RESTORE Council Activity Description

General Information

Sponsor:
U.S. Department of the Interior

Title:
Develop Ecological Flow Decision-Support for Mobile River and Perdido River Basins

Project Abstract:
The RESTORE Council has approved $3.4M in planning and implementation funds as FPL Category 1 in Council-Selected Restoration Component funding for the Develop Ecological Flow Decision Support for Mobile River and Perdido River Basins project, sponsored by the U.S. Department of the Interior, on behalf of the U.S. Geological Survey (USGS). The project will support the primary RESTORE Comprehensive Plan goal to restore water quality and quantity through activities to create a decision support model to provide information on freshwater inflows to streams, bays, and wetlands. The Operational Analysis and Simulation of Integrated Systems (OASIS) model will simulate the routing of water through watersheds in the river basins, providing a tool for resource managers to evaluate questions of concern, such as the influence of water resource alteration on restoring and conserving habitat, water quality, and living coastal resources. New gaging stations will be installed to fill critical freshwater inflow data gaps and support data needs for future monitoring assessments.

The Alabama Water Agencies Working Group and other water resource managers have identified a critical need for data on inflows and models to understand how the timing and delivery of flow affects downstream ecological resources. The OASIS model will provide state and local agencies with modeled outcomes on various water-use strategies and supporting information to guide water resource management activities and restoration areas to focus on in the future. Project duration is 4 years.

FPL Category: Cat1: Planning/ Cat1: Implementation

Activity Type: Project

Program: N/A

Co-sponsoring Agency(ies): N/A

Is this a construction project?: No

RESTORE Act Priority Criteria:
(II) Large-scale projects and programs that are projected to substantially contribute to restoring and protecting the natural resources, ecosystems, fisheries, marine and wildlife habitats, beaches, and coastal wetlands of the Gulf Coast ecosystem.

Priority Criteria Justification:
The flow-accounting model for the Mobile and Perdido River basins primarily meets the second RESTORE Act Comprehensive Plan goal that addresses large-scale projects that are projected to substantially contribute to restoring and protecting the water quality and quantity of natural resources, ecosystems, fisheries, marine and wildlife habitats, beaches, and coastal wetlands of the Gulf Coast ecosystem. This large-scale project covers over 42,000 square miles, includes the Mobile Bay/Mobile-

Tensaw Delta and Perdido Bay and River priority geographic areas in Alabama, Florida, and Mississippi, and crosses geopolitical boundaries to capture the ecoregional gradient (i.e., upland, riparian, estuarine and coastal habitats). This project will have far-reaching measurable and sustainable effects by providing the needed tools (e.g. model and streamgages), data, and information that could be used by state and local decision-makers to restore more naturalized timing and delivery of freshwater supported by the monitoring of discharge in coastal river systems of Alabama, Florida, and Mississippi. Restoration of the timing of freshwater inflows can positively affect shellfish, fisheries, habitat, and water quality. Increasingly, state and local decision-makers and federal agencies are turning their attention to the restoration of flows as part of a holistic approach to restore water quality and habitat and to protect and replenish living coastal and marine resources and the livelihoods that depend on them. Once the framework is developed and delivered to the decision-makers, it can be used well beyond the duration of the project.

Project Duration (in years): 4

Goals

Primary Comprehensive Plan Goal:
Restore Water Quality and Quantity

Primary Comprehensive Plan Objective:
Improve Science-Based Decision Making Process

Secondary Comprehensive Plan Objectives:
N/A

Secondary Comprehensive Plan Goals:
N/A

PF Restoration Technique(s):
Improve science-based decision-making processes: Develop tools for planning and evaluation

Location

Location:
The decision-support framework will be built for the Mobile River basin which covers approximately 41,000 square miles (65% of the State of AL, 12% MS, portions of GA and TN) and the Perdido River basin which covers approximately 1,100 square miles (70% of the State of AL, 30% FL) (Figure 1).

HUC8 Watershed(s):
South Atlantic-Gulf Region(Choctawhatchee-Escambia) - Florida Panhandle Coastal(Perdido Bay)
South Atlantic-Gulf Region(Choctawhatchee-Escambia) - Escambia(Upper Conecuh)
South Atlantic-Gulf Region(Choctawhatchee-Escambia) - Escambia(Patsaliga)
South Atlantic-Gulf Region(Choctawhatchee-Escambia) - Escambia(Sepulga)
South Atlantic-Gulf Region(Choctawhatchee-Escambia) - Escambia(Lower Conecuh)
South Atlantic-Gulf Region(Alabama) - Coosa-Tallapoosa(Middle Coosa)
South Atlantic-Gulf Region(Alabama) - Coosa-Tallapoosa(Lower Coosa)
South Atlantic-Gulf Region(Alabama) - Coosa-Tallapoosa(Middle Tallapoosa)
South Atlantic-Gulf Region(Alabama) - Coosa-Tallapoosa(Lower Tallapoosa)
South Atlantic-Gulf Region(Alabama) - Alabama(Upper Alabama)
South Atlantic-Gulf Region(Alabama) - Alabama(Cahaba)
South Atlantic-Gulf Region(Alabama) - Alabama(Middle Alabama)
South Atlantic-Gulf Region(Alabama) - Alabama(Lower Alabama)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Luxapallila)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Sipsey)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Mulberry)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Sipsey Fork)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Locust)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Upper Black Warrior)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Lower Black Warrior)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Mobile Bay-Tombigbee(Middle Tombigbee-Chickasaw)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Mobile Bay-Tombigbee(Lower Tombigbee)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Mobile Bay-Tombigbee(Mobile-Tensaw)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Mobile Bay-Tombigbee(Mobile Bay)
Tennessee Region(Middle Tennessee-Elk) - Middle Tennessee-Elk(Bear)
South Atlantic-Gulf Region(Choctawhatchee-Escambia) - Florida Panhandle Coastal(Perdido)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Middle Tombigbee-Lubbub)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Noxubee)
South Atlantic-Gulf Region(Pascagoula) - Pascagoula(Upper Chickasawhay)
South Atlantic-Gulf Region(Choctawhatchee-Escambia) - Florida Panhandle Coastal(Pensacola Bay)
South Atlantic-Gulf Region(Choctawhatchee-Escambia) - Choctawhatchee(Pea)
South Atlantic-Gulf Region(Choctawhatchee-Escambia) - Escambia(Escambia)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Town)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Tibbee)
South Atlantic-Gulf Region(Pascagoula) - Pascagoula(Chunky-Okatibbee)
South Atlantic-Gulf Region(Pearl) - Pearl(Upper Pearl)
Lower Mississippi Region(Lower Mississippi-Yazoo) - Yazoo(Little Tallahatchie)
Lower Mississippi Region(Lower Mississippi-Yazoo) - Yazoo(Yalobusha)
Lower Mississippi Region(Lower Mississippi-Big Black) - Big Black-Homochitto(Upper Big Black)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Upper Tombigbee)
South Atlantic-Gulf Region(Mobile-Tombigbee) - Black Warrior-Tombigbee(Buttahatchee)

South Atlantic-Gulf Region(Mobile-Tombigbee) - Mobile Bay-Tombigbee(Sucarnoochee)
South Atlantic-Gulf Region(Pascagoula) - Pascagoula(Escatawpa)
South Atlantic-Gulf Region(Pascagoula) - Pascagoula(Mississippi Coastal)

State(s):
Alabama
Mississippi
Florida

County/Parish(es):
AL - Autauga
AL - Baldwin
AL - Blount
AL - Bullock
AL - Butler
AL - Calhoun
AL - Chambers
AL - Cherokee
AL - Chilton
AL - Choctaw
AL - Clarke
AL - Conecuh
AL - Coosa
AL - Crenshaw
AL - Cullman
AL - Dallas
AL - DeKalb
AL - Elmore
AL - Escambia
AL - Etowah
AL - Greene
AL - Hale
AL - Jefferson
AL - Lawrence
AL - Lee
AL - Lowndes
AL - Macon
AL - Marengo
AL - Marshall
AL - Mobile
AL - Monroe
AL - Montgomery
AL - Morgan
AL - Perry
AL - Pickens
AL - Pike
AL - Russell
AL - St. Clair

AL - Shelby
AL - Sumter
AL - Talladega
AL - Tallapoosa
AL - Tuscaloosa
AL - Walker
AL - Washington
AL - Wilcox
AL - Bibb
AL - Clay
AL - Cleburne
AL - Fayette
AL - Franklin
FL - Escambia
AL - Lamar
AL - Marion
AL - Randolph
AL - Winston
MS - Choctaw
MS - Clay
MS - Chickasaw
MS - Clarke
MS - Itawamba
MS - Lowndes
MS - Kemper
MS - Lauderdale
MS - Lee
MS - Monroe
MS - Noxubee
MS - Oktibbeha
MS - Pontotoc
MS - Prentiss
MS - Tippah
MS - Tishomingo
MS - Union
MS - Webster
MS - Wayne
MS - Winston

Congressional District(s):
AL - 5
AL - 6
AL - 2
MS - 1
MS - 3
AL - 1
AL - 4
MS - 4

AL - 3
FL - 1
AL - 7

Narratives

Introduction and Overview:

The overall objective of the Clean Water Act (CWA) is to "restore and maintain the chemical, physical and biological integrity of the nation's waters" [section 101(a)]. The interim goal of the CWA is to provide for "water quality which provides for the protection and propagation of fish, shellfish and wildlife and provides for recreation in and on the water" (section 101(a)]. The EPA and the State agencies tasked with implementing CWA programs have made substantial progress in protecting the waters of Alabama, Florida, and Mississippi for more than 40 years. However, based on the National Coastal Assessment survey and other water quality reporting data, there is still substantial work to be accomplished, and new and complex challenges continue to emerge and need to be addressed. The water quality index for the coastal waters of the Gulf Coast region is rated only fair, with 24 % of the coastal area rated poor and 58 % of the area rated fair for water quality condition (USEPA, 2016) (See Figure 2).

In the Mobile and Perdido River basins and across the Gulf region, a wide variety of land use factors have been identified that could contribute to the declining water quality of the Alabama and western Florida coast (Kennicutt, 2017). Land use factors such as deforestation, agriculture, industrialization, and urbanization can alter water quantity and quality and can affect downstream uses. However, there has yet to be comprehensive regional analyses to evaluate one of the most essential factors for the health of the Gulf – the timing and delivery of fresh water to the bays, estuaries and coastal communities. Freshwater flows are widely considered within the scientific community to be the "master variable" for support of healthy and functional riverine ecosystems because instream flow is a major factor for healthy ecological systems in estuaries, affecting all levels of physical, chemical and biological functions (Poff et al., 1997). Every aspect of the lives of aquatic plants and animals is cued by and inextricably linked to the natural variability of our rivers and streams (SIFN, 2010).

For more than six decades, there has been recognition that freshwater inflow is essential to support the health and function of estuaries. The scientific community has expressed the need to more fully evaluate and respond to concerns about reductions to or changes in the timing and delivery of freshwater flows to estuaries, including bays and estuaries within the Gulf of Mexico. As early as 1953, the vital importance of flows to the fisheries of Texas bays and estuaries was recognized (Hildebrand and Gunter, 1953). According to the Alabama Department of Economic and Community Affairs and the Alabama Water Association Working Group, compiling data regarding water use and trends is vital to assessing the water resources of the state with emphasis on baseline conditions. In addition to this baseline data, the state sets out in detail the need for a more comprehensive accounting of the water resources in Alabama (Water Management Issues in Alabama, 2012).

Anthropogenic changes to the timing, volume, and distribution of freshwater flows to bays and estuaries affects salinity, sediments and particulate matter and can affect loss of habitat and nursery areas, declines in spawning and productivity, and alteration in species composition and abundance (Harte Institute, 2014; Albers, 2002). Therefore, maintaining the natural timing and delivery of freshwater flows from rivers to estuaries is critical for establishing appropriate estuarine circulation patterns, salinity gradients, sediment transport, and nutrient supplies that support the production of valuable coastal fisheries. (Powell et al., 2002). Despite this recognition, the natural resource community has yet to undertake a comprehensive approach to collecting and evaluating instream flows.

Many estuarine and coastal habitats, critical for estuarine health, are significantly degraded by changes to the timing and delivery of freshwater flows. Seagrass beds, for instance, are one of the most important near shore coastal habitats in the Mobile and Perdido River Basins and are very vulnerable to anthropogenic changes because they are particularly sensitive to water quality changes. Seagrasses support fish and invertebrate community structure, are extremely productive and are used by a wide variety of species as nurseries, feeding grounds, and refuge from predation (Livingston, 1990). Seagrasses are a vital part of the food web and provide food for many organisms. Similarly, oyster beds, mangroves, marsh lands and soft-bottom un-vegetated sediment habitats are all vulnerable to degradation based on anthropogenic alteration of the land and water that causes changes to the timing and delivery of freshwater flows.

Freshwater flows carry nutrients, sediments, pollutants and organic matter; therefore, upstream changes in flow delivery can affect: (1) downstream water quality such as alteration of water salinities; (2) variation in oxygen and temperature conditions; and (3) changes in the distribution and transport of nutrients, carbon and particulate organic matter to the estuary. This could lead to an increased susceptibility to algal blooms and other habitat impairments. Quantitative relationships between alteration in flow frequency, duration, and/or magnitude and downstream ecological responses of fishes and macroinvertebrates have been documented in the literature (Irwin et al., 2019; Freeman and Marcinek, 2006; Poff and Zimmermann, 2009). Quantifying the connection between freshwater flow and water quality is challenging due to site specificity and the complex nature of estuarine ecosystems. The unavailability of comprehensive datasets that capture the physical, chemical and biological interactions within habitats have limited the ability to understand and model these systems.

The state-of-the-science for implementing restoration of flows for freshwater and estuarine ecosystem health has improved markedly over the past two decades. Some example approaches include modification of operational flow regimes through dam re-regulation, dam removal, conservation and efficiency practices, and improved placement and operation of surface and groundwater withdrawals. However, these efforts can often be hampered by the lack of readily available data on stream flows and available monitoring gages to collect those data. Often projects are implemented without an understanding of historical changes in the timing and delivery of flow over time, as well as the complex nature of the data and the models needed to interpret results for decision-making.

To improve the opportunity for science-based decision-making processes, we will to collect data and develop a flow accounting model that will incorporate vital information relating water resources management actions, such as maintenance of minimum flows, to support freshwater habitat in Alabama, Florida, and Mississippi watersheds included in the Mobile River and Perdido River basins. This need for streamflow modeling was identified in recommendations related to evaluation of instream-flow science and decision making put forth by the Alabama Water Agencies Working Group (AWAWG; 2013, 2017). The USGS Lower Mississippi Gulf Water Science Center has performed studies similar to this project. Flow-accounting models have been developed for the Obed Wild and Scenic River in Tennessee and is in development for the Pearl and Pascagoula River basins in Mississippi. Flow-accounting models are commonly used and have been the focus of many peer-reviewed studies (Pearsall et al., 2005; Richter, 2007; Sheer and Dehoff, 2009; Stephenson, 2011; Sauchyn et al., 2016; WaterSMART, 2016, 2018; NASEM, 2018).

This 4-year, $3.4 million project will provide a comprehensive assessment of flow ecology and develop a basin-wide model for state and local decision-makers to use for restoration and natural resource management projects in Alabama, Florida, and Mississippi. It also supports a process to engage stakeholders and decision makers in development of this decision support tool. Specifically, the project includes:

- Providing focused watershed studies;
- Developing decision-support model/system for stakeholders; and

• Working with state partners to determine priorities for installing new gages.

The project will utilize USGS “Approved” streamflow data publicly available through the USGS National Water Information System (https://waterdata.usgs.gov/nwis/sw). This data is quality-assured by USGS Hydrographers. Nationally, USGS streamflow data describes stream levels, streamflow, lake and reservoir levels and surface-water quality. In addition to USGS data, this project will utilize withdrawal and discharge data from public utilities and industry provided by cooperators (GSA, ADECA, ADCNR) in the study area. The USGS will use U.S. Environmental Protection Agency discharge permit data publicly available via the EPA Enforcement and Compliance History Online website. Biological data collected using sampling protocols by the State of Alabama will be used to determine the flow-ecology relationship in combination with discharge data within the focus watershed. In addition to data listed, the project will utilize operations data from reservoirs within the watershed as input for the flow-accounting model, trend analysis, streamflow alteration analysis, low-flow analysis, and flow-ecology analysis.

The Operational Analysis and Simulation of Integrated Systems (OASIS) model will be used to simulate the routing of water through watersheds in the basin. OASIS is a flow-accounting model which balances inflows with outflows. It can dynamically link with other available groundwater, water quality and watershed models, providing flexibility to address complex interactions (Frei et al., 2012). The OASIS post-processor also allows for easy end-to-end linkages between modeled flows and ecological responses. In the Obed River Basin in Tennessee, output from the model was linked to the USGS’s EflowStats package in R, which was then used to automatically compute ecological habitat metrics that could be compared across scenarios (Cartwright et al., 2017). This software provides a robust tool for decision-makers to evaluate planning alternatives, such as the impact of various water resource alterations on restoring and conserving habitat, water quality, and living coastal and marine resources throughout the basin and in the receiving estuary. It can also be used to evaluate key uncertainties, such as how climate change could be mitigated by various management strategies or planning alternatives (WaterSmart, 2018).

This OASIS model has been used around the world and has provided water resource managers and stakeholders with simulated benefits of various water use scenarios, such as declines in reservoir storage. The OASIS flow-accounting models and other hydrological decision-support frameworks with linkages to OASIS have been utilized in over 40 River Basins in the United States as well as in the Bay of Plenty Region, New Zealand and Yellow River Basin, China. The models have been used to inform management decisions and aid in:

o Evaluating and improving the reliability of water supply system
o Allocation and management of water resources
o Evaluation of proposed release protocol from impoundments
o Water availability assessments
o Evaluation of the impact of multiple operation scenarios
o Dispute resolution
o Informing environmental flow policies
o Refining safe yield estimates with/without optimal operation
o Developing probabilistic triggers to avoid water shortages
o Developing basin-wide water management strategies
o Simulating various hydropower operation scenarios
o Assessing basin-wide effects of various operation scenarios
o Testing and implementation of water shortage response plans
o Assessing instream flow regulations

The evaluation of various water use scenarios provides information upon which to base conservation measures to ensure freshwater flow to support not only community needs but the needs of ecosystems and biota within river basins. In many instances, the OASIS model has provided a basis by which communities have altered their water management plans to more closely mimic natural flows. The OASIS model has been "bench-tested" and has informed many management decisions. For example, it was applied to develop the NYC Operations support tool used for planning and operations of NYC's complex reservoir system, as well as to inform management decisions in Alberta Canada (https://watersmartsolutions.ca/knowledge-base/bow-river-project-final-report/), and the state of North Carolina (https://deq.nc.gov/about/divisions/water-resources/water-planning/modelingassessment/basinwide-hydrologic-modeling). The previously described use and applications of the OASIS model suggest that it is an appropriate choice for evaluating instream-flow alternatives in the Mobile and Perdido River basins.

Methods:

Flow accounting models provide a tool that managers can use to evaluate how streamflow alteration in upstream basins affects downstream conditions. Ideally, models such as these must be empirically based, flexible, compatible with other platforms, while also being easy to use and providing readily interpretable output.

The OASIS model (Hazen and Sawyer (formerly HydroLogics, Inc.), 2011) is an excellent example of such a model and is a unique software program that realistically simulates the routing of water through a watershed. OASIS has been used by environmental groups, industrial clients, and water utilities throughout the United States and informs the allocation of water for approximately 20% of the population of the United States at locations such as the lower Rio Grande-Pecos-Conchos, Savannah, Cape Fear, Pamlico, Neuse, and Roanoke rivers basins. OASIS is an extremely powerful tool that estimates streamflow availability in the context of varying supply demands, management options, and changes in operational rules and constraints. This tool enables parties with diverse and often conflicting goals to work together to develop solutions that mutually satisfy diverse objectives. In application, OASIS will allow resource managers in Alabama, Florida, and Mississippi to understand the frequency and duration that existing or proposed operating rules may be violated and will provide a straightforward means to evaluate alternatives. The model identifies the best means of moving water through the Mobile and Perdido River basins to meet a prescribed set of goals and constraints.

As a flow-accounting model, OASIS will enable water resource managers in Alabama, Florida, and Mississippi to evaluate a range of potential management scenarios, such as modifying release curves for selected reservoirs upstream in order to evaluate changes in freshwater delivery to an estuary. It is a mass-balance model which is resource specific and automatically writes continuity of flow equations and reduces errors when building models describing river basins. The model uses an Operations Control Language (OCL), which provides a way to evaluate operating rules that are tested and implemented. As a mass-balance model, OASIS does not predict water quality parameters, however, it is easy to integrate output from other models (i.e., groundwater and water quality). OASIS and its easy-to-use graphical user interface, dashboards, and processing programs is a tool for stakeholders and water resource managers designed to enable various drought and water use and availability exercises.

Input datasets for the OASIS model include monthly and daily demands, surface water withdrawal and discharge timeseries data, reservoir storage-area-elevation data, reservoir rule curves and model weightings, and evaporation/precipitation data. Statistical analyses of the data to establish and model streamflow relationships will include Mann-Kendall trend analysis, cluster analysis, correlation analysis, Quantile-Kendall analysis, and various low-flow analyses. The OASIS post-processor will compute basic statistics, and perhaps more importantly will produce output in a variety of formats for statistical analysis in other programs. Additionally, the OASIS OCL language will be used to create and track user-defined variables that represent performance measures specific to the basin. In addition to running standard simulations (i.e., a set period of hydrology sequentially), OASIS also has a model called "Position Analysis" (PA) which runs ensembles forecasts. OASIS can automatically generate the ensembles inflows, based on the historic inflow record, and statistically adjust them based on antecedent flows. It also can be configured to run ensemble inflows from external data sources and display potential future flow conditions in a probabilistic way.

The flow accounting model takes hypothetical flow alterations and translates them into characteristics of streamflow. It describes predicted characteristics of streamflow such as magnitude, duration, frequency, timing, and rate of change. The mass-balance model is spatially explicit and operates at a daily time step which enables the model to calculate flow by adding inflow (e.g., flow upstream and effluent discharge) and subtracting outflow (e.g., water withdrawals, reservoir evaporation). The model is designed to be interactive and enables Alabama, Florida, and Mississippi resource managers to evaluate strategies and gather additional stakeholder input.

The methods utilized and outputs developed are going to be similar to the peer-reviewed data, reports and journal articles generated in the 'Obed National Wild and Scenic River' study and the RESTORE FPL1 'Baseline Flows' study. Listed below are several of the publications from the USGS Lower Mississippi Gulf Water Science Center exploring flow-ecology relationships and the collection of data required for those studies:

- Putting Flow–Ecology Relationships into Practice: A Decision-Support System to Assess Fish Community Response to Water-Management Scenarios (Cartwright et al., 2017);
- Modelling ecological flow regime: an example from the Tennessee and Cumberland River basins (Knight et al., 2012);
- Hydrologic Data for the Obed River Watershed, Tennessee (Knight et al., 2014);
- Species-Richness Responses to Water-Withdrawal Scenarios and Minimum Flow Levels: Evaluation Presumptive Standards in the Tennessee and Cumberland River Basins (Driver et al., 2020);
- Copula Theory as a Generalized Framework for Flow-Duration Curve Based Streamflow Estimates in Ungaged and Partially Gage Catchments (Worland et al., 2019);
- Freshwater Delivery to the Gulf of Mexico: An Analysis of Streamflow Trends in the Southeast US from 1950 – 2015 in review (Rodgers et al., 2020);
- Prediction and Inference of Flow Duration Curves Using Multioutput Neural Networks (Worland et al., 2019); and
- The use of support vectors from support vector machines for hydrometeorologic monitoring network analyses (Asquith, 2020).

Stakeholders in Alabama (GSA, ADECA, ADCNR), Mississippi (MDEQ), and Florida (Northwest Florida Water Management District [NWFLWMD], FLDEP) along with other federal, state and local agencies will participate in providing input data on water withdrawals, wastewater discharges, inter-basin transfer and biological data for the OASIS model. A Technical Advisory Committee (TAC) with State members representing the Mobile and Perdido River basins will be established to discuss, plan and provide data for model construction and to discuss how the model output will be used to address management needs. This involvement during model development and verification will ensure all parties are represented, that there is transparency in the process, and that performance measures and the evaluation of alternative and current management strategies are developed collaboratively. TAC involvement from model conception to scenario development and outcomes will create a collaborative environment based upon a shared knowledge and understanding of the methods employed by the flow accounting model and the physical capabilities and limitation of the hydrologic systems they are charged with managing.

Flow Ecology

Streamflow metrics and aquatic biota community data for freshwater sites throughout the river basins will be evaluated using multivariate techniques to determine which components of the annual hydrograph are critical to the health of freshwater biota. The analysis will be conducted using streamflow metrics and their respective deviation from reference hydrologic profiles developed in RESTORE FPL1 'Baseline Flows' study (Knight et al., 2008; Carlisle et al., 2010a, and 2010b). The result of the analysis will be a subset of streamflow metrics that, when altered, result in an observed ecological response, or ecological limit function (Knight et al., 2012). This function can be used to evaluate potential changes to streamflow (water use, landscape / land use change, and climate) in terms of potential ecological response (degradation). The results will provide managers with a scientific basis for decision making.

This flow ecology analysis described in Knight et al., 2012 and Cartwright et al., 2017 will be a multistep process (Figure 3) that includes:

1. Definition of one or more hypothetical or proposed flow alterations;
2. Translation of the flow alterations into predicted streamflow characteristics (e.g., magnitude, frequency, timing, duration, rate of change, and predictability of high- and low- flow events);
3. Formatting of predicted streamflow characteristics as an independent variable in the flow-ecology relationship under the hypothetical or proposed alteration; and
4. Application of the flow-ecology relationship to the independent variable in order to predict the ecological response to the proposed alteration/alterations.

The process is designed to incorporate existing flow-ecology relationships into the flow-accounting model such that it:

1. Integrates multiple water-management decisions and their hydro-ecologic effects;
2. Uses a methodology that is consistent and transparent;
3. Is adaptable, flexible, and allows for updates of locations of ecological assessments, scenarios, and water-management assets;
4. Derives specific ecological predictions from translated water-management decisions;
5. Subsets ecological predictions into meaningful ecological categories;
6. Engages with end-users throughout model development; and
7. Is efficient and cost-effective for end-users.

Installation of Streamflow Gages

As part of the RESTORE Baseflow study, the USGS performed a network analysis to determine gaps in the streamgaging networks of the 5 Gulf states. The USGS will leverage the results of this analysis to inform stakeholders of potential locations for 5 new streamgages in year 1 and provide operating and maintenance support in years 2-4 in the Mobile and/or Perdido River basins to address the gaps identified. Funding for the operation and maintenance of the streamgages is included in the budget for the duration of this project. Additional funding would have to be secured for O&M of the gages after year 4 of this project. The funds requested for streamgage installation are intended to cover 5 streamgages; however, final decisions will be based on sites chosen and reflect installation costs.

Milestones

Stakeholders were engaged prior to project proposal submittal to determine interest in the project and to discuss how best the USGS, State and local experts can work together to assemble the necessary datasets, conduct targeted analyses, and generate an operational tool that will provide federal, state, and local agencies with supporting data necessary to inform science-based decisions for restoration, flood, and drought management efforts in the Mobile River and Perdido River basins. Listed below are milestones identified from stakeholder conversations which will be used to judge the success of the project:

Year 1:
- Evaluate which streamflow metrics are most critical to ecological endpoints in Focus Watershed.
- Start building input data sets and setting up input data sets for the OASIS model.
- Evaluate temporal changes in critical streamflow metrics along large rivers in the Focus Watershed.
- Work jointly with ADECA, GSA, ADCNR, NWFLWMD on installation of new streamflow gages at pre-determined locations.

Year 2:
- Finalize all components of the OASIS model.
- Continue streamflow metric analysis.
- Work jointly with ADECA, GSA, ADCNR to assess how temporal changes in critical streamflow metrics along large rivers in the Focus Watershed are impacting aquatic biology health (SAV, macroinvertebrates, etc.).
- Conduct streamflow gage O&M.
- Journal article on focused streamflow trends analysis.
- Journal article on focused hydrologic alteration.

Year 3:
- Journal article on streamflow-ecology model.
- Journal article on streamflow metrics trends at key large river nodes in the Focus Watershed.
- Journal article on low-flow statistics for focused study area.
- Conduct streamflow gage O&M.

Year 4:
- Release OASIS model and model documentation.
- Cooperator/USGS OASIS model training.
- Journal article on OASIS model.
- Conduct streamflow gage O&M.

Environmental Benefits:

The USGS, working with water resource management agencies, have long been at the forefront of developing and implementing environmental flow science, and improving models used by resource managers to implement flow regimes to protect and restore critical habitat and protect and maintain species. The benefits of providing advanced decision-support models and data include the ability to evaluate indirect environmental benefits of various water resource management and restoration projects and actions, and hopefully improving the efficacy of those actions. An additional benefit of the project is associated with the potential mitigation of future risks such as sea level rise, subsidence, and/or storms. The flow-accounting model will allow resource managers to generate “what if” scenarios in reallocating water flows to address long-term risks and uncertainties. Scenarios of water-use change affected by industry, urbanization, agriculture, climate change and other future risks and uncertainties can be incorporated into water use allocations in the flow-accounting model to better understand threats to downstream ecological resources. The flow-accounting model will provide state and local agencies (e.g. GSA, ADCNR, ADECA, NWFLWMD and others) with modeled outcomes on water-use strategies and allow comparisons of benefits and tradeoffs among various water resource projects.

Metrics:

Metric Title: PRM012: Tool development for decision-making - # tools developed
Target: 1
Narrative: Success of PRM012 will be measured by the completion and delivery of the OASIS model to shareholders and decision makers in Alabama, Florida, and Mississippi. Upon delivery, Hazen and Sawyer (formerly HydroLogics, Inc.) will provide training to the states on model use and the graphical user interface. The tutorial will enable the continued use of the model including the adaptation of previous scenarios when new data becomes available. In addition to model delivery, a report describing model output will be submitted for publication.

Metric Title: PRM006: Monitoring - # streams/sites being monitored
Target: 5
Narrative: Success of PRM006 will be measured by the construction and installation of five streamgages in year 1, operation and maintenance in years 2-4, and delivery of publicly available, quality-controlled data via the web.

Risk and Uncertainties:

There is limited risk in using a flow-accounting model for application in the Mobile and Perdido River basins. The OASIS model has been previously developed and applied in numerous river systems throughout the U.S., including parts of the Mobile River basin and a RESTORE FPL1 application in the Pascagoula-Pearl in Mississippi. However, streamgage damage or destruction is an operational risk in implementing the second component of this project. The uncertainty that exists in regard to model development is primarily associated with uncertainty in the input data provided, since the flow accounting model is just a mass-balance of inputs and outputs. There are measurement and equipment errors associated with the input data that need to be accounted for. The OASIS model development process includes verification of inflows, through simulations forcing the model to match historic operational data and looking at overall simulation agreement and making adjustments where necessary. Once the OASIS model is built, it will be easy to switch inputs to quickly look at the model’s sensitivity to uncertainty in inputs. OASIS can be called by a batch program to facilitate running a large set of alternative inflow datasets, for example, from downscaled Global Climate Change models or from inflows generated through Monte Carlo simulation.

Mitigation - Streamgages are subject to vandalism and/or destruction by natural events (e.g., overtopping, washed off bridges, lightning strikes). The USGS assumes the financial risk for these events when operating streamgages. If a gage funded through this project is damaged through natural events or vandalism, instrumentation will be replaced. If vandalism becomes a continuous problem, an alternate location (different location on same stream or potentially different stream) will be identified. Downtime in gage operations will be minimized by completing repairs as quickly as possible.

There are also operational benefits associated with the mitigation of future risks. The water use accountability model generated by this project will allow resource managers to generate “what if” scenarios in reallocating water flows to address long-term risks and uncertainties. Scenarios of water-use change affected by industry, urbanization, agriculture, climate change and other future risks and uncertainties can be incorporated into water use allocations in the OASIS model to better understand threats to downstream ecological resources.

Monitoring and Adaptive Management:

This project will be completed with state-of-the-art scientific methods utilizing data generated and described in the RESTORE FPL1 Baseline flows project (https://www.sciencebase.gov/catalog/item/59b7ed9be4b08b1644df5d50) and existing water use and ecological data from State partners. The network analysis performed as a part of the ‘Baseline Flows’ project will be used to inform locations of 5 new continuous streamflow gages, that will be installed, maintained and monitored for four years following USGS National Standards, and data will be made available through the USGS National Water Information System (https://waterdata.usgs.gov/nwis/sw). In addition, the lessons learned from the focused watershed study in the Baseflow project will be applied to this project. As new and emerging processes or methods become available, they will be incorporated.

Data Management:

Data and corresponding FGDC-compliant metadata used in analysis will be managed in accordance with the U.S. Geological Survey data archival and publishing standards and are subject to those described in White House OSTP Memorandum and OMB Open Data Policy. These policies require federal agencies to collect or create information in a way that supports downstream information processing and dissemination activities. This includes using machine readable and open formats, data standards, and common core and extensible metadata for all new information creation and collection efforts. The required metadata will facilitate the discovery of relevant project information and promote data use for future Gulf restoration efforts. Data sets (tabular and GIS) assembled and used in analyses will be stored on a dedicated local server and backed up in accordance with USGS Lower Mississippi River-Gulf WSC data stewardship and preservation policies and in accordance with RESTORE Council Guidelines. Derivatives of published or existing data and metadata generated during this project will be published and made publicly available in standard machine-readable formats through recognized outlets, such as the ScienceBase USGS data release community folder. ScienceBase also provides a centralized permanent archive for USGS data and information products.

The model will be delivered and installed at a location determined by the State of Alabama along with complete documentation including all assumptions, operating rules, inputs, inflow development and various model parameters. Training for State of Alabama staff and other stakeholders will be provided over 2 days. Model developers have extensive experience in providing training for users of the models to ensure sufficient skills for running the model, modifying inputs/assumptions for new scenarios, and generating and analyzing output. The training will also include materials that can be used for training of new staff. Trained staff will be able to update input datasets and run and utilize the model well beyond the life of this project.

Collaboration:
The USGS has consulted with Commissioner Chris Blankenship (and his staff) and Alabama water agencies concerning this project. These conversations helped develop the initial proposal and refinements that include construction of new streamflow gages in the river basins. Presentations of the proposal were provided to RESTORE Council members in Alabama, Florida and Mississippi. On the local level, conversations occurred with members of the Northwest Florida Water Management District who have minimum flow objectives in the Perdido River basin that this project could help support, along with state agencies in Alabama, Florida, and Mississippi. Additionally, the Technical Advisory Committee (TAC) State members from Alabama and Mississippi that were established under the 'Baseline Flows' (EGID1 from FPL1) project have had further collaboration discussions on the scope of the project.

Public Engagement, Outreach, and Education:
This project is particularly well-suited for providing a significant amount of outreach and educational opportunities to both the public as well as to state and local decision-makers. It will expand the general knowledge of the importance of streamflow and provide newly emerging information that demonstrates the ecological and economic benefits of maintaining or restoring ecological flows. Two elements of this project that will be emphasized in the communication strategy are:

1. Communicating Information on the Ecological and Economic Benefits of Restoring Flows. The state-of-the science on understanding freshwater flows might not be well understood by the public. The project will incorporate information on the ecological and economic importance of freshwater flows to coastal communities -- in fact sheets, press briefs, on-line tools and publicly-accessible publications. Outreach materials will demonstrate how stream flow information is vital to management and policy decisions regarding flood and drought protection, industrial and municipal water supply, pollution control, storm water management, and stream ecosystem health; how the OASIS model is used to evaluate the various competing priorities for water use (e.g., population growth, irrigation, power generation, restoration of aquatic habitat) in Mobile and Perdido River basins; how stream flow records from long-term streamgages are essential to assessing how the stream flow metrics related to floods, droughts, and aquatic stream health are being modified by human actions; and how stream flow data are essential for effective restoration planning and assessment of water resources projects.

2. Publishing Successful Stories of Flow Restorations. USGS will profile and publicize successful flow restorations that have taken place in the Gulf of Mexico region resulting in ecological and economic benefits for communities. Flow restoration projects in Alabama, Florida, and Mississippi will be highlighted and used to educate stakeholders on the consequences of flow alteration on downstream ecological resources and how restoration of flows can provide both ecological and economic benefits.

Leveraging:

Funds: $1,500,000.00
Type: Bldg on Others
Status: Received
Source Type: Other Federal
Description: The RESTORE FPL1 'Baseline Flows' project will provide foundational datasets and statistical analyses for model development that will be incorporated into the decision-support

framework for the Mobile and Perdido River basins (estimated at $1.5-$2M). Datasets generated during the ‘Baseline Flows’ project will be used to determine potential locations of new streamflow gages and flow-ecology methodologies employed to create the flow-accounting model.

Funds: $1,000,000.00
Type: Bldg on Others
Status: Received
Source Type: State
Description: This project will leverage a fish and invertebrate sampling program and database (estimated at greater than $1M) funded by the Geological Survey of Alabama (GSA). This database is critical for describing ecological response to various flow regimes, which could then be evaluated using the OASIS model.

Environmental Compliance:
The modeling component of this project is a planning effort and will utilize the Council’s Categorical Exclusion for the National Environmental Policy Act. Installation of streamgages is considered implementation and will require a categorical exclusion. The Council is using USGS Categorical Exclusion (CE) USGS 516 DM 9.5E, E. Operation, construction, installation, and removal of scientific equipment. This CE and associated documentation addresses the Endangered Species Act and the National Historic Preservation Act.

Bibliography:

Alabama Water Agencies Working Group. 2013. Mapping the Future of Alabama Water Resources Management: Policy Options and Recommendations. Available on-line at: https://adeca.alabama.gov/wp-content/uploads/December-2013-Alabama-Water-Resources-Management-Policy-Report.pdf

Alabama Water Agencies Working Group. 2017. Water Management Issues in Alabama. Available on-line at: https://alabamarivers.org/project/alabama-water-plan/

Albers, M., 2002. A Conceptual Model of Estuarine Freshwater Inflow Management. Estuaries. 25(6B):1246-1261.

Asquith, W.H., 2020. The use of support vectors from support vector machines for hydrometerologic monitoring analyses. https://doi.org/10.1016/j.jhydrol.2019.124522

Carlisle, D.M., Falcone, J., Wolock, D.M., Meador, M.R., and Norris, R.H. 2010a. Predicting the natural flow regime: models for assessing hydrological alteration in streams. River Research and Applications 26:118– 136.doi: 10.1002/rra.1247.

Carlisle, D.M., Wolock, D.M., and Meador, M.R. 2010b. Alteration of streamflow magnitudes and potential ecological consequences: a multiregional assessment. Frontiers in Ecology and the Environment. doi: 10.1890/100053.

Cartwright, J.; Caldwell, C.; Nebiker, S.; Knight, R. 2017. Putting Flow–Ecology Relationships into Practice: A Decision-Support System to Assess Fish Community Response to Water-Management Scenarios. Water 9, 196.

Driver, L.J.; Cartwright, J.M.; Knight, R.R.; Wolfe, W.J. 2020. Species-Richness Responses to WaterWithdrawal Scenarios and Minimum Flow Levels: Evaluating Presumptive Standards in the Tennessee and Cumberland River Basins. Water 12, 1334.

Freeman M.C., and Marcinek, P.A., 2006. Fish assemblage responses to water withdrawals and water supply reservoirs in piedmont streams. Environmental Management, 38: 435–450.

Harte Research Institute. Freshwater Inflow Tools webpage accessed in October and November 2014 at http://www.freshwaterinflow.org/

Hildebrand, H.H., and Gunter, G., 1953. Correlation of rainfall with Texas catch of white shrimp, Penaeus setiferus (Linnaeus), Transactions of the American Fisheries Society, 82:151–155.

Hydrologics. 2011. Hydrologics: Advancing the management of water resources. Hydrologics, Inc. http://www.hydrologics.net/index.html (October 2014)

Irwin, E.R., ed., 2019, Adaptive management of flows from R.L. Harris Dam (Tallapoosa River, Alabama)—Stakeholder process and use of biological monitoring data for decision making: U.S. Geological Survey Open-File Report 2019–1026, 93 p., https://doi.org/10.3133/ofr20191026.

Kennicutt M.C. 2017. Water Quality of the Gulf of Mexico. In: Ward C. (eds) Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill. Springer, New York, NY

Knight, R.R., Brian Gregory, M. and Wales, A.K. 2008. Relating streamflow characteristics to specialized insectivores in the Tennessee River Valley: a regional approach. Ecohydrology, 1:394–407. doi: 10.1002/eco.32

Knight, R.R., Murphy, J.C., Wolfe, W.J., Saylor, C.F., and Wales, A.K. 2012. Ecological limit functions relating fish community response to hydrologic departures of the ecological flow regime in the Tennessee River basin, USA. Ecohydrology (accepted article) DOI:10.1002/eco.1460

Knight, R.R., Wolfe, W.J., and Law, G.S., 2014, Hydrologic data for the Obed River watershed, Tennessee: U.S. Geological Survey Open-File Report 2014–1102, 24 p., https://dx.doi.org/10.3133/ofr20141102.

Livingston, Robert J. "Inshore Marine Habitats" Ecosystems of Florida. Edited by Ronald L. Myers and John J. Ewel. The University of Central Florida Press, 1990.

Matonse, A.H., Pierson, D.C., Frei, A., Zion, M.S., Anandhi, A., Schneiderman, E., and Wright, B. 2012. Investigating the impact of climate change on New York City's primary water supply. Climatic Change. 116. 10.1007/s10584-012-0515-4.

National Academies of Sciences, Engineering, and Medicine (NASEM). 2018. Review of the New York City Department of Environmental Protection Operations Support Tool for Water Supply. Washington, DC: The National Academies Press. https://doi.org/10.17226/25218.

Pearsall S.H., McCrodden B.J., Townsend P.A. 2005. Adaptive management of flows in the lower Roanoke River, North Carolina, USA. Environmental Management 35(4):353-367. doi:10.1007/s00267003-0255-3

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E., and Stromberg, J.C. 1997. The Natural Flow Regime. Bioscience 47(11):769-784.

Poff, N.L., and Zimmerman, J.K.H. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology. 55: 194–205.

Powell, G. L., Matsumoto, J., and Brock, D.A. 2002. Methods for determining minimum freshwater inflow needs of Texas bays and estuaries. Estuaries 25:1262–1274.

Richter, B., 2007. Meeting urban water demands while protecting rivers: A case study from the Rivanna River in Virginia. Journal AWWA 99(6):24-26

Rodgers, K.D., Hoos, A.B., Roland, V.L., and Knight, R.R., 2018. Trend analysis results for sites used in RESTORE Streamflow alteration assessments (ver. 1.1, November 2019): U.S. Geological Survey data release, https://doi.org/10.5066/P9YSE754.

Sauchyn, D.J., Jacques, J., Barrow, E., Nemeth, M.W., Macdonald, R.J., Sheer, A., and Sheer, D. 2016. Adaptive Water Resource Planning in the South Saskatchewan River Basin: Use of Scenarios of Hydroclimatic Variability and Extremes. Journal of the American Water Resources Association. 52(1):222-240.

Sheer, D.P., and Dehoff, A. 2009. Science-based Collaboration: Finding Better Ways to Operate the Conowingo Pond. Journal of the American Water Works Association 101(6):20-24

Southern Instream Flow Research Agenda; A Proposal to Advance the Science For Instream Flow Protection in Southern Rivers by Southern Instream Flow Network, March 2010.

Stephenson, S.K. 2011. Converging Waters: Integrating Collaborative Modeling with Participatory Processes to Make Water Resources Decisions. Washington, D.C. U.S. Army Corps of Engineers.

U.S. Environmental Protection Agency. 2016. National Coastal Condition Assessment 2010. Washington, DC, Office of Research and Development/Office of Water. EPA-841-R-15-006.

WaterSMART Solutions Ltd. 2018. A Roadmap for Sustainable Water Management in the Athabasca River Basin. Produced by WaterSMART Solutions Ltd. for Alberta Innovates, Calgary, Alberta, Canada. 247 pages. Available online at http://www.albertawatersmart.com/.

WaterSMART. 2016. Climate Vulnerability and Sustainable Water Management in the South Saskatchewan River Basin, Final Report. 129 pages. Available online at http://albertawater.com/ and http://www.ai-ees.ca

Worland, S. C., Steinschneider, S., Asquith, W., Knight, R., and Wieczorek, M. 2019. Prediction and inference of flow-duration curves using multi-output neural networks. Water Resources Research, 55: 6850–6868. https://doi.org/10.1029/2018WR024463

Budget

Project Budget Narrative:

Year 1: $850,000 Focus Watershed Assessments and Streamflow Gage Installation
Evaluate which streamflow metrics are most critical to ecological endpoints in Focus Watershed. Start building input data sets and setting up input data sets for the OASIS model.
Evaluate temporal changes in critical streamflow metrics along large rivers in the Focus Watershed.
Work jointly with ADECA, GSA, ADCNR, NWFLWMD on installation of new streamflow gages at predetermined locations.

Year 2: $850,000 Focus Watershed Assessments and Streamflow Gage Operation and Maintenance
Finalize all components of the OASIS model Continue streamflow metric analysis.
Work jointly with ADECA, GSA, ADCNR to assess how temporal changes in critical streamflow metrics along large rivers in the Focus Watershed are impacting aquatic biology health (SAV, macroinvertebrates, etc.).
Streamflow Gage O&M.
Article on focused streamflow trends analysis.
Article on focused hydrologic alteration.

Year 3: $1,000,000 Focus Watershed Assessments and Streamflow Gage Operation and Maintenance
Article on streamflow-ecology model.
Article on how streamflows metrics have changed over time at key large river nodes in the Focus Watershed.
Article on low flow statistics for focused study area.
Determine funding source for continuation of new streamflow gages.
Streamflow Gage O&M

Year 4: $700,000 Focus Watershed Assessments and Streamflow Gage Operation and Maintenance
Release OASIS model.
Article on OASIS model.
Communication Blitz on key results and application of the model.
Streamflow Gage O&M

Total FPL 3 Project/Program Budget:
$ 3,400,000.00

Estimated Percent Monitoring and Adaptive Management: 5 %
Estimated Percent Planning: 67 %
Estimated Percent Implementation: 12 %
Estimated Percent Project Management: 9 %
Estimated Percent Data Management: 7 %
Estimated Percent Contingency: 0 %

Environmental Compliance

Environmental Requirement	Has the Requirement Been Addressed?	Compliance Notes (e.g., title and date of document, permit number, weblink etc.)
National Environmental Policy Act	Yes	Council NEPA Categorical Exclusion for planning will be utilized for the modeling component of this project. See uploaded USGS categorical exclusion documentation for streamgage installation - USGS concluded that the installation of streamgages is not a major federal action.
Endangered Species Act	Yes	See uploaded USGS categorical exclusion documentation for streamgage installation under NEPA upload.
National Historic Preservation Act	Yes	See uploaded USGS categorical exclusion documentation for streamgage installation under NEPA upload.
Magnuson-Stevens Act	N/A	
Fish and Wildlife Conservation Act	N/A	
Coastal Zone Management Act	N/A	
Coastal Barrier Resources Act	N/A	
Farmland Protection Policy Act	N/A	
Clean Water Act (Section 404)	Yes	See uploaded USGS categorical exclusion documentation for streamgage installation under NEPA upload.
River and Harbors Act (Section 10)	Yes	See uploaded USGS categorical exclusion documentation for streamgage installation under NEPA upload.

Marine Protection, Research and Sanctuaries Act	N/A	
Marine Mammal Protection Act	N/A	
National Marine Sanctuaries Act	N/A	
Migratory Bird Treaty Act	Yes	See uploaded USGS categorical exclusion documentation for streamgage installation under NEPA upload.
Bald and Golden Eagle Protection Act	Yes	See uploaded USGS categorical exclusion documentation for streamgage installation under NEPA upload.
Clean Air Act	N/A	
Other Applicable Environmental Compliance Laws or Regulations	N/A	Included additional note regarding Native American sacred sites.

Maps, Charts, Figures

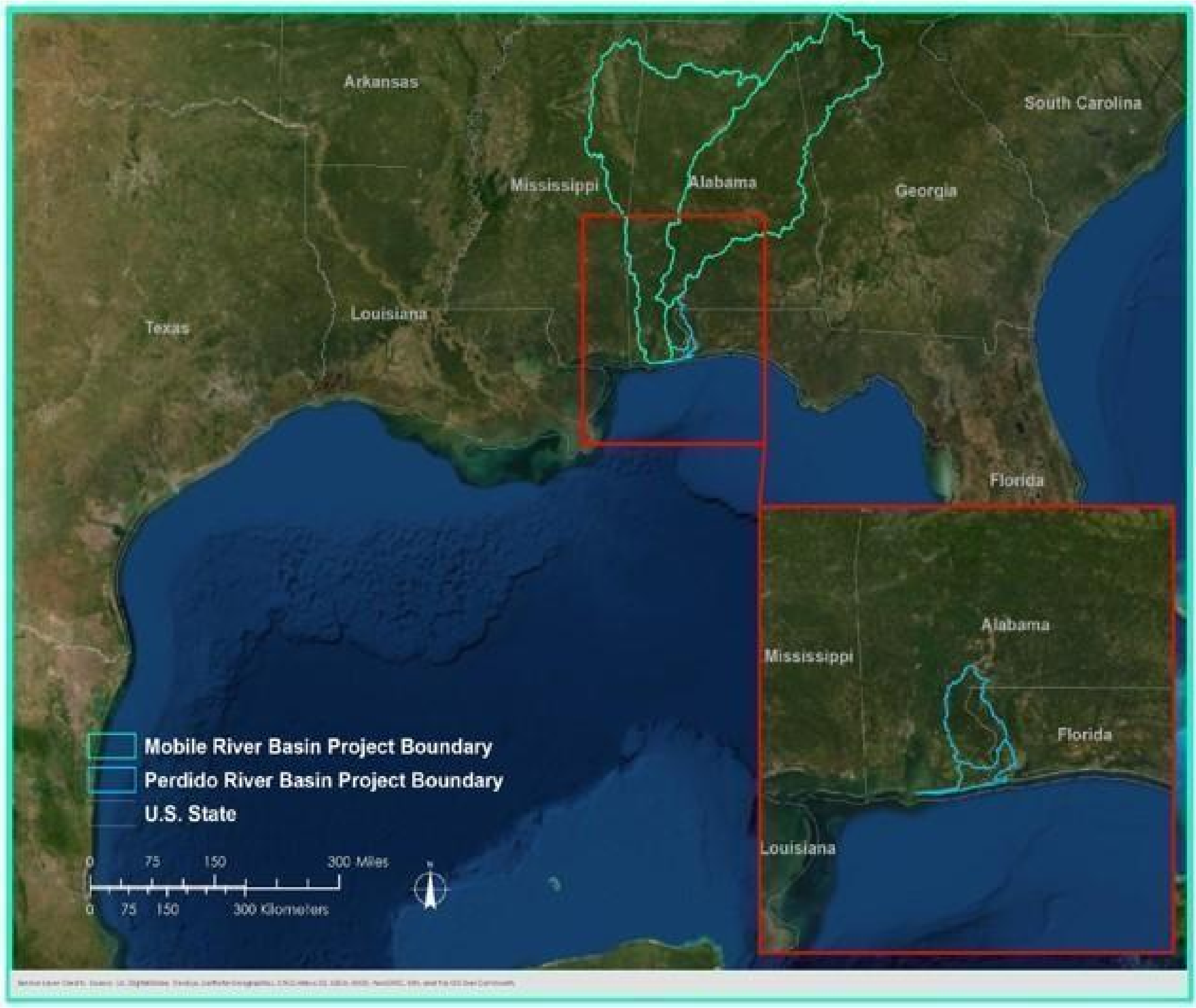

Figure 1: DOI/USGS Ecological flow project location

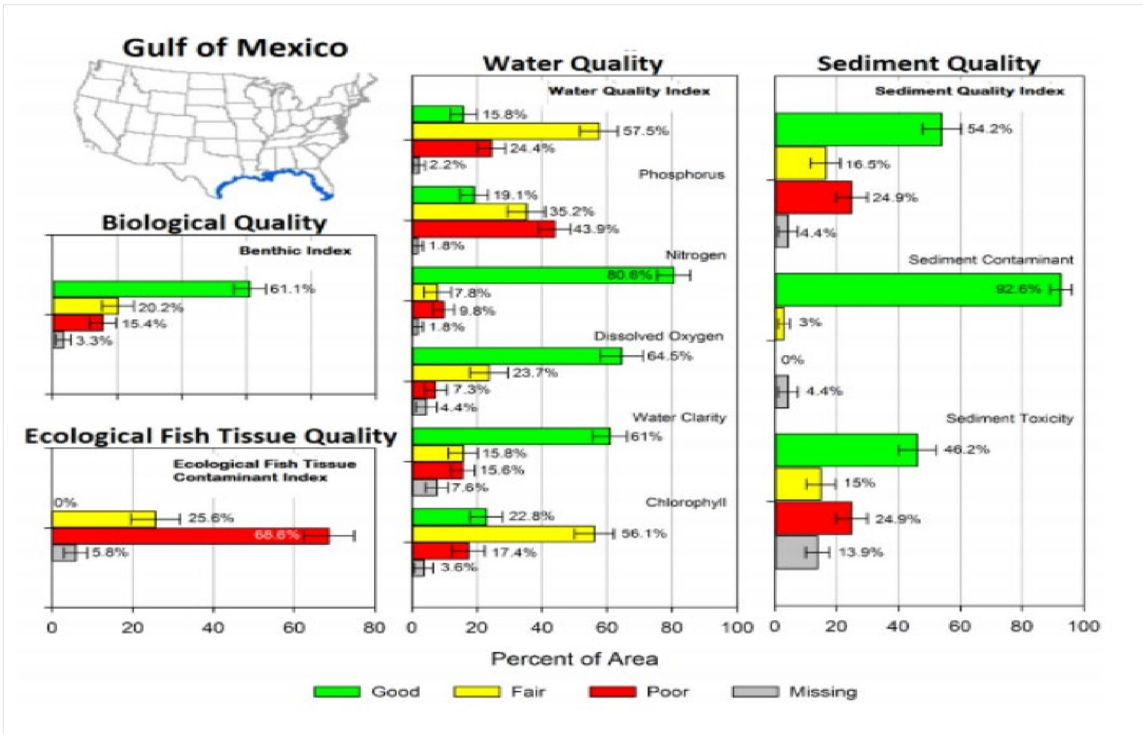

Figure 2: Overall water quality conditions of Gulf Coast estuaries (USEPA, 2016)

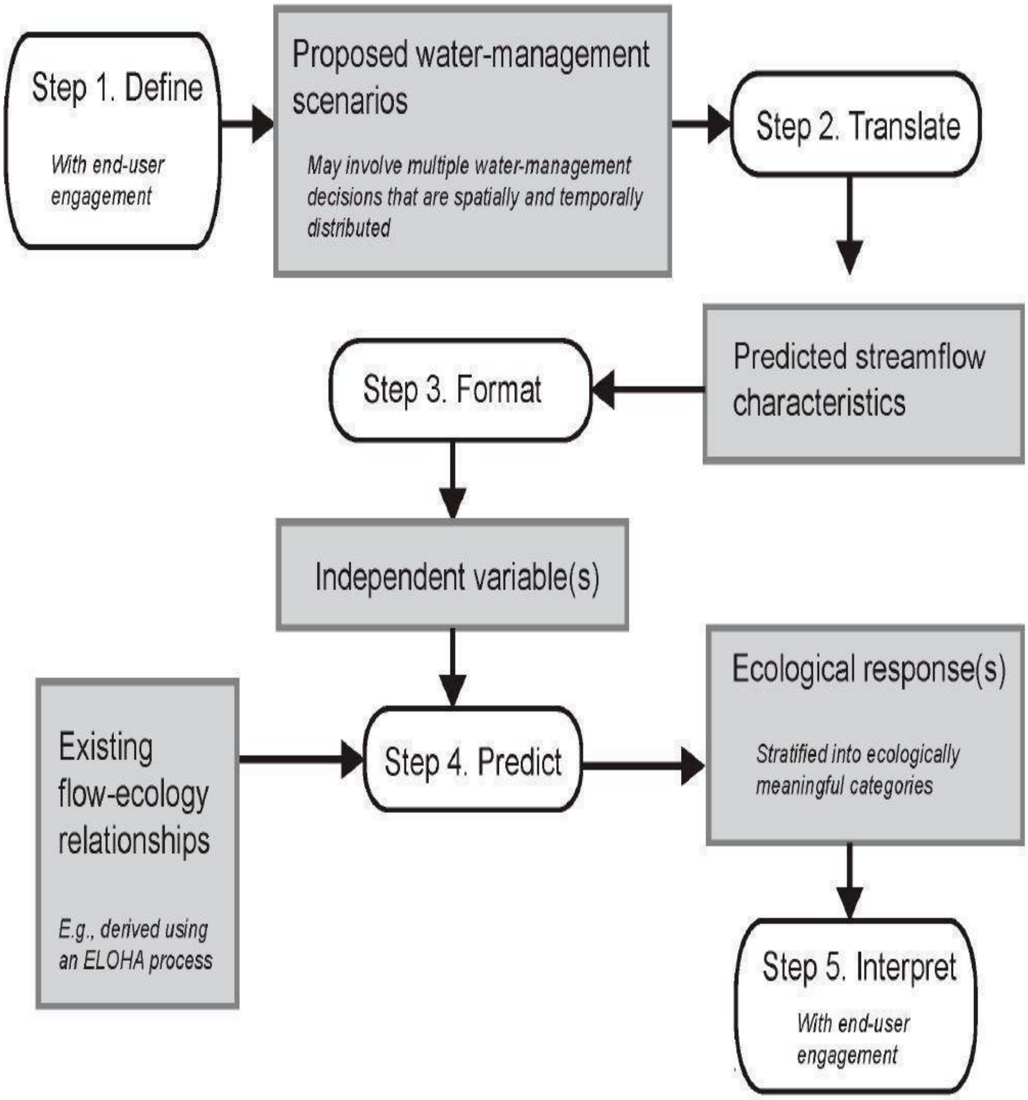

Figure 3: Conceptual model to operationalize flow-ecology relationships into decision-support systems for water resource managers (Cartwright et al., 2017)