small or medium-sized rivers with rocky shoals	Only occurs in the Piedmont portions of the Oconee and Ocmulgee river systems, and in upstream reaches of the Ogeechee River.	Upper Oconee River system, primarily upstream from Lake Oconee and Lake Sinclair.	Hybridization with stocked, non-native bass species (e.g., spotted bass). Stream sedimentation, pollution
Goldstripe Darter *Etheostoma parvipinne* GA:R	A small (~3 inches) darter fish in the perch family (Percidae).	Small streams and seeps with vegetation	Occurs in Coastal Plain streams from Texas to the Altamaha River basin in GA	Tributary systems in the Lower Oconee River system	Sedimentation, pollution, and flow alteration in small streams and spring seeps
Oconee burrowing crayfish *Cambarus truncates* GA:T	A pale to bright orange crayfish (family Cambaridae) that constructs and inhabits tunnels (burrows) in wet riparian areas and wetlands near streams	Riparian areas along streams and wetlands	Only known from the Oconee River basin	Lower Oconee River system	Land disturbance along streams and wetlands that destroys burrows or alters streamflow
Chattahoochee crayfish *Cambarus howardi* GA:T	A bluish-green crayfish (family Cambaridae) that inhabits stream riffles	Smaller tributaries to mainstem rivers with swift-flowing riffles	Only known from the Chattahoochee, Flint, Ocmulgee and Oconee river basins	Upper Oconee River: streams in the Mulberry River and Middle Oconee River systems	Stream sedimentation, pollution, impoundment; non-native crayfishes
Inflated floater *Pyganodon gibbosa*	A large (to over 7 inches) freshwater mussel (family Unionidae)	Mainstem rivers, oxbows, reservoirs, in soft sediments	Only occurs in the Altamaha River basin, GA	Lake Oconee, localities in the lower Oconee River system	Pollution, flow alteration, threats to host fish populations and barriers to host fish movements
Altamaha arcmussel	A freshwater mussel (family Unionidae), usually less than 3 inches	Mainstem rivers, oxbows,	Altamaha, Ogeechee and	Lower Oconee River system	Excess sedimentation, habitat disturbance

Alasmidonta arcula GA:T		reservoirs, usually in sand and soft sediments	Savannah river basins		
Pup Elimia *Elimia darwini*	A freshwater snail (family Pleuroceridae)	Small streams and springs	Only known from a single tributary in the lower Oconee River system	Rocky Creek in the lower Oconee River system	Pollution, habitat disturbance