Scope of Work For

Project # 20-009
Ozone Measurements and Platform Emission Factors in the Gulf of Mexico

Prepared for

Air Quality Research Program (AQRP)
The University of Texas at Austin

By

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Aerodyne Research, Inc.

June 19, 2020
Version #3

QA Requirements: Audits of Data Quality: 10% Required
Report of QA Findings: Required in Final Report

NOTE: The workplan package consists of three independent documents: Scope of Work, Quality Assurance Project Plan (QAPP), and budget and justification. The QAPP and Budget/Budget Justification were submitted as separate documents.

Approvals

This Scope of Work was approved electronically on 6/19/2020 by

Vincent M. Torres
Project Manager, Texas Air Quality Research Program
The University of Texas at Austin

This Scope of Work was approved electronically on 06/24/20 by

Doug Boyer
Project Liaison, Texas Commission on Environmental Quality (TCEQ)

Table of Contents

1.0 Abstract

A ship-based measurement campaign of offshore oil and gas rigs in the Gulf of Mexico has been funded by the United Nations Environment Programme (UNEP) through the Clear Air and Climate Coalition (CACC). This campaign is expected to occur in the late winter/spring of 2021, at the beginning of Houston's ozone season. This proposal aims to supplement the instrument manifest with an ozone monitor, and to support the analysis of emission factors using existing measurements of methane (CH_4), ethane (C_2H_6), carbon monoxide (CO), carbon dioxide (CO_2) and the oxides of nitrogen (NOx).

Figure 1. The proposed measurement vessel (left), the Research Vessel Trident, owned and operated by Texas A&M University out of Galveston. This vessel's laboratory space (right) is used to house measurement instrumentation.

As of this writing, we are in negotiations with UNEP, two platform operating companies as well as Texas A&M – Galveston regarding the timing and logistics of this project. All parties are committed to a successful deployment, but we do not have a guarantee on the exact timing of the project. Because the proposed work here is contingent on the other project, we do not yet have confirmed dates for the UNEP sponsored project. UNEP campaign leadership continues to explore new venues to publicize the project and search for a platform operator willing to host the central UNEP portion of the campaign.

2.0 Background

The United Nations Environment Programme – in the framework of activities of the Climate and Clean Air Coalition – is managing a series of scientific studies to be published in the peer-reviewed literature to improve the understanding of methane emissions from the oil and gas sector. The main campaign goal is to study dispersion at sea and to measure and estimate methane emissions from offshore platforms. However, this campaign presents an opportunity to make offshore measurements of ozone and related precursors early in the regional ozone season, and to mine the collected data for emission factors from offshore flares, compressors,

and other equipment. This study seeks to close gaps in publicly available data through the performance of direct, basic research measurements. The results of this study – a dataset of offshore ozone measurements, and emission factors for offshore platform flares – will better guide government policy and mitigation actions.

A similar project was performed during February 2018 (Yacovitch et al., 2020). A ship was outfitted with sensitive equipment able to measure trace gas concentrations as well as local meteorological conditions, including wind speed. The team sailed in proximity to oil and gas platforms in the northern Gulf of Mexico, and measured emissions emanating from the infrastructure by crisscrossing the plume as it dispersed downwind. Lessons learned from this campaign will be applied to the upcoming experiment. For example, one challenge was that platform locations were uncertain due to inconsistent or out-of-date databases. We intend to pre-download and display the latest Bureau of Ocean Energy Management (BOEM) platform datasets, state datasets, and NOAA navigational charts on the main analysis computer on the vessel. We also intend to record a timestamped video of the vessel's radar screen to provide an independent measure of platform (and interfering ship) locations and their distance from the vessel.

The current UNEP campaign has two main goals. First, to reduce the uncertainty in dispersion estimates of methane emissions by staging tracer releases at one or two offshore platforms. Second, to collect measurement data downwind of a sample of offshore platforms. All concentration measurements are done from the research vessel. The transit legs to and from the platforms, and the second part of the study will benefit from additional measurements and analysis proposed here. By adding ozone measurements to this campaign, we can address the AQRP goal of verifying high offshore ozone levels in the Gulf of Mexico, at a relatively low cost. By analyzing the dataset for flare emission factors, we can add further value and context to this unique offshore dataset.

COVID-19 Impact

As stated in our proposal, the dates for the offshore UNEP project are not yet known. The UNEP project relies on securing access to an offshore platform where a tracer-release will occur, and negotiations with offshore operators were still in progress when the novel coronavirus emerged. As a result of these prolonged negotiations, and of the effect of COVID-19-related closures on operators, the UNEP campaign has been pushed forward by a year, to winter/spring 2021.

A winter/spring 2021 campaign will still allow us to achieve all project goals and expend the entire budget before August 31, 2021. We are adjusting our workplan and schedule accordingly. We do not anticipate any change in the scope of work.

A final decision on whether the campaign occurs (go/no-go) will need to happen approximately 3 months prior the campaign execution. On the current February 2021 timeline, this will be in December 2020.

Aerodyne Research, Inc. is located in Massachusetts, which was in a state-mandated lockdown until May 18, 2020, and is currently undergoing a phased reopening. A corporate plan has been developed for a safe reopening following state guidelines. This plan includes modifications to building ventilation; maximizing work-from-home arrangements; shift scheduling to dramatically reduce building occupancy; priority access to workers with instrument-related tasks; mandated mask wearing; closing off shared office spaces; and expanded sick-leave policies. Aerodyne employees are continuing to do productive work at home, and laboratory and instrument workspaces are being staffed according to the plan.

COVID-19-related safety measures will be included in the planning phase of the UNEP campaign as necessary, and will be discussed in monthly reports.

3.0 Objectives

There are two goals for the AQRP-funded portion of this project:

1. Measure ozone levels in the Gulf of Mexico by adding ozone instrumentation to a research vessel operating as part of a UNEP-funded campaign.
2. Use UNEP-funded measurements of methane, ethane CO, CO_2 and NOx to calculate flare emission factors for offshore platforms.

All concentration measurements will be done from the research vessel (none will be performed directly on platforms).

4.0 Task Descriptions

4.1 Instrument Integration and Campaign execution

The AQRP has called for research monitoring ozone in Galveston bay and offshore, in part to verify the high simulated ozone levels over the Gulf of Mexico. The offshore measurement project is planned for late winter/early spring of 2021. This time period covers the early part of ozone season for Houston. Locations sampled are likely to include waters off the coast of Texas and Louisiana in the Gulf of Mexico, and will include some data in Galveston Bay. The exact measurement locations will depend on the greater campaign design, and are pending industry decisions on the choice of offshore platform where approximately half the campaign is to be staged. The remaining time will be spent sampling other offshore platforms, and will include transit legs to and from the home port of the research vessel, in Galveston.

In the first task of the proposal, a 2B Tech ozone instrument will be integrated onto the Research Vessel Trident (R/V Trident), a vessel owned and operated by Texas A&M University out of Galveston (Figure 1). The instrument will sample from the same mast-mounted inlet as the other instrumentation (e.g. methane, combustion tracers) and will benefit from all of the core measurements, including global positioning system (GPS) and wind data, from the UNEP-funded campaign.

In order to ensure a high-quality dataset, the ozone instrument will be monitored by a researcher multiple times daily over the course of the campaign. Instrument data is timestamped, logged, and displayed live on a computer used by the researchers for data display and preliminary analysis, navigation, and note-taking. The campaign will occur over approximately 9 measurement days over a 2-week period in late winter/early spring of 2021.

During this deployment, plume encounters will be identified live. We will tag those plumes showing enhancements in combustion tracers for subsequent analysis of emission factors. Periods of self-sampling (sampling of the vessel exhaust) will not be included in this tagging, and the data will undergo post-analysis to eliminate this sort of artifact.

-Deliverables

- Campaign integration updates and campaign summary to be included in monthly and final reports.

4.2 Production of an Ozone Dataset

After the campaign, the collected ozone time trace will be quality assured and cleaned up according to established protocols. Figure 2 shows an example of quality assurance for this instrument done for the 2017 San Antonio Field Study. Regular deliveries of clean air (in this case from a zero-air-generator, ZAG) are used to assess instrument performance over the course of the campaign and to deduce a 1-minute average performance, for this dataset a value of 0.37 ppb (1-sigma). The zeroes will be removed from the final dataset, and the resulting time trace delivered along with the measured vessel coordinates.

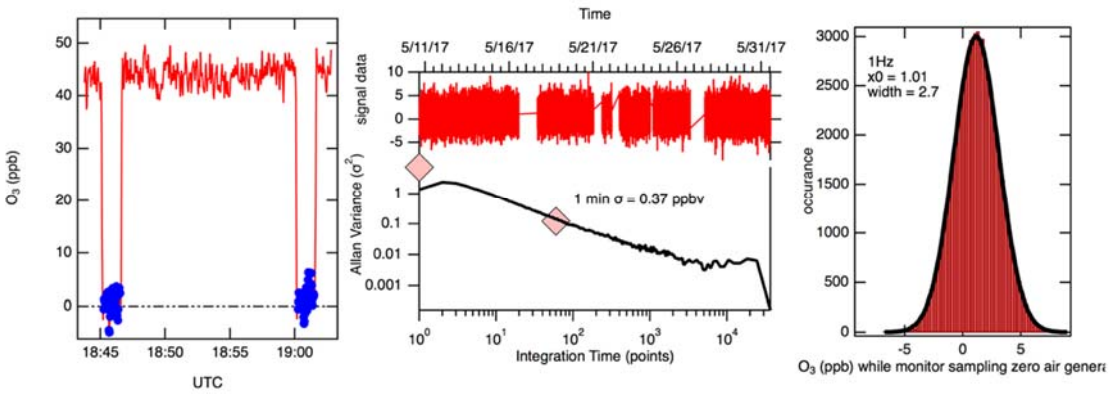

Figure 2. Ozone performance during overblow by zero air generator. Left most panel: The blue points are an example of the ZAG overblow in time. Central panel: collected ZAG ozone data for whole campaign and Allan-Werle variance calculation result. Right most panel: raw histogram of ZAG ozone data.

Other quality assurance (QA) may be required, particularly during periods sampling strong exhaust signatures (i.e. accidental sampling of the vessel's own exhaust). These periods will be flagged using the other available measurements (e.g. CO) and assessed and excised if needed.

Deliverables:

- Quality assured dataset of ozone measurements, in simple text-file format and including vessel GPS position

4.3 Emission Factors and Other Analysis

The Bureau of Ocean Energy Management (BOEM) publishes a database of air pollutant measurements related to oil and gas production in the Gulf of Mexico (platform, non-platform, vessels) every three years per the Clean Air Act. The most recent study released in 2019 uses data collected during 2017 from lessees and lease operators (Wilson, 2019). Notable ozone precursors in the platform dataset include NOx, CO, and volatile organic compounds (VOCs) (2,2,4-trimethylpentane, acetaldehyde, hexane, formaldehyde, benzene, toluene, ethylbenzene, xylenes). In the report, the authors note "improvements in […] emission factors" as one of the major factors affecting emission estimates. The United States Environmental Protection Agency (US EPA) relies on activity data from this dataset to calculate offshore platform emissions based on emission factors determined from previous BOEM datasets (US EPA, 2015; US EPA, 2019).

In a report commissioned by TCEQ in 2010, Eastern Research Group (ERG) compiled emission factors relevant to offshore oil and gas platform activity from several state and government datasets (TCEQ, 2010). Many of these emission factors (VOCs, NOx, CO, HAPs) are directly related to processes determining ozone production. In another report commissioned by TCEQ in 2007, ERG reported emission estimates (ton $year^{-1}$) for ozone precursors within a Texas

county or lease block in the Gulf of Mexico (TCEQ, 2007). Emissions of NOx from offshore activities were attributed to natural gas turbines, diesel engines, and compressor engines in both state and federal waters. These sources contributed ~4% of the total NOx emissions in the state of Texas. Emissions from compressor engines and natural gas turbines on offshore platforms contributed ~5% of the total CO emissions throughout the state.

Given the number of inventory datasets covering ozone precursor emissions from specific equipment types and offshore areas there is ample opportunity for comparison with an *in-situ* dataset collected in state waters.

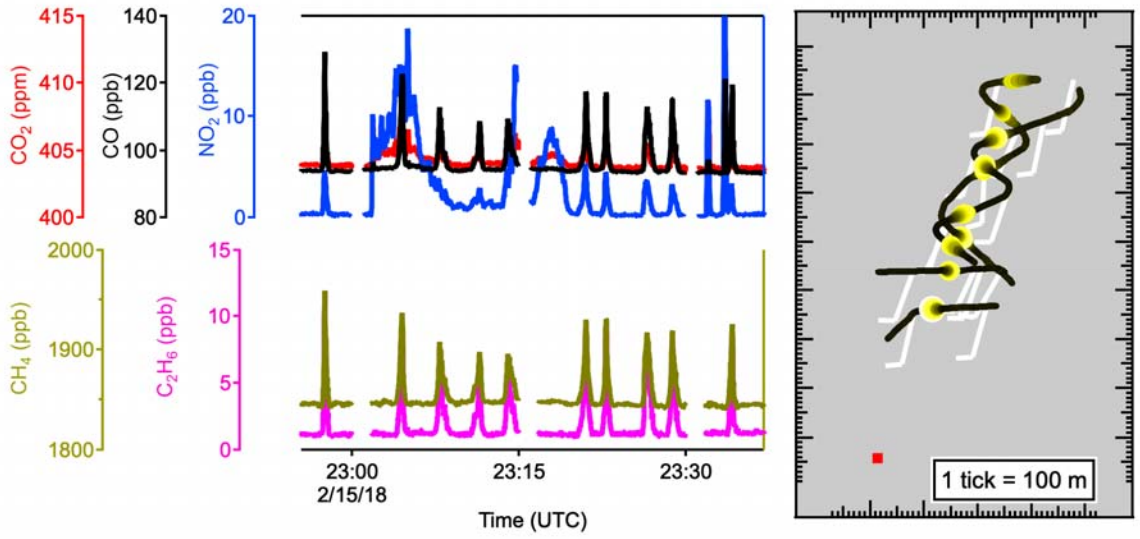

Figure 3. Time traces (left) and map (right) of downwind measurements for an offshore platform in the Gulf of Mexico. The combustion tracers CO_2, CO and nitrogen dioxide (NO_2) are shown above the natural gas species CH_4 and C_2H_6. The platform is located at the red dot. Wind is from the south-south-west (white barbs). The map shows the vessel path (zig zag trace) colored and sized by methane concentration (gold). The NO_2 trace (blue) shows likely influence from ships or other far-away combustion sources (broad elevations) and in one case the measurement vessel exhaust (sharp spike without associated CH_4 and C_2H_6). The CO/CO_2 ratio for this example is 11.9 ppb/ppm corresponding to a modified combustion efficiency of 98.8%.

Figure 3 shows an example of a platform plume dataset from 2018 including both natural gas species CH_4 and C_2H_6 and combustion tracers CO, CO_2 and NO_2. The CO/CO_2 ratio for this example is 11.9 ppb/ppm corresponding to a modified combustion efficiency (MCE) of 98.8%.

$$MCE = \frac{\Delta CO_2}{\Delta CO_2 + \Delta CO}$$

The NO_2 trace (blue) shows likely influence from ships or other far-away combustion sources (broad elevations) and in one case the measurement vessel exhaust (sharp spike without associated CH_4 and C_2H_6). However, there are subsections of the time trace that are clean and with additional QA, a NO_2 emission factor could be deduced.

For platforms with numerous combustion sources (e.g. compressors, diesel engines, a flare), distinguishing the combustion plumes from individual sources will be challenging. At a distance, emissions merge into a single plume, for which an overall platform emission factor can be determined. At closer distances, and for simpler platforms with less infrastructure, it may be possible to distinguish sub-plumes from different components. We will be relying on the measurement of speciated VOCs to check whether the data show evidence of multiple individual sources. For example, diesel engines/generators might be distinguishable from natural gas flares. In emissions inventory work (Wilson, 2019), each individual platform component is tabulated (diesel and gasoline engines, treatment and processing equipment, flares, storage tanks and flashing emissions, etc.) Overall platform emission factors can thus provide a valuable check of these bottom-up inventory methods.

Emission factors for flaring will depend on source gas composition and flare characteristics, and should not change seasonally. Operator behavior might change seasonally, however. The question of operator behavior and its potential impact on emission sources (particularly flaring emissions) will be brought up in discussions with participating operators.

In addition to the analysis of emission factors, the data collected as part of the UNEP/AQRP project will include VOCs, NO_2, ozone (Task 1) and others. The dataset will provide an opportunity to evaluate real-world ozone photochemistry. It is relatively difficult and rare to track a single oil and gas emitter's plume on land for distances beyond a few kilometers. Plume ageing experiments in the real world typically involve very large sources (e.g. forest fires) in remote locations, and may require measurement platforms like aircraft that can travel far distances. This offshore dataset will offer a chance at this type of experiment on a smaller scale.

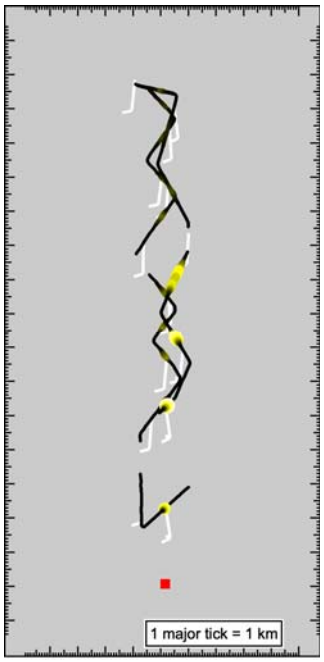

Figure 4. Example of a platform (red dot) whose emissions were measured as far as 15 km downwind.

Offshore plume dispersion is often occurring under extremely stable conditions, and measurements in 2018 confirmed this. In some uncongested areas of the gulf, we tracked a single platform's emissions for nearly 15 kilometers (Figure 4), without other interfering sources. This distance suggests the emissions have been diluting in air for ~ 40 minutes.

In order to get an initial handle on what could be anticipated for observing chemistry in the plume, we consider xylene and methane. The rate coefficients for the hydroxyl radical (OH) initiated oxidation of methane and xylene isomers are ~ 6E-15 and ~ 1.5E-11 cm^3 $molecules^{-1}$ s^{-1}. For this example, we will measure an "initial" emission ratio (ER) of xylene to methane at a close pass to the platform of ER_0. If the marine boundary layer sustains a modest OH number density of ~ 5E5 molecules cm^3, the ratio of xylene to methane at that distance should be 0.96 * ER_0. We anticipate that the variability in the ambient signals will be constant enough to observe subtle changes in VOC ratios due to chemistry in the diluting plume. The dominant wind in the Gulf of Mexico is from the south, meaning that backgrounds are relatively clean. An alternative analysis that will be relevant on the plume scale will be to plot odd oxygen (O_3 + NO_2) against NOx. If this slope is greater than one in the plumes downwind, it is a direct observation of ozone being produced by the plume. This experiment is like a real-world chamber experiment, examining how emissions from the oil and gas sector age and get processed in the atmosphere, and may help inform the understanding of ozone formation mechanisms onshore.

Deliverables:

- Dataset of emission factors for offshore platforms
- Other plume analysis results to be presented in monthly and final reports

Task 4.4 Project Reporting and Presentation

As specified in Section 7.0 "Deliverables" of this Scope of Work, AQRP requires the regular and timely submission of monthly technical, monthly financial status and quarterly reports as well as an abstract at project initiation and, near the end of the project, submission of the draft final and final reports. Additionally, at least one member of the project team will attend and present at the AQRP data workshop. For each reporting deliverable, one report per project will be submitted (collaborators will not submit separate reports), with the exception of the Financial Status Reports (FSRs). The lead PI (or their designee) will electronically submit each report to both the AQRP and TCEQ liaisons and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources. The report templates and accessibility guidelines found on the AQRP website at http://aqrp.ceer.utexas.edu/ will be followed. ****Draft copies of any planned presentations (such as at technical conferences) or manuscripts to be submitted for publication resulting from this project will be provided to both the AQRP and TCEQ liaisons per the Publication/Publicity Guidelines included in Attachment G of the subaward.**** Finally, our team will prepare and submit our final project data and associated metadata to the AQRP archive.

Deliverables:

- Abstract
- Monthly Technical reports, Monthly Financial Reports and Quarterly Reports
- Draft Final Report (30 days before end of project) and Final Report
- Attendance and presentation at AQRP workshop (~30 days before end of project)
- Submissions of presentations and manuscripts for approval
- Submission of project data and associated metadata.

Schedule: The schedule for Task 4.4 Deliverables are shown in Section 7.

5.0 Project Participants and Responsibilities

The roles and responsibilities for each participant of this project are outlined below.

Tara Yacovitch, Project PI

- Project management and reporting
- All data analysis, including production of an ozone dataset, analysis of emission factors, and other plume analysis.
- Data Quality Assurance Officer

Scott Herndon

- Campaign execution
- Identification of combustion plumes

Conner Daube

- Ozone instrument integration
- Campaign execution
- Monitoring of O_3 instrument
- Identification of combustion plumes

6.0 Timeline

A schedule of project activities is shown below. This schedule assumes that the campaign occurs in February 2021. However, changes in this schedule can easily be accommodated due to the relatively modest analysis requirements for this project.

Task	Description	Year	2020							2021							
		Mo	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Task 1	**Instrument Integration and Campaign**																
	Ozone instrument integration																
	Campaign execution																
	De-integration																
Task 2	**Production of an Ozone Dataset**																
	Apply zeros and basic QA																
	Advanced QA using other tracers																
	GPS data merge in csv format																
Task 3	**Emission Factors and Other Analysis**																
	Identify combustion tracer plumes																
	Compute emission factors																
	Plume photochemistry analysis																
Task 4	**Reporting**																
	Monthly Reports																
	Interim Reports																
	Draft Final Report Preparaton																
	Final Report Preparation																
	Austin Meeting																

7.0 Deliverables

AQRP requires certain reports to be submitted on a timely basis and at regular intervals. A description of the specific reports to be submitted and their due dates are outlined below. One report per project will be submitted (collaborators will not submit separate reports), with the exception of the Financial Status Reports (FSRs). The lead PI will submit the reports, unless that responsibility is otherwise delegated with the approval of the AQRP Project Manager. All reports will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources. Report

templates and accessibility guidelines found on the AQRP website at http://aqrp.ceer.utexas.edu/ will be followed.

Abstract: At the beginning of the project, an Abstract will be submitted to the AQRP Project Manager for use on the AQRP website. The Abstract will provide a brief description of the planned project activities, and will be written for a non-technical audience.

Abstract Due Date: Friday, July 31, 2020

Quarterly Reports: Each Quarterly Report will provide a summary of the project status for each reporting period. It will be submitted to the Project Manager as a Microsoft Word file. It will not exceed 2 pages and will be text only. No cover page is required. This document will be inserted into an AQRP compiled report to the TCEQ.

Quarterly Report Due Dates:

Report	Period Covered	Due Date
Quarterly Report #1	May, June, July 2020	Friday, July 31, 2020
Quarterly Report #2	August, September, October 2020	Friday, October 30, 2020
Quarterly Report #3	November, December 2020, January 2021	Friday, January 29, 2021
Quarterly Report #4	February, March, April 2021	Friday, April 30, 2021
Quarterly Report #5	May, June, July 2021	Friday, July 30, 2021
Quarterly Report #6	August, September, October 2021	Friday, October 29, 2021

Monthly Technical Reports (MTRs): Technical Reports will be submitted monthly to the Project Manager and TCEQ Liaison in Microsoft Word format using the AQRP FY20-21 MTR Template found on the AQRP website.

MTR Due Dates:

Report	Period Covered	Due Date
Technical Report #1	Project Start - June 30, 2020	Wednesday, July 10, 2020
Technical Report #2	July 1 - 31, 2020	Friday, August 10, 2020
Technical Report #3	August 1 - 31, 2020	Monday, September 10, 2020
Technical Report #4	September 1 - 30 2020	Thursday, October 10, 2020
Technical Report #5	October 1 - 31, 2020	Friday, November 9, 2020
Technical Report #6	November 1 - 30, 2020	Tuesday, December 10, 2020
Technical Report #7	December 1 - 31, 2020	Thursday, January 10, 2021
Technical Report #8	January 1 - 31, 2021	Friday, February 8, 2021
Technical Report #9	February 1 - 28, 2021	Wednesday, March 10, 2021
Technical Report #10	March 1 - 31, 2021	Wednesday, April 10, 2021
Technical Report #11	April 1 - 30, 2021	Friday, May 9, 2021
Technical Report #12	May 1 - 31, 2021	Monday, June 10, 2021
Technical Report #13	June 1 - 30, 2021	Thursday, July 10, 2021
Technical Report #14	July 1 - 31, 2021	Friday, August 9, 2021

DUE TO PROJECT MANAGER

Financial Status Reports (FSRs): Financial Status Reports will be submitted monthly to the AQRP Grant Manager (RoseAnna Goewey) by each institution on the project using the AQRP 20-21 FSR Template found on the AQRP website.

FSR Due Dates:

Report	Period Covered	Due Date
FSR #1	Project Start - June 30	Wednesday, July 15, 2020
FSR #2	July 1 - 31, 2020	Friday, August 14, 2020
FSR #3	August 1 - 31, 2020	Tuesday, September 15, 2020
FSR #4	September 1 - 30 2020	Thursday, October 15, 2020
FSR #5	October 1 - 31, 2020	Friday, November 13, 2020
FSR #6	November 1 - 31, 2020	Tuesday, December 15, 2020
FSR #7	December 1 - 31, 2020	Friday, January 15, 2021
FSR #8	January 1 - 31, 2021	Monday, February 15, 2021
FSR #9	February 1 - 28, 2021	Monday, March 15, 2021
FSR #10	March 1 - 31, 2021	Thursday, April 15, 2021
FSR #11	April 1 - 30, 2021	Friday, May 14, 2021
FSR #12	May 1 - 31, 2021	Tuesday, June 15, 2021
FSR #13	June 1 - 30, 2021	Thursday, July 15, 2021
FSR #14	July 1 - 31, 2021	Friday, August 13, 2021
FSR #15	August 1 - 31, 2021	Wednesday, September 14, 2021
FSR #16	Final FSR	Friday, October 15, 2021

DUE TO GRANT MANAGER

Draft Final Report: A Draft Final Report will be submitted to the Project Manager and the TCEQ Liaison. It will include an Executive Summary. It will be written in third person and will follow

the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources. It will also include a report of the QA findings.

Draft Final Report Due Date: Monday, August 2, 2021

Final Report: A Final Report incorporating comments from the AQRP and TCEQ review of the Draft Final Report will be submitted to the Project Manager and the TCEQ Liaison. It will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources.

Final Report Due Date: Tuesday, August 31, 2021

Project Data: All project data including but not limited to QA/QC measurement data, metadata, databases, modeling inputs and outputs, etc., will be submitted to the AQRP Project Manager within 30 days of project completion (September 20, 2021). The data will be submitted in a format that will allow AQRP or TCEQ or other outside parties to utilize the information. It will also include a report of the QA findings.

AQRP Workshop: A representative from the project will present at the AQRP Workshop in the first half of August 2021.

Presentations and Publications/Posters: All data and other information developed under this project which is included in **published papers, symposia, presentations, press releases, websites and/or other publications** shall be submitted to the AQRP Project Manager and the TCEQ Liaison per the Publication/Publicity Guidelines included in Attachment G of the Subaward.

8.0 References

Wilson D, Billings R, Chang R, Do B, Enoch S, Perez H, Sellers J. (2019). Year 2017 emissions inventory study. New Orleans (LA): US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2019-072. 231 p.

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