A Spatial Measurement and Survey Approach for Improving Emission Inventory Factors and Input Data for Ozone Modeling Associated with the Pinedale Anticline Project Area

Proposal submitted by the University of Wyoming

For consideration by the Pinedale Intra-Agency Office

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ABSTRACT

Title: A spatial measurement and survey approach for improving emission inventory factors and input data for ozone modeling associated with the Pinedale Anticline Project Area

Institution: University of Wyoming, Laramie, Wyoming
Project Period: January 2010 to August 2012
Total Project Cost: **$657,486**
Proposal Request Cost: **$477,334**
UW School of Energy Resources Contribution: **$180,152**

Objective:

In recent years, air quality has deteriorated in rural areas associated with oil and gas development, increasing concerns regarding human exposure to volatile organic compounds (VOC), ozone, and other pollutant species. The development of mitigating strategies to combat non-attainment episodes requires that a thorough understanding of their nature be obtained. Central to achieving this goal is the need to appreciate the time-dependent spatial distribution of relevant primary and secondary pollutant species. In this context, the recent appearance of wintertime ozone episodes in Sublette County, Wyoming, is a challenging problem.

We propose to conduct air quality measurements and analyses to assist the Wyoming DEQ with their development of emission inventory and ozone modeling data used for the Pinedale Anticline Project Area (PAPA). We propose to use an approach that combines a spatial network of both passive and canister measurements with longer-term ambient air monitoring downwind of PAPA. Mitigation of air quality impacts from oil and gas fields is a complex undertaking. These developments contain numerous permanent, temporary, fixed, and mobile emission sources, with varying spatial and temporal behavior. Wintertime ozone is a relatively new phenomenon that must be fully understood to support mitigation efforts.

1. Our first objective is to conduct spatial surveys of BTEX (benzene, toluene, ethyl benzene, and m-xylene, p-xylene and o-xylene) in and around PAPA using passive samplers, to establish the spatial distribution of aromatic VOC.
   a. This objective is designed to assist assessments required by the 2008 Record of Decision (ROD).

2. Our second objective is to carry out spatial surveys of the oxides of nitrogen (NO_x, NO_2 and NO) using passive sampling, to establish the spatial distribution of oxides of nitrogen.
   a. Combined, these two objectives will aid decision-makers understanding of the relative composition of ozone precursors by providing the BTEX/NO_x ratio in different sampling grids.
   b. Knowledge of the relative ambient concentrations of ozone precursors is important information for ozone mitigation.

3. The third objective is an assessment of the spatial behavior of a wider range of VOC species through the use of canister sampling. Selected VOC are closely associated with oil and gas development operations.

a. This information will help us understand VOC emissions and distribution. When irradiated with sunlight, a mixture of these compounds and the oxides of nitrogen, form ozone.

b. Objective will improve the quality of inputs for box models under development by the Wyoming DEQ for SIP model demonstrations of ozone generation. The input data for the box model is (a): a BTEX number for each of 40 grid cells, and (b) a NO_X/NO number together with concentrations of specific VOC species (16 grid cells).

These inputs yield high quality spatially accurate measurements at relatively low cost. We anticipate that achieving this objective will significantly enhance the quality of the model input data now available, which will in turn tend to maximize the positive impacts of any policy decisions based on model performance.

4. Our fourth objective is to conduct continuous air quality monitoring downwind of PAPA using the UW Mobile Air Quality Laboratory. This facility will be equipped with an ozone precursor VOC measurement system, and a separate suite of inorganic pollutant analyzers, for species such as NO_x, ozone, and carbon monoxide, as well as meteorological parameters.

a. This objective and associated back trajectory analyses will help determine the relative importance of different pollution sources and emission areas. This will provide ambient air quality data downwind of the sources. The data will be used to estimate the relative level of VOC, and will also permit comparisons to be made with concentration levels predicted from emission factors.

Each objective is summarized in appendix A, which therefore makes available a summary reference to the sampling approach (pollutants and averaging time) and methodology (location and instrumentation).

Approach:

Our objectives will be achieved by carrying out measurements that consider both spatial and temporal pollution behavior. Our approach is to use proven methods (employing passive samplers and canister samplers) to conduct spatial pollutant distribution measurements, and to use a mobile air quality laboratory for continuous monitoring downwind of PAPA. Contributions associated with specific sources and areas will be assessed through subsequent analyses.

Expected Results:

This study will assess emission inventories as required by the 2008 ROD and also provide critical inputs to photochemical ozone models. The results of our data analysis, in particular with respect to objectives 3 and 4, will compare actual levels with those expected from emission inventories. This assessment will consider areas of different sizes with a variety of emission sources.

Additionally our data, in particular those derived from objectives 1, 2 and 3, will be used as input factors for photochemical ozone modeling by Wyoming DEQ. Such data are invaluable for the on-going development of site-specific box models. These models rely upon accurate grid aggregated data with both upwind, grid, and downwind measurements. The data will improve the performance of associated photochemical ozone models. The combined and complimentary use of models and measurements will provide support for mitigation decisions.

RESEARCH PLAN

Introduction

Improvements to numerical simulations of local and regional air quality require that photochemical models use more sophisticated descriptions of relevant chemical and meteorological processes, as well as better descriptions of temporal and spatial variations of emissions of all chemical species relevant in the air shed of interest. The predictive capability of models as judged by comparisons with observations of atmospheric concentrations of key pollutant species, is often limited by the quality of emissions inventory inputs. Understanding measurements of pollutants originating from numerous sources poses a significant challenge. Oil and gas field developments exemplify such a scenario. This proposal directly addresses issues pertinent to the refinement of emissions inventories and predictive ozone models for PAPA.

Relevance of Proposal for Consideration by the Pinedale Intra-Agency Office

Our proposal will provide important data for the on-going Wyoming DEQ development of more accurate information for ozone modeling and emission inventories. The provision of sound emission inventory information cannot be overemphasized given its relevance to policy decision-making. Our proposed work will provide high quality monitoring data that can be used by all interested parties to better understand actual ambient pollution levels, in particular for Volatile Organic Compounds (VOC).

The PAPA Supplemental Environmental Impact Statement (SEIS) ROD requires Ultra, Shell, and Questar to install liquids gathering systems. This action is particularly significant and is expected to eliminate approximately 165,000 truck trips annually during peak production periods. The Pinedale Anticline Monitoring and Mitigation Fund (PAMMF), created by the ROD, aims to support mitigation and project-related activities in the PAPA vicinity, including accumulation of scientific data gathered by additional air quality monitoring. As stated in the ROD the Fund may also be used to promote monitoring to assess impacts resulting from development and to measure the effectiveness of mitigation efforts. Our proposal not only complies with these criteria, but it is in the mainstream of activities intended for support by the PAMMF. In addition it strengthens links between actual ambient air quality measurements and emission inventory development. Improving these connections will address the requirements for adaptive management that necessitates monitoring and subsequent evaluation to determine whether new practices achieve desired objectives in a timely and efficient manner.

Air quality, particularly visibility degradation and ozone episodes, remains a concern of the BLM, Wyoming residents, cooperating agencies, and others. To address these concerns, this ROD requires continued monitoring and aggressive mitigation. The Wyoming DEQ and BLM are committed to assuring that any mitigation necessary to reduce PAPA's contribution to ozone concentrations will be implemented, and that emission rates of ozone precursors will be below applicable regulatory standards. Our proposal supports this shared goal.

Background

Sublette County, Wyoming

Sublette County is a rural county in western Wyoming, considered to be one of the most remote locations in the lower forty-eight states. The county is located within the Greater Yellowstone Ecosystem, and bounded by Jim Bridger Wilderness and the relatively undisturbed

Wyoming Range. Historically, these characteristics have meant pristine air and water quality, as well as abundant wildlife. Since about 2000, this area has also included the rapidly developing Pinedale Anticline and Jonah oil and gas fields.

The PAPA is an important natural gas resource for the United States, and contributes a significant portion of the nation's energy supply. This contribution is made possible by twenty-four hour operation of drill rigs and pipeline compressors powered by diesel or natural gas engines, and generating 150 million watts of power at any one time (Schnell, et al., 2009). In 2008 an estimated 531 wells per year were completed in Sublette County, up from 172 in 2000. There were approximately 2,200 wells operating in the Jonah Field and PAPA during 2008, with 10,000 expected by 2020. The Wyoming Department of Environmental Quality (Wyoming DEQ) estimated 1,143,614,170 million cubic feet (Mcf) of gas production in 2008 (Wyoming DEQ, 2009).

Since 2000, Sublette County has undergone increasingly intense development, leading to environmental degradation, in particular with respect to air quality. In fact, it is estimated that 94% of volatile organic compound (VOC) emissions and 60% of oxides of nitrogen (NO_x) emissions in the area are attributable to locally sourced oil and gas production. Wyoming DEQ has indicated that elevated ozone levels are primarily a consequence of the activities associated with local oil and gas development. The area is located in a basin surrounded on three sides by mountains, with a wind flow regime that prohibits transport of other major source emissions into the affected area. Elevated ozone levels are associated with a specific set of meteorological conditions including snow cover and the presence of stationary high-pressure systems and capping inversions, which also serve to limit transport (Wyoming DEQ, 2009).

In a letter dated March 2009, Wyoming's Office of the Governor made nonattainment recommendations for the 2008 National Ambient Air Quality Standard for 8-hour ozone. The recommended area encompasses the proposed study area and includes three major gas fields. In his letter, the Governor acknowledged that there are significant challenges to understanding and dealing with ozone behavior in this region due to unique topography, limited applicability of EPA regulatory strategies for the natural gas industry, and a lack of available analytical tools. As an additional challenge, the letter notes that ozone behavior in the area is instigated by meteorological conditions that are difficult to predict accurately (Freudenthal, 2009).

Natural Gas Production

Natural gas production is a large scale, multi-stage operation. Stages include drilling and completion, extraction and processing, storage and transmission, and distribution. Each of these stages has the potential to generate large amounts of pollutants. Additionally, fugitive emissions are significant, as gas operations utilize large numbers of valves, gauges, pumps, flanges, unions, and other connections subject to wear, corrosion or leakage.

Well drilling is required prior to production. During this stage, diesel or natural gas fueled rigs drill to depths of up to 14,000 ft. To reach this depth significant amounts of power are consumed, and the use of natural gas engines raises fuel requirements in order to provide the necessary torque. During a drilling operation, gas, condensates, and water are driven up through the borehole. A typical well completion can release 1,000 – 24,000 Mcf of natural gas, with a median value of 5,000 Mcf (Armendariz, 2008). Wyoming DEQ estimates well drilling and completion emissions were 166 tons of VOC, and 915 tons of NO_x during the first quarter of 2007 (Wyoming DEQ, 2009). Produced water, often containing condensates, is typically stored in on-site evaporation ponds while gas is vented to the atmosphere or flared.

Important point sources present during natural gas extraction and processing include liquids separation and storage, glycol dehydration and combustion activities. Hydrocarbon liquids, or condensates, that are separated from the gaseous phase are stored at the production site prior to being transported to remote sites for further processing. Condensate storage tanks are a significant source of methane (CH_4) and VOC. Glycol dehydrators function to remove water from source gas, and in the process often produce significant quantities of BTEX, all of which have the potential to not only induce adverse health effects, but to promote ozone formation. In addition to BTEX emissions, glycol dehydrators are a significant source of other ozone precursor VOC, as well as methane (Rueter, et al., 1995). Combustion processes at the well site include heating and flares.

Pressurized natural gas is moved from production areas to distribution areas via pipeline. Compressor engines used to pressurize natural gas are fueled by either diesel or natural gas. In addition to methane (and NO_x) emissions from natural gas engines, fugitive emissions from pipelines are significant. The largest source of methane emissions, leaks from pipeline networks, can occur at any point due to corrosion. Pipe unions, and pigging (pipeline cleaning) operations are also important variables that should be accounted for when considering pipeline fugitives.

Pneumatic valves are employed throughout natural gas production, processing, and transmission pipeline systems. During the course of operation, these devices regularly bleed gas to the atmosphere, and have been found to be one of the largest sources of CH_4 emissions in the industry, in addition to being a significant source of VOC (Armendariz, 2008). Overall, fugitive and intermittent sources are estimated to be 1.4% of gross production of natural gas (Harrison, et al., 1996).

Emission Inventories

In the case of natural gas operations in Sublette County, the pollutant of principle concern is ozone, a secondary pollutant formed by photochemical reactions of VOC and NO_x. In order to understand ozone behavior, State and Federal regulators depend on photochemical models to aid in the development of control strategies. Photochemical grid models can under-predict ozone concentrations anywhere from 35% (Harley et al., 1993) to a factor of two (Hanna et al., 19996). Because of unique emissions, meteorology, and geographic features, Wyoming DEQ is in the process of developing a site-specific local scale ozone model (Wyoming DEQ, 2009).

For any photochemical model to be able to predict pollutant concentrations accurately, detailed emission inventories that are both spatially and temporally accurate are required (Harley, et al., 1993). NARSTO (Mobley, et al., 2005) critical assessments judge NO_x and VOC emission inventories as having medium-high, and low to low-medium relative confidence, respectively. These general ratings would probably be even lower for areas of oil and gas development due to emission spikes (such as those that occur during drilling operations) and fugitive emissions, that have high levels of uncertainty. Emission inventories for natural gas production are frequently based on estimates that do not account for accidents, leakages, or abnormal operating conditions. Although it is generally appropriate to use lower resolution analysis grids in rural areas, large averaging volumes can lead to unacceptable errors, especially where source distributions are very heterogeneous (Russell and Dennis, 2000). Detailed speciation is needed to understand emissions on the micro scale. On-ground measurements are important to validate emission inventory data at the resolution necessary for location specific air quality modeling. Appropriate field measurements must be used if regulatory models for this and similar locales are to be expected to describe the time evolution of spatial ozone concentrations adequately (Hanna, et al., 1996).

Objectives and Hypotheses

The primary aim of our proposal is to provide a spatial measurement survey of key ozone precursors for improving emission inventories and as input data for associated predictive ozone modeling.

Basic inputs used to initialize air quality models are often outdated or not applicable on the local scale. This introduces additional uncertainty into predictive model outputs, so that the potential disagreements with up-to-date air quality data, are difficult to discern. While uncertainty is often assigned to input variables, other model parameters may also be inappropriate. In situations where predictions have implications for natural resource development or adherence to national ambient air quality standards, it is important to reduce input assumptions to a minimum. When realistic, reliable emissions data are used for inputs, more attention can be focused on model mechanisms. This is especially important in scenarios with complex emission patterns and meteorological conditions, as is the case for wintertime ozone exceedance episodes in Sublette County. These unusual air pollution events are associated with emissions from oil and gas development and specific meteorological conditions: snow cover, strong temperature inversions, low wind speed, and clear skies.

A high quality, up-to-date and realistic distribution of emission sources is therefore an important basis for modeling the influence of oil and gas development on air quality. It also enables a comparative assessment of emission sources to inform development of mitigation strategies. In many cases, emission factors employed by air quality regulators are known to have uncertainty but are nevertheless applied as a uniform, single factor. In most cases, inventories use total VOC rather than speciated composition. This is an enormous simplification, especially when considering the formation of secondary pollutants such as ozone, because ozone production is critically dependent on VOC reactivity and the relative concentrations of VOC and NO_x.

The importance of high quality information for the spatial and temporal behavior of key pollutants associated with the formation of ozone cannot be underestimated. This information is required to improve the quality of input variables for box models being developed by the Wyoming DEQ to predict ozone generation. It is useful to gain data over a wide area as well as at specific locations.

OBJECTIVE ONE: Assessment of spatial variability of atmospheric BTEX concentrations

Two spatial surveys of BTEX using up to sixty passive samplers in each survey will be carried out to assess whether there are any substantive differences in atmospheric distributions between Jonah and PAPA. The spatial variation data will be useful in Wyoming DEQ's on going effort to model ozone in the Upper Green River Basin and also to check model performance. This will yield a total of 120 samples. This work will be undertaken simultaneously with objective 2.

Each survey will produce weekly averages of the following pollutants:

- Benzene
- Toluene
- Ethyl-benzene
- m-Xylene
- p-Xylene
- o-Xylene

OBJECTIVE TWO: Assessment of spatial variability of atmospheric oxides of nitrogen concentrations

Two spatial surveys of oxides of nitrogen using up to sixty passive samplers in each survey will be undertaken to assess their distribution in PAPA. This will yield a total of 80 samples. This activity will inform an understanding of the relative levels of these key ozone precursors and their distribution throughout PAPA, to help Wyoming AQD in the planning and implementation of mitigation activities. This work will be undertaken simultaneously with objective 1.

Each survey will produce weekly averages of the following pollutants:

- Oxides of Nitrogen (NO_x)
- Nitric Oxide
- Nitrogen Dioxide

OBJECTIVE THREE: Determination of relative levels of different VOC species in PAPA

During the course of the project, twelve surveys using up to twelve canisters will be undertaken to assess VOC distribution in PAPA. This will yield a total of 144 samples. Extensive measurement of speciated, locally applicable speciated ambient VOC measurements at well-chosen locations will provide high quality input data to assist AQD in its efforts to develop a workable ozone model to assess wintertime ozone formation, and allow Wyoming DEQ to evaluate alternative mitigation strategies. This work will be undertaken simultaneously with objective 4. It should also be noted that each canister will be measured by both the VOC system as well as by the CH_4/NMHC analyzer. This approach enhances the information gained by the mobile laboratory in objective 4.

Each survey will produce either daily or weekly averages of the following pollutants:

- Methane
- Total Non-methane Hydrocarbons
- Ethane
- ethene (ethylene)
- ethyne (acetylene)
- propane
- propene (propylene)
- prop-1-yne (propyne)
- butane
- 2-methylpropane (i-butane)
- but-1-ene
- i-butene (isobutene)
- trans-but-2-ene (trans-2-butene)
- cis-but-2-ene (cis-2-butene)
- 1,3-butadiene
- pentane
- 2-methylbutane (i-pentane)
- 1-pentene
- trans-pent-2-ene (trans-2-pentene)
- 2-methyl-1,3-butadiene (isoprene)

- hexane
- 2-methylpentane (i-hexane)
- heptane
- octane
- i-octane (2,2,4 –trimethylpentane)
- benzene
- toluene
- ethyl-benzene
- m-Xylene
- p-Xylene
- o-Xylene
- 1,2,4-trimethylbenzene
- 1,3,5-trimethylbenzene

OBJECTIVE FOUR: Collect longer-term speciated VOC data, along with supporting data (inorganic air pollutants and meteorological parameters)

A mobile laboratory will run for six months at a site downwind of PAPA for two winter seasons. This will yield a total of approximately 8,000 hourly samples. This data will allow Wyoming DEQ and others to qualitatively evaluate existing data o emissions from PAPA sources VOC measurements from the UW mobile air quality laboratory situated downwind of the oil and gas development can be used to make a qualified evaluation of emission inventories. Back trajectory analyses of normal and unusual VOC profiles measured at the UW mobile air quality laboratory can be used to assess uncertainty of input VOC levels used in ozone modeling and account for anomalies.

Information gained from project objectives is of particular relevance for characterization of air quality in Sublette County, where it will be invaluable for Wyoming DEQ's on-going development of a site-specific model. This data will also help define regulators future approaches to emissions inventories in other areas with spatial and temporal variations of pollutant sources and intensities. This work will be undertaken simultaneously with objective 3.

Minute and 5-minute averages will be obtained:

- Wind speed
- Wind direction
- Relative humidity
- Temperature
- Barometric Pressure
- Ozone
- Carbon Monoxide
- Oxides of Nitrogen
- Nitric Oxide
- Nitrogen Dioxide
- Methane
- Total Non-methane Hydrocarbons

Each survey will produce hourly averages of the following parameters:

- Ethane
- ethene (ethylene)
- ethyne (acetylene)
- propane
- propene (propylene)
- prop-1-yne (propyne)
- butane
- 2-methylpropane (i-butane)
- but-1-ene
- i-butene (isobutene)
- trans-but-2-ene (trans-2-butene)
- cis-but-2-ene (cis-2-butene)
- 1,3-butadiene
- pentane
- 2-methylbutane (i-pentane)
- 1-pentene
- trans-pent-2-ene (trans-2-pentene)
- 2-methyl-1,3-butadiene (isoprene)
- hexane
- 2-methylpentane (i-hexane)
- heptane
- octane
- i-octane (2,2,4 –trimethylpentane)
- benzene
- toluene
- ethyl-benzene
- m-Xylene
- p-Xylene
- o-Xylene
- 1,2,4-trimethylbenzene
- 1,3,5-trimethylbenzene

METHODOLOGY

The project design combines traditional literature research with a monitoring program that incorporates state of the art air quality measurements of ambient air, with a novel spatial and temporal survey approach. Project objectives support refinement of emission inventories and inputs for predictive modeling of photochemical ozone. The methods and techniques that are applied to meet each research design objective are given below.

Objective One – Assessment of spatial variability of atmospheric BTEX concentrations

Using existing knowledge of the area we will identify the geographic areas of interest. Once the extent of the area is determined, we will set-up a grid to aid selection of suitable sampling sites. Up to forty sites will be selected in PAPA and twenty sites will be selected in the Jonah development area. Over the course of the project two weeklong surveys will be conducted using passive sampling techniques to measure aromatic VOC (BTEX). Results will be used to provide a comparison of relative levels of pollutant in Jonah and PAPA.

Objective Two – Assessment of spatial variability of atmospheric oxides of nitrogen concentrations

Using existing knowledge of the area we will identify target emission sources and geographic areas of interest. Once the extent of the area is determined, we will set-up a grid to aid selection of suitable sampling sites. Up to forty sites will be selected in PAPA. These sites will be co-located with sampling sites used for objective one. Over the course of the project, two surveys will be conducted using passive samplers that can measure weekly, time-averaged concentrations of NO and NO_x, thereby NO_2, to compare precursor levels.

Objective Three – Determination of relative levels of different VOC species in PAPA

Using existing knowledge of the area we will identify target emission sources and geographic areas of interest. Once the extent of the area is determined we will set-up a grid to aid selection of twelve suitable sampling sites. These sites will be selected from forty co-located sites to enable comparison with passive sampling. Site selection is flexible based on the need to perform air toxics measurements in the town of Pinedale. Up to twelve sites will be in PAPA, and co-located with samplers used for objective one. Over the course of the project twelve surveys will be conducted with samples collected for up to one week.

Objective Four – Collect longer-term speciated VOC data, along with supporting data (inorganic air pollutants and meteorological parameters)

Using existing knowledge of the area we will select a suitable site downwind of PAPA. The UW mobile air quality laboratory will perform two long-term surveys: November 2010 – April 2011, and November 2011 – April 2012. Initial work will focus on set-up of a continuous gas chromatographic system. Deployment and operation will be performed using protocols developed from 2008 to 2009.

EXPECTED BENEFITS

Project objectives can be tested. The generated data will be of known quality, having undergone rigorous quality assurance procedures. Measurements and surveys will be performed according to standard procedures with state-of-the-art equipment and programs with rigorous quality assurance and control.

For passive and canister sampling measurements, the use of a systematic monitoring approach will give an indication of the spatial and temporal variation of pollutants associated with key emission sources. The characterization of emission source variations is of great importance for emission inventories and subsequent modeling approaches, both for describing current conditions, and for predicting those in the future. Canister sampling serves a dual purpose. Canister measurements are inherently valuable when constructing speciated emissions inventories, even when some samples may reflect emissions originating from more than one source. Additionally, these measurements are necessary to adequately address health concerns expressed by the public about exposure to potentially toxic primary pollutants, emitted as a result of oil and gas development.

A major problem associated with understanding emissions from oil and gas development results from the complexity of the operation. There are a number of relevant processes, including drilling, fracturing, completion, separation and processing, storage, and compression and transport. It should be noted that this list of important processes is not comprehensive, due to non-standard practices such as flaring operations, or the presence of fugitive emissions. In addition, condensate removal is not standardized; it is either shipped via tanker trucks or transported by pipeline. Because the rate of well development and completion is rapid within the proposed study area, activities associated with each of these operations are variable. There are also multiple operators in the development, now identified as an ozone non-attainment area by the Wyoming Governor, each with their own set of different standard operating procedures. The past three years have seen over 400 wells per year completed in Sublette County.

Operation of the UW mobile air quality laboratory with a continuous gas chromatograph is critical for a number of reasons. The continuous gas chromatograph will measure both ambient air quality and analyze canister samples. Ambient data will allow for a downwind assessment of the air quality impacts. Under appropriate conditions, back trajectory analyses will help identify sources that impact advecting air parcels, and will facilitate comparisons of modeled and measured species concentrations.

Monitoring and measurement results are critical to supporting mitigation measures to address environmental problems. While this project focuses on measurements in a specific area, the approach to be used is widely applicable. The proposed project will provide important data, such as accurate ground-truthed ambient ozone precursor data, needed to address this problem, as well as developing protocols suitable for application in other areas. In Wyoming, much of the work to date has focused upon the role that prevailing meteorological conditions play in ozone formation, as well as the temporal and spatial scales of high ozone concentration distributions. With a non-attainment designation, it is now necessary to improve predictive modeling.

Ozone has impacts not only upon human health, but also at the ecosystem level. Because ozone is a secondary pollutant, accurate understanding of the spatial and temporal behavior of ozone precursor emissions is essential. This project will strengthen the knowledge base that will be used to define solutions to mitigating the production of ozone, thereby protecting both human health and the ecosystem.

General Project Information

A number of factors will be instrumental in the success of this project. Most important is the high level of support given by regulators and industry, whose cooperation will facilitate project execution. With the recommendation to EPA by the Wyoming State Governor that Sublette County and parts of adjacent counties should be designated as a non-attainment area for ozone, there is a great incentive for immediate action-oriented work to improve air quality in the region to bring the area into attainment with health-based ozone standards. State and Federal regulators, industry and citizens are all motivated towards the goal of reducing ozone levels in this region. During 2008-2009 the research team from the University of Wyoming, in cooperation with a number of stakeholders, conducted a scoping study of the spatial extent of ozone concentrations on days when meteorological conditions were conducive to the production of elevated ozone concentrations. Fourteen teams placed fifty samplers over an area of approximately 1600 square miles, with the goal of producing iso-concentration contour maps representative of the areal extent of elevated ozone concentrations. The three regulatory monitoring stations in the area could not provide this information. The US Bureau of Land Management, US Forest Service, Wyoming DEQ, Sublette County Conservation District, the Town of Pinedale, Citizens United for Responsible Energy Development, The Log Cabin Motel, British Petroleum, QUESTAR, Shell, and the University of Wyoming all provided teams for this work. This investigation also measured human exposure to ozone for a group of twenty citizen volunteers. Research by the University of Wyoming team has provided an independent assessment of the scope of the ozone problem. This on-going exercise has built trust between the PI of this proposal and local and regional stakeholders, a mutual respect that has been gained through on-site investigation and local meetings. These groups will provide valuable input to this project. Having a good working knowledge of the geographic and political make-up of the region is invaluable.

Facilities

As part of the ozone spatial sampling study noted above, the PI of this proposal and his colleagues were awarded a grant from the University of Wyoming's School of Energy Resources, which allowed for the construction and development of the UW mobile air quality laboratory. This facility is of the highest quality with in-house set-up and data acquisition systems coupled with instruments produced by leading manufacturers. Consequently, the current proposal will only incur costs associated with the installation and testing of the VOC sampling systems. The lead PI has secured an agreement of support from the United Kingdom National Hydrocarbon Network in the design of data treatment protocols. These procedures were initially developed from his collaborative work with the UK Government's Harwell Laboratory.

The UW mobile air quality, commissioned in January 2009, is intended for use in the project. The laboratory was successfully deployed in the field during the first six months of 2009. It is a climate-controlled, stand-alone, secure laboratory, capable of being deployed at any field location with an available 240V 50-amp power supply. A collapsible-railing protected instrumentation platform, accessible via a permanently mounted ladder is mounted on the laboratory roof, allowing deployment of meteorological and radiation sensors. Interior space is designed to accommodate either custom or standard 19" instrument racks, mounted to floor and wall rails. Weather-tight hatches are provided both in the sidewalls and roof to permit ambient air sampling inlet installation. The trailer is currently equipped with a dedicated data acquisition and instrument control system that can be interfaced as necessary to air sampling or other instrumentation. Data from the various instruments are collected via a Windows/Labview based

data acquisition system or using proprietary software from the instrument manufacturers. It permits remote acquisition of archived data.

Personnel Expertise/Experience

The lead PI, Robert Field, has considerable experience with the monitoring of VOC. His initial experience was developed through PhD research at Imperial College on motor vehicle emissions with the operation of a continuous gas chromatograph housed at Exhibition Road. This work supported the implementation of air quality standards for benzene and 1,3-butadiene for the United Kingdom. Field also worked on the implementation of the UK National Hydrocarbon Network, developing novel data management procedures that closed the loop between instrument oversight and data management. This work also involved validation of the UK National Emission Inventory through comparison with ambient network data. His most recent work in the field of VOC sampling has been related to assessments of human exposure to benzene and instrument and laboratory inter-comparison studies. As such, Field has the experience required to deliver the data needed to meet the objectives of this proposal. Given the interdisciplinary nature of the objectives of this work, several important co-workers with valuable background and experience have agreed to collaborate on this project.

The ATSC Department at the University of Wyoming has a worldwide reputation in the field of atmospheric science and has been recognized as such by the National Science Foundation, the Department of Energy, and other organizations. The department provides the primary technical, logistical and analytical support for our ground-level air quality work.

The inclusion of the Enhance Oil Recovery Institute (EOR) ensures that the research team has a strong technical understanding of the processes involved at all stages of oil and gas development. Thyne brings considerable expertise for understanding emission sources and the reasons associated with variation of operational styles between different developers.

Project Schedules

Table 1 outlines the broad project schedule, anticipating completion in three years. The table indicates objectives to be achieved, along with necessary relevant specific activities, identified in the preceding text. Work related to each of the two primary objectives will continue throughout the proposed study.

Table 1: Project Schedule January 2010 to August 2012

Year	Activities
1	• Set-up of protocols and procurement
2	• Set-up of VOC monitoring systems • First monitoring campaign and data validation • Interim assessment of emissions and VOC behavior
3	• Second monitoring campaign and data validation • Final assessment including full assessment of emissions and VOC behavior

Proposed Management Interactions

The lead researcher, as part of the Atmospheric Science Department (ATSC) at the University of Wyoming will control the management of the project through a clearly defined Quality Assurance Project Plan (QAPP). Lines of communication will be established as indicated

in Figure 1. It is important to note that communication with stakeholders will be both through Wyoming DEQ and independently. This ensures good information flow as industry and citizens have established working relationships with the Wyoming DEQ through permitting and other regulatory processes.

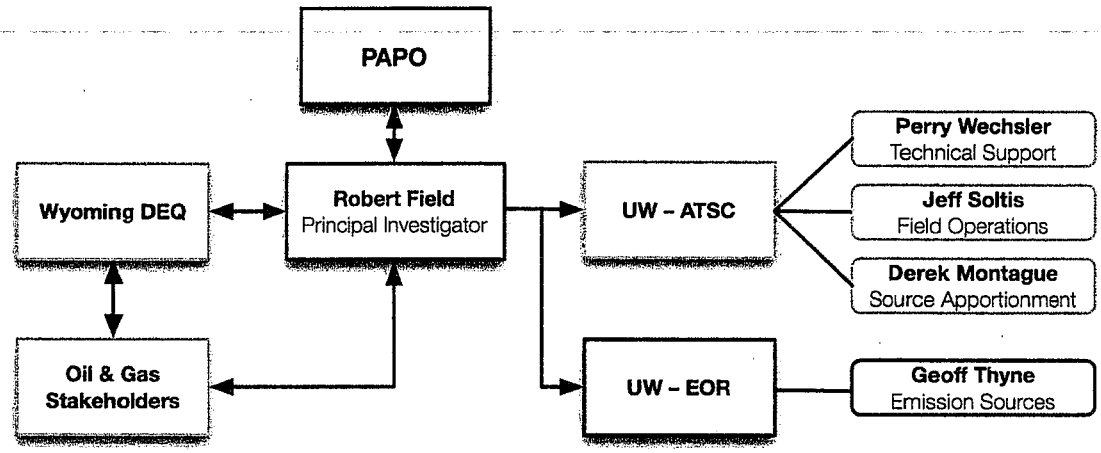

Figure 1: Project Management Structure

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Russell, A., R. Dennis. NARSTO Critical Review of Photochemical Models and Modeling. *Atmospheric Environment* 34: 2283-324. (2000).

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Wyoming Department of Environmental Quality, Air Quality Division. Technical Support Document for Recommended 8-Hour Ozone Designation for the Upper Green River Basin, WY. (2009).

BUDGET

PROPOSED BUDGET: Novel Approaches to Improving Emission Information

Three Year Budget	Year 1 Amount Rate	Year 1 Unit Month	Year 1 Total		Year 2 Amount Rate	Year 2 Unit Month	Year 2 Total		Year 3 Amount Rate	Year 3 Unit Month	Year 3 Total		Total	UW Input	
SENIOR PERSONNEL															
Field PI	$6,404	1	$6,404		$6,660	6	$39,961		$6,927	6	$41,559				
Montague	$5,971	0.25	$1,493		$6,210	0.5	$3,105		$6,458	0.5	$3,229				
Thynne	$6,500	0	$0		$6,760	0.25	$1,690		$7,030	0.25	$1,758				
Total Senior Personnel				$7,897				$44,756				$46,546	$99,199	$35,460	
OTHER PERSONNEL															
Solis	$3,120	1	$3,120		$3,245	12	$38,938		$3,375	12	$40,495			$9,306	
DAS Technical Support	$4,460	3	$13,380		$4,638	1	$4,638		$4,824	1	$4,824				
Total Other Personnel				$17,993				$48,371				$50,306	$116,659	$44,766	
FRINGE (41%)				$10,615				$38,182				$39,709	$88,506	$18,354	
STUDENT PERSONNEL															
Student Stipend	$20,000		$20,000		$20,000		$20,000		$0		$0				
				$20,000				$20,000				$0	$40,000	$40,000	
FRINGE (1%)				$200				$200				$0	$400	$400	
Student Tuition and Fees	$6,586		$6,586	$6,586	$6,586		$6,586	$6,586	$0		$0	$0	$13,172	$13,172	
TOTAL SALARIES & FRINGE				$56,704				$151,509				$136,561	$344,774	$103,520	
EQUIPMENT-VOC System															
Perkin Elmer Precursor Instrument*	$95,000	1	$95,000		$0	0	$0		$0	0	$0				
Canister set-up*	$18,000	1	$18,000		$0	0	$0		$0	0	$0			$12,500	
Total Equipment				$113,000				$0				$0	$113,000	$12,500	
TRAVEL															
Calibration and audits	$400	0	$0		$400	9	$3,600		$400	9	$3,600				
Calibration and canister deployments	$600	0	$0		$600	6	$3,600		$600	6	$3,600				
Canister collection and analysis	$800	0	$0		$800	6	$4,800		$800	6	$4,800				
Passive sampling surveys	$800	0	$0		$800	1	$800		$800	1	$800				
Update Meetings	$400	1	$400		$400	1	$400		$400	1	$400				
Total Travel				$400				$13,200				$13,200	$26,800	$23,130	
Mobile Laboratory Consumables															
Nitrogen cylinders	$0	0	$0		$350	3	$1,050		$364	3	$1,092				
Inorganic calibration cylinders	$0	0	$0		$715	2	$1,430		$744	2	$1,487				
VOC calibration standard	$0	0	$0		$5,000	2	$10,000		$5,000	1	$5,000				
Cylinder rental charges*	$0	0	$0		$50	5	$250		$50	5	$250				
NOx passive samplers	$100	0	$0		$100	0	$0		$100	0	$0				
NOx filters	$112	0	$0		$116	4	$466		$121	4	$485				
NOx Sampler shelters	$22	40	$880		$22	0	$0		$22	0	$0				
BTEX Conditioning	$750	0	$0		$750	1	$750		$750	1	$750				
BTEX Passive samplers	$100	20	$2,000		$150	0	$0		$150	0	$0				
BTEX Sampler shelters	$20	20	$400		$30	0	$0		$30	0	$0				
				$3,280				$13,946				$9,064	$26,290	$0	
Sub-contractor services:															
Passive sampler analysis BTEX	$105	0	$0		$109	65	$7,098		$114	65	$7,382				
Passive sampler analysis NO/NO_x	$66	0	$0		$69	45	$3,089		$71	45	$3,212				
Acquisition and analysis software	$20,000	1	$20,000		$20,000	0	$0		$20,000	0	$0				
Technician Training	$1,500	1	$1,500		$1,500	0	$0		$0	0	$0				
				$21,500				$10,187				$10,594	$42,281	$0	
Other															
Electrical and telemetry charges	$0	0	$0		$150	12	$1,800		$150	6	$900				
				$0				$1,800				$900	$2,700	$0	
TOTAL DIRECT COSTS				$201,470				$197,228				$170,319	$569,017	$152,322	
INDIRECT COSTS		0.2		$16,377		0.2		$38,078		0.2		$34,014	$88,469	$27,830	
Exempt*: Equipment > $5,000															
Exempt*: Rental and student fees															
AMOUNT OF REQUEST				$217,847				$235,306				$204,333	$657,486	$180,152	$477,334 PAPO Request

APPENDIX A: Proposal Objectives Summary Sheet

OBJECTIVE ONE:
Assessment of spatial variability of atmospheric BTEX concentrations

Scope:
Two spatial surveys of BTEX using up to sixty passive samplers in each survey will be carried out.

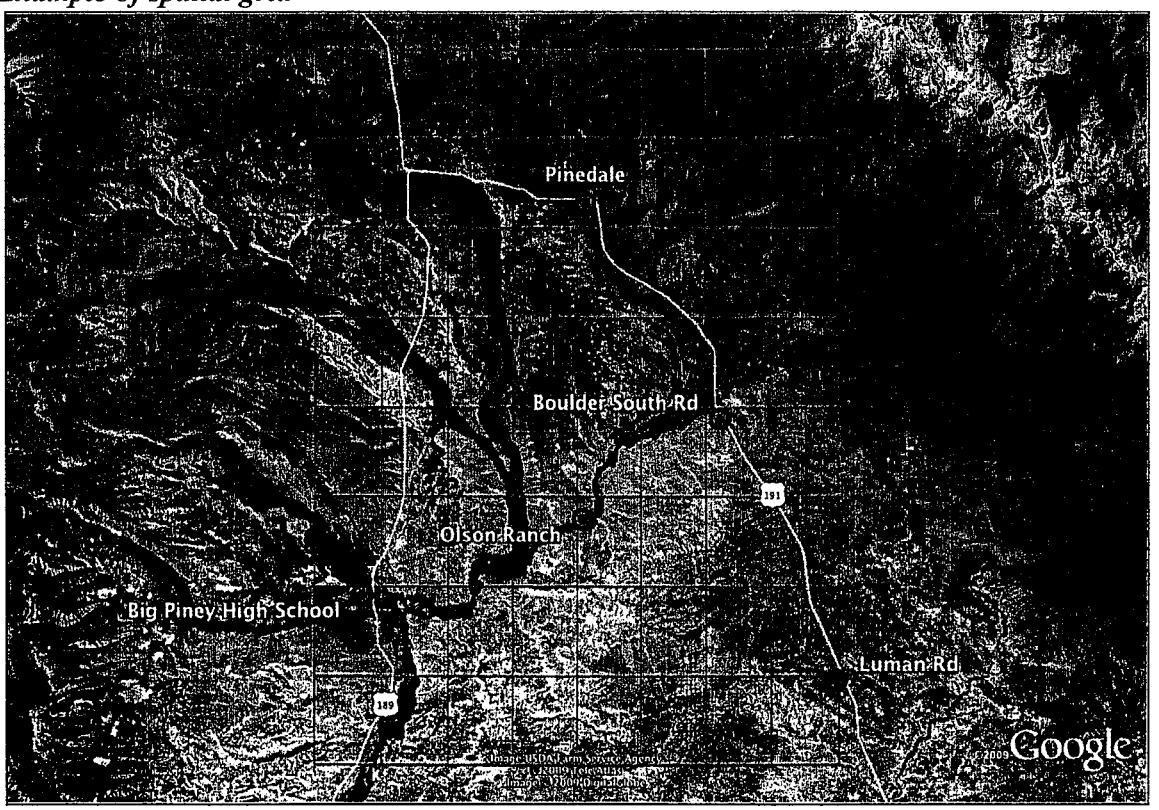
Samples:
This will yield a total of 120 samples.

Pollutants:
Each survey will produce weekly averages of the following pollutants:

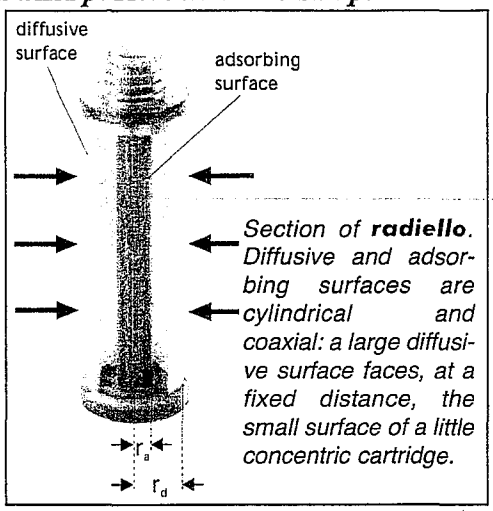
- Benzene
- Toluene
- Ethyl-benzene
- m-Xylene
- p-Xylene
- o-Xylene

Approach:
The surveys use passive samplers in a spatial grid distribution.

Example of spatial grid



BTEX passive Radiello sampler



*Section of **radiello**. Diffusive and adsorbing surfaces are cylindrical and coaxial: a large diffusive surface faces, at a fixed distance, the small surface of a little concentric cartridge.*

Example of BTEX passive Radiello sampler measuring human exposure

OBJECTIVE TWO:
Assessment of spatial variability of atmospheric concentrations of oxides of nitrogen

Scope:
Two spatial surveys of oxides of nitrogen using up to fourty passive samplers in each survey will be carried out.

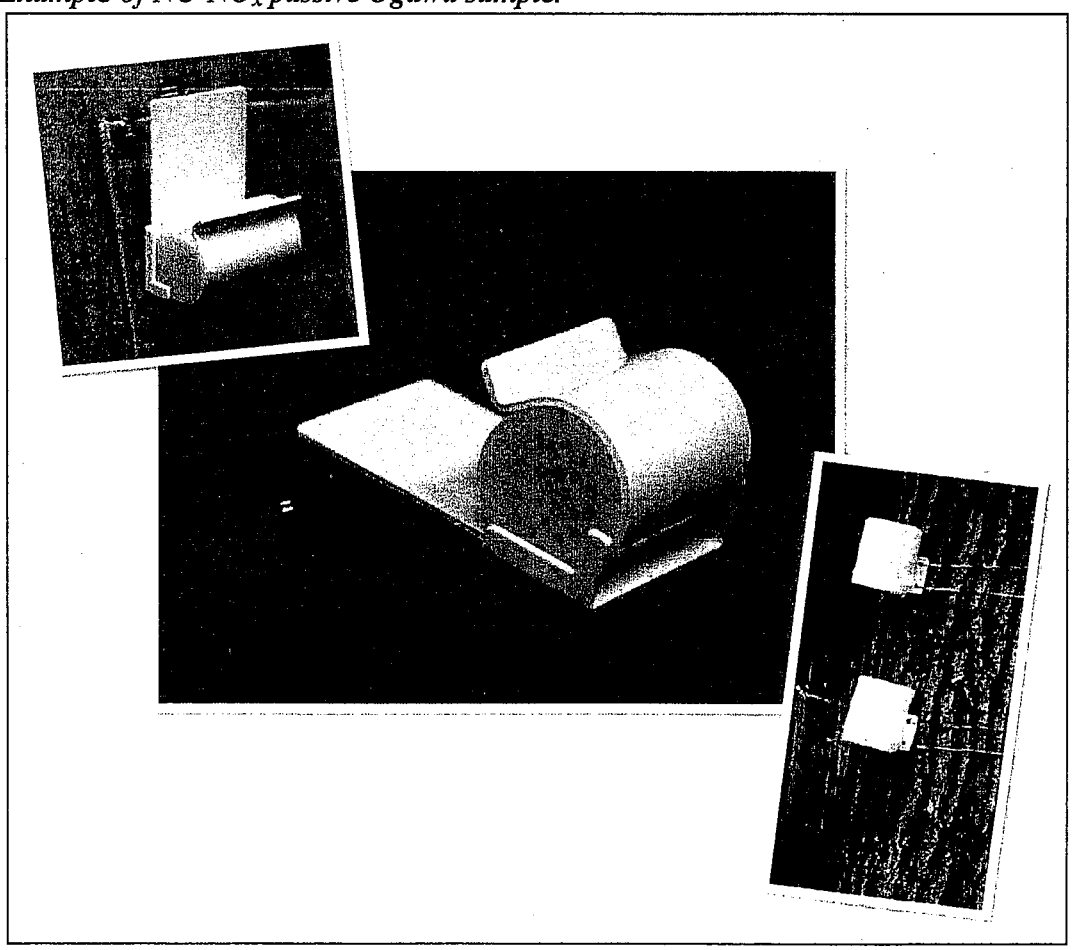
Samples:
This will yield a total of 80 samples.

Pollutants:
Each survey will produce weekly averages of the following pollutants:

- Oxides of Nitrogen (NO_x)
- Nitric Oxide
- Nitrogen Dioxide

Approach:
The surveys use passive samplers in a grid distribution.

Example of NO-NO_x passive Ogawa sampler



OBJECTIVE THREE:
Determination of relative levels of different VOC species in PAPA

Scope:
During the course of the project, at least twelve surveys using up to twelve canisters will be undertaken to assess VOC distribution

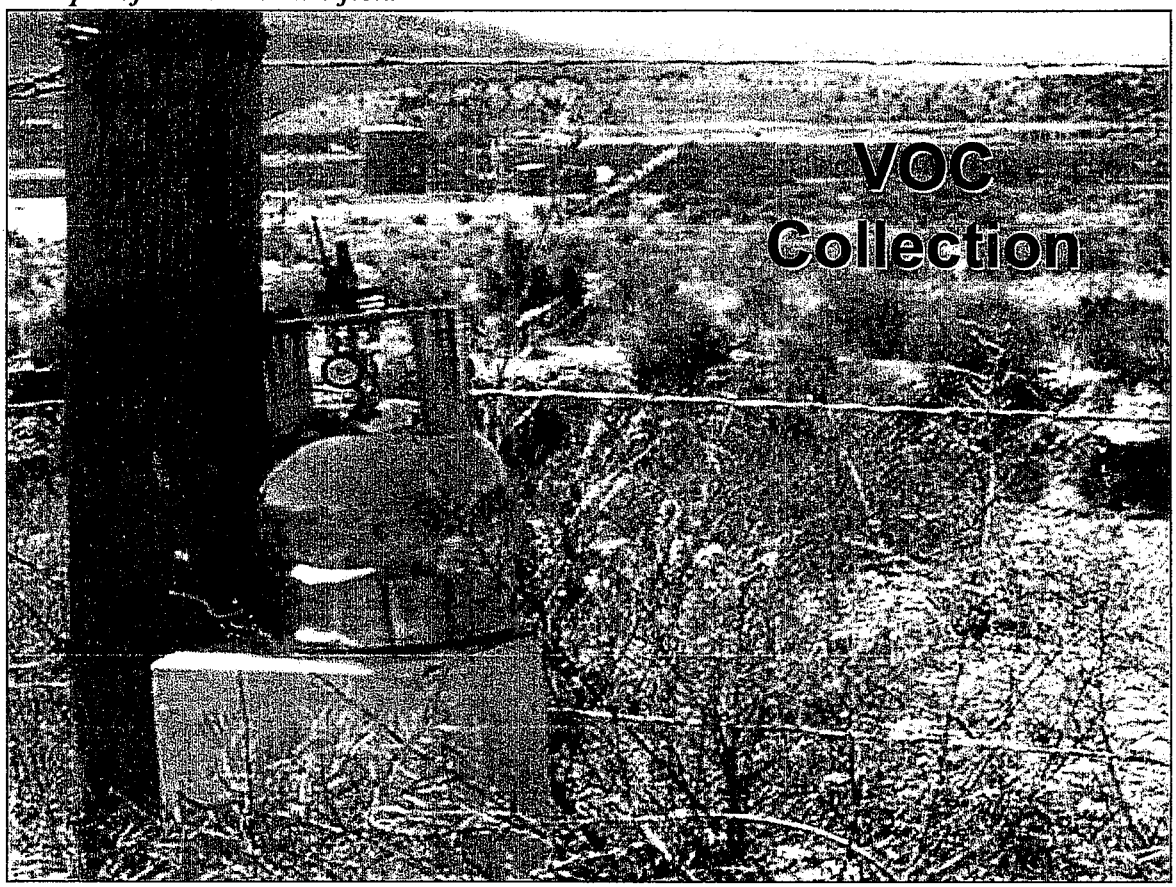
Samples:
This will yield a minimum total of 144 samples.

Pollutants:
Each survey will produce either daily or weekly averages of the following pollutants:

- *Methane*
- *Total Non-methane Hydrocarbons*
- *Ethane*
- *ethene (ethylene)*
- *ethyne (acetylene)*
- *propane*
- *propene (propylene)*
- *prop-1-yne (propyne)*
- *butane*
- *2-methylpropane (i-butane)*
- *but-1-ene*
- *i-butene (isobutene)*
- *trans-but-2-ene (trans-2-butene)*
- *cis-but-2-ene (cis-2-butene)*
- *1,3-butadiene*
- *pentane*
- *2-methylbutane (i-pentane)*
- *1-pentene*
- *trans-pent-2-ene (trans-2-pentene)*
- *2-methyl-1,3-butadiene (isoprene)*
- *hexane*
- *2-methylpentane (i-hexane)*
- *heptane*
- *octane*
- *i-octane (2,2,4 –trimethylpentane)*
- *benzene*
- *toluene*
- *ethyl-benzene*
- *m-Xylene*
- *p-Xylene*
- *o-Xylene*
- *1,2,4-trimethylbenzene*
- *1,3,5-trimethylbenzene*

Approach:
The surveys use canister samplers in a grid distribution.

Example of canister in the field



OBJECTIVE FOUR:
Collect longer-term speciated VOC data, along with supporting data (inorganic air pollutants and meteorological parameters)

Scope:
During the course of the project, two monitoring periods of 6 months duration will be undertaken.

Samples:
This will yield a minimum total of approximately 8,000 hourly samples.

Pollutants:
Each monitoring period will produce hourly averages of the following pollutants:

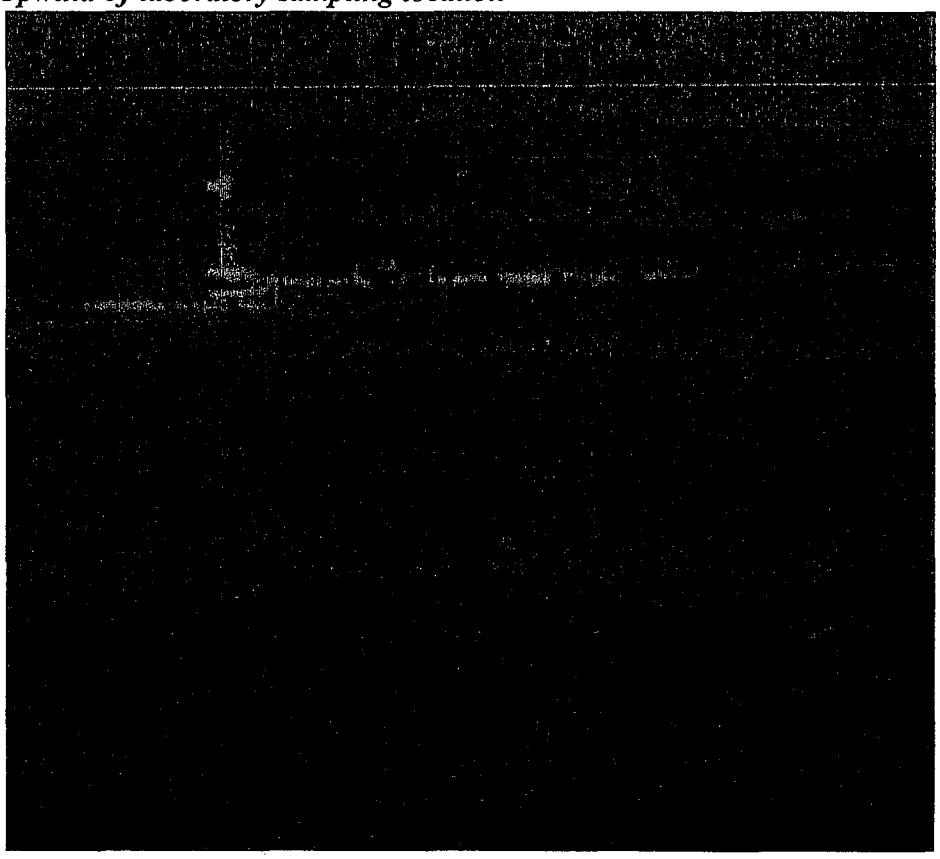
- *Methane*
- *Total Non-methane Hydrocarbons*
- *Ethane*
- *ethene (ethylene)*
- *ethyne (acetylene)*
- *propane*
- *propene (propylene)*
- *prop-1-yne (propyne)*
- *butane*
- *2-methylpropane (i-butane)*
- *but-1-ene*
- *i-butene (isobutene)*
- *trans-but-2-ene (trans-2-butene)*
- *cis-but-2-ene (cis-2-butene)*
- *1,3-butadiene*
- *pentane*
- *2-methylbutane (i-pentane)*
- *1-pentene*
- *trans-pent-2-ene (trans-2-pentene)*
- *2-methyl-1,3-butadiene (isoprene)*
- *hexane*
- *2-methylpentane (i-hexane)*
- *heptane*
- *octane*
- *i-octane (2,2,4 –trimethylpentane)*
- *benzene*
- *toluene*
- *ethyl-benzene*
- *m-Xylene*
- *p-Xylene*
- *o-Xylene*
- *1,2,4-trimethylbenzene*
- *1,3,5-trimethylbenzene*

Each monitoring period will produce one-minute, five-minute, and hourly averages of the following:

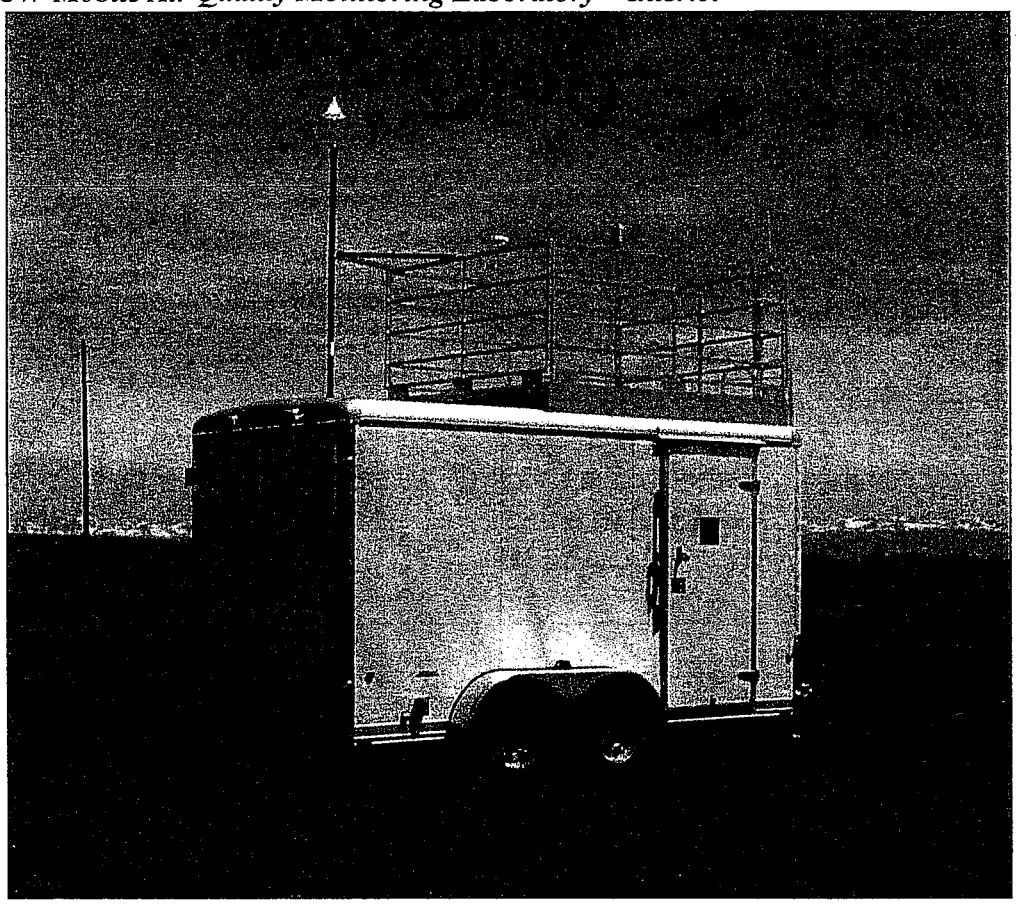
- Wind speed
- Wind direction
- Relative humidity
- Temperature
- Barometric Pressure
- Ozone
- Carbon Monoxide
- Oxides of Nitrogen
- Nitric Oxide
- Nitrogen Dioxide
- Methane
- Total Non-methane Hydrocarbons

Approach:
The UW Mobile Air Quality Monitoring Laboratory will be used to make continuous and hourly measurements.

Upwind of laboratory sampling location

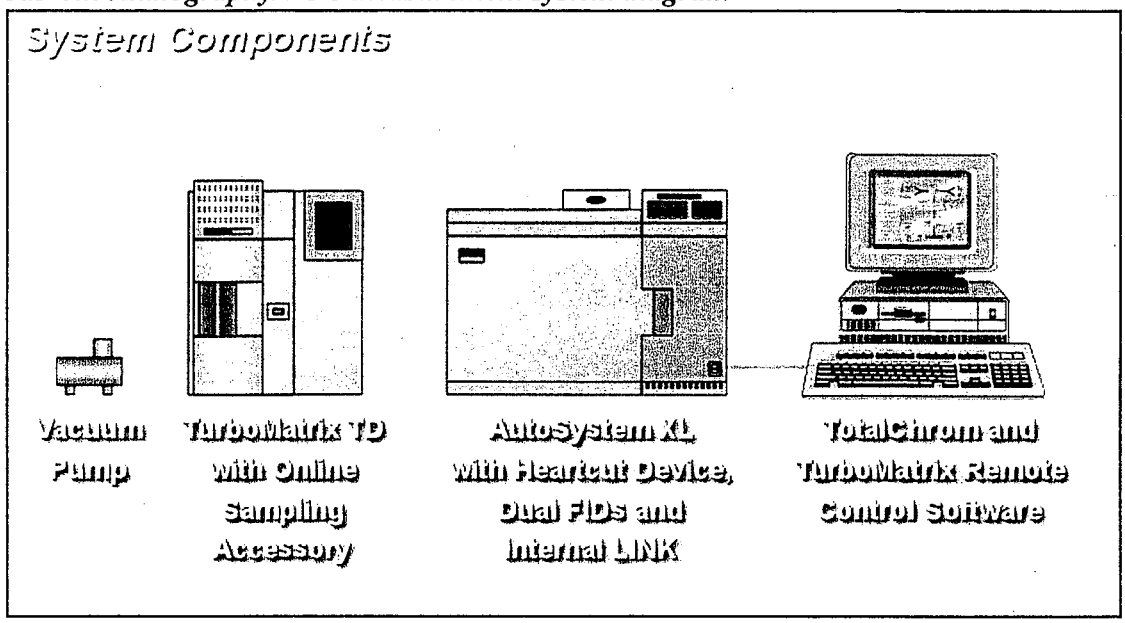


UW Mobile Air Quality Monitoring Laboratory – exterior

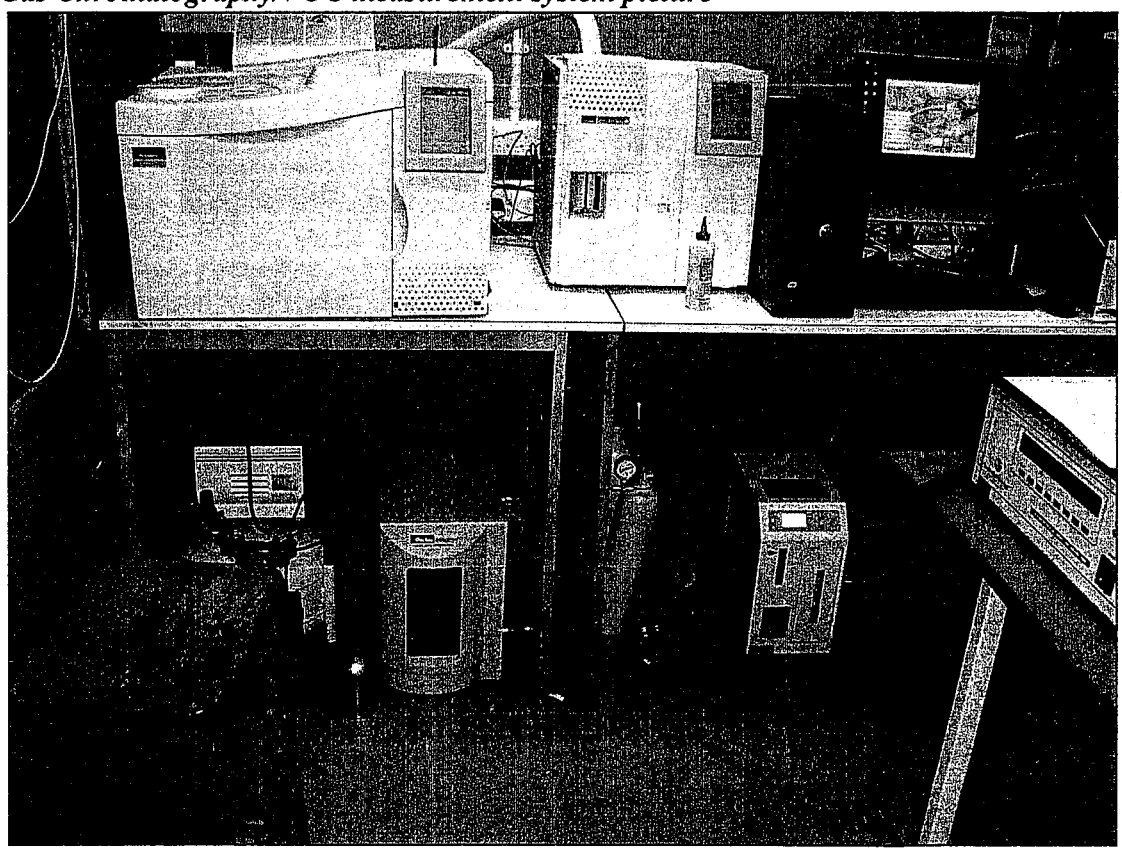


UW Mobile Air Quality Monitoring Laboratory – interior

Gas Chromatography/VOC measurement system diagram



Gas Chromatography/VOC measurement system picture



APPENDIX B: Curricula Vitae

CURRICULUM VITAE

Robert A. Field

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82072, USA.

April 2009
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EDUCATION

Kingston Polytechnic, Surrey, UK: 1989 B.Sc. (Hons.) (Upper II) Resources Science
Imperial College, London, UK: 1995 Ph.D. Environmental Engineering

RESEARCH INTERESTS

- Air pollution measurements and human exposure to air pollutants
- Environmental monitoring strategies and environmental impact statements
- Communication of environmental science and policy to diverse audiences

PROFESSIONAL POSITIONS

1994 to 1997: Higher Scientific Officer and Data Ratification Manager; National Environmental Technology Centre, AEA Technology plc, Oxfordshire, UK

1998 to 2002: Academic Professional Lecturer; Department of Physics and Astronomy and School of Environment and Natural Resources, University of Wyoming, USA

2002 to 2006: Research Fellow; European Commission, Joint Research Centre, Institute for Environment and Sustainability, European Reference Laboratory of Air Pollution, Italy

2006 to 2009: Temporary Associate Professor of Environment and Natural Resources; School of Environment and Natural Resources, University of Wyoming, USA

2009 onwards: Research Scientist, Department of Atmospheric Science, University of Wyoming, USA

PUBLICATIONS: Education

B.Sc. (Hons.) Dissertation (1989). A comparative study of the major uses of the Rhine and Danube rivers. Kingston University, Surrey, UK

Ph. D. Thesis (1995). The sources and behaviour of selected urban air pollutants. University of London, Imperial College of Science, Technology and Medicine, London, UK

WORK EXPERIENCE PROFILES

2006 to 2009 Temporary Associate Professor and Research Scientist
Initially I revised the capstone class of the ENR academic program to a two semester series and also developed an international section. I then developed an air pollution mobile laboratory to pursue research in an emerging air quality issue in Wyoming.

2002 to 2006 Research Fellow and Auxiliary Agent
My main role was as technical project manager of the PEOPLE (Population Exposure to Air Pollutants in Europe) project. This project involved large scale monitoring of air quality; including outdoor, indoor and exposure sampling. The project required the inclusion and support of the media and public and included awareness raising and educational components. The project undertook six campaigns in selected capital cities of Europe; Brussels, Lisbon, Ljubljana, Bucharest, Dublin and Madrid.

1998 to 2002 Academic Professional Lecturer
I supported the Director of the School of Environment and Natural Resources (SENR) for the core classes of the program. At this time only a minor was offered to form part of other undergraduate degrees. I assisted the subsequent growth of this program to offer joint majors, for both undergraduate and graduate students.

1994 to 1997 Higher Scientific Officer
I was part of the team that developed the National Hydrocarbon Air Monitoring Network. I devised and implemented a novel QA/QC system. This work instigated "on line cradle to grave" ratification procedures that reduced data validation time from 6 months to 2 weeks while improving both data quantity and quality. These procedures, modified and improved, are still in use today. This work was complemented by instrument inter-comparisons and support to local authorities. The operation of the network provided valuable data for the assessment of photochemical pollution control while supporting the construction of emission inventories for pollution sources for the United Kingdom.

PUBLICATIONS: Selected Peer Reviewed International Journals
Derwent R.G., Middleton D.R., Field R.A. et al. (1995) Analysis and interpretation of air quality data from an urban roadside location in central London over the period from July 1991 to July 1992. Atmospheric Environment 29, 8, 923-946.

Field R.A. et al. (1996) Trends in motor vehicle related air pollutants in central London. Environmental Monitoring and Assessment 43, 101-116.

Field R.A.et al. (1996) Polycyclic aromatic hydrocarbons in central London air during 1991 and 1992. Science of the Total Environment177, 73-84.

Derwent R.G., Field R.A. et al. (2000) Analysis and interpretation of the continuous hourly monitoring data for 26 C_2 - C_8 hydrocarbons at twelve United Kingdom sites during 1996; Atmospheric Environment; 34, 8, 297-312.

Pérez Ballesta P., Field R.A. and De Saeger E.G. (2001) Inter-laboratory exercises for volatile organic compound determination; Atmospheric Environment; 35, 5729 - 5740.

Pérez Ballesta P., Field R.A. et al. (2006) Population Exposure to Benzene: One day cross sections in six European cities; Atmospheric Environment; 40, 3355 - 3366.

Pérez Ballesta P., R. A. Field, et al. (2008) An approach for the evaluation of exposure patterns of urban populations to air pollution; Atmospheric Environment; 42, 21, 5350 - 5364.

PUBLICATIONS: Selected Technical Reports
Field R.A. et al. (2005) Air Quality, Human Exposure and Health Impact Assessment of Air Pollution in Ljubljana, Slovenia, Joint Research Centre, Italy, EUR 21649 EN.

Field R.A. et al. (2005) Population Exposure to Air Pollutants in Europe (PEOPLE), Methodological Strategy and Basic Results, Joint Research Centre, Italy, EUR 21810 EN.

Pérez-Ballesta P., Field R.A. et al. (2006) First EU JRC aromatic (BTEX) compounds inter-comparison with automatic analyzers; Joint Research Centre, Italy, EUR 22523 EN

Pérez Ballesta P., Field R.A. and DeSaeger E. (2007) Communicating European Research 2005. How clean is the air in European cities? ISBN-10-4020-5357-6 (HB), Chapter 37 p209-216, Springer, The Netherlands.

CURRICULUM VITAE

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EDUCATION

Ph.D., Physical Chemistry, University of Southampton, U.K., 1967
B.Sc.(Hons.) I, Chemistry, University of Southampton, U.K., 1964

PROFESSIONAL APPOINTMENTS:

1988-Present	**Associate Professor**, Atmospheric Science, University of Wyoming Affiliate Associate Professor both in Environmental and Natural Resources and in the Science and Math Teaching Center, College of Education
1979-1988	**Assistant Professor**, Atmospheric Science, University of California, Los Angeles
1978-1979	**Assistant Research Chemist**, University of California, Irvine
1972-1978	**Teaching Fellow and Research Lecturer**, University of Leeds, U.K.
1970-1972	**Temporary Lecturer,** University of Reading, U.K.
1969-1970	**Research Fellow**, University of Cambridge, U.K.

RESEARCH INTERESTS

Current research interests are focused on air quality and atmospheric chemistry issues, especially those associated with aerosol optical and hygroscopic properties, and atmospheric visibility. Experimental studies, in the laboratory, at the department's Elk Mountain Observatory, and using the Wyoming King Air research aircraft, have investigated the physical, chemical, and optical characteristics of the tropospheric aerosol as well as the distribution of trace gases, in both clean and polluted tropospheric environments. Aerosol mass spectrometry is now being used to advance these investigations. Previous studies have included those of the budgetary cycles of trace gases that influence global climate change and/or stratospheric ozone, cloudwater and raindrop chemistry, especially in supercooled clouds, the scavenging of trace species by precipitation, and ice crystal and crystal aggregate growth mechanisms.

SELECTED AND MORE RECENT PUBLICATIONS

Methane: Interhemispheric concentration gradient and atmospheric residence time. *Proc. Nat. Acad. Sci.*, 79, 1366-1370, 1982, Mayer, E.W., Blake, D.R., Tyler, S.C., Makide, Y., Montague, D.C., and Rowland, F.S.

Dichlorofluoromethane, CCl_2F_2, in the Earth's atmosphere. *Geophys. Res. Lett.*, 9, 481-484, 1982, Rowland, F.S., Tyler, S.C., Montague, D.C., and Makide, Y.

On the scavenging of organic gases by cloud and rain. I. A theoretical and experimental study of acetaldehyde. J. Atm. Chem., 1, 325 (1984) (with J.H. Topalian, S. Mitra, A. Quintanar, and H.R. Pruppacher).

A theoretical study of the collision efficiency of small planar ice crystals colliding with large supercooled water drops. *J. Atmos. Sci.*, 42, 857-862, 1985, Lew, J.K., Kingsmill, D.E., and Montague, D.C.

A wind tunnel investigation on the riming of snowflakes. Part I: Porous disks and large stellars. *J. Atmos. Sci.*, 43, 2392-2409, 1986, Lew, J.K., Montague, D.C., Pruppacher, H.R., and Rasmussen, R.M.

Preliminary assessment of the greenhouse warming implications of halocarbon substitutes for CFC-11 and CFC-12. *Atmos. Environ.*, 24A, 1331-1339, 1990, Perrine, R.L. and Montague, D.C.

Hydrogen peroxide retention in rime ice. *J. Geophys. Res.*, 97, 7569-7578, 1992, Snider, J.R., Montague, D.C., and Vali, G.

Airborne measurements of aerosol extinction in the lower and middle troposphere over Wyoming, U.S.A. *Atmos. Environ.*, 37, 789-802, 2003, Han, Z, Montague, D.C., and Snider, J.R.

Determination of Index of Refraction and Size of Supermicrometer Particles from Light Scattering Measurements at Two Angles. *J. Geophys. Res.*, 113, D16206, doi:10.1029/2007JD009607, 2008, Eidhammer, T., Montague, D.C., and Deshler, T.

Performance Characteristics of the Ultra High Sensitivity Aerosol Spectrometer for Particles between 55 and 1000 nm: Laboratory and Field Studies. *J. Aerosol Sci.*, 39, 759-769, 2008, Cai, Y., Montague, D.C., Mooiweer-Bryan, W., and Deshler, T.

SELECTED RECENT PRESENTATIONS

Optical Properties of Mineral Dust Particles in a Small Urban Continental Location, Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract A53D-0221, 2006, Eidhammer, T., Montague, D.C., and Deshler, T.

Characterization of Ambient Aerosol in Summer and Winter in a Small Urban Setting and in Summer at a Remote Mountaintop Site, AAAR 26th Annual Conf., Abstract 11J.5, Reno, NV, 2007, Montague, D.C., Petrenko, M.M., Mooiweer, W., Cai, Y., and Deshler, T.

Dependence of Aerosol Scattering on Relative Humidity and Particulate Composition, AAAR 26th Annual Conf., Abstract 11D.18, Reno, NV, 2007, Mooiweer, W., Montague, D.C., Cai, Y., and Deshler, T.

Comparison of measured and calculated scattering from aerosol at the surface using three size distribution instruments (PCASP, SMPS, UHSAS) and a nephelometer, AAAR 26th Annual Conf., Abstract 14D.3, Reno, NV, 2007, Cai, Y., Montague, D.C., Mooiweer, W., and Deshler, T

Assessment of Baseline Air Quality in Wyoming's Green River Basin Prior to Accelerated Gas and Oil Well Development, AMS 88th Annual Mtg., New Orleans, 2008, Bargo, S., and Montague, D.C.

RECENT AND CURRENT RESEARCH SUPPORT

Enhancement of Atmospheric Aerosol Research at the University of Wyoming (Co-PI with T. Deshler and G. Vali). W.M. Keck Foundation: $800,000 (2000 – 2003)

Comprehensive Physical and Chemical Measurements to Test Predictions of Radiative and Hygroscopic Properties of Surface Atmospheric Aerosol (with T. Deshler)
National Science Foundation: $280,783 (2004 – 2007)

Upper Green River Basin Ozone Monitoring Study (with R. Field) UW SER $97,952 (2008 - 2009)

Upper Green River Basin Ozone Investigation (O3I) (with R. Field) Wyoming DEQ $163,474 (2008 - 2009)

CURRENT AND RECENT GRADUATE STUDENTS (PRINCIPAL ADVISOR)

Wiesje Mooiweer, M.S , 2008: Dependence of aerosol scattering and hygroscopic growth on particle size and chemical composition. (Outstanding UW M.S. Thesis Award, April, 2009)

Sera Bargo, M.S., 2009 (pending): Green River Basin Air Quality: Spring 1996

Mariya Shcherbyna, M.S., 2006: Aerosol optical properties: Dependence on particle size-resolved chemical composition.

Ziguang Han, M.S., 1999: Characterization of the optical properties of continental aerosols during the Southwest Wyoming Visibility Study.

Haiqing Li, M.S., 1999: A simulation of stable wintertime airflow patterns in southwest Wyoming.

PROFESSIONAL AFFILIATIONS

American Geophysical Union
American Meteorological Society
American Chemical Society
American Association for Aerosol Research

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EDUCATION
University of Wyoming Laramie, WY
M.S. Soil Science and Interdisciplinary Water Resources
• Minor in Environment and Natural Resources
Marquette University Milwaukee, WI
Professional Teacher Training Program
• Secondary Education—Journalism
University of Dayton, Dayton, OH
B.A. Communications—Public Relations

WORK EXPERIENCE 2008- Present
Assistant Research Scientist, Department of Atmospheric Science – University of Wyoming, Laramie, WY
I am currently Field Operations Manager for the Upper Green River Ozone Investigation. In this position, I am working with volunteers from all walks of life, including ranchers, gas industry employees, citizens, and individuals from Federal, State, and local governments. Other duties include the operation of an air quality monitoring facility, logistical support, and selection of fifty ozone monitoring sites in Sublette County.

2008 Consultant, State of Wyoming, Cheyenne, WY
Conducted a review of State of Wyoming Cooperating Agency participation in National Environmental Policy Act planning.

2007-2008 Graduate Teaching Assistant, University of Wyoming, Laramie, WY
The emphasis of this position was grading of student writing, and directing students during development of an Environmental Assessment of the *Transistmica* highway construction project in the Panama Canal Zone. During this time I also developed a research project that measured the success of Wyoming DEQs watershed based permitting process in the Powder River Basin.

2007-2008 UW-Extension CBM Workshop Coordinator, University of Wyoming, Laramie, WY, I planned two workshops in conjunction with UW-Extension and local Conservation Districts for landowners affected by CBM development in Sheridan and Rawlins. Planning included media outreach and interviews.

2006-2007 Laboratory Instructor, University of Wyoming, Laramie, WY
As an introductory biology laboratory instructor, I created lesson plans and taught in a lab setting.

2005-2006 Biological Control Lab Assistant, University of Wyoming, Laramie, WY
Conducted greenhouse experiments to investigate the effects of *C. litura*, a stem boring weevil, on Dalmation Toadflax, an invasive plant species.

2002-2004 Dog Musher, Jackson Hole Iditarod, Bondurant, WY
As a musher I led 12- and 20-mile dog sled tours, and provided day-to-day care, training and handling for a team of 21 sled dogs.

2002-2004 Chef, Dell Creek Diner at the Elkhorn, Bondurant, WY
Duties included the selection and preparation of nightly dinner specials, and all other kitchen duties, such as ordering, task assignments and menu design.

1997-2001 Hotel Director & Purser, Cruise West, Seattle, WA
As a cruise ship officer I managed and administered on-board hotel and guest service operations n Alaska and Baja Mexico. Played lead role in training crew, and in development and implementation of all hotel department procedures. Also wore the hat of project manager during seasonal maintenance periods.

PROFESSIONAL SKILLS

Project Management Skills

• As a vessel project manager I directed preparation of cruise ships during maintenance periods. Including the coordination of a multitude of seasonal maintenance tasks, such as arranging equipment repair and maintenance, staff training and design of crew procedures.
• I designed a procurement system that tracked inventory, and calculated purchase requirements, providing department heads with a clear, organized way.

Writing and Media Skills

• My undergraduate training in Public Relations and Journalism has given me the skills necessary
for developing media relations.
• I have designed and distributed media packets, written press releases, and created events.
• I have written for subscriber newsletters as an employee of the Florentine Opera Company of Milwaukee, and as a board member of The Needle's Eye: A Resource Center for Peace and Justice.

Environmental Resource Policy & Assessment

• Recent course work includes the University of Wyoming's MS in Soil Science curriculum, as well as topics such as Water Law and Fluvial Geomorphology.
• Wrote the air quality section of a proposal to perform an *Environmental Assessment on the Effects of Climate Change in the Colorado River Basin.*
• Wrote the air quality section of *Environmental Assessment of Construction of an LNG Terminal in Ensenada, Baja, B.C.S.*

Public Involvement Programs

• My current position involves extensive work with the public.
• My MS thesis research examined stakeholder participation in DEQ's watershed based permitting
program in the Powder River Basin.
• I developed workshops for landowners affected by CBM development in Sheridan and Rawlins in conjunction with UW-Extension, local Conservation Districts, and Wyoming DEQ-WQD.

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Education

1986 - 1991: University of Wyoming: Ph.D. Geology
1975 - 1980: Texas A & M University: M.S. Oceanography
1970 - 1975: University of South Florida: B.A. Chemistry and Zoology

Professional Experience

2006-present	*Enhanced oil Recovery Institute*	Senior Research Scientist
2005-06	*Colorado Energy Research Institute*	Project Manager
1999-2008	*Colorado School of Mines*	Research Associate Professor
1997-1998		Research Assistant Professor
1996-1997		Adjunct Assistant Professor
1992-1996	*California State University, Bakersfield*	Assistant Professor
1990-1991	*Colorado School of Mines*	Postdoctoral Research Fellow
1986-1990	*University of Wyoming*	Graduate Research Assistant
1984-1986	*ARCO Oil and Gas R& D*	Research Geochemist
1982-1984		Associate Research Geochemist
1980-1982		Senior Engineering Technician

Selected Publications

Alvarado, V., **Thyne, G**. and G. R. Murrell, 2008, Screening strategy for chemical enhanced oil recovery in Wyoming basins, Society of Petroleum Engineers Proceedings, SPE Paper #115940.

Skold, M., **Thyne, G.**, and J. Drexler and J. McCray, 2007, Determining conditional stability constants for Pb complexation by carboxymethyl-beta-cyclodextrin (CMCD). J. Contaminant Hydrology 93 (1-4), 203-15.

Skold, M. E., **G. D. Thyne** and J. E. McCray, 2007, Using UCODE_2005 and PHREEQC to Determine Thermodynamic Constants from Experimental Data. Groundwater 45(3), 368-373.

Navarre-Sitchler, A. and **G. D. Thyne**, 2007, Effects of carbon dioxide on mineral weathering rates at earth surface
conditions, Chemical Geology 243(1-2), p. 53-63.

Lipson, D.L., McCray, J.E., **Thyne, G.D.**, 2007, Using PHREEQC to simulate solute transport in fractured bedrock, Ground Water, 45(4), 468-472.

Güler, C. and **G. D. Thyne**, 2006, Statistical Clustering of Major Solutes: Use as a Tracer for Evaluating Interbasin Groundwater Flow into Indian Wells Valley, California, *Environmental and Engineering Geoscience* 12(1), 53-65.

Thyne, G., 2005, Geochemical Modeling - Computer Codes, GW-246. In *The Encyclopedia of Water*, Jay Lehr, Editor, John Wiley and Sons.

Thyne, G.D., Guler, C. and Poeter, E., 2004, Sequential analysis of hydrochemical data for watershed characterization, *Ground Water* 42 (5), 711-723.

Thyne, G.D., Pasternack, I. and Anderson, D.S., 2004, Contributions to *Wyoming Geological Association Guidebook*, Preliminary Assessment of Reservoir Quality Controls in Lewis Shale Sandstones, south-central Wyoming.

Güler C. and **Thyne, G.D.**, 2004, Hydrologic and geologic factors controlling surface and ground water chemistry in Indian Wells-Owens Valley area and surrounding ranges, California, U.S.A. *J. Hydrology* 285, 177-198.

Güler, C., **Thyne, G.D.**, McCray, J.E. and Turner, A.K., 2002, Evaluation of the graphical and multivariate statistical methods used for classification of water-chemistry data. *Hydrogeology Journal* 10, 455-474.

Thyne, G.D., 2001, A model for diagenetic mass transfer between adjacent sandstone and shale. *Marine and Petroleum Geology* 18, 743-755.

Thyne, G.D., Boudreau, B., Ramm, M. and Midtbø, R.E., 2001, A reaction-transport model of K-spar dissolution and illitization in the Statfjord Formation, North Sea. *AAPG Bulletin* 85, 621-636.

Thyne, G.D., Gillespie, J.M. and Ostdick, J.R., 1999, Evidence for interbasin flow through crystalline rocks, southeastern Sierra Nevada. *GSA Bulletin*, 111 (11), 1600-1616.

O'Brien, N.R., **Thyne, G.D**. and Slatt, R.M., 1996, Morphology of hydrocarbons during migration: Visual example from the Monterey Formation (Miocene, California). *AAPG Bulletin* 80, 1710-1718.

Swartz, R.J., **Thyne, G.D**. and Gillespie, J. M., 1996, Hydrochemical evidence for the source of arsenic in ground water in the Kern Water Bank, Southern San Joaquin Valley, California. *Environmental Geosciences* 3, 143-153.

Thyne, G.D. and Gwinn, C.J., 1994, Evidence for a paleoaquifer from early diagenetic siderite of the Cardium Formation, Alberta Canada. *J. Sedimentary Research*, A64, 726-732.

Harrison, W.J. and **Thyne, G.D.**, 1994, Geochemical models of rock-water interactions in the presence of organic acids. Ch. 12 in Organic Acids in Geological Processes, (Pittman and Lewan, eds.). Springer-Verlag, NY.

Thyne, G.D., Harrison, W.J. and Alloway, M.D., 1992, Experimental study of the stability of the Al-oxalate complex at 100°C and calculations of the effects of complexation on clastic diagenesis. Water-Rock Interaction 7, Kharaka Y. K. and A. S. Maest, (eds.), 353-357.

Harrison, W.J. and **Thyne, G.D.**, 1992, Predictions of clastic diagenesis in the presence of organic acids. *Geochimica Cosmochimica Acta*, 56, 565-586.

Technical Reports

Thyne, G. D., 2008, Review of Phase II Hydrogeologic Study, http://www.garfield-county.com/Index.aspx?page+570.

Thyne, G. D., 2004, Review and analysis of Divide Creek gas seep for Garfield County. Presented at August 16th COGCC hearing, Glenwood Springs, CO.

Thyne, G. D., 2000, Evaluation of the proposed kerogen cementation model to predict the changes in reservoir quality during burial due to diagenesis. Technical Report for Norsk Hydro A. S., 52p.

Thyne, G.D., 2000, Evaluation of Reservoir Quality and Diagenesis in the Oseberg Formation, Oseberg Field. Technical Report prepared for Norsk Hydro A. S., 62p.