Issue Analysis Form

Date: November 24, 2020

Item: Prince George Raw Water Intake Modeling

Lead Department: Engineering & Utilities

Contact Persons: Frank Haltom, Director

Description and Current Status

Prince George County has submitted an application for a permit to withdrawal water from the Appomattox River to provide a long-term water supply to serve the County. In consideration of issuing a permit, Virginia Marine Resource Commission (VMRC), in consultation with the Virginia Institute of Marine Science (VIMS), requires an environmental assessment to be performed to determine if the raw water intake can be approved without harming the fish habit or cause other environmental impacts.

To provide sound scientific-based information for the environmental assessment, a numerical modeling approach will be used to simulate the impacts to the ecosystem caused by the intake. VIMS will conduct the modeling study and develop a fine-resolution model to simulate tidal flow and larval transport processes. With the use of the model, the changes in hydrodynamic conditions in terms of currents and water exchange can be evaluated, which will provide information for an accurate risk assessment by understanding the impacts of the proposed intake on the ecosystems of the adjacent region. VIMS has proposed to perform these efforts for $80,085.

In order to further our efforts to obtain the Appomattox River water withdrawal permit, Staff recommends authorizing the expenditure of $80,085 to allow VIMS to perform the required hydrodynamic model.

The Government Path

Does this require IDA action?	☐ Yes	☒ No
Does this require BZA action?	☐ Yes	☒ No
Does this require Planning Commission action?	☐ Yes	☒ No
Does this require Board of Supervisors action?	☒ Yes	☐ No

Board Action Requested:
A resolution to authorize the expenditure of $80,085 for VIMS to perform the required hydrodynamic modeling.

Fiscal Impact Statement

The appropriated budget within the Utility CIP fund will cover the cost of these services and no additional appropriation is required.

Prince George County Impact

The expenditure will continue the County's efforts to obtain a permit to withdrawal water from the Appomattox River.

Notes

None.

Board of Supervisors
County of Prince George, Virginia

Resolution

At a regular meeting of the Board of Supervisors of the County of Prince George held in the Boardroom, Third Floor, County Administration Building, 6602 Courts Drive, Prince George, Virginia, this 24th day of November, 2020:

Present:	Vote:
Donald Hunter, Chairman	
Alan R. Carmichael, Vice-Chair	
Floyd M. Brown, Jr.	
Marlene J. Waymack	
T. J. Webb	

A-4

On motion of ______________, seconded by _____________, which carried unanimously, the following Resolution was adopted:

RESOLUTION: AUTHORITY TO MAKE EXPENDITURES FOR REQUIRED HYDRODYNAMIC MODELING ($80,085 TO BE PERFORMED BY THE VIRGINIA INSTITUTE OF MARINE SCIENCE).

WHEREAS, Prince George County has submitted an application for a permit to withdrawal water from the Appomattox River to provide a long-term water supply to serve the County; and

WHEREAS, Virginia Marine Resource Commission (VMRC), in consultation with the Virginia Institute of Marine Science (VIMS), requires an environmental assessment to be performed to determine if the raw water intake can be approved without harming the fish habit or cause other environmental impacts; and

WHEREAS, to provide sound scientific-based information for the environmental assessment, a numerical modeling approach will be used to simulate the impacts to the ecosystem caused by the intake; and

WHEREAS, VIMS proposes to conduct a modeling study and develop a fine-resolution model to simulate tidal flow and larval transport processes, and evaluate the changes in hydrodynamic conditions, which will provide information for an accurate risk assessment by understanding the impacts of the proposed intake on the ecosystems of the adjacent region; and

WHEREAS, VIMS proposes to perform these efforts for $80,085.

NOW, THEREFORE BE IT RESOLVED that the Board of Supervisors of the County of Prince George this 24th day of November, 2020, hereby approves the expenditure of $80,085 for the required hydrodynamic model to be performed by VIMS.

A Copy Teste:

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Percy C. Ashcraft
County Administrator

Apply a Particle Tracking Model to Analyze Impacts of Water Intake on Ichthyoplankton Mortality in the Appomattox and the James Rivers

A Proposal Submitted to

County of Prince George, Virginia

P.O. Box 68 Prince George, VA 23875

by

Virginia Institute of Marine Science
School of Marine Science
William & Mary
Gloucester Point, Virginia 23062

Project Duration: December 1, 2020 – August 15, 2021

Jian Shen
Principal Investigator

Qubin Qin
Co-Principal Investigator

Troy Tuckey, Co-PI

Courtney Harris, Chair

Mark Luckenbach
Associate Dean of Research

Connie Motley
Assistant Director, VIMS Sponsored Programs and Advisory Services

November 11, 2020

Introduction

A surface water municipal intake proposed by Prince George County in tidal water is currently in the regulatory review process. The intake would be located just upstream of the I-295 bridge about 5 km upstream from the mouth of Appomattox River (Fig. 1). The intake location is influenced by the tide and the mean tidal range is about 2.61 ft. Impacts of the intake on the mortality of ichthyoplankton and the ecosystems in the tidal Appomattox River and the upper tidal James River are not well known. Because the Appomattox and the James are connected, water exchange occurs in the two rivers due to tidally induced flow, which creates a difficult situation for accurate analyses of environmental impacts of the intake if the impacts are only evaluated locally.

One of the key potential impacts of intake operation on marine resources is causing an increase in the mortality of fish eggs and larvae. Because of the complex geometry in this tidal freshwater region, the tidal flow can transport ichthyoplankton from one area to other areas, which are influenced by tide and freshwater discharge. However, ichthyoplankton transport pathways are unknown for this area. It is unclear if ichthyoplankton spawned in this freshwater region will be affected by the intake. To provide sound scientific-based information for the environmental assessment, a numerical modeling approach can be used to simulate ichthyoplankton dispersion and changes in mortality caused by the intake.

Virginia Institute of Marine Science (VIMS) will support Prince George County to conduct the modeling study. We propose to develop a fine-resolution model to simulate tidal flow and larval transport processes. With the use of the model, the changes in hydrodynamic conditions in terms of currents and water exchange can be evaluated, which will provide good information for understanding the impacts of intake on the ecosystems of the adjacent region and ichthyoplankton transport. We will use a particle tracking model to simulate fish egg and larval movement and to accurately evaluate probabilistic increases of mortality due to the intake under different hydrological conditions. The model results can provide information for an accurate risk assessment. This approach not only can address the current issues, but also be able to address future needs in this region.

Figure 1. Location of proposed intake.

Approaches

1. Hydrodynamic Model Development

We are planning to develop a fine-resolution model for this region and use the numerical model to conduct the analysis of impacts under different hydrological conditions (e.g., high flow vs. low flow) during fish spawning periods assumed to occur in the Appomattox River. Although VIMS has several structured grid models encompassing this region, they were developed for the entire James River for water quality simulation with relatively coarse model grids in the tidal freshwater (Shen et al., 2016), which do not have sufficient resolution for the Appomattox River.

Recently, we developed an unstructured grid model for the James River to simulate the change of dynamics due to geometry change in College Creek. The SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model) was applied to develop the model for the James River. SCHISM uses a semi-implicit time-stepping scheme applied in a hybrid finite-element and finite-volume framework to solve Navier-Stokes equations and uses a Eulerian-Lagrangian method to treat the momentum advection. In the vertical dimension, the model uses a highly flexible and efficient hybrid coordinate system (Zhang et al. 2015). This model simulates the entire James River that incorporates the upstream and lateral freshwater discharges obtained from EPA Phase 6 watershed model. The model grid is shown in Figure 2. It can be seen that a model grid with very high resolution can be placed in the area of interest. The unstructured grid model is flexible and is capable of simulating complex change of geometry within 5 -10 m resolution.

Figure 3 shows an example of the model simulation of bridge pilings (scale 1-2 m) and its induced flow change. The grid size varies is 1-2 m near the bridge pilings and can as large as km scale in the downstream (Liu et al., 2018). It shows that the model is able to simulate complex dynamics in the near-field of the intake. We are planning to use this model as the baseline model and refine the model grid in the tidal Appomattox and the upper tidal James to accurately represent the complex geometry and bathymetry in the tidal freshwater region. As this model has been well-calibrated for the James River, it will greatly speed up the model development and application for conducting model simulations.

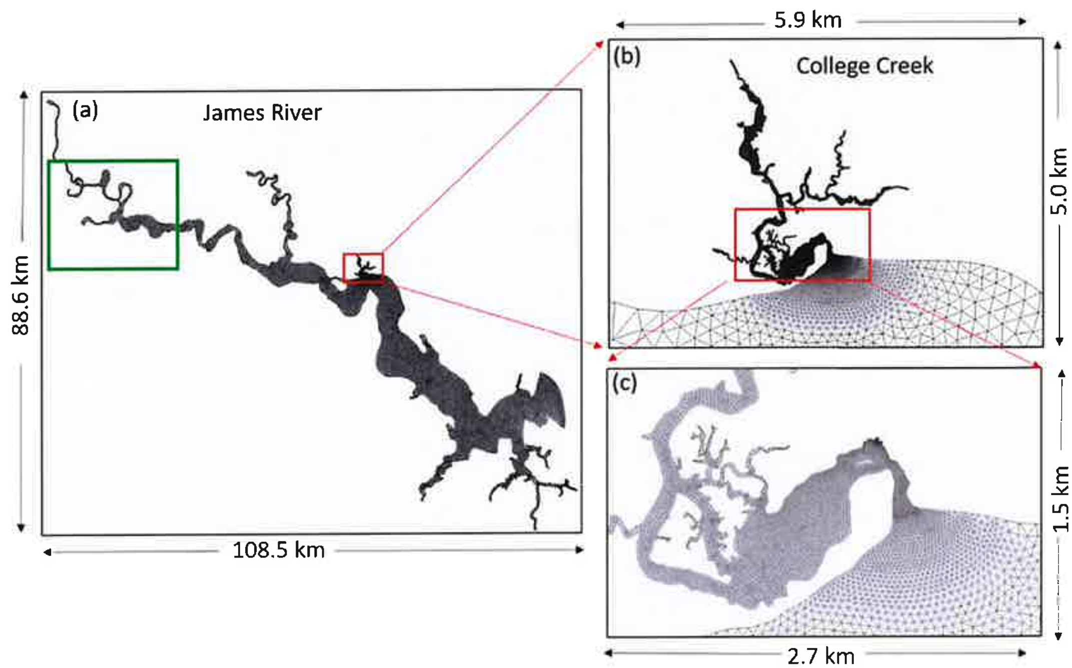

Figure 2. The James River model grid with high resolution near the vicinity of College Creek (Green box indicates the area that needs model grid refinement).

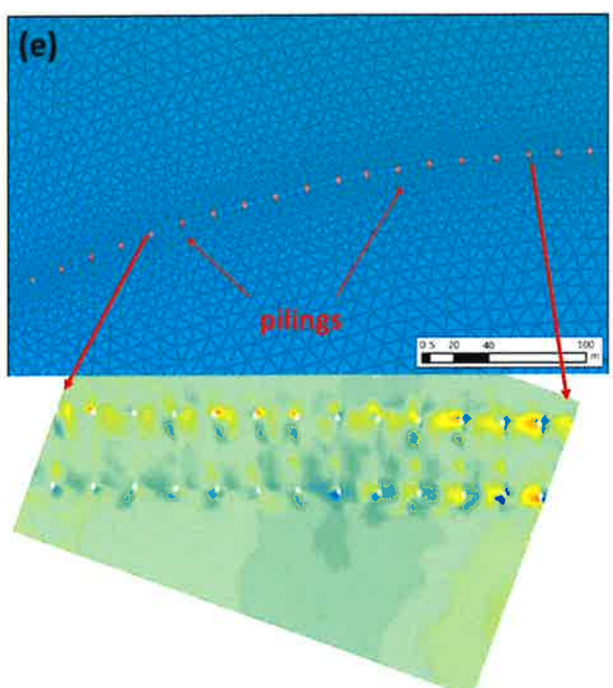

Figure 3. An example of a simulation of flow changes near the pilings (Courtsey of Lui et al., 2018).

2. *Particle Tracking model*

We will use a particle tracking model to simulate fish egg and larval transport. The Particle Tracking Model (PTM) is a Lagrangian particle tracker designed to allow the user to simulate particle transport processes. PTM has been developed for application to dredging and coastal projects including studies of dredged material dispersion and fate, oyster and fish larval dispersion and recruitment (Blumberg et al., 2004; Gallego et al, 2007). The model can contain algorithms that appropriately represent transport, settling, deposition, mixing, and resuspension processes. Each particle can be used to represent an individual or a cluster of ichthyoplankton. Different densities and mortality rates of eggs and larvae of different species can be added to the model to simulate physical and biological behaviors. An example shows how a PTM can track particle movement (Figure 4). Multiple particles representing ichthyoplankton can be released at different locations at different times. Although we don't know actual densities of eggs/larvae with limited local ichthyoplankton data, we would be estimating proportions of organisms in river which could probably encounter the intake. As particle movement depends highly on changes in local dynamics and in bathymetry and geometry, a high-resolution numerical model is needed. This high-resolution model will provide an accurate dynamic field for the Particle Tracking model. A robust PTM included in the SCHISM is capable to do the simulation. The changes we need to do is to add the capability for representing different densities, morality, and other larval behaviors into the model, if necessary.

Near an intake, flows are typically complex, having high swirl levels and vortices because of water pumping. There is no general method for determining the near-field number of larvae or egg entrainment in the grid box of an intake (Blumberg et al., 2004) if the grid is coarse. Therefore, the probability method has been used for determining entrainment (Varnell et al., 2008; Blumberg et al., 2004). The scale of the intake screen is about 100 foot (about 30 m) by 29 foot (about 9 m), and the width of the intake pipes with surrounding concrete is 30 foot (about 9 m). With the use of an unstructured grid model, the model grid can represent the surrounding structure accurately and it is possible to use a grid of small size to directly simulate the local entrainment and simulate intake pipes directly (~1 m). Figure 5 shows a schematic model grid surrounding the intake. The structure of the intake construction can be directly represented by the model grid with a size of about 1-5 m. Mortality due to the intake can be better simulated using the high-resolution model.

3. *Data Analysis and Scenario Design*

VIMS scientists will compile early life history data for different fish species from existing literature and databases and provide information on the season and periods of spawning. The possible concentration and density of larvae will also be empirically estimated. We will determine release locations and design simulation scenarios for review. We will communicate with scientific advisors to the County to discuss these simulation scenarios before running simulations during the course of the project, and use inputs from scientific advisors to the County to revise and finalize simulation experiments. Each scenario will target a specific location or multiple locations of release under a specific hydrological condition.

4. *Model Result Analysis*

We will analyze changes in hydrodynamic conditions and mortality of egg and larval stages due to intake. Changes in hydrodynamics will be analyzed by comparing shifts in currents in the area adjacent to the intake. The impacts of the intake on transport and mortality of fish eggs/larvae will be conducted based on particle tracking model results. Each particle is used to represent a certain number of fish eggs/larvae in the estuary. By releasing particles at different locations during spawning periods and by tracking the movement of these particles, transport of fish eggs or larvae and increases in mortality due to the intake will be estimated. A number of scenarios will be conducted for the intake impacts under different hydrological conditions. By analyzing model results under these different hydrological conditions, the theoretical impacts of intake on the marine resource and environment can be evaluated.

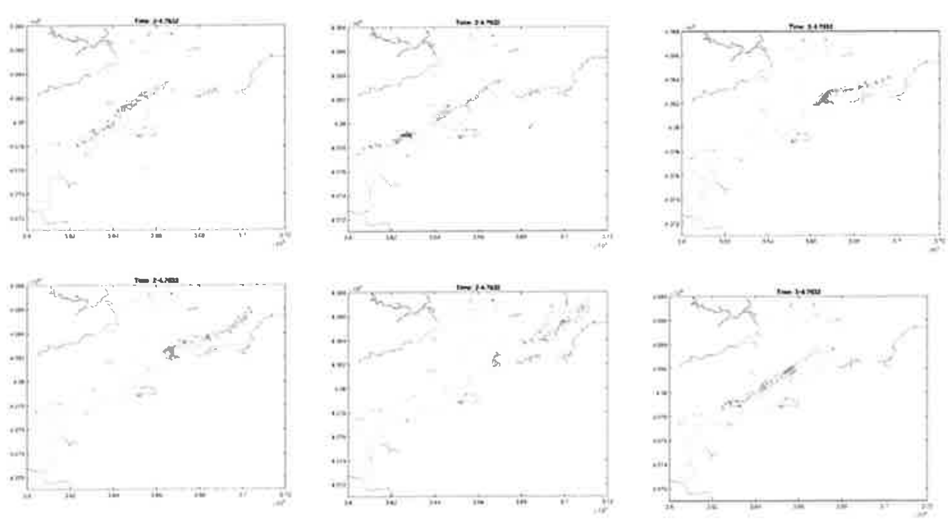

Figure 4. An example of particle tracking for oyster larvae in the Nansemond River. Blue circle is the release location and red points are the locations of particle movement at different times during the model simulation period.

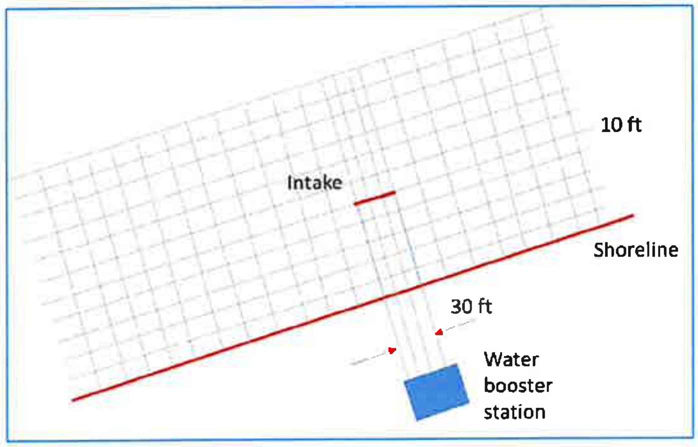

Figure 5. An example of the near-field model grid (model grid will be designed to figure the real scale of the intake; each grid represents 1-3 grids in the model).

Scope of Work

1. Refine the existing model grid and modify the model algorithm of particle tracking

   This project uses an existing James river model and refines the model grid in the tidal Appomattox River and upper tidal James River. The Appomattox River will be included in the model grid. There are 2 upper tributaries of the Appomattox River (beyond the 95 highway) in the watershed. Both Swift Creek Lake and Lake Chesdin are located at upper stream of these 2 tributaries. The mode grid will include these tributaries either extending to the downstream of the Swift Creek Lake and Lake Chesdin or in the middle between lakes and 95 highway. Therefore, USGS flow and watershed output of freshwater discharge can be prescribed at the headwater of the model grid. The model grid will follow the geometry of the river. The resolution of the grid will be sufficiently fine to represent the structure of the intake so that mortality due to the intake can be directly simulated.

   Estimated work load: 25%

2. Conduct the model calibration and test the particle tracking model

   Once the refinement of the model grid is completed, the model will be calibrated again for tide and salinity (downstream). As there is no available data of the currents, the calibration will focus on tidal elevations near the mouth of the Appomattox River and the Rice Center located downstream of the Appomattox River.

   This high-resolution model will be used to represent the intake location within the water column and direct withdrawal will be simulated. Particles contacting the intake can be directly estimated, which is a 'zero' distance approach and will be used to determine the loss of eggs/larvae. We will test this approach and modify grids as needed to ensure the accuracy of the morality estimates.

We will revise the existing particle tracking model to include density effect, natural mortality, and other effects deemed necessary.

Estimated work load: 20%

3. Conduct the background study and design simulation scenarios

Conduct background and literature research to determine key parameters for model simulation including location and densities of eggs and larvae in the area and natural mortality rates. VIMS has two seine survey stations in the James River that are close to the project site; one above and one below the mouth of the Appomattox River. These sites will be used to inform the species present in the area. The seine survey has been in operation since 1980 and thus provides a robust inventory of the fish community. By analyzing these data in conjunction with other available information, we will develop a relatively accurate picture of resident and migratory fish communities. We will incorporate any available information relevant to this study for the background analysis. Daily natural mortality rates for reducing fish eggs/larvae will be determined from studies conducted in similar habitats. Considering the wide range of species and associated mortality rates, we would choose a low mortality rate and a high mortality rate to provide an estimate for the range of possible mortality rates observed in the region. Estimated egg and larval densities will be based on previous research as there are not sufficient data in this region of the James River. Nevertheless, this is appropriate for this study because the focus will be the percentage of loss due to the intake and the concentration can be scaled up or scaled down. The proposed scenarios will be recommended and reported to the County. The final model input scenarios, including what fish species and associated particle characteristics are being simulated, will be determined in consultation with scientific advisors to the County.

Estimated work load: 15%

4. Modeling workshop for scenario design

A workshop will be held to report the model setup and discuss model scenarios design. VIMS and County scientists review will discuss in detail how to use the fisheries datasets from VCU and/or VIMS and apply to the model. VIMS and County scientists review will come to an agreement on fish species, particle characteristics, particle densities, mortalities, and any other key input variables which will be used for model simulations. This workshop will be arranged prior to VIMS running the model simulations.

5. Conduct model simulation and results analysis

Conduct model simulations for each scenario. For each scenario, three simulations will be conducted for the conditions of high flow and low flow. If different densities of larvae need to be considered, each release with specific density will be simulated.

For example, for 4 releases with 3 different densities and 2 different mortalities, the estimated simulations will be:

$$4 \times 3 \text{ (densities)} \times 2 \text{ (high flow vs. low flow)} \times 2 \text{ (mortalities)} = 48 \text{ (simulations)}$$

The moralities (high and low estimates) are natural mortalities (daily reduce in the number of eggs and larvae). The number of scenarios will be finalized during the course of this project. We estimate about 48 simulations at most to be conducted, though we foresee fewer scenarios are needed to fulfill the requirement. For comparison, we also need to simulate existing conditions without intake under different hydrological condition and natural mortality. The challenge is the time constraint, since each run will take time, which also depends on the available time resource of the high-performance computer. We will arrange these runs effectively and plan to complete them in May 2021.

Once the model results are obtained, data analysis will be conducted. To account for the model uncertainty and provide meaningful results for assessment, we will conduct model simulations with a fixed number of fish eggs under multiple hydrological conditions with and without natural mortality. This will establish a baseline condition under the existing condition. We will estimate the loss of fish egg/larval with intake under different mortalities and hydrological conditions. The results can be compared against the baseline condition and the percent loss due to intake can be computed and the influence of intake can be evaluated. The uncertainties associated with estimated mortality and fish density values will also be quantified based on multiple model simulations with different density and mortality values. As proposed intake will use 1 mm wedge wire screen, the percent loss will be reduced. The uncertainty due to this loss will be considered when estimating the percent loss due to intake. A range of percent loss of fish egg/larval will be provided and quantified by the mean and confidence interval due to uncertainties associated with model parameters. These results will be provided in the forms of tables and figures for assessment.

We will consult with county scientists and manager for finalizing model results and presenting them in the format suitable for review.

<u>Estimated work load: 30%</u>

6. Prepare the model report and participate in meetings to report model results

We will provide an executive summary before May 30, 2021 which will provide sufficient information for evaluation in the regulatory review process. We will present our findings to County and scientific advisors to the County. After receiving feedback and comments, we will finalize the report including all detailed processes for the modeling exercise.

<u>Estimated work load: 10%</u>

Required data and information

Some of the basic data are needed from the County for the model development.

1. Details of construction of the intake (location, size, etc.)
2. Bathymetry near the intake (the data presented in the previous review document will be useful)
3. Pumping rates and operation methods
4. Any additional information that may be useful for this project.

Budget

A 1.0-month time is budgeted for a faculty member at VIMS to oversee the project, work on methodology, particle tracking model development, analyze model results, and prepare model reports. A three-month time is allocated for a postdoctoral researcher to calibrate model, conduct scenario simulations, analyze results, and prepare report. A three-month time is allocated to a PhD student to assist on model grid refinement, model calibration, and model simulations. One-month time is allocated for a faculty member in fisheries department to conduct background study, provide background information, design model simulation scenarios, and review model results.

An estimation of total budget is $80,085 including $40,113 for personal cost, $13,545 for fringe, and $25,827 (47.6%) for administrative cost. We budged $300 for computer supply to archive data and $300 for travel for meetings.

Schedule and deliverable

The project period is proposed from December 20, 2020-August 2021. We will provide model results and draft report between May to June. We will continue to address any comments, suggestions, and revise simulations if it is needed.

Task	Task description	Percent	Cost	Schedule
Task 1	Refine the existing model grid and conduct the model calibration	25%	$20,021	December 2020-Febuary 2021
Task 2	Modify the model algorithm of particle tracking and test the particle tracking model	20%	$16,017	February 2021-March 2021
Task 3	Conduct the background study and design simulation scenarios	15%	$12,013	December, 2020 –February 2021
Task 4	Workshop	0%	$0	March 2021
Task 5	Conduct model simulation and results analysis	30%	$24,026	April-May 2021
Task 6	Prepare the model report and participate in meetings to report model results	10%	$8,009	Provide model results and submit draft results in May-June Revise report and provide final report in August 2021
Total		100%	**$80,085**	

References

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