UTICA SHALE ENERGY AND ENVIRONMENT LABORATORY

FINAL SCIENTIFIC/TECHNICAL REPORT

October 1, 2014 – September 18, 2017

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ABSTRACT

The Ohio State University (OSU) was awarded a contract on October 1, 2014, from the Department of Energy National Energy Technology Laboratory (DOE-NETL) to develop the Utica Shale Energy and Environment Laboratory (USEEL) in the Utica-Point Pleasant shale play of the Appalachian Basin. It was designed to be an environmental and technology development lab that would enable the academic, industry, government, and non-governmental organization (NGO) research communities to better understand unconventional oil and gas (UOG) engineering practices and technology to increase production and safety, and decrease environmental effects. Political and economic consequences necessitated changes in project site location and design, from the Ohio State Eastern Agricultural Research Station (EARS) and the Muskingum Watershed Conservancy District (MWCD) in east-central Ohio to a site located at an Energy Corporation of America (ECA) Marcellus drill pad in Greene County, Pennsylvania.

Although the overall project progressed little beyond planning and administration before termination on September 18, 2017, significant research and MS or PhD investigations were completed or continue today. An experimental study design for site specific and regional baseline assessments was developed utilizing ecoregions, United States Geological Survey (USGS) Hydraulic Unit Code watersheds, and GIS technology and databases. This can be utilized to build a defensible and scalable management and research framework for UOG investigations that can be extrapolated for predictive and comparative analyses. The most commonly mentioned perceived risks of shale energy development identified in a socioeconomic analysis included impacts to the environment and water resources, traffic and road deterioration, and crime. Economic benefits, such as the windfall wealth to residents, job opportunities, and the demand for hotels and restaurants emerged, as the main positive impact to the community. Preliminary results of an analysis of the location and mechanisms for extremely high pore pressures of the deep Utica-Point Pleasant formations of southwestern Pennsylvania and their possible relationship to high initial production rates indicate that the overpressure is caused by a combination disequilibrium compaction and fluid expansion. Drilling fluids research designed a proof-of-concept device to evaluate desalination and solvent separation in hydraulic fracturing flowback water that could facilitate water recycling and potentially mitigate deep-well injection. A groundwater study was devised to characterize the subsurface aquifers in terms of the geological framework and groundwater chemistry, including the chemistry of dissolved gases and salts. Brines and gases associated with hydrocarbon migration in groundwater (including noble gases and hydrocarbons) were to be specifically fingerprinted for use as tracers of fluid migration. Trace element analysis of fish otoliths, using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), is being utilized to assess surface water quality. This methodology will be used to reconstruct the exposure histories of fish from watersheds and discriminate between the signatures associated with hydraulic fracturing and coal mining activities.

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1.0 Executive Summary

The Ohio State University was awarded a contract on October 1, 2014, from the Department of Energy National Energy Technology Laboratory (DOE-NETL) to develop the Utica Shale Energy and Environment Laboratory (USEEL). USEEL was designed to be an environmental and technology development lab that would enable the academic, industry, government, and NGO research communities to better understand unconventional oil and gas (UOG) resource development; and advance engineering practices and technology to increase production and safety, and decrease environmental effects. Specifically, USEEL was to be located in the Utica-Point Pleasant shale play in the Appalachian Basin, and was initially to be hosted and developed at the 760 acre Ohio State Eastern Agricultural Research Station (EARS) in Noble County, Ohio. However, in late October 2014, the University was notified that it would not be permitted to drill on State lands. Discussions with the Muskingum Watershed Conservancy District (MWCD) identified a 1500 acre area located in the nearby Piedmont and Clendening Lake area of Belmont and Harrison counties that had many of the attributes of the Ohio State EARS site. Unfortunately, due to a downturn in the shale industry, the potential MWCD project site was lost. In December 2016, OSU identified a site located at an Energy Corporation of America (ECA) Marcellus drill pad in Greene County, Pennsylvania, within one of the deepest portions of the Utica-Point Pleasant shale play of the Appalachian Basin. Changes in project costs, incremental funding, budget periods, and project objectives were approved, but on August 29, 2017, ECA withdrew from the project as a result of a third party. The rescission by ECA resulted in noncompliance with the requirements set forth under the cooperative agreement and the project was unilaterally terminated by DOE on September 18, 2017.

Political and economic consequences necessitated changes in project site location and design, and ultimately resulted in termination of the project before most project objectives could be achieved. The USEEL project tasks and subtasks were initially designed with almost equal emphasis on the environmental and socioeconomic effects of UOG hydraulic fracturing activities, and the development of engineering practices and technology to increase UOG production and safety. This approach was especially relevant when the proposed USEEL project sites were the relatively pristine EARS and the MWCD areas of east-central Ohio. Later, when the project site was relocated to the ECA Marcellus pad in the moderately well-developed area of Greene County, Pennsylvania, the focus changed to subsurface geological, geophysical, and geochemical activities.

Although the overall project progressed little beyond planning and administration, significant investigations by project researchers were completed or continue today. An experimental study design for site specific and regional baseline assessments was developed utilizing ecoregions, USGS Hydraulic Unit Code watersheds, and GIS technology and databases to build a defensible and scalable management and research framework that can be extrapolated for predictive and comparative analyses. This approach categorizes and quantifies the ecological effects of hydraulic fracturing as well as other large-scale environmental disturbances that can be used for predictive and comparative analyses for various ecosystems throughout the United States. Preliminary results indicate that surface coal mining, urbanization, logging, and agricultural disturbances have an overall greater potential for primary environmental impacts in eastern Ohio, western West Virginia, and southwestern Pennsylvania than conventional and unconventional oil and gas development.

A socioeconomic analysis and opinion assessment explored potential impacts and perceived risks and benefits associated with UOG shale energy development. It sought to uncover processes influencing the perceptions of technology as risky or beneficial and to develop methods to facilitate a more inclusive decision-making and planning process for future development. The most commonly mentioned

perceived risks of shale energy development included impacts to the environment and water resources, traffic and road deterioration, and crime. Economic benefits, like the windfall wealth to residents, job opportunities, and the demand for hotels and restaurants emerged as the main positive impact to the community, as cited by participants. Factors influencing perceptions of shale energy development included empowerment, uncertainty, previous experience with energy development, attachment to the physical environment or community, and direct economic benefits.

The location and mechanisms for extremely high pore pressures of the deep Utica-Point Pleasant formations of southwestern Pennsylvania and their possible relationship to high initial production rates are being evaluated by a borehole geophysics research project. If completed, the study would have used a combination of geophysical well logs from the planned USEEL well and 19 previously drilled Marcellus wells in Greene County, Pennsylvania, plus two additional Utica wells; and a 3-D seismic volume. Preliminary analyses indicate that the overpressure is caused by a combination disequilibrium compaction and fluid expansion.

Drilling fluids research designed a hybrid microchannel-nanochannel proof-of-concept device that could extract useful water from hydraulic fracturing flowback and facilitate water recycling and potentially mitigate deep-well injection. This device would also be capable of separating volatile organic compounds from water during shale gas production. A fundamental understanding of water transport was investigated in order to design novel membranes with enhanced flux and selectivity, thereby improving the state-of-the-art technologies for membrane based filtration. Although shale flowback water was never collected from the USEEL project well, flowback water was collected from two different wells in the Utica play and one from the Marcellus play and used in prototype fabrication and surface modification experiments to evaluate desalination and solvent separation.

Other researchers developed approaches and methodologies for MS and PhD graduate studies that addressed changing project locations and objectives. All completed extensive literature reviews, primary data compilation and analyses, and draft quality assurance project and/or sampling activity plans; and coordinated with various local, state, or federal agencies. A groundwater study was devised to characterize the subsurface aquifers in terms of the geological framework and groundwater chemistry, including the chemistry of dissolved gases and salts. Brines and gases associated with hydrocarbon migration in groundwater (including noble gases and hydrocarbons) were to be specifically fingerprinted for use as tracers of fluid migration. Trace element analysis of fish otoliths, using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), is being utilized to assess surface water quality. This methodology will be used to reconstruct the exposure histories of fish from watersheds that contain various energy-related resource extraction activities. Additionally, otolith microchemistry will be compared between fish in watersheds that have either hydraulic fracturing or coal mining activity in an attempt to discriminate between the signatures associated with each set of processes.

2.0 Introduction

2.1 Background

The Ohio State University was awarded a contract on October 1, 2014, from the DOE-NETL to develop the USEEL. Definitized on August 1, 2015, USEEL was designed to be an environmental and technology development lab that would enable the academic, industry, government, and NGO research communities to better understand UOG resource development; and advance engineering practices and technology to increase production and safety, and decrease environmental effects. Specifically, USEEL was to be located in the Utica-Point Pleasant shale play in the Appalachian Basin (Figure 1). Oil and gas production from the Appalachian Basin has been a major contributor to U.S. energy needs for almost 200 years. Recently, unparalleled UOG development of the natural gas-rich Paleozoic Marcellus and underlying Utica-Point Pleasant shale formations has significantly increased the Nation's energy security.

USEEL initially was to be hosted and developed at the EARS in Noble County (Figure 2). Ohio State owns all of the surface and subsurface rights for this property that consists of 760 acres and already had on site facilities to support the planned research activities. As the owner of the property, Ohio State was in a unique position to frame a Production Agreement with a key operator. However, in October 2014, the University was notified by the State that it would not be permitted to drill on State lands. Immediately following this notification, a search began for an alternative site that met the key requirements of NETL, the research communities, and the key financial and fiduciary responsibilities of Ohio State. Discussions with the MWCD quickly identified a common set of goals: (1) the prudent and environmentally sound development of UOG assets, (2) the advancement of best management practices for the industry and the region, (3) and the active outreach and engagement of local communities in activities and the research results. Based on initial discussions with the MWCD staff, Ohio State proposed that the Piedmont and Clendening Lake area of Belmont and Harrison counties be evaluated as the site of the first USEEL research lab (Figure 2). It is an area of over 1500 acres within the Utica-Pt Pleasant Play and had many of the attributes of the Ohio State EARS site. MWCD owns the surface rights to this area and the operator, Gulfport, and Ohio State had a good working relationship.

Unfortunately, due to a downturn in the shale industry, the potential MWCD project site was lost. Ohio State began evaluating other possible locations for the project and in December 2016 a site was identified at an ECA Marcellus drill pad in Greene County, Pennsylvania (Figure 3). The proposed site lies within one of the deepest portions of the Utica-Point Pleasant shale play of the Appalachian Basin. Ohio State presented a plan forward for the project at this new site in January 2017. DOE completed a major modification to the award dated April 1, 2017.

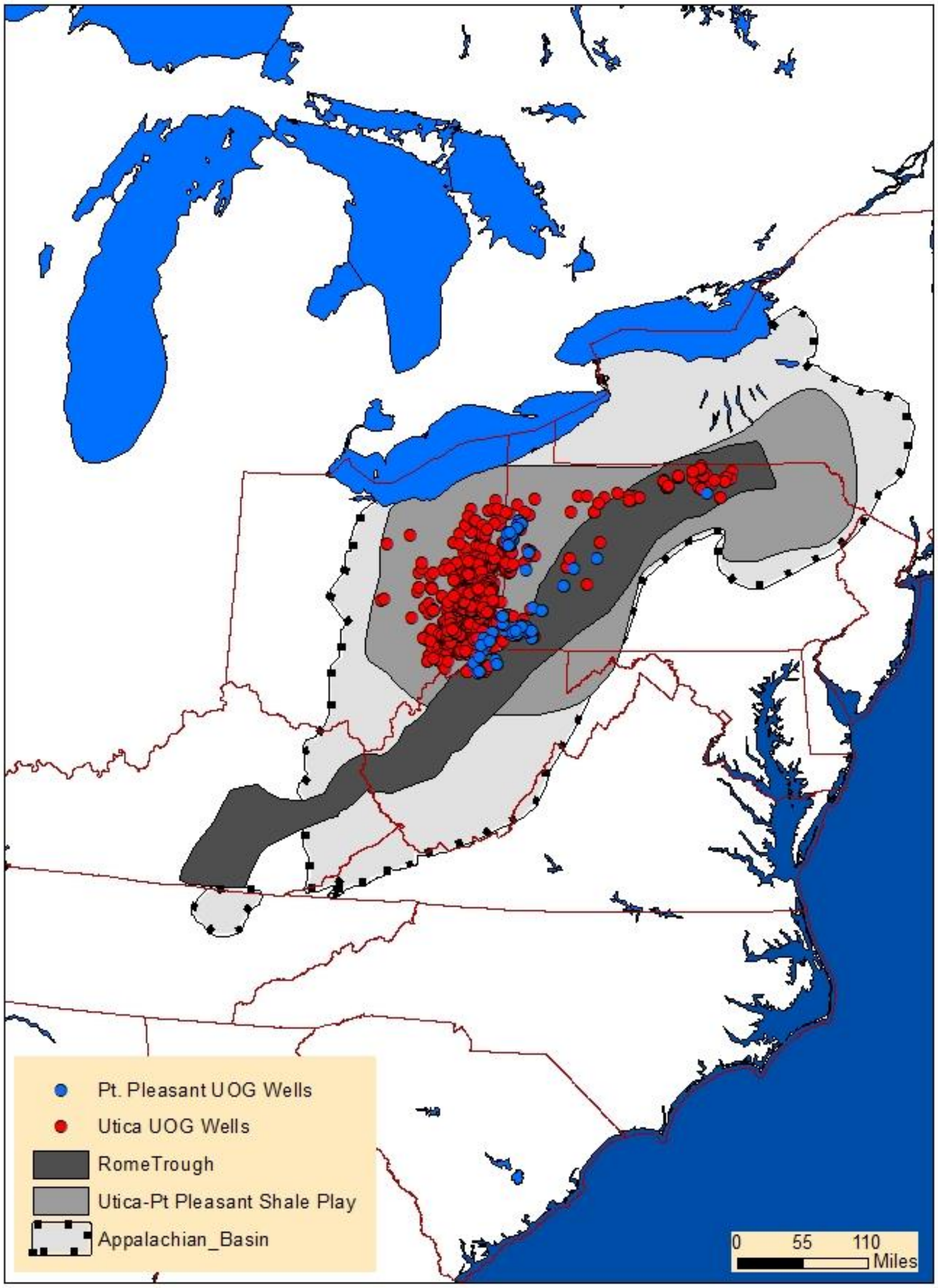

Figure 1. Utica-Point Pleasant UOG wells in the Appalachian Basin

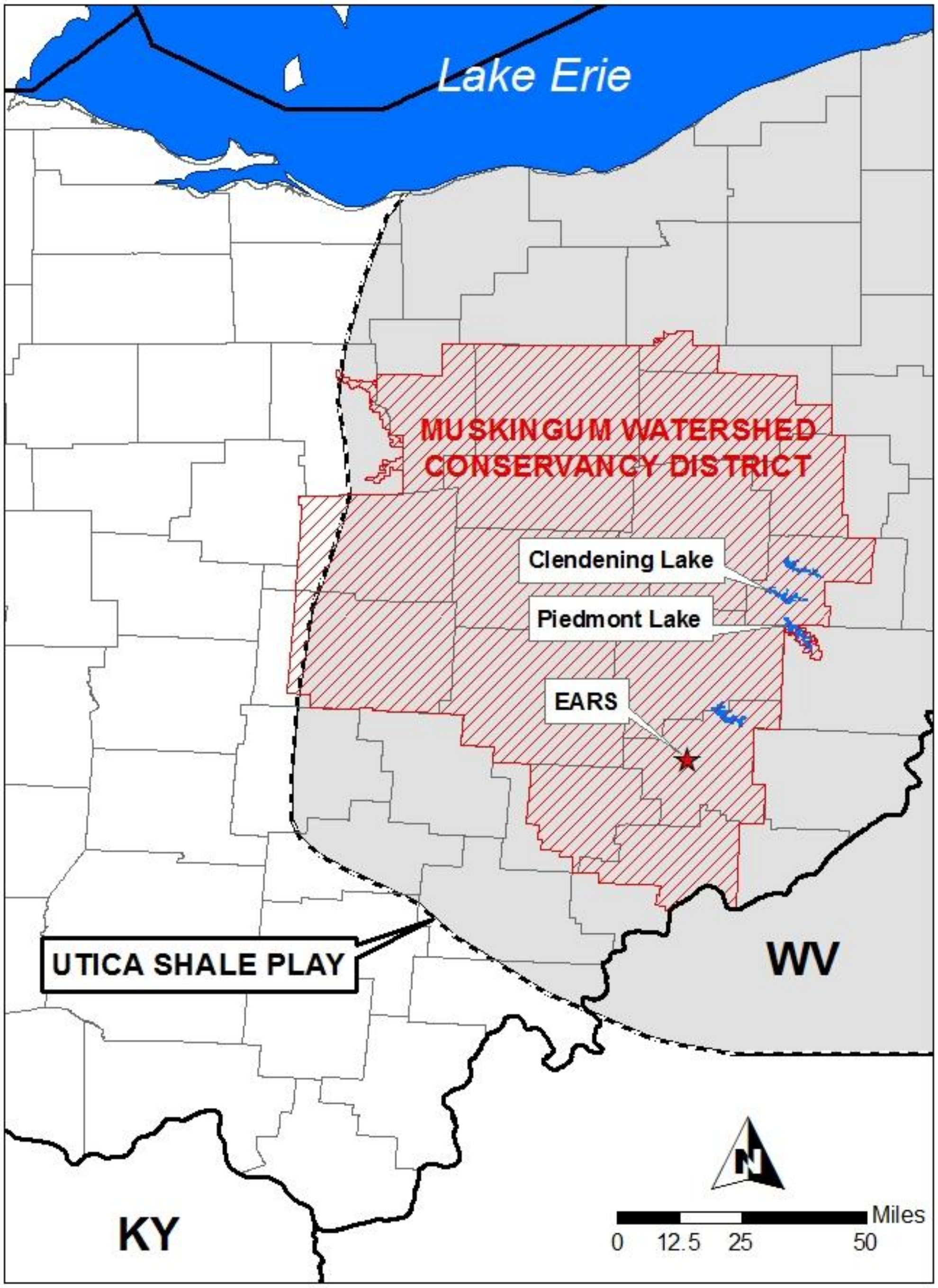

Figure 2. Proposed EARS and Muskingum Watershed Conservancy District USEEL sites

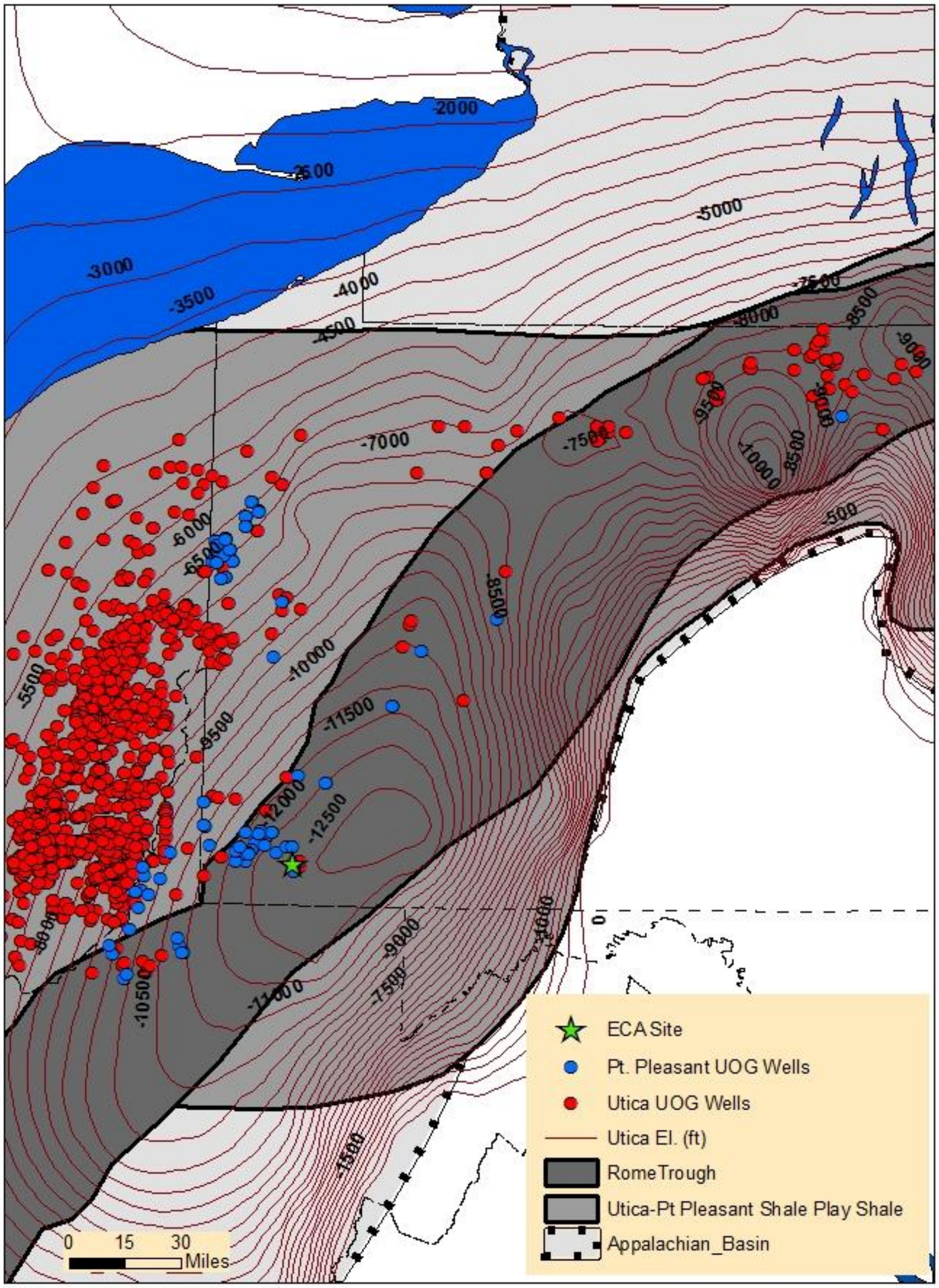

Figure 3. Proposed ECA USEEL site

In Modification 0007, new sub recipients ECA and Texas A&M and a new site location were identified; and changes in project costs, incremental funding, budget periods, and project objectives were approved. Subsequent Amendments 0008 and 0009, clarified award sub recipients and budget periods.

ECA notified OSU on August 29, 2017, that as a result of a significant transaction with a third party, they must immediately withdraw from USEEL project. The Ohio State University received STRIPES documentation: Courtesy Copy-Award notification on September 19, 2017. This included Amendment 0010, which stated the following: "The rescission by ECA resulted in noncompliance on the part of the Recipient with the requirements set forth under the cooperative agreement. As a result, the cooperative agreement was unilaterally terminated by DOE in accordance with 10 CFR 600.161(a)(1) on 09/18/2017." At this time, all USEEL project activities except those specified as allowable in Section B.5. Limitations of Activities and Costs – Award Closeout of Amendment 0010, were terminated.

2.2 Project Objectives

The USEEL project objectives evolved with the changes in USEEL site locations documented above. Correspondingly, the research projects developed by the project graduate research Associate (GRA) and presented below (Section 4.0 Results and Conclusions) were modified, whenever possible. Initially, OSU was seeking a USEEL site that could serve as a dedicated working laboratory for *in situ* UOG research, and had the following characteristics:

- Location within the wet gas and/or condensate window of the Utica – Point Pleasant play.
- Research team access to areas around the drill pad for environmental baseline and monitoring measurements before, during, and post drilling (production phase).
- The potential for multiple wells and ongoing production and environmental research well beyond the life of the DOE/NETL grant.

These characteristics were met by the EARS and MWCD sites in east-central Ohio (Figure 2) where the following general project objectives could be effectively accomplished:

- Conduct baseline and real-time monitoring of land, air, water, and biological communities as well as demonstrating mitigation technologies.
- Investigate and define the geological characteristics of the Utica-Point Pleasant formations through borehole geophysical monitoring and geochemical sampling of rocks and fluids.
- Conduct borehole tests for improved characterization of reservoir conditions, fracture development and propagation, fluid emplacement, reservoir response, and rock volume stimulation that will lead to more efficient production methods.
- Develop an active outreach and community engagement program to assess local socioeconomic effects and acceptance of UOG development.
- Provide access to site area and well(s) for other sponsored researchers.

- Define the prudent and environmentally sound development of UOG assets for the region.

A primary focus of these early USEEL studies, as specified in the DOE/NETL proposal request and emphasized in the OSU proposal, was the consideration of the "whole picture" from subsurface geology, geophysics, and geochemistry investigations to environmental baseline and real-time monitoring of air, water, soil, and biota. Baseline studies were also recommended to address induced seismicity, local socioeconomic consequences, and UOG infrastructure. The USEEL project was designed to present a definitive, comprehensive, and multidisciplinary suite of studies conducted from beginning (pre-drilling, baseline) to end (production) on a single site.

However, political and economic circumstances unexpectedly eliminated the EARS and MWCD sites as potential USEEL project locations. In December 2016, the identification of a potential USEEL project site at an ECA Marcellus well pad in Greene County, Pennsylvania, provided an opportunity to evaluate one of the deepest portions of the Utica-Point Pleasant formations in the Appalachian Basin (Figure 3). The USEEL project was redesigned to include the following key objectives:

- Characterize the petrophysical, geological, geophysical, and geochemical conditions of reservoir rock and seals before, during, and after reservoir stimulation. Analysis of rock properties within the borehole and using borehole samples (e.g., core, cuttings, fluids) to provide a basis for understanding the physical and chemical compositions of shale.

- Determine the seal formation and sealing mechanisms that preserve modest to high gas pressures and sizable quantities of gas.

- Constrain the mechanism(s) and physical locations for gas storage and quantify reliable gas in-place estimates, a largely unknown quantity.

- Quantify the static state of stress and how this stress field affects induced fracture geometry (i.e., stimulated reservoir volume (SRV)).

- Predict the optimum well spacing based on integration of 3-D microseismic data with fiber optic temperature and acoustic sensing and completion monitoring.

- Delineate the permeability and hydrodynamic properties (i.e., flow pathways) of a deep shale that control how gas will migrate during stimulation.

- Monitor the evolution of flowback and produced water (e.g., fluid geochemistry) with time to quantify the volume of rock accessed by the frac fluid.

- Develop a predictive geo-model that integrates all information leading to improved well completion, stimulation, and extraction processes.

- Determine the stimulated reservoir volume using fluid geochemistry.

- Evaluate the effects of Marcellus pad expansion for drilling to the deep Utica have on the integrity of existing producing wells, ground disruption and slope stability, and ultimate efforts to conduct site reclamation.

- Enable third-party collection and archiving of field and laboratory data to demonstrate and validate technologies for improved characterization/visualization/quantification of reservoir conditions, fracture development and propagation, fluid migration and emplacement, and reservoir response.

These project objectives were focused on subsurface studies to improve the understanding of the Utica-Point Pleasant system and enable more efficient (higher yield rates) and cost effective recovery from shales, thus decreasing the number of holes needed to produce the play and improve the efficacy of oil and gas development in the region. While selected environmental base line and monitoring data were to be collected, targeted environmental studies were not planned. Unlike the relatively pristine EARS and MWCD sites, the ECA Greene County site area is moderately well-developed and includes many active Marcellus well pads and infrastructure.

3.0 Experimental Design and Methods

3.1 Eastern Agricultural Research Station – Ohio

The Ohio State University formed a not-for-profit consortium of academic, industry, and regulatory partners to frame and systematically answer essential questions relating to optimal management of UOG shale energy resources. This consortium created USEEL, an *in situ* virtual laboratory, located in the Utica-Point Pleasant shale play of the Appalachian Basin (Figure 1). The multi-year multi-phase USEEL project was conceived to study surface and subsurface geotechnical and environmental aspects of UOG development by executing a series of research tasks that address the project goals and objectives presented above.

Phase 1 (Year 1) involved an extensive baseline effort to document applicable geologic/hydrogeologic and environmental aspects of both the site and the area surrounding the site. Environmental studies included monitoring the air, surface and ground waters, soil, and associated ecosystems. The baseline study also included a surface geophysical 3-D seismic survey complemented by detailed evaluation of existing regional gravity and magnetic data sets. These data were to be added to an existing geodatabase consisting of geologic, structural and stratigraphic information that would form the basis of a “geomodel” to better target the location of the vertical exploratory borehole.

Phase 2 was to commence at the beginning of Year 2, with the drilling of a vertical test well. Approximately 100 feet of core above and below target formations was to be extracted from the hole, along with fluid and drill cuttings for characterization, including analysis for Naturally Occurring Radioactive Material (NORM). Extensive subsurface and laboratory measurements on vertical test well samples were expected to provide a varied and comprehensive set of geological, geochemical, and geophysical data. A suite of geophysical well logs were planned in the vertical hole for fluid monitoring and microseismic measurements associated with drilling the horizontal well. Environmental monitoring of various parameters at the surface was to continue during drilling so the data could be compared to baseline (i.e. pre-drilling/-operation) data.

In Phase 3 (Year 3), a horizontal production well was to be drilled and chip samples, mud logs, produced gas, and mud samples collected. The vertical portion of the well was to be logged with a standard suite of geophysical well logs, cement bond logs, measurement-while-drilling (MWD) readings of bit pressure and drilling rates, and a fracture definition survey conducted in the lateral portion of the hole prior to hydraulic fracturing. Samples were to be collected from the injection fluid prior to hydraulic fracturing, flowback water after hydraulic fracturing, and the production water throughout the study. These measurements, along with drilling and disposal records, were to be used to produce a detailed report on the frac water (input and output) and the potential environmental aspects of water disposal. The results of water analyses would have provided an opportunity to develop new processes and procedures for handling and filtering water and chip samples, and transferring this technology to industry. Environmental monitoring was to continue beyond the hydraulic fracturing stage to characterize conditions during long-term resource extraction. All project data generated during Phases 1, 2 and 3, including raw data, statistical analysis, and interpretation, were to be posted on the USEEL website for open file sharing with the research community as well as producers, industry, NGOs and the public.

In addition, the scope of work included a primary overarching task to analyze the socioeconomic benefits/drawbacks of UOG development in surrounding communities. This investigation was to identify the economic stake that local communities have in UOG development, the potential challenges this development poses, as well as policies and investments that enhance the rewards and minimize the risk of UOG production. Promising approaches to community engagement prior to UOG development would be identified. Active outreach and community engagement programs that communicate on- and off-site environmental baseline and monitoring measurements help to inform the local and regional populations, and sociological assessments provide insights into the changes in communities and attitudes brought about by an evolving UOG industry in the region. The impact of the environmental baseline (site-specific and regional) and community studies establish a clearer picture of the linkages between social attitudes, community changes, and changes in the local environment.

The research represented inputs from industry and academia as well as requirements of the U.S. Government's Multi-Agency Working Group to Support Safe and Responsible Development of Unconventional Domestic Natural Gas Resources and DOE/NETL's Annual R&D Plan for 2013. The consortium OSU assembled for USEEL integrated the capabilities of leading researchers with those of exploration and production companies, environmental and community groups, NGOs, and government laboratories. Key members included NETL, West Virginia University (WVU), the Houston Advanced Research Center (HARC) and its Environmentally Friendly Drilling (EFD) program, CSI Technologies, General Synfuels International (GSI), and the Ohio Geological Survey. USEEL was designed and developed to facilitate the transition of its research and technologies to stakeholders in the region and across the nation. Pre- to post-drilling surface and subsurface environmental, geologic, geophysical, geochemical hard data, as well as design and validation data for new technologies, were to be openly disseminated to qualified external groups. The multi-purpose test and evaluation facility was framed to ensure an open, collaborative, and integrated program of science and development/testing; and provide0 researchers with unencumbered access to surface and subsurface assets.

3.2 Muskingum Watershed Conservancy District – Ohio

The change in the USEEL project site from the EARS to the MWCD lakes area located approximately 50 miles to the northeast (Figure 2), did not significantly alter the EARS project experimental design or methodology presented above. Similar site characteristics allowed initial project goals and objectives developed for the EARS site, as well as overall project schedule and timeline, to be remain essentially unchanged. However, MWCD stewardship for the 8000 mi^2 district specifically focuses on watershed flood reduction, conservation, and recreational use; and necessitated minor modifications to the study plan to address baseline water quality of adjacent lakes and the socioeconomic concerns of nearby communities. A detailed summary of experimental methods and instrumentation/equipment by work breakdown structure (WBS) tasks and subtasks is presented in Section 4.2 of Results and Discussions.

3.3 Energy Corporation of America Marcellus drill pad - Greene County, Pennsylvania

After the loss of the MWCD site, OSU identified a potential site located on an ECA Marcellus drill pad in Greene County, Pennsylvania, in December 2016. This site provided an opportunity to characterize and quantify the gas-producing attributes of one of the deepest portions of the Utica-Point Pleasant formations in the Appalachian Basin (Figure 3). The ECA USEEL project was redesigned to develop a first-ever predictive geo-model of the deep Utica Shale play with an anticipated extremely high pressure gradient of 0.95psi/feet. With its location on an existing Marcellus drill pad, the USEEL project also had an unprecedented opportunity to evaluate the economic and environmental effects of Marcellus pad expansion on the integrity of near-by existing production wells, ground disruption and slope stability, and ultimate efforts to conduct site reclamation. Combined with overall goals of an improved understanding of the Utica-Point Pleasant system and more cost effective recovery from shales in the region, decreasing the number of drill pads could improve the efficacy of UOG development across the Appalachian Basin.

The relocation of the USEEL project site to the deepest portion of Appalachian Basin in Greene County, Pennsylvania, significantly altered previous project scope and objectives. Project objectives now were focused on subsurface studies to improve the understanding of the deep Utica-Point Pleasant system and enable more efficient (higher yield rates) and cost effective recovery from shales; and Marcellus pad expansion to decrease the number of new well pads and infrastructure required for Utica-Point Pleasant oil and gas development in the region. Decreased emphasis was placed on environmental issues because of the existing development and infrastructure. In spite of multiple changes in site location, the entire USEEL project was to be completed on schedule, in mid-2019.

A baseline data mining effort to document applicable geological and hydrogeological aspects of both the site and the surrounding area was initiated in late spring-early summer, following the receipt of Modification 0007 on April 1, 2017. These data were added to an existing geodatabase consisting of geologic, structural, and stratigraphic information and would be the basis of a "geomodel" to better target future extraction from the Utica-Point Pleasant formations. A significant acquisition was ECA's 3-D seismic data of the study area.

Baseline air, groundwater, and surface water measurements at locations that are representative of topographic and drainage basin variations of the study site and surrounding area were scheduled for early fall. These data were to be used as a benchmark for environmental and subsurface measurements in the region and a "tie point" for other Appalachian studies. Selected measurements were to be taken throughout the life cycle of the production well.

Ideally, drilling of the UOG well was to be conducted in three stages. Stage 1 include drilling the vertical portion of the UOG well through the Marcellus and Utica-Point Pleasant formations (vertical extension of the UOG well). Stage 2 consisted of plugging the vertical extension of the UOG well back to the "kick-off point" for the lateral portion of the UOG well. Stage 3 was the drilling of the horizontal or lateral portion of the UOG well.

During drilling of the vertical portion of the well (approximately 14,000 feet) and the vertical extension of the well (estimated 2000 feet), approximately 150 feet of core above, through, and below the Utica-Point Pleasant formations would be extracted; sidewall cores taken (approximately 120) from key formations in the well (e.g., Utica, Point Pleasant, Rogersville, Trenton/Black River, Reedsville, Salina, Marcellus within the Rome Trough); and fluid and drill cuttings sampled to characterize mineralogy, petrography, and geochemistry. Extensive subsurface and laboratory measurements on vertical test well samples were expected to provide a varied and comprehensive set of geological, geochemical, and geophysical data. A suite of geophysical well logs were to be acquired in the vertical hole, and it was tentatively planned to install instruments in the vertical well extension that could be used for fluid monitoring and microseismic measurements, or other measurements (e.g., neutron density, gamma log) during the drilling of the horizontal well. The vertical portion of the well was to be logged with a standard suite of geophysical well logs, cement bond logs, MWD readings of bit pressure and drilling rates, and

In horizontal well placement, collection of drill cuttings, chip samples, mud logs, produced gases, flowback fluid and mud samples were recommended. A fracture definition survey was to be conducted in the lateral portion of the hole prior to hydraulic fracturing. Additionally, fiber optic cable was to be installed throughout the horizontal well to precisely monitor temperature and acoustic responses from the reservoir to characterize flow pathways. Samples from the injection fluid prior to hydraulic fracturing, and from the production water were to be collected throughout the study. A detailed summary of experimental methods and instrumentation/equipment by WBS tasks and subtasks is presented in Section 4.3 of Results and Discussions.

4.0 Results and Discussions

Results and discussions for the USEEL project are presented for the three different site locations. Tables briefly summarize descriptions, discussions, and results of all proposed WBS tasks and subtasks. Detailed results and discussions of specific completed or in-progress research topics are treated as separate entries in the report (highlighted in blue). The numbering of subheadings includes the section number and the appropriate WBS element. Note: many of the WBS elements were not performed to due to loss of the site and/or the operator.

4.1 Eastern Agricultural Research Station – OH

The EARS site was disqualified before any tasks/subtasks of the experimental design and methodology could be initiated.

4.2 Muskingum Watershed Conservancy District – OH

Tables 4.2.1 through 4.2.7 summarize by WBS number, the results of the limited work completed on MWCD tasks/subtasks before it was eliminated as a potential USEEL site.

Table 4.2.1 MWCD Project Management and Planning Activities (Task 1.0)

WBS	Subtask	Description	Discussion	Result
1.1	Selection of Operator and Drill Site	Identify a UOG developer in the Utica Shale Play with an active lease supportive of the project's research	All options considered	No operators identified due to a downturn in the shale industry
1.2	Operator Agreement	A binding agreement specifying roles of the operator and their specific research support activities	Agreement reviewed and approved by NETL prior to approval and signature by OSU and the operator	N/A
1.3	Project Management Plan	Documentation of the project's budget, schedule, objectives, milestones, and planned risk management activities.	A project deliverable and milestone	Submitted on 10/09/2015; site eliminated before NETL review and approval
1.4	Quarterly Project Status Reports	A report on project progress relative to schedule, budget and objectives.	Project deliverables	Quarterly reports were submitted as specified in Federal Assistance Reporting Checklist and Instructions
1.5	Quarterly Financial Reports	A report on expenditures by task and cost category	Project deliverables	Quarterly reports were submitted as specified in Federal Assistance Reporting Checklist and Instructions
1.6	Website Development and Maintenance	Development and maintenance of the USEEL website	The website was designed to inform the public about the project and provide stakeholders access to relevant documents and research results.	Preliminary website developed and operational before site eliminated

Table 4.2.2 MWCD Development of Accessibility Guidelines (Task 2.0)

WBS	Task	Description	Discussion	Result
2.0	Access Guidelines Report	Development and maintenance of the USEEL website	Guidelines included visit request, safety, media contact and publication policies and procedures	Site withdrawn before completion

Table 4.2.3 MWCD Regional Studies and Community Outreach (Task 3.0)

WBS	Subtask	Description	Discussion	Result
3.1	Community Participation and Engagement	OSUE organize at least two participatory dialogue events every year in communities affected by UOG development	Events to understand concerns and assess benefits and drawbacks, and to identify further needs for environmental and human health research	Site withdrawn before completion
3.2	Impact Analysis and Opinion Assessment	Studies addressing the social and economic impacts of UOG development, and the public perceptions and attitudes about that development and its risks	Studies examined the perceived impacts, concerns, and opinions of UOG development in Eastern Ohio	**See Section 4.2.3.2 Impact Analysis and Opinion Assessment Final Report**
3.3	Scientific Education for OSUE Educators	Educational workshops based on scientific findings from the project and other sources	OSUE educators are highly visible and well respected in each of the counties where UOG development is occurring	Site withdrawn before completion
3.4	Infrastructure Impact Assessment	Baseline assessment and monitoring of roads and bridges and traffic counting conducted on and around the site	Included a regional assessment and proven survey and statistical methods	Site withdrawn before completion

4.2.3.2 Impact Analysis and Opinion Assessment Final Report

Hagley, Paige. *Empowerment and Perceived Impacts of Shale Energy Development in Eastern Ohio.* Master of Science in Environmental Science Thesis, The Ohio State University (In progress).

4.2.3.2.1 Introduction

The increase in the production of oil and natural gas from unconventional shale resources has substantially altered the energy landscape in the United States. The associated activities can also affect communities where this development is taking place. Residents are responsible for the progression of development due to privately-retained mineral rights and personally negotiate shale leases with oil and gas companies. They must also cope with the consequences of development, necessitating research efforts and decision-making which incorporates input from the community. This study investigated how individuals living in a community where shale energy development is occurring (Belmont County, Ohio, USA) experience and perceive this development and the factors that influence their perceptions of risks and benefits. It extended a methodology that considers perceptions and their severity to include empowerment as a potential mitigating factor. Concerns about traffic or road deterioration and economic benefits for the community are expressed most often, and that different avenues of empowerment (e.g., voices being heard, collective bargaining of leases) can improve perceived outcomes for landowners. Uncertainty about future impacts appear to be a motivating factor when deciding to lease. Landowners who did not lease expressed certainty and severe concern about negative environmental and social impacts. Those who leased their land framed their lack of concern for these impacts in the context of uncertainty about negative outcomes later, relative to certain financial gains now. This study addressed questions concerning the variety of attitudes, concerns, and impacts attributed to shale energy development.

4.2.3.2.2 Objectives

This project sought to understand how development of shale resources to produce oil and natural gas affects individuals and communities in eastern Ohio. It investigated experiences with shale energy development, perceived impacts of shale energy development, and the factors that influence these perceptions. The following research questions guided this study:

1. What factors influence perceived outcomes for individuals and communities?
2. What are the perceived risks and benefits of shale energy development?
3. What factors influence perceptions of shale energy development?

4.2.3.2.3 Approach

Nineteen semi-structured interviews were conducted with residents of Belmont County between September and December 2016. These interviews were then transcribed and thematically coded using

NVivo 10 software. Belmont County was chosen as the case study because it had a connection with Ohio State Extension in the county. Belmont County Extension provided a list of contacts, which included landowners in the area who were not a part of another effort by OSU Extension. Following an interview, each participant was asked to provide a list of residents who might be interested in speaking about shale development and may belong to various stakeholder groups (renters, farmers, members of environmental organizations, coal mine workers, and county and township administration). In addition to this snowball sampling, four participants were recruited through primary contact while in Belmont County (at the county fair, a restaurant, and a mall).

Additionally, a Participatory Risk Mapping (PRM) was modified to include perceived empowerment as a framework for investigating influences on perceived risks associated with shale energy development. PRM demonstrates the variety of perceived risks in a population, including the perceived severity and number of times a perceived risk is mentioned. This methodology was selected because of its ability to complement or inform technical risk assessment and the ability to visually portray concerns to potential decision-makers. Perceived severity, awareness, and perceived empowerment together provide a more holistic picture of how perceptions of risks and hazards are formed and influenced. There are relationships, though, between these three factors, as demonstrated in the Hagley-Bielicki Hazard Perception Map (Figure 1).

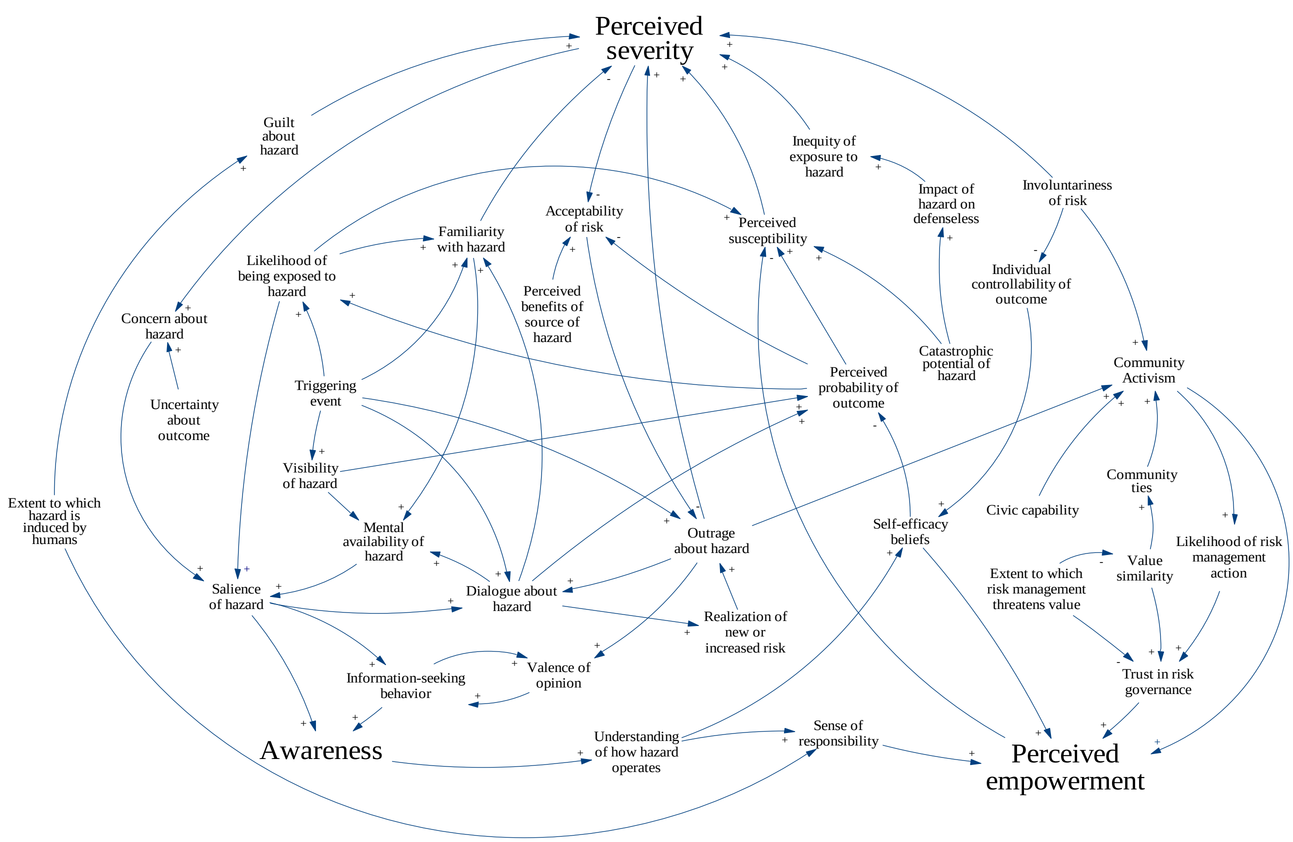

Figure 1. Hagley-Bielicki Hazard Perception Map. Perceived severity, awareness, and perceived empowerment are the three main dimensions in this hazard perception model. Relationships between variables have a direction and positive or negative impact on other variables, indicated by the polarity of the arrow.

To map the concerns associated with shale energy development, participants were asked to list and rank their concerns from most severe to least severe and most empowered to least empowered to address. Concerns were sorted into thematic categories analysis based on the content of the concern (Table 1). To normalize rankings among participant lists with different numbers of concerns, values for perceived severity and empowerment were calculated by:

$$V_{score} = 1 - \frac{r-1}{n-1}$$

In this equation, r is the rank of severity (*s*) or empowerment (*e*) given by the participant and *n* is the number of concerns the participant listed. This equation is based on the calculation done by Smith, Barrett, and Box for Participatory Risk Mapping (Smith et al., 2000).

4.2.3.2.4 Discussion/Summary of Findings

This research adds to the literature of potential impacts and perceived risks and benefits associated with shale energy development. It was found that landowners who leased through a landowner group could collectively bargain the terms of their oil and gas lease and perceived their outcomes as better off than if they had not leased with the group. But, none of the landowners who leased their land voiced regret about their decision to lease, regardless of their affiliation with the landowner group or gas company with whom they leased. Very few landowners who were approached to lease ended up refusing. This lack of apprehension may have led to high satisfaction in the leased group. Many landowners had not had their land drilled yet meaning they had not begun receiving royalty payments, so their perceptions on the outcomes of shale energy development may change if and when these royalty payments are distributed.

The most commonly mentioned perceived risks of shale energy development included impacts to the environment and water resources, traffic and road deterioration, and crime (Figure 2). Economic benefits, like the windfall wealth to residents, job opportunities, and the demand for hotels and restaurants emerged as the main positive impact to the community, as cited by participants.

Factors influencing perceptions of shale energy development included empowerment, uncertainty, and previous experience with energy development, attachment to the physical environment or community, and direct economic benefits (Figure 2). Perceptions of the risks and benefits of shale energy may drive landowners' decisions to lease their land to drilling or drive residents to oppose drilling absolutely, including engaging in activism. Studying these perceptions may inform policymakers' decision-making regarding this industry. Communication addressing perceived consequences of development has the potential to increase trust with the community, reducing opposition. Additionally, minimizing actual and perceived environmental impacts and increasing economic impact for all residents, not just landowners and lease holders, may decrease perceived inequality.

Table 1: Concern Categories and Participant Responses

Category	Specific concerns
Boom and Bust	Bust cycle; losses after “boom”; new buildings etc., once “boom” is over – abandoned; increase of temporary housing – hotels, apartments, empty when business leaves; Boom & Bust economy; reliance on a nonrenewable energy/déjà vu of coal industry
Community Values	Excessive monetary influence/change in values; destruction of small, close-knit communities; preserving our communities; breakdown in culture and community, i.e. neighbor vs. neighbor
Company	Accurate royalty; people getting taken advantage of by company; shale companies deducting more from royalties than allowed
Crime	Increase in local crime; drug use/abuse increase; fear of thievery in area – has increased since influx of workers; sex trafficking; unsavory people coming into community; negative social impacts – crime, prostitution; lone wolf terrorism, threat to well pads
Earthquakes	Earthquakes associated with fracking/injection wells; land being disturbed; future land movement
Economy	Taxes collected from shale industry going to other parts of state and not staying in area to correct problems created by shale industry; money coming into the towns; are our old infrastructures able to support new development if not who is responsible for the cost – possible tax increase?
Emergency Services	1st responder knowledge of operation; first responder (traffic increased accidents, materials being utilized, training)
Environment	Damage to the environment; deforestation; air pollution; reclamation of well pads; global warming; hazardous spills; drilling damage; land losses; where are the waste products being disposed; illegal dumping; risk of explosion or other catastrophe; disposal water concern; wildlife – animals have no place to go as the trees are being cut down to place oil pads and roads to oil pads
Human Error	
Jobs	Lack of jobs, losing jobs; residents moving out of the area to find work; employment local – not enough; job creation; training and educating our residents for employment opportunities; when finished – lost jobs
Noise	Noise pollution; noise
Pipelines	Pipeline reclamation; segregation of landscape (pipelines)

Policy	Lack of consistent regulations; environmental regulations
Population Influx	Not able to handle influx of people to area; increase demand on local healthcare services; influx of people; increase of population
Rent	Rise in rent; people raising rent on properties to the point that locals cannot afford rent
Schools	Influx of workers (sending children to school without paying taxes); schools overcrowding
Traffic and Roads	Traffic on local roads; heavy truck/vehicle traffic; road deterioration/maintenance; hazardous roads – dust conditions
Uncertainty	Long term impacts on local towns; individuals making informed decisions; what will happen in the future with all the wells being drilled here
Water	Captina watershed/hellbender habitat protection; water table sinking; water quality; drinking water safety; fresh water use (taken out of system); water sources; use of city water; water contamination
Workers	Family life (of workers); transitioning of workers – here for a period of time then replaced by someone else

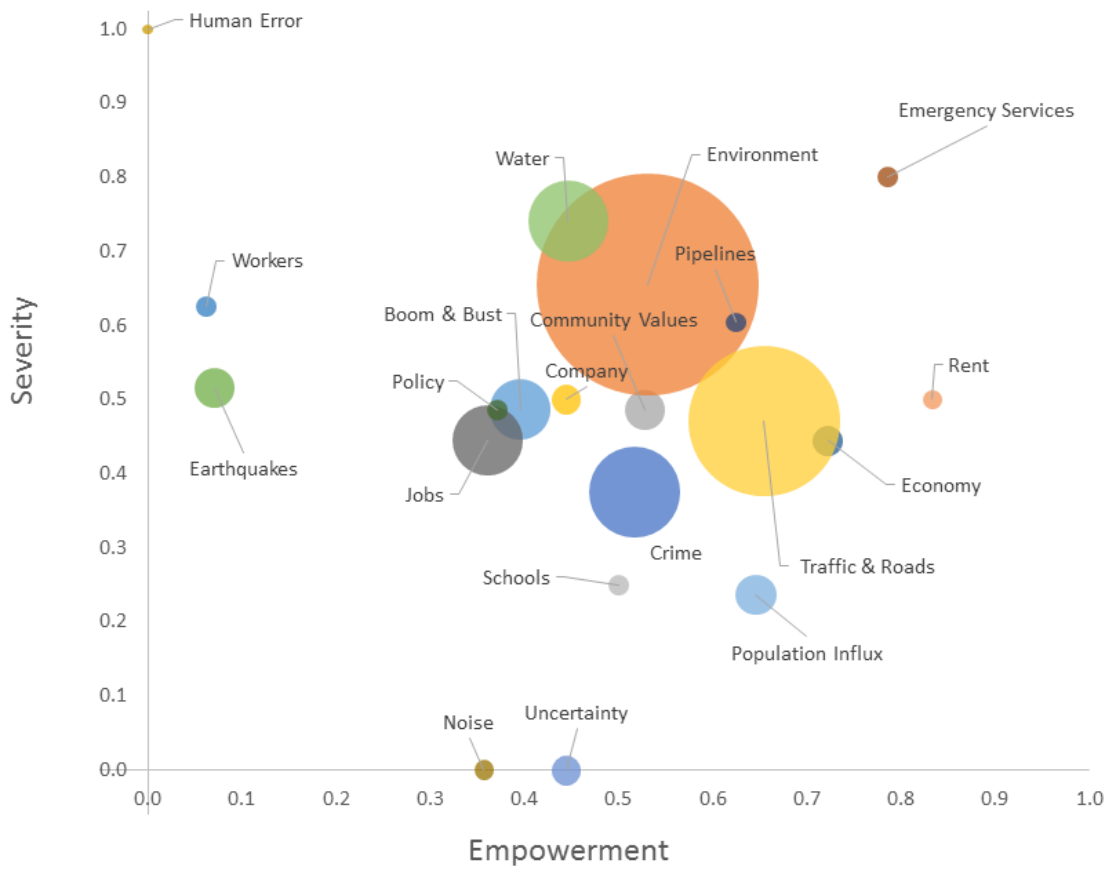

Figure 2. Concerns about shale energy development expressed by participants (Bubble size indicates the number of times a concern was mentioned.)

This project may shed light on issues facing eastern Ohio residents and their communities. Although there is currently a lull in natural gas drilling in the region, development of shale resources is projected to grow and operate in the Utica Shale for decades to come. Exploring the social and community effects of this technology can help alleviate concerns and inform decisions that will protect vulnerable populations during this growth. Most social research on shale energy development has focused on North Dakota, Texas, Louisiana, and Pennsylvania. The potential impacts facing Ohio through Utica Shale development have been less documented. This research sought to uncover processes influencing the perceptions of technology as risky or beneficial and to develop methods to facilitate a more inclusive decision-making and planning process for future development.

Publications, Papers, and Presentations

Hagley, Paige. Perceptions of shale energy development. *RURL SOC 1500 - Introduction to Rural Sociology guest lecture*. [30 October 2016]

Hagley, Paige; Bielicki, Jeffrey M. Community perceptions of shale energy development in eastern Ohio. *Energy for Society: 1st International Conference on Energy Research & Social Science abstract submission.* [3 November 2016]

Hagley, Paige. Perceptions of shale energy development. *ENR 3900 - Metrics of Sustainability guest lecture*. [30 November 2016]

Hagley, Paige. Perceptions of shale energy development. *Ohio State Shale Energy Workgroup Meeting.* [28 February 2017]

Hagley, Paige; Bielicki, Jeffrey M. Community perceptions of shale energy development in eastern Ohio. *Energy Impacts Symposium abstract submission.* [1 March 2017]

Hagley, Paige. Perceptions of shale energy development. *Shale Energy Meeting.* [10 March 2017]

Hagley, Paige. Perceptions of Shale Energy Development in Eastern Ohio. *Environmental Science Graduate Program Exit Seminar*. [24 March 2017]

Hagley, Paige; Bielicki, Jeffrey M. Community perceptions of shale energy development in eastern Ohio. *Energy Impacts Symposium Poster Session, Committee's Choice for Best Poster.* [26 July 2017]

Hagley, Paige. Empowerment and Perceived Impacts of Shale Energy Development in Eastern Ohio. *Master of Science in Environmental Science Thesis.* [in progress]

Table 4.2.4 MWCD Site-Specific and Regional Baseline Studies (Task 4.0): Surface Environmental Assessment (Subtask 4.1)

WBS	Task/Subtask	Description	Discussion	Result
4.0	Site-Specific and Regional Baseline Studies	Studies performed to characterize surface and subsurface environmental conditions	Chemical, biological, and physical agents monitored to assess potential environmental effects of UOG development at site and in the surrounding region	**See Section 4.2.4 Site Specific and Regional Baseline Studies Final Report**
4.1.1	Air Quality	Atmospheric concentrations of various chemical agents and levels of physical agents measured in the area of interest and near the drill site	Methane, ambient hydrocarbons, particulate matter, ionizing radiation, sound, and illumination to establish a regional baseline and site-specific measurements	Site withdrawn before completion
4.1.2	Surface Water Quality	Water quality parameters measured in major lakes, ponds, and streams within 5 km of the drill site	Fish otolith trace element microchemistry used as a proxy for historic water chemistry data	Site withdrawn before completion **See Section 4.2.4.1.2 Surface Water Quality Final Report**
4.1.3	Soil Quality	Physical measurements made on soils taken from the site	Compaction, bulk density, texture, pH, metals, anions, radionuclides, nutrients, organic chemicals	Site withdrawn before completion
4.1.4	Biological Parameters	Whole organism, population and community level measurements	Micro and macro effects of habitat change due to hydraulic fracturing on rodent and tick communities	Site withdrawn before completion **See Section 4.2.4.1.4 Biological Parameters Final Report**

4.2.4 Site Specific and Regional Baseline Studies Final Report

Allen, Gerald R. *A Study Design for the Assessment of the Environmental Effects of Unconventional Oil and Gas Development in the Appalachian Region of Ohio, Pennsylvania, and West Virginia.* Research Specialist, The Ohio State University (In Review).

4.2.4.1 Introduction

Unconventional oil and gas (UOG) resources, can help restore economic competiveness as well as create geopolitical advantages for the U.S. (Porter et al 2015). Unfortunately, a derisive, unproductive, and often misinformed debate threatens economic and environmental goals. One of the greatest challenges in quantifying the environmental effects of hydraulic fracturing is the enormous potential for variation within and among different ecosystems and the differing hydraulic fracturing operation sizes, pad densities, and quality-control measures. The goal is to balance industry's immediate needs with the comparatively slow pace of individual, university, and consortium research.

The development of UOG resources (including associated activities such as construction of roads, power grids, pipelines, well pads, and increased truck traffic) has the potential to produce significant environmental risks to water, air, land, and ecological and anthropogenic communities which must be clearly acknowledged. Improvements in the development of transparent and consistent environmental performance data can minimize local environmental effects of UOG development by creating a foundation for establishing baseline conditions, monitoring compliance, and stimulating innovation. However, resources (money, people, and time) are limited and insufficient to measure everything. An understanding of the costs, environmental concerns and economic and security benefits must be balanced at all levels in a systematic approach so optimal decisions can be made.

4.2.4.2 Goal and Objectives

The focus of UOG and, in particular, high volume horizontal hydraulic fracturing (HVHHF) research activities must not only be specific and comprehensive, but broad and regional in concept to address the above concerns and satisfy scientists, industry, policymakers, and the general public. The goal of this paper is the development and utilization of a performance database within a defensible and scalable management and research framework that can be extrapolated for predictive and comparative analyses for UOG research.

4.2.4.3 Approach

This paper presents an experimental study design based on a framework of ecoregions, Hydrologic Unit Code (HUC) watersheds that is supported by geographic or geographical information system (GIS) technology and databases.

Ecoregions are abstract entities that resist precise definition, but are broadly described as areas exhibiting relative homogeneity of ecosystems (Figure 1). They are increasingly important in

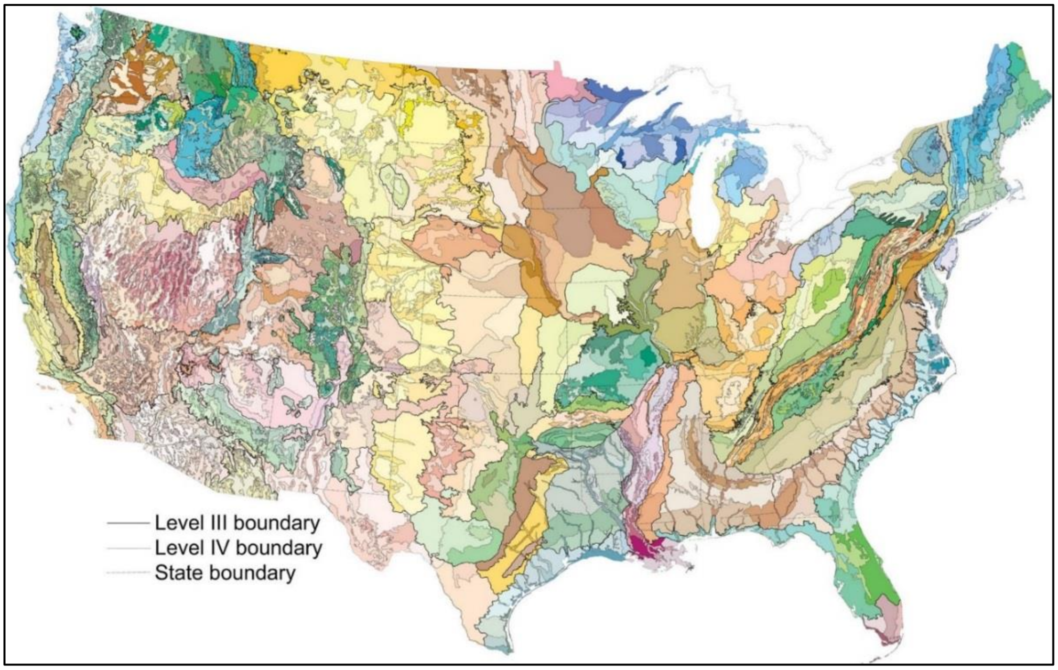

Figure 1. Level III and IV ecoregions of the conterminous United States (Omernik and Griffin 2014)

environmental assessment and management and provide a holistic framework for flexible, comparative analysis of complex environmental problems (Loveland and Merchant 2004). Ecoregions and their I to IV (coarsest to finest) Roman numeral hierarchy have been used as a framework for environmental management for decades (Bailey 1976, 1983, 1987, 1989a, b; Bailey et al 1985; Omernik 1987, 1995; Omernik and Bailey 1997; U.S. Environmental Protection Agency 1988; Bryce et al 1999). There are 15 and 967 Level I and IV ecoregions, respectively, for the conterminous United States (Omernik and Griffin 2014).

Hydrologic Unit Code (HUC) units are a more specialized hydrological framework of the Watershed Boundary Dataset (WBD) designed by the United States Geological Survey (USGS). The WBD divides the United States into six HUC units (2, 4, 6, 8, 10, and 12). The smallest element in the hierarchy (HUC 12) is designated as a cataloguing unit and is defined as a geographic area representing part or all of a surface drainage basin, a combination of drainage basins, or a distinct hydrologic feature (USGS 2013). There are 2264 cataloguing units (sometimes called "watersheds") in the nation. Figure 2 presents the Level IV ecoregions and HUC 4 watersheds for the study area.

The initial step in the development of an inclusive methodology to assess the potential environmental consequences of HVHHF is to build a comprehensive framework based ecoregions and HUCs. A GIS mapping software such as Esri® ArcGIS-ArcMap™ is requisite in the design and subsequent development of the comprehensive framework. Most public and private agencies that collect or generate geospatial or geographical information store data as GIS shape or raster files or tabulated data files that can be converted to GIS format. All available existing and generated data in an HVHHF environmental assessment project should be compiled, presented, and archived as GIS files, whenever possible.

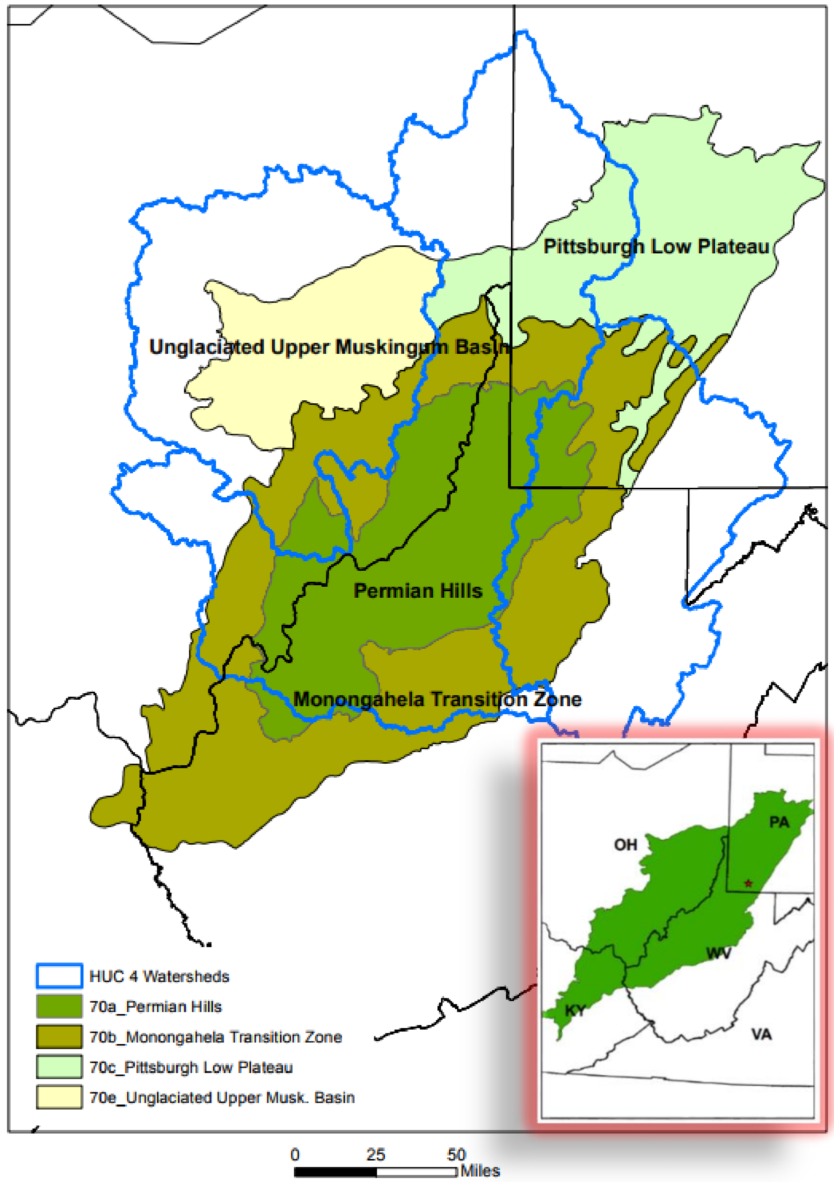

Figure 2. Level IV Ecoregions and HUC 4 watersheds

4.3.4.4 Discussion/Summary of Findings

Although results are still under review, Figure 2 summarizes the environmental disturbances and potential primary impacts commonly found in the Permian Hills, Monongahela Transition Zone, and Unglaciated Upper Muskingum Basin Level IV ecoregions of eastern Ohio, western West Virginia, and southwestern Pennsylvania. While several of the primary impacts listed for the selected environmental disturbances presented on Figure 3 are the same (e.g., land use/cover), they may be significantly different in severity. For example, the land use/cover impact associated with a typical recreational disturbance will most likely be significantly less than that associated with surface coal mining or logging operations. Also, some primary impacts may only be temporary (e.g., air quality at a logging project, or noise and light at conventional and unconventional oil and gas projects). Conventional and

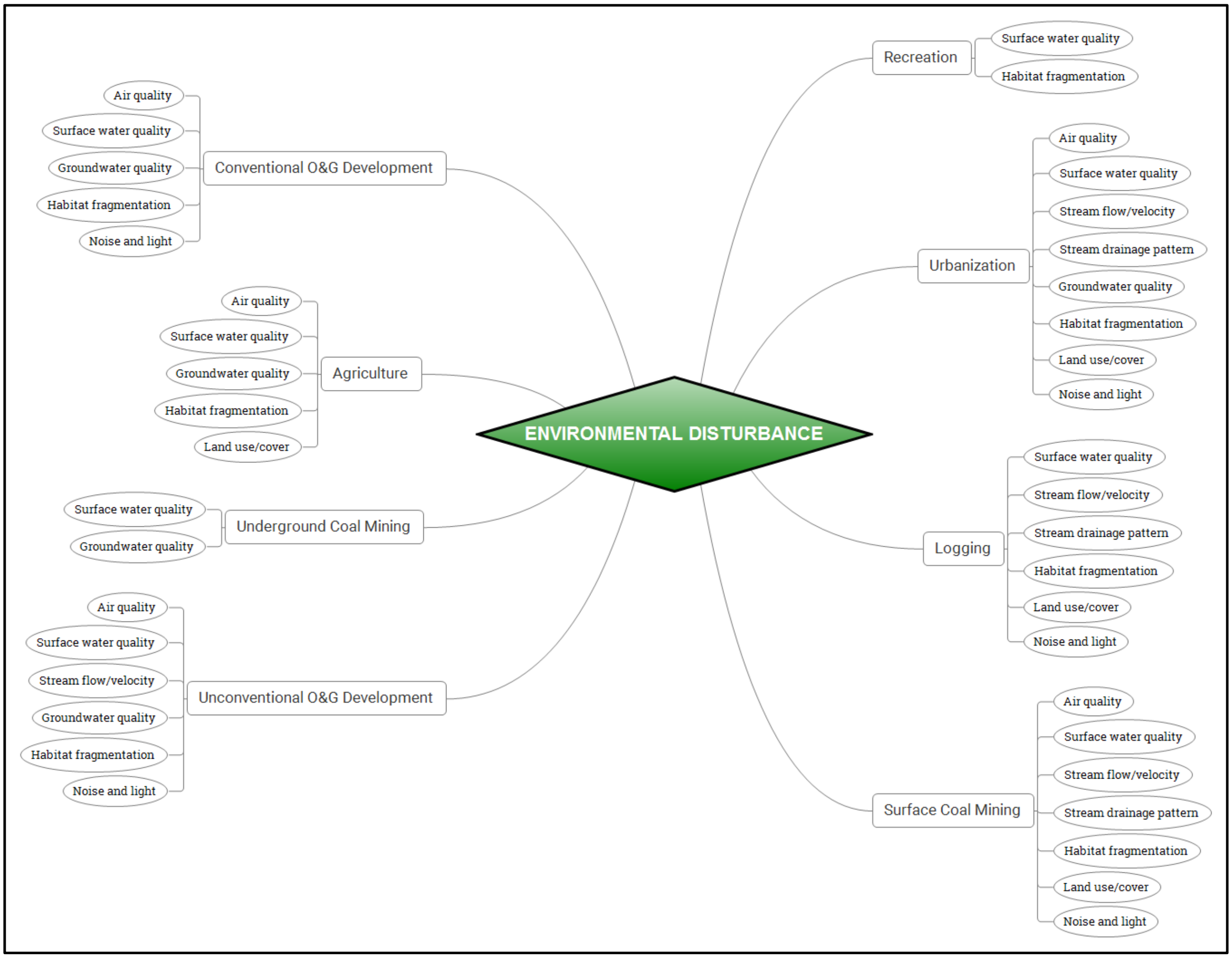

Figure 3. Environmental disturbances and potential primary environmental impacts in eastern Ohio, western West Virginia, and southwestern Pennsylvania

unconventional oil and gas development are listed as separate environmental disturbances, but they are very similar from an environmental impact perspective. The major differences or considerations are the procurement of water for UOG development HVHHF and the disposal of flowback and produced waters and their effects on surface water. Table 1 summarizes the issues and their potential primary, secondary, tertiary, and residual impacts and associated stressors that should be considered for most environmental disturbances; especially surface coal mining, conventional and unconventional oil and gas development, and agriculture in the Permian Hills, Monongahela Transition Zone, and Unglaciated Upper Muskingum Basin Level IV ecoregions. Overall, surface coal mining, urbanization, logging and agricultural disturbances have the greatest potential primary environmental impacts in the Level IV ecoregions of eastern Ohio, western West Virginia, and southwestern Pennsylvania. Specifically referring to streams, the USEPA lists the greatest national probable cause of impaired streams as

Issue	Primary Impact	Secondary Impact	Tertiary Impact	Residual Impact	Stressors
Air	Decrease in air quality	Temporary increase in environmental and human health hazards	--	Long-term increase in environmental and human health hazards	Particulate Matter, VOCs, PAHs, methane
Water	Decrease in surface water quality	Aquatic/benthic ecosystem degradation	Groundwater contamination	--	Sediments, nutrients, BTEX, PAHs, toxic organic/inorganic compounds, NORM*
	Decrease in stream flow/velocity	Sedimentation	--	Aquatic and benthic ecosystem degradation	Sediments
	Change in stream drainage pattern	Surface runoff, erosion, channelization; sedimentation; flooding	Flooding; loss of floral and faunal biodiversity	Wetland, aquatic, and benthic ecosystems degradation	Sediments; changes in stream reach and gradient
	Decrease in groundwater quality	Loss of drinking water supply	--	--	Sediments, nutrients, BTEX, PAHs, toxic organic/inorganic compounds
Habitat	Habitat fragmentation	Disruption of animal and insect movement and migration; change in climax vegetation and plant succession; edge effects	Increase in invasive plants and animals; altered biological processes; changes in hydrology and soil properties, including runoff and infiltration rates	Change in climax community; terrestrial habitat degradation; decreased carbon sequestration	Invasive plants and animals; water quantity; sediments; physical and chemical properties of water and soil
	Change in land use/cover	Loss of primary land use/function; change in climax vegetation and plant succession	*Ditto*	*Ditto*	*Ditto*
Noise and Light	Increase in noise and light	Temporary adverse response in human and environmental receptors	Disruption in reproduction, feeding, and rest patterns in micro- and mega fauna	--	Lumens and decibels

***NORM = Naturally Occurring Radioactive Material**

Table 1. Environmental issues, potential impacts, and stressors

agriculture, followed by urbanization and resource extraction (Burton et al 2014). Atypically large individual disturbances, or concurrent multiple individual disturbances in the same area will significantly increase potential primary, secondary, tertiary, or residual environmental impacts. Consequently, any assessment of environmental (or ecological) effects from HVHHF projects must evaluate the potential impacts of other anthropogenic activities in the ecoregion or watershed.

Exacerbating a comprehensive understanding of regional disturbance patterns, potential impacts, and environmental stressors, is the complex interrelationships among natural resources (Figure 4). Although usually closely interdependent, surface water and groundwater are presented as separate resources because potential impacts and stressors can be differentiated and quantified for most environmental disturbances. The relationships between resources is often bi-directional. For example, infiltration of contaminated surface water can directly degrade groundwater quality. But, contaminated groundwater commonly discharges pollutants to surface water under effluent stream conditions. Rainfall and surface water infiltration are necessary for the development and stability of soil horizons. Excessive rainfall and surface water runoff can erode soil which is deposited as sediments in streams. In addition, degraded and eroded soils disrupt natural surface water infiltration rates resulting in changes to groundwater quality and quantity. Any of these and a multitude of other disturbances to natural resources can result in primary, secondary, tertiary, or residual impacts to terrestrial, aquatic, and benthic ecosystems.

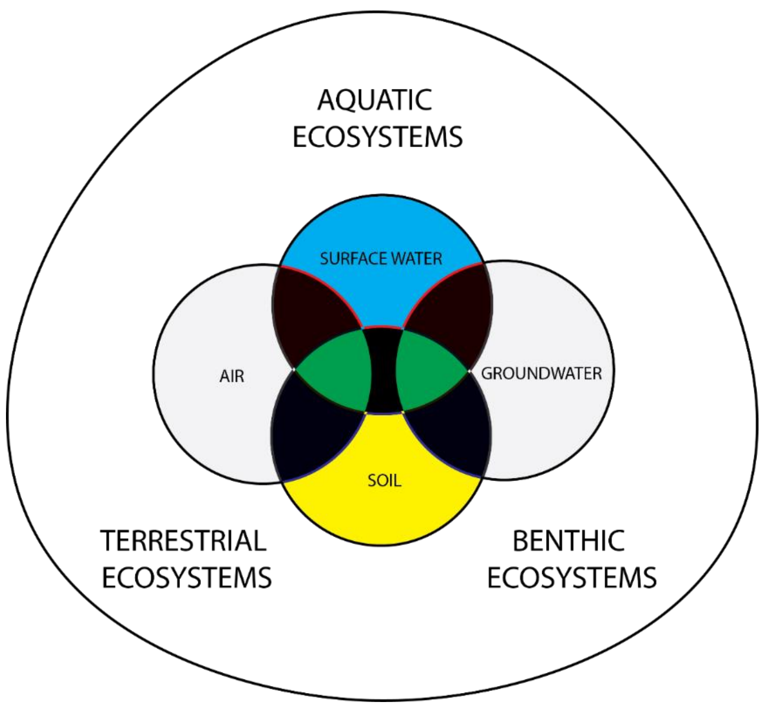

Figure 4. The interrelationships of natural resources and ecosystems in an HVHHF project

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4.2.4.1.2 USEEL Surface Water Quality Final Report

Bailes, Nicholas J. *Reconstructing Exposure Histories of Fish in Watersheds with Mineral Extraction Industry Activity through Otolith Microchemistry.* Master of Science Thesis in Environmental Science, The Ohio State University (In progress)

4.2.4.1.2.1 Introduction

The proliferation of unconventional oil and gas wells that utilize high volume horizontal hydraulic fracturing (HVHHF) technology has yielded enormous quantities of highly saline produced waste waters. Despite the implementation of various safety protocols, releases of these waste waters into surface waters has occurred. In the absence of continuous monitoring of baseline water chemistry, it is difficult to quantitatively assess the exposure of aquatic organisms to contaminants originating from HVHHF processes. Developing and applying effective methods to monitor exposure to not only HVHHF waste water but to other effluents produced by energy-related resource extraction operations (e.g., coal mining) in surface waters is crucial for understanding and mitigating the potential risks of these technologies. Teleost fish bioaccumulate metals from the aquatic environment into their otoliths throughout their life history and thus represent potentially valuable tools for tracking metal exposures associated with energy¬-related resource extraction processes. Accessing this exposure history through trace element analysis of the otolith using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), is a proposed method to reconstruct the exposure histories of fish from watersheds that contain various energy-related resource extraction activities. Otolith microchemistry will be compared between fish sampled from watersheds with no resource extraction activity and those from watersheds with resource extraction activities to determine a baseline presence/absence signal for trace element exposure. Additionally, otolith microchemistry will be compared between fish in watersheds that have either HVHHF or coal mining activity in an attempt to discriminate between the signatures associated with each set of processes.

4.2.4.1.2.2 Objectives

The objective of this project is to explore the efficacy and feasibility of using otolith trace element microchemistry as a proxy for historic water chemistry data to assess long-term changes in regional water chemistry where energy-related resource extraction activities have taken place. Using otolith trace element profiles, temporally specific water chemistry data will be reconstructed to evaluate the possible impact of energy-related resource extraction activities on surface water chemistry. This method is of particular value because changes in water chemistry could be detected after the fact. Since ongoing monitoring of water chemistry does not take place around most sites utilized by energy related resource extraction industries, these data could contribute to an understanding of any potential long-term effects of these activities on water chemistry and aquatic habitats.

4.2.4.1.2.3 Approach

The period of time this work was supported by the USEEL grant was spent developing the following hypotheses and methods. Only initial sampling had begun when the support of the USEEL grant was terminated.

Hypotheses:

1. If energy-related resource extraction industries are causing specific changes to the trace element chemistry of surface waters, then these changes will be reflected in the trace element microchemistry of otoliths of fish residing in these watersheds.

2. Given the chronologic specificity of trace element accumulation in fish otoliths, if water chemistry changes are occurring during the lifetime of an individual fish then otolith trace element levels will reflect the temporal changes in trace element water chemistry and will enable us to draw conclusions about the timing and nature of those water chemistry changes.

Methods:
The fish species targeted for this study were selected primarily based on their abundance throughout the desired region of study. Otoliths were harvested from largemouth bass (*Micropterus salmoides*), and several species of sunfish (*Lepomis* sp.). Fish were collected using seine nets, backpack electro-shockers, stream trawl nets, or hook and line, depending upon the accessibility and topography of the lakes and streams. Upon capture, fish of the appropriate species and size/age class were euthanized by exposure to a solution of tricaine methane sulfonate (TMS, MS-222). Fish not of the correct species and size/age class were immediately returned to their habitat. After euthanasia, each fish was be measured and weighed. Once these data are recorded for each individual, the fish were transported back to laboratory facilities at the Ohio State University where they were dissected and their otoliths retrieved and prepared for analysis.

Otoliths for LA-ICP-MS must first be cleaned to remove any non-otolith tissue from the sample. Once this is accomplished, they are left to dry and then mounted in an epoxy resin. The otoliths will then be sectioned, ground and polished, and mounted onto a slide.

4.2.4.1.2.4 Discussion/Summary of Finding

Work is ongoing.

4.2.4.1.4 Biological Parameters Final Report

Mielke, Sarah R. *Micro and Macro Effects of Habitat Change due to Hydraulic Fracturing on Rodent and Tick Communities.* PhD Candidate in the College of Veterinary Medicine, The Ohio State University (In Progress).

4.2.4.1.4.1 Introduction

The blacklegged tick *(Ixodes scapularis* (Isc)) is the vector responsible for transmitting the pathogen *Borrelia burgdorferi* (Bb), the causative agent of Lyme disease. The range of these two organisms is expanding, exposing more human populations to disease risk. The spread and prevalence of Isc and Bb is tied to the ecology of their mammalian hosts, which in turn, is determined by habitat and predator-prey dynamics. Habitat fragmentation should affect the density of infected ticks by changing distribution of mammalian reservoir species such as the white-footed mouse, shrews, and eastern chipmunk. Habitat fragmentation may also alter predator-prey interactions that influence prey abundance and subsequently alter vector and pathogen density and prevalence. However, testing how ecological model predictions affect the prevalence of Lyme disease in the real world has been difficult due to the diverse species involved and the nuances of landscape configurations.

4.2.4.1.4.2 Approach

Predictions were to be tested in a replicated set of control and newly fragmented forest habitats associated with high volume horizontal hydraulic fracturing (HF) techniques in the Muskingum Watershed Conservancy District (MWCD) of eastern Ohio, where Isc and Bb have recently appeared, laboratory confirmed presence of Bb within mammalian hosts in 2012, and Isc presence suggests that Bb has become persistent in Ohio. HF is hypothesized to increase the density of Isc and prevalence of Bb and speed the transition to persistence of the vector and pathogen populations within the impact zone and to a lesser extent in the areas adjacent to the impact zone. Associated changes in climate, habitat, mammalian hosts and predators in the ecosystem of the HF sites and surrounding areas are hypothesized to drive the observed changes in Isc and Bb populations.

These hypotheses were to be tested with agent-based and meta-population models of the pathogen, tick, and mammalian communities. To evaluate vector and pathogen distribution and prevalence from these theoretical models, the mammals and ticks from proposed HF sites and control sites were to be sampled. Live trap and drag sampling for mammalian species and tick vectors, respectively, would be used on study sites. To evaluate species movement patterns, for reservoir, host, and predator-prey interactions, a camera trap system was proposed for use with stratified random design across each site, along with fitting GPS collars on a prime predator, the red fox. Combining new empirical data with previous research and historical data would be used to test hypotheses and assess the effects of HF activities on vector, host, and pathogen distribution across a landscape.

4.2.4.1.4.3 Summary of Study Activities:

1. Developed a 3.0 Study Design, Data Generation and Acquisition Plan that included a detailed site plan site, subject(s), laboratory materials, methods, and personnel necessary for completion of habitat fragmentation study.

2. Established Institutional Animal Care and Use Protocols

3. Created numerous budgets and sampling plans for multiple alternatives to accomplishing USEEL objectives as site locations were modified

4. Site was withdrawn before field activities could be initiated

Table 4.2.5 MWCD Site-Specific and Regional Baseline Studies (Task 4.0): Groundwater Assessment (Subtask 4.2); Background Seismic Monitoring (Subtask 4.3), and Seismic Survey (Subtask 4.4)

WBS	Subtask	Description	Discussion	Result
4.2	Groundwater Assessment	Groundwater samples collected in the study area for analyses	Characterization of groundwater chemistry in the study area, including the chemistry of dissolved gases and salts in the water	Site withdrawn before completion **See Section 4.2.4.2 Groundwater Assessment Final Report**
4.3	Background Seismic Monitoring	Instrumentation placed to monitor site-specific seismic activity before, during, and after the proposed drilling operations	Existing broadband instrumentation deployed; site-specific readings analyzed and compared to readings from the regional seismic network	Site withdrawn before completion
4.4	Seismic Survey	Seismic data acquired from existing surveys in the region provide adequate lateral control of the subsurface geology away from the drilling locations	Mechanical properties extracted from the seismic data and correlated with the logs; multi-azimuth acquisition to analyze velocity variation with azimuth to detect fracture/stress anisotropy	Site withdrawn before completion

4.2.4.2 Groundwater Assessment Final Report

Grove, Benjamin S. PhD Candidate in the School of Earth Science, The Ohio State University.

4.2.4.2.1 Introduction

The original focus of work can be divided into two distinct "projects" within USEEL. The first "project" was to characterize the subsurface within the study area in terms of the geological framework and in respect to natural fractures and other subsurface pathways. In order to investigate and monitor groundwater chemistry, the aquifer must be characterized/defined. Geophysical well logs were used to create a "geomodel" of the subsurface which included defining formation tops and creating well-to-well cross sections. Characterizing the stratigraphy allowed a better understanding of the aquifer system and identification of potential zones in which fluid can migrate or be confined. In addition to using well logs, fractures were mapped in the rock on the surface to identify areas of high fracture intensity. Defining areas of differing fracture intensity aided in determining groundwater monitoring sites because fractures control hydrology as conduits for fluid flow. Characterizing the subsurface geology was critical to understanding how fluids/gases will potentially migrate through the system prior to, during, and after drilling occurs.

The second "project" was designed to characterize the chemistry of groundwater in the study area. This included the chemistry of dissolved gases and salts in the water. Brines and gases associated with hydrocarbon migration (including noble gases and hydrocarbons) in groundwater were to be specifically fingerprinted to use as tracers of fluid migration. Analyses were to be performed throughout the entirety of the project (prior to, during, and after drilling) to monitor any potential fluid migration associated with the process of completing a hydraulically fractured well. Characterizing the baseline chemistry of the groundwater prior to any activity was critical to differentiating the presence of natural gases/brines in water and those introduced through anthropogenic activity.

4.2.4.2.2 Objectives

Original research questions included:

- What are the fundamental geological, hydrogeological, and fluid flow constraints on subsurface hydrocarbon flow within conventional and unconventional stratigraphic units?
- How do these factors influence groundwater quality?
- Have these processes changed in light of unconventional drilling?

The following research objectives were proposed to address these questions:

- Characterize subsurface geology and tectonic features (fractures),
- Characterize baseline chemistry of groundwater and develop geochemical fingerprints of natural gases/brines,
- Monitor groundwater chemistry prior to, during, and after drilling,
- Identify possible mechanisms for brine/gas migration from drilling activity, and
- Determine if and how the groundwater chemistry changes due to anthropogenic activity (i.e., does unconventional energy production induce new environmental concerns)

Associated hypotheses included:

- The composition of groundwater is influenced by the spatial distribution and properties of natural deformational features (e.g., fractures, faults)
- The presence of hydrocarbons and salt-rich waters are influenced by the old tectonic framework as well as current hydrology
- Multiple lines of geochemical evidence can differentiate between naturally occurring contaminants such as oil, salt, and gas versus a diverse suite of anthropogenic contaminants (e.g., natural gases and brines from abandoned oil and gas wells, a history of local coal mining, modern unconventional drilling)

By characterizing the baseline chemistry of groundwater, it would be possible to fingerprint subsurface fluids and effectively monitor brine and gas migration through the subsurface. The use of isotope chemistry of the gases (including noble gases and hydrocarbons) as tracers can determine the course source of any fluid migration into the aquifer and discern whether the mechanisms are natural or from anthropogenic activity. From drilling activity, these tracers could also be used to determine the specific migration mechanisms (i.e., through fractures at depth, through well casing, etc.).

4.2.4.2.3 Approach

The period of time this work was supported by the USEEL grant was spent developing an approach and methodologies to address the stated project objectives. Approach activities undertaken before the project was terminated are chronologically summarized below.

- Performed extensive literature reviews on site-specific geology (subsurface stratigraphy, structure, and tectonic history), regional aquifer systems, latest groundwater quality research related to energy development, and general environmental impacts of unconventional energy development, particularly in the Appalachian Basin.

- Created maps of water and oil/gas wells (permitted and completed) within the proposed study area.

- Coordinated with local and state agencies to compile an inventory of wells in eastern Ohio that penetrate the Utica Shale and have accessible geophysical well log data. This was followed by the acquisition of data from the state survey to be used in building a local static-earth model of the initially proposed study area within MWCD land.

- Initiated a site-specific research and sampling plan for groundwater assessment and subsurface geology and fracture characterization spanning from the Utica up to shallow aquifers.

- Reviewed geophysical well logs that penetrate the Utica Shale to become familiar with particular geophysical responses that are characteristic of each formation. This primer allowed for formation tops to be chosen from the well logs acquired.

- Developed an extensive sampling and analysis protocol/QAPP for the collection and analysis of gas and water samples. This work entailed adapting lab protocol to be integrated into a project-wide QAPP document that covers proper sampling techniques and protocol for the collection of groundwater and produced gas samples as well as protocol for laboratory analytical techniques and methods for a range of sample types and target analytes. Equipment and corresponding analytes include a Thermo Fisher Helix SFT Noble Gas MS (abundance and isotopes of He, Ne, Ar, Kr, and Xe), quadrupole mass spectrometers and gas chromatographs with FIDs (Major gas compositions including CO2, CH4-C6H14, N2, O2, Ar, and H2S), ICP-MS and ICP-OES (for major ions (Cl, Br, I, Na, Ca, Mg, K, HCO3, SO4), metals (Fe, Mn, As, Pb, etc.), and trace elements), and Isotope ratio mass spectrometers (stable isotopes of carbon, etc.). This elaborate document combines standard protocols for sampling and analysis from the USGS, USEPA, and Dr. Tom Darrah's OSU laboratory.

- Performed additional literature reviews on subsurface stratigraphy and tectonics, regional aquifer systems, and region-specific groundwater chemistry for potential field sites in Pennsylvania and West Virginia as the potential USEEL site location shifted from Ohio to other potential regions.

- Reviewed and revised original objectives and research plan that was directed more toward improving production efficacy and efficiency and less directed toward environmental monitoring. This plan included developing a greater understanding of reservoir properties by establishing geochemical isotopic techniques to characterize reservoir properties and verifying these techniques with state-of-the-art petrophysical data.

4.3.4.2.4 Discussion/Summary of Findings

The findings for this study are limited by the lack of new data generation due to the project being terminated prior to drilling the science well. Perhaps the most significant deliverable that was generated as part of this study was the extensive sampling and analysis protocol quality assurance project plan

(QAPP) for groundwater and produced gases/brines. As stated above, this elaborate document combines sampling and analytical methods from the USGS, EPA and OSU laboratory protocols and serves as a complete guide for sampling and analysis in environmental and energy-related studies. While this protocol was developed specifically for USEEL research objectives, the standard operating procedures it details can be used in any study that targets the sample types and analytes discussed within it.

Despite the lack of the science well, a geochemical tool was developed that utilizes noble gas isotope ratios to characterize conditions of fluid migration in the subsurface. Results of this effort were presented at:

- USEEL-related research in Denver, Colorado at the 2016 GSA meeting (oral presentation).
- USEEL-related research at an MSEEL project meeting in Morgantown, West Virginia (poster presentation).
- USEEL-related research in Evora, Portugal at the 2016 Water-Rock Interactions International Symposium (oral presentation).

Table 4.2.6 MWCD Drilling and Construction of Vertical Well (Task 5.0)

WBS	Task/Subtask	Description	Discussion	Result
5.0	Vertical Drilling	Operator responsible for drilling the vertical portion of the production well and participation in a number of research activities	Best practices as defined by the Center for Sustainable Shale Development (http://sustainableshale.org/) and adapted to vertical drilling	Site withdrawn before completion
5.1	Environmental Monitoring	Subtasks 4.1.1 through 4.1.5 and 4.2 and 4.3 continue during drilling of the vertical well	Continuation of environmental monitoring and assessment during drilling of vertical well	Site withdrawn before completion
5.2	Borehole Geophysics Analysis	Logging of vertical drill hole with state-of-the-art wireline tools will included the collection of: caliper, gamma ray, neutron porosity, bulk density, induction resistivity, photoelectric effect, elemental spectroscopy (rock geochemistry and total organic carbon), permeability, acoustic velocity, azimuthal resistivity, dielectric, as well as micro-image logs.	Development of a plan to cover all aspects of vertical drill hole logging and the use of collected data and results incorporated into the subsurface 3-D model	Site withdrawn before completion
5.3	Core Acquisition and Assessment	Obtain oriented whole core of key intervals, cuttings samples at regular intervals during drilling, and sidewall cores of selected geologic units	Petrophysical, mineralogical, geochemical and microbial characterization consisting of classic industry-based methods complemented by interrogation using more unique tools available at OSU and partner institutions	Site withdrawn before completion
5.4	Sampling of Drill Cuttings, Mud, and Fluids	Chip samples, mud logs, geologic logs, field notes, cuttings, and mud samples collected and photographed at the vertical well.	Liquid and solid samples labeled, photographed, stored temporarily on-site, and shipped to the Ohio Geological Survey core storage facility for long-term storage and controlled access	Site withdrawn before completion

5.5	Mechanisms and Pathways for Methane Migration	Fluxes of methane at ground surface measured using flux chambers in the immediate vicinity of the wellhead and at regularly spaced distances from the wellhead	Isotopic composition (C13/C12) measured to distinguish biogenic and thermogenic methane and the genetic fingerprint of various thermal gases in target and adjacent formations in this area	Site withdrawn before completion

Table 4.2.7 MWCD Horizontal Well Drilling, Hydraulic Fracturing, and Analyses (Task 6.0)

WBS	Task/Subtask	Description	Discussion	Result
6.0	Horizontal Drilling	Operator responsible for drilling the horizontal portion of the production well and participation in a number of research activities	Best practices as defined by the Center for Sustainable Shale Development (http://sustainableshale.org/) and adapted to horizontal drilling	Site withdrawn before completion
6.1	Environmental Monitoring	Tasks 4.1.2 through 4.1.5 and 4.2 and 4.3 continue during drilling of the horizontal well	Continuation of environmental monitoring and assessment during drilling of horizontal well	Site withdrawn before completion
6.2	Microseismic Monitoring Analysis	Microseismic or other hydraulic fracturing monitoring survey performed during horizontal drilling and hydraulic fracturing	Surface sensors used to gather acoustical signatures off subsurface activities	Site withdrawn before completion
6.3	Fluids and Gas Sampling and Analysis	Detailed geochemical, isotopic, and microbial characterization of fluids and gases produced during horizontal drilling and production	Petrophysical, mineralogical, geochemical and microbial characterization of classic industry-based methods complemented by interrogation using unique tools available at OSU and its partner institutions	Site withdrawn before completion
6.4	Cuttings Acquisition and Analysis	Drill cuttings collected, analyzed, and stored	Petrophysical, mineralogical, geochemical and microbial characterization	Site withdrawn before completion

6.5	Drilling Fluids Acquisition and Assessment	Fluid samples (including hydraulic fracturing fluid, flow back, and production water) collected, analyzed, and stored from the vertical hole and the horizontal well	Fluids utilized for testing new membranes and water treatment technologies allowing expanded or improved reuse of flowback and produced water	Site withdrawn before completion **See Section 4.2.6.5 Drilling Fluids Acquisition and Assessment Final Report**
6.6	Borehole Analysis	Geophysical logging-while-drilling and wireline measurements collected in the horizontal well	Gamma ray, neutron porosity, bulk density, elemental spectroscopy, resistivity, and image logs and incorporated into the subsurface 3-D model	Site withdrawn before completion
6.7	Design of Optimal Cement	Recommendations for optimal slurry designs	Operational considerations and contingency plans for field jobs evaluated	Site withdrawn before completion
- - -	Hydraulic Fracturing	The well construction and hydraulic fracturing plan was to be provided by the operator of the well(s) and reviewed by the science and technical advisory committees	Best practices as defined by the Center for Sustainable Shale Development (http://sustainableshale.org/) and adapted to horizontal drilling	Site withdrawn before completion

4.2.6.5 Drilling Fluids Acquisition and Assessment Final Report

Rangharajan, Kaushik: PhD Candidate in Mechanical Engineering, The Ohio State University.

4.2.6.5 Introduction

Abundant reserves of unconventional oil and gas coupled with favorable policy for exploration and production implies the shale industry is expected to play a major role in the United States economy for the next several years [1, 2]. Hydraulic fracturing, a process used to extract oil and gas from various shale formations has been used by industries over the years where 3 - 5 million gallons of fresh water mixed with additives, collectively termed as 'frac' fluid is pumped at a high pressure to instigate fracture [1]. The additives prevent fractures from closure and ensure continuous supply of fossil fuels for extraction. Based on the geology of individual shale formation, a certain percentage of the pumped water begins to resurface over the next several weeks, which however is mixed with excessive salts, high organic content including hydrocarbons, biological materials, possible radionuclides, and a variety of materials from the sub-surface [1 - 3]. The flowback water can be up to 6-8 times saltier than sea water [1, 2]. As a result, recycling the flowback water as frac fluid may not be the most efficient use. Disposal of the flowback water may be a more viable option [1, 2].

Traditional wastewater treatment plants have severely restricted intake of flowback water for treatment as most commercial membranes are optimized for treating waters with salinity content equivalent to sea water, and typically do not survive in hyper-saline (brine, at concentrations well over 150,000 ppm) solutions. As a result, millions of gallons of flowback water generated daily is disposed *via* deep-well injections, where the flowback water is pumped several thousand feet under the ground. Recent research shows possible correlation between a direct increase in number of measurable seismic activity in regions that permit deep-well injection such as Oklahoma [3] and Youngstown, Ohio, triggering drastic needs for developing alternate disposal or treatment options.

4.2.6.5.2 Objectives

The broad objective of the research was to advance technology and engineering practices to increase safety and decrease environmental impact during and after hydraulic fracturing. Environmental impact-mitigation technologies that have been developed with DOE support were to be demonstrated at the end of the project term. However, the project was terminated early and before the proposed end-date. In this work, a prototype based on the novel physics that govern nanoscale water transport will be developed to (a) extract useful water from flowback water facilitating water recycling and potentially mitigating deep-well injection, and (b) be capable of separating volatile organic compounds from water found during shale gas production. In the process, fundamental understanding of water transport will be investigated in order to design novel membranes with enhanced flux and selectivity, thereby improving the state-of-the-art technologies for membrane based filtration.

4.2.6.5.3 Approach

Although shale flowback water was never collected from the USEEL project well, flowback water was collected from two different wells in the Utica play and one from the Marcellus play and used in the following experiments.

Prototype Fabrication: A hybrid microchannel-nanochannel proof-of-concept device, using two microfluidic channels (8 µm (H) x 50 µm (W) x 3 cm (L)) as fluidic reservoirs for a bank of three nanochannels (80 nm (H) x 30 µm (W) x 2.5 mm (L)), were fabricated in borosilicate glass. Known calcium based bonding recipes for microscale bonding was extended here to seal the nanoscale channels with (soda lime) glass slides with drilled holes. The recipe was refined to obtain a device yield > 90%.

Surface Modification: A recipe was developed to pattern tunable sections of functionalized hydrophobicity inside the nanochannel that provided a high-energy barrier for transport of liquid water. The key advance here was the ability to tune the length of the functionalized section within the nanochannel to yield varying hydrophobic lengths (Figure 1).

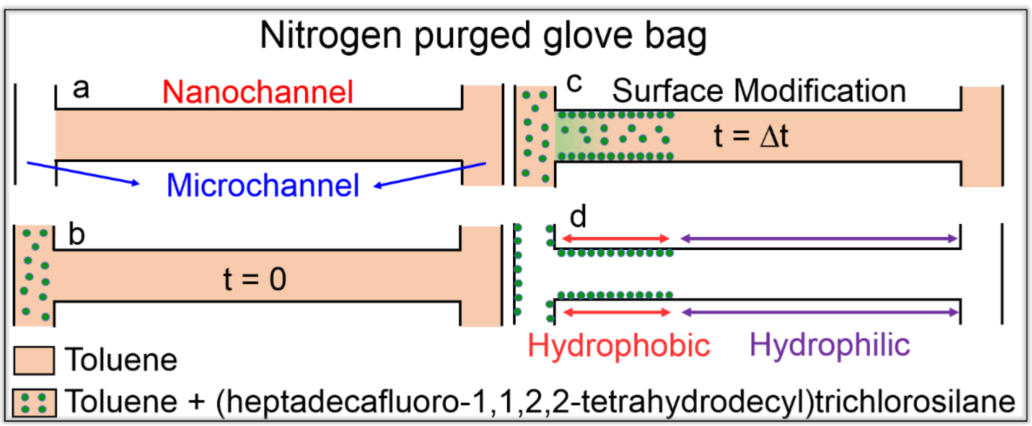

Figure 1. Recipe to pattern hydrophobic coatings of tunable length inside nanochannels.

4.2.6.5.4 Discussion/Summary of Findings

Baseline flowback water monitoring: Drill Fluid Sample collection and Analysis: Shale flowback water from two different wells in the Utica play and one from the Marcellus play were collected and ionic composition analyzed via Inductively-coupled plasma mass spectroscopy (ICP-MS) for cations and Ion-chromatography for anions as shown in Table 1.

Table 2. Flowback water composition of Utica and Marcellus shale plays.

Content	UTICA			MARCELLUS
Date	Well A (9/10/15)	Well A (10/8/15)	Well B (11/12/15)	*N.A.*
TDS	179,000	184,000	187,000	80,500
Na^{+}	46,707.39 ± 270.95	49,250.19 ± 125.97	51,038.94 ± 112.96	38,541.32 ± 174.96
Mg^{2+}	1,703.41 ± 4.71	1,831.76 ± 9.55	1,854.9 ± 14.78	887.37 ± 0.7
K^{+}	616.3 ± 2.84	638.62 ± 3.74	673.47 ± 1.61	252.54 ± 1.7
Ca^{2+}	14,582.01 ± 107.71	15,203.47 ± 82.42	15,532.65 ± 159.23	8,448.15 ± 30.5
Si^{4+}	20.65 ± 0.28	22.28 ± 0.53	17.16 ± 0.9	56.77 ± 1.27
Sr^{2+}	3,774.91 ± 9.89	4,115.39 ± 78.47	4,120.34 ± 50.63	1,756.61 ± 9.87
Ba^{2+}	1,128.94 ± 6.67	1,236.26 ± 12.62	1,341.04 ± 1.15	2,712.75 ± 16.88
Li^{+}	57.55 ± 0.57	61.07 ± 0.07	63.06 ± 0.47	100.33 ± 0.4
Fe^{2+}/Fe^{3+}	117.3 ± 0.89	144.03 ± 1.51	125.1 ± 2.13	153.56 ± 2.05
Mn^{2+}	7.97 ± 0.05	8.6 ± 0.02	9.66 ± 0.05	15.21 ± 0.2
Cl^{-}	126,530.21 ± 650.61	120,202.10 ± 4922.60	120,498.14 ± 4070.54	47,363.25 ± 3505.42
Br^{-}	1225.98 ± 103.00	1380.20± 8.63	1382.33 ± 28.16	304.68 ± 23.05
F^{-}	2.29 ± 0.06	2.25± 0.09	2.10 ± 0.09	1.90± 0.01
SO_4^{2-}	111.38 ± 0.48	113.25 ± 0.57	111.86 ± 0.24	110.46± 0.37
PO_4^{3-}	18.89 ± 3.514	20.904± 0.84	21.43 ± 0.18	17.35± 3.34

Desalination Experiments: The prototype was introduced to direct Utica shale water at 3 M on one side of the hydrophobic patch and 5 M NaCl on the other side of the hydrophobic patch (Fig. 2A). The hydrophobic nanochannel provided a high-energy barrier for liquid transport facilitating an evaporation-condensation based filtration. In this case, fresh water was recovered from the multi-component shale water which was at a higher vapor pressure compared to 5 M NaCl resulting in a 95% desalting of draw (from 5M to 0.25 M) over 20 min. It is important to note that nearly all existing membranes are optimized for treating solutions up to seawater salinity and the results of the present research provide a platform for hyper-saline brine treatment.

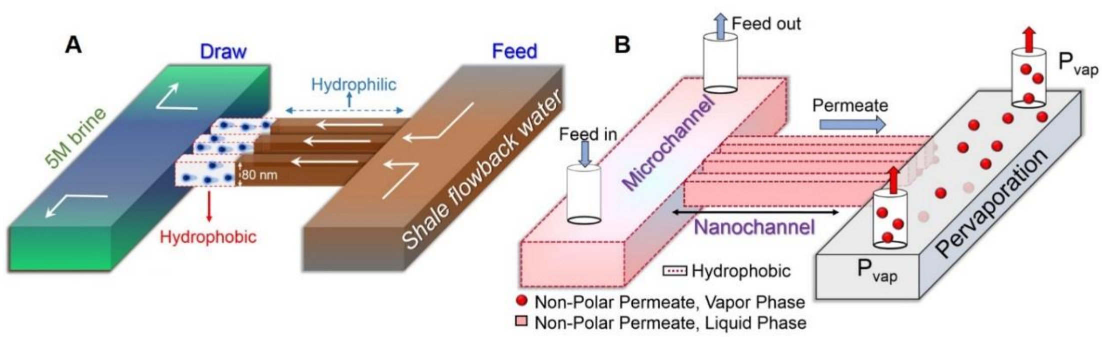

Figure 2. Nanofluidic proof of concept system for (**A**) desalination of hyper-saline shale flowback water, and (**B**) water-volatile organic compound separation via pervaporation.

Separation Experiments: The same prototype was used for separating solvents of lower polarity (w.r.t water) such as toluene and chloroform from water. In the context of sustainability, it is known that produced water from both Marcellus and Barnett shale reserves contain volatile aromatic hydrocarbons including toluene [2]. Incomplete filtration leaves residual organics, which upon release pose challenges to source surface and groundwater. Using the fabricated prototype, trace amounts of toluene and chloroform (diluted 200 fold) were separated from water using pervaporation techniques (Fig. 2B). In traditional pervaporation process, a hydrophobic membrane first separates a non-polar solute (permeate) from an aqueous solvent and the separated permeate is subsequently collected via vaporization. Here, net pervaporation flux measured directly was 50 times (toluene) and 170 times (chloroform) higher when compared to established [4, 5] and recently developed hybrid membranes [6], by reducing transmission resistance inside the nanochannel.

Selected References

[1] José M. Estrada, *et al.*, Fuel, **182**, 292 (2016).
[2] Maguire-Boyle *et al.*, Environmental Science: Processes & Impacts, **16**, 2237 (2014).
[3] Walsh, *et al.*, Science Advances, **1**, 1500195 (2015).
[4] Schnabel, *et al.,* Journal of Membrane Science **142**, 129 (1998).
[5] Simone, *et al.*, Separation and Purification Technology, **90,** 147 (2012).
[6] Shams, *et al.*, Desalination and Water Treatment, **57,** 6852 (2016).

Publications based on USEEL Research

1. "Near–Elastic Collision of Water Vapor Molecules with Hydrophobic Nanochannel Walls: Applications for High Salinity Brine Treatment". In preparation.

Peer-Reviewed Conference Publications

1. "Nanofluidic system for desalination and solvent removal from water sources" Rangharajan, K.K., Mohanasundaram, P., Conlisk, A.T., Prakash, S., 255th ACS National Meeting & Exposition, Mar 18 – 22, 2018. New Orleans, LA, USA. (Submitted)

2. "Surface Wettability Directed High Flux Separation of Trace Amounts of Toluene and Chloroform from Water". Rangharajan, K.K., Prakash, S., The 21st International Conference on Miniaturized Systems for Chemistry and Life Sciences (MicroTAS 2017), Oct 22 – 26, 2017. Savannah, Georgia, USA. (Poster)

3. "Desalting high salinity shale flowback water via High-Flux Nanofluidic Evaporation-Condensation". Rangharajan, K.K., Varun, Prakash, S., The 30th IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2017), Jan 22 – 26, 2017. Las Vegas, Nevada, USA. (Presentation)

4.3 Energy Corporation of America Marcellus drill pad – Greene County, PA

Tables 4.3.1 to 4.3.7 summarize by WBS number, the results of the limited work completed on ECA tasks/subtasks before the Greene County, Pennsylvania, site was withdrawn as a potential USEEL site. Proposed research activities were focused on subsurface studies to improve the understanding of the Utica-Point Pleasant shale play. While selected environmental base line and monitoring data were to be collected, environmental studies were greatly reduced from those planned at the relatively pristine EARS and MWCD sites.

Table 4.3.1 ECA Project Management and Planning Activities (Task 1.0)

WBS	Subtask	Description	Discussion	Result
1.1	Selection of Operator and Drill Site	Identify a UOG developer in the Utica Shale Play with an active lease supportive of the project's research	All options considered	ECA and a Marcellus well drill pad in Greene Co., PA, were identified as a potential USEEL site.
1.2	Operator Agreement	A binding agreement specifying roles of the operator and their specific research support activities	Agreement reviewed and approved by NETL prior to approval and signature by OSU and the operator	A Memorandum of Agreement was signed by ECA and OSU on 11/29/2016. ECA notified OSU that it was withdrawing from the USEEL project on 08/29/2017.
1.3	Project Management Plan	Documentation of the project's budget, schedule, objectives, milestones, and planned risk management activities.	A project deliverable and milestone	A draft PMP was completed on 08/25/2017, but was not reviewed by DOE
1.4	Quarterly Project Status Reports	A report on project progress relative to schedule, budget and objectives.	Project deliverables	Quarterly reports were submitted as specified in Federal Assistance Reporting Checklist and Instructions
1.5	Quarterly Financial Reports	A report on expenditures by task and cost category	Project deliverables	Quarterly reports were submitted as specified in Federal Assistance Reporting Checklist and Instructions
1.6	Website Development and Maintenance	Development and maintenance of the USEEL website	The website was designed to inform the public about the project and provide stakeholders access to relevant documents and research results.	Preliminary website and data management model developed and operational before site was withdrawn.

Table 4.3.2 ECA Development of Accessibility Guidelines (Task 2.0)

WBS	Task	Description	Discussion	Result
2.0	Access Guidelines Report	Development and maintenance of the USEEL website	Guidelines included visit request, safety, media contact and publication policies and procedures	Site withdrawn before completion

Table 4.3.3 ECA Scientific Education for OSUE (Task 3.0)

WBS	Subtask	Description	Discussion	Result
3.0	Scientific Education for OSUE Educators	Educational workshops based on scientific findings from the project and other sources	OSUE educators are highly visible and well respected in each of the counties where UOG development is occurring	Site withdrawn before completion

Table 4.3.4 ECA Site-Specific and Regional Baseline Studies (Task 4.0): Surface Environmental Assessment (Subtask 4.1)

WBS	Subtask	Description	Discussion	Result
4.1.1	Air Quality	Atmospheric concentrations of various chemical agents and levels of physical agents measured in the area of interest and near the drill site	Methane, ambient hydrocarbons, particulate matter, and ionizing radiation, to establish a regional baseline and site-specific measurements	Site withdrawn before completion
4.1.2	Surface Water Quality	Water quality parameters measured in major lakes, ponds, and streams within 5 km of the drill site	Measurements of hydrocarbons, anions, metals, radio-chemicals, stable isotopes, and basic physical and chemical parameters in first-order streams and ponds subject to surface runoff in the vicinity of the drill site	Site withdrawn before completion

Table 4.3.5 ECA Site-Specific and Regional Baseline Studies (Task 4.0): Groundwater Assessment (Subtask 4.2); Background Seismic Monitoring (Subtask 4.3), and Three Dimensional Seismic Survey (Subtask 4.4)

WBS	Subtask	Description	Discussion	Result
4.2	Groundwater Assessment	Groundwater samples collected in the study area for analyses	Characterization of groundwater chemistry in the study area, including the chemistry of dissolved gases and salts in the water	Site withdrawn before completion
4.3	Background Seismic Monitoring	Instrumentation placed to monitor site-specific seismic activity before, during, and after the proposed drilling operations	Existing broadband instrumentation deployed; site-specific readings analyzed and compared to readings from the regional seismic network	Site withdrawn before completion
4.4	3-D Seismic Survey	Seismic data acquired from ECA in the region provide adequate lateral control of the subsurface geology away from the drilling locations	Mechanical properties extracted from the seismic data and correlated with the logs; multi-azimuth acquisition to analyze velocity variation with azimuth to detect fracture/stress anisotropy	Site withdrawn before completion; preliminary analysis performed for 5.2 Borehole Geophysics Analysis

Table 4.3.6 ECA Drilling and Construction of Vertical Well (Task 5.0)

WBS	Task/Subtask	Description	Discussion	Result
5.0	Vertical Drilling	ECA responsible for drilling the vertical portion of the production well and participation in a number of research activities	Best practices as defined by the Center for Sustainable Shale Development (http://sustainableshale.org/) and adapted to vertical drilling	Site withdrawn before completion
5.1	Environmental Monitoring	Subtasks 4.1.1, 4.1.2, 4.2, and 4.3 continue during drilling of the vertical well	Continuation of environmental monitoring and assessment during drilling of vertical well	Site withdrawn before completion
5.2	Borehole Geophysics Analysis	Logging of vertical drill hole with state-of-the-art wireline tools will included the collection of: caliper, gamma ray, neutron porosity, bulk density, induction resistivity, photoelectric effect, elemental spectroscopy (rock geochemistry and total organic carbon), permeability, acoustic velocity, azimuthal resistivity, dielectric, as well as micro-image logs.	Development of a plan to cover all aspects of vertical drill hole logging and the use of collected data and results incorporated into the subsurface 3-D model	Site withdrawn before completion **See Section 4.3.5.2 Borehole Geophysics Analysis Final Report**
5.3	Core Acquisition and Assessment	Obtain oriented whole core of key intervals, cuttings samples at regular intervals during drilling, and sidewall cores of selected geologic units	Petrophysical, mineralogical, geochemical and microbial characterization consisting of classic industry-based methods complemented by interrogation using more unique tools available at OSU and partner institutions	Site withdrawn before completion
5.4	Sampling of Drill Cuttings, Mud, and Fluids	Chip samples, mud logs, geologic logs, field notes, cuttings, and mud samples collected and photographed at the vertical well.	Liquid and solid samples labeled, photographed, stored temporarily on-site, and shipped to the Ohio Geological Survey core storage facility for long-term storage and controlled access	Site withdrawn before completion

4.3.5.2 Borehole Geophysics Analysis Final Report

Trotter, Bennett. ***Pore Pressure in Utica Shale and Point Pleasant Formation.*** **Master of Science Candidate in the School of Earth Science Thesis, The Ohio State University (In Progress)**

4.3.5.2.1 Introduction

In some areas of the Appalachian Basin the Utica and Point Pleasant formations are under extremely high pore pressure: One of these areas is in St. Lawrence Lowlands in Quebec (Chatellier et al., *2013)*. The processes responsible for generating this high pore pressure and how it is able to be maintained is poorly understood. If the cause of the high pore pressure can be determined it will allow for a more accurate pore pressure prediction model to be developed. The highest initial production rates from the Utica and Point Pleasant shale plays have been observed in wells that have targeted these areas of high pore pressure, suggesting that there is a relationship between high pore pressure and production. The region in southwestern Pennsylvania where ECA and USEEL had planned on installing a well, was within one of these zones of high pore pressure**.**

High pore pressures in sedimentary basins like that observed in the Utica and Point Pleasant can be generated by a number of different processes: 1) a reduction in pore volume caused by either disequilibrium compaction or tectonic compression; 2) a change in fluid volume caused by hydrocarbon generation or aquathermal expansion; or 3) by fluid movement into or within the reservoir driven by differences in densities (Osborne and Swarbrick, 1997). Determining which of these processes is responsible for the high pore pressure can be difficult considering many of these processes have similar representations in geophysical data and multiple processes can be occurring simultaneously within the same reservoir. A method for distinguishing between disequilibrium compaction and a change in fluid volume, has been used in the North Sea (Hermanrud et al., 1998) and in Brunei Darussalam (Tingay et al., 2009), and may be applicable to the Utica and Point Pleasant formations. This method involves comparing density and sonic log response in the zone of overpressure.

4.3.5.2.2 Objectives

If high pore pressure existed and was quantifiable in the proposed USEEL well, the cause of high pore pressure could have been investigated. If the mechanisms responsible for generating the high pore pressure could be determined this would have allowed for the development of a more accurate pore pressure prediction model. Developing an accurate pore pressure prediction model is important for drilling and well completion to identify where the zones of high pressure are and to quantify what the pressures are within those zones. During drilling, the mud weight will need to be adjusted to counteract the changes in pressure, to prevent blowouts or unwanted fracturing of the rock. It is also important in target selection and well completion to insure the highest relative pore pressure zones are being targeted and fractured properly to generate the highest possible production rates.

4.3.5.2.3 Approach

The proposed study would have consisted of three parts: 1) locating the zones of high pore pressure and quantifying the pore pressure within these zones; 2) investigating which mechanisms are responsible for generating the high pore pressure; and 3) developing a pre-drill pore pressure prediction model that can be applied to a 3-D seismic volume. The study would have been conducted using a combination geophysical well logs from the planned USEEL well and 19 previously drilled Marcellus wells in Greene County, plus the two additional Utica wells; and a 3-D seismic volume that has been acquired by ECA (Figure 1).

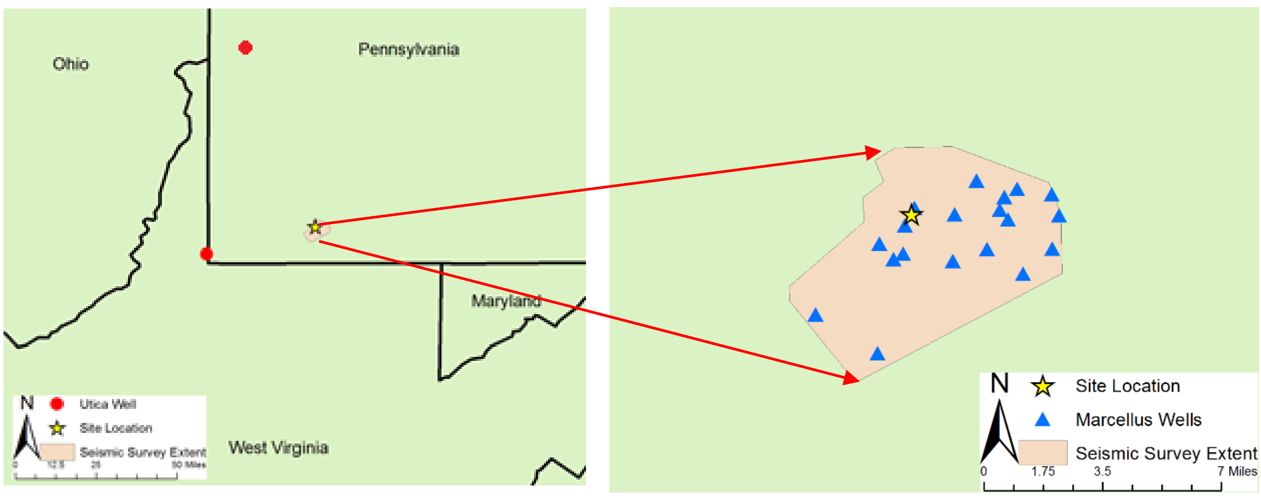

Figure 1. Drilling site location, Marcellus wells locations, Utica Well Location and seismic survey extent in southwestenn, PA.

Before starting the study a literature review was conducted to better understand regional geology, overpressure in sedimentary basins, and pore pressure prediction. Then all the public geophysical well log data within 50 miles of the planned USEEL well site was compiled and reviewed to see if any wells had the right combination of high quality geophysical logs over the Utica and Point Pleasant formations. All data acquired either from public databases or from ECA was loaded into Kingdom Suite for future seismic interpretation, ArcGIS for map making, and Geolog for future well log interpretation. After all data was acquired and loaded, baseline seismic data interpretation was conducted in preparation for the acquisition of the planned USEEL well data.

The first part of the study was conducted to predict pore pressure in the public wells that had the adequate logs and data quality. This part of the study involved creating a Normal Compaction Trend Line (NCTL) based on the bulk density and sonic velocity logs. This was done by determining the normal shale values for bulk density and sonic velocity at a relatively shallow depth in the well where there is no overpressure. Then, utilizing a normal compaction equation, the bulk density and sonic velocity values can be predicted for a deeper shale. The bulk density and sonic velocity data can be compared to this

NCTL to locate zones of overpressure; anywhere the sonic velocity and or bulk density value diverge from the NCTL could potentially be a zone of overpressure (Zhang, 2011). Once the zones of overpressure were located Eaton's equation for pore pressure prediction was applied to quantify the pore pressure within the well by comparing log derived porosity to the porosity derived from the normal compaction trend (Zoback, 2007). A plot of the pore pressure prediction utilizing Eaton's method in one of the publicly available Utica wells is illustrated in (Figure 2).

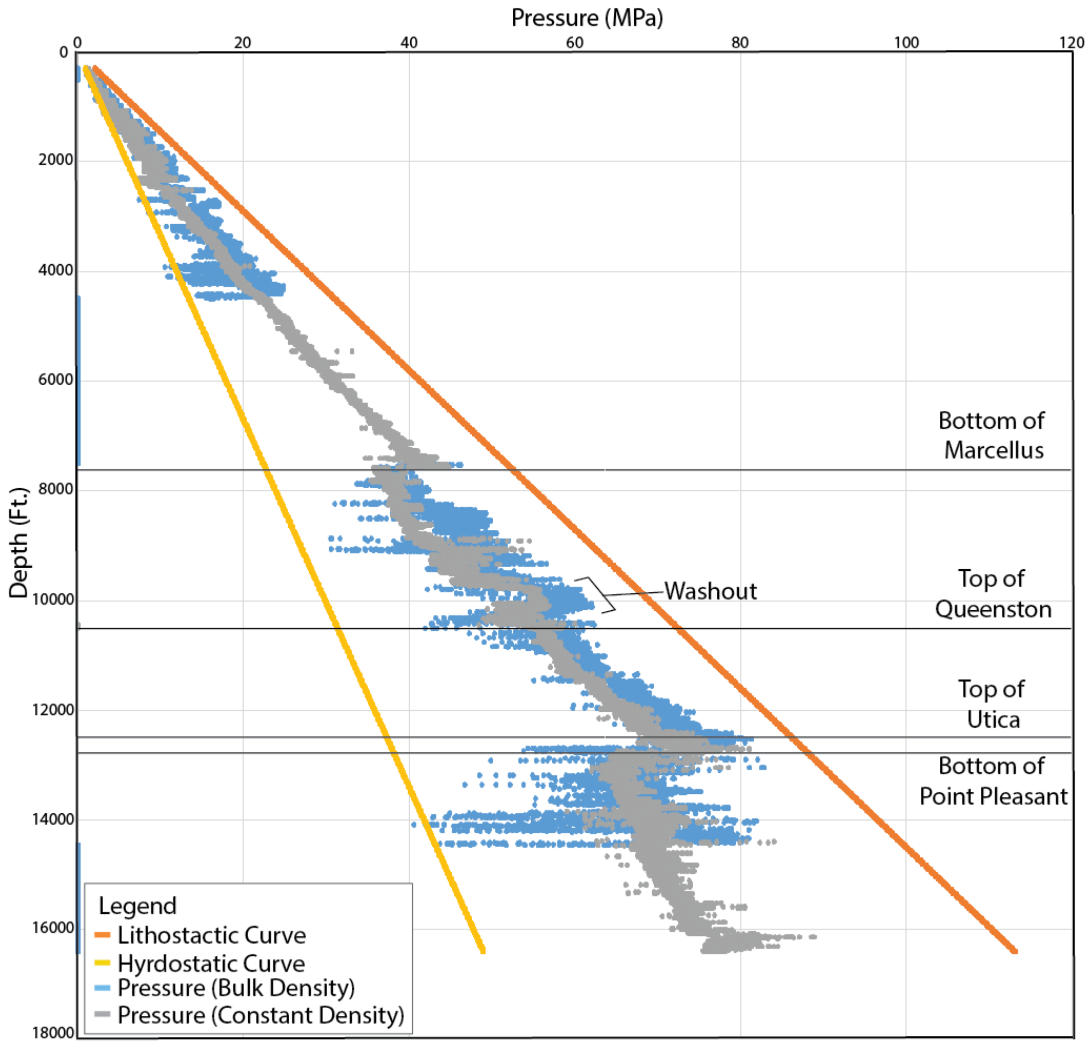

Figure 2. A plot of density porosity log, the sonic porosity log, and normal compaction trend (NCT) porosity, from a well targeting the Utica, 42 miles northwest of the USEEL well location. The plot is filtered to only show the porosity values for shale.

After the areas of high pore pressure were located and quantified the second part of the study began by creating a Bower's plot of porosity data, derived from the bulk density log, and sonic velocity log data. The Bower's plot was used to determine if the overpressure is related to disequilibrium compaction or fluid expansion. If the overpressure is caused by disequilibrium compaction the expected observation would be a deviation in the density porosity and sonic velocity data from the NCTL, signifying that the rock is under compacted. If the overpressure is caused by fluid expansion the expected observation would be a deviation in only the sonic velocity data from the NCTL, as the rock was compacted normally, and the pore fluids expanded after compaction. Therefore, the density porosity data follows the NCTL (Tingay et al., 2009 and Hermanrud et al., 1998). An example of the Bower's plot of the sonic porosity log vs. the density porosity log in one of the publicly available Utica wells is illustrated in (Figure 3).

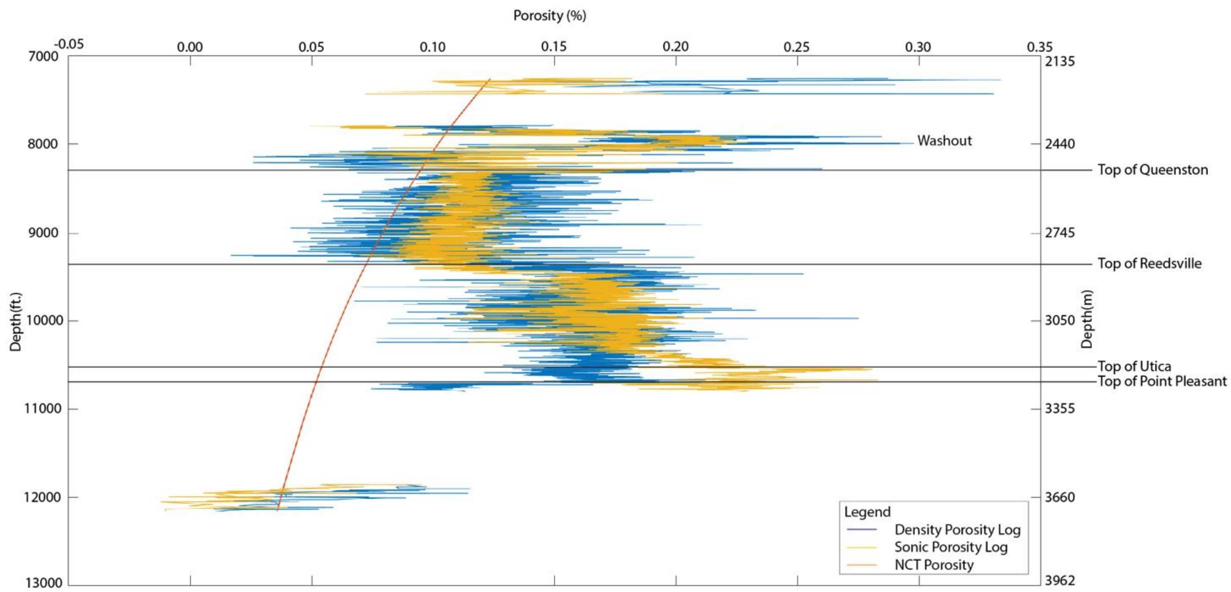

Figure 3. A plot of density porosity log, the sonic porosity log, and normal compaction trend (NCT) porosity, from a well targeting the Utica, 42 miles northwest of the USEEL well location. The plot is filtered to only show the porosity values for shale.

The third part of the study was unable to be conducted with the public well data because no publicly available well that penetrated the Utica was drilled within the seismic survey extent.

4.3.5.2.4 Discussion/ Summary of Findings

Based upon the pore pressure prediction analysis conducted on the two public wells that had adequate data to run the analysis, it does appear that the Utica and Point Pleasant formations are significantly over pressured in southwestern Pennsylvania. Based upon the Bowers plot, the overpressure in the Utica and Point Pleasant is caused by a combination disequilibrium compaction and fluid expansion mechanisms. More public data is being acquired across the Appalachian basin to confirm the results of the pore pressure prediction observed in the wells used in this study. This study provided insight into where high pore pressures are located within the Utica and Point Pleasant formations and what mechanisms are responsible for generating the high pore pressures. All the public data used in this study was acquired without charge, making this study extremely economical.

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Table 4.3.7 ECA Horizontal Well Drilling, Hydraulic Fracturing, and Analyses (Task 6.0)

WBS	Task/Subtask	Description	Discussion	Result
6.0	Horizontal Drilling	ECA responsible for drilling the horizontal portion of the production well and participation in a number of research activities	Best practices as defined by the Center for Sustainable Shale Development (http://sustainableshale.org/) and adapted to horizontal drilling	Site withdrawn before completion
6.1	Environmental Monitoring	Tasks 4.1.1, 4.1.2, 4.2 and 4.3 continue during drilling of the horizontal well	Continuation of environmental monitoring and assessment during drilling of horizontal well	Site withdrawn before completion
6.2	Microseismic Monitoring Analysis	Microseismic or other hydraulic fracturing monitoring survey performed during horizontal drilling and hydraulic fracturing	Surface sensors used to gather acoustical signatures off subsurface activities	Site withdrawn before completion
6.3	Fluids and Gas Sampling and Analysis	Detailed geochemical, isotopic, and microbial characterization of fluids and gases produced during horizontal drilling and production	Petrophysical, mineralogical, geochemical and microbial characterization of classic industry-based methods complemented by interrogation using unique tools available at OSU and its partner institutions	Site withdrawn before completion
6.4	Cuttings Acquisition and Analysis	Drill cuttings collected, analyzed, and stored	Petrophysical, mineralogical, geochemical and microbial characterization	Site withdrawn before completion
6.5	Drill Fluids Acquisition and Assessment	Fluid samples (including hydraulic fracturing fluid, flow back, and production water) collected, analyzed, and stored from the vertical hole and the horizontal well	Fluids utilized for testing new membranes and water treatment technologies allowing expanded or improved reuse of flowback and produced water	Site withdrawn before completion **See Section 4.2.6.5 Drill Fluids Acquisition and Assessment Final Report**
6.6	Borehole Analysis	Geophysical logging-while-drilling and wireline measurements collected in the horizontal well	Gamma ray, neutron porosity, bulk density, elemental spectroscopy, resistivity, and image logs and incorporated into the subsurface 3-D model	Site withdrawn before completion **See Section 4.3.5.2 Borehole Geophysics Analysis Final Report**

6.7	Design of Optimal Cement	Recommendations for optimal slurry designs	Operational considerations and contingency plans for field jobs evaluated	Site withdrawn before completion
6.8	Pipe Conveyed Logging	PCL measurements made in the horizontal well prior to the installation	PCL logs include mechanical properties, natural gamma ray, conductivity, and sidewall imaging	Site withdrawn before completion
6.9	Fiber Optics for Distributed Acoustic Sensing and Distributed Temperature Sensing	A fiber optics cable emplaced along the drill pipe to monitor hydraulic fracturing at each stage	DAS and DTS measurements conducted before, during, and after hydraulic fracturing establish production efficiency and model the extent of fracture development	Site withdrawn before completion
- - -	Hydraulic Fracturing	The well construction and hydraulic fracturing plan was to be provided by the operator of the well(s) and reviewed by the science and technical advisory committees	Best practices as defined by the Center for Sustainable Shale Development (http://sustainableshale.org/) and adapted to horizontal drilling	Site withdrawn before completion

5.0 Conclusions

The Ohio State University was awarded a contract on October 1, 2014, from the Department of Energy National Energy Technology Laboratory to develop the Utica Shale Energy Laboratory. USEEL was designed to be an environmental and technology development lab that would enable the academic, industry, government, and NGO research communities to better understand UOG resource development; and advance engineering practices and technology to increase production and safety, and decrease environmental effects. However, political and economic consequences necessitated changes in project site location and focus, and ultimately resulted in the termination of the project on September 30, 2017, before most project objectives could be achieved.

The USEEL project was initially designed with an almost equal emphasis on the environmental and socioeconomic effects of UOG hydraulic fracturing activities, and the development of engineering practices and technology to increase UOG production and safety. This concept was especially relevant when the proposed USEEL project site was at the relatively pristine EARS and the MWCD areas of east-central Ohio. Later, when the proposed project site was located on the ECA Marcellus pad in the relatively well developed area of Greene County, Pennsylvania, the focus was on subsurface geological, geophysical, and geochemical activities. Although the overall project progressed little beyond planning and administration, the following funded research projects by Graduate Research Assistants were completed or continue today.

- **Socioeconomic Impact Analysis and Opinion Assessment.** This research adds to the literature of potential impacts and perceived risks and benefits associated with shale energy development. It sought to uncover processes influencing the perceptions of technology as risky or beneficial and to develop methods to facilitate a more inclusive decision-making and planning process for future development. Critical issues facing the residents of eastern Ohio and other areas with UOG development were identified.

  The most commonly mentioned perceived risks of shale energy development included impacts to the environment and water resources, traffic and road deterioration, and crime. Economic benefits, like the windfall wealth to residents, job opportunities, and the demand for hotels and restaurants emerged as the main positive impact to the community, as cited by participants. Factors influencing perceptions of shale energy development included empowerment, uncertainty, previous experience with energy development, attachment to the physical environment or community, and direct economic benefits.

- **Experimental Study Design for Site Specific and Regional Baseline Assessments.** One of the greatest challenges in quantifying the ecological effects of hydraulic fracturing is the enormous potential for variation within and among different ecosystems and the differing hydraulic operations. Exacerbating this challenge are not only the complex interrelationships among natural resources (air, water, and soil), but disturbances associated with recreational activities, urbanization, agriculture, and other energy and mineral extractions. A full assessment of whether ecological systems are at risk from hydraulic fracturing operations requires a comprehensive research and management approach.

This research presents an experimental study design based on a framework of ecoregions (I to IV or coarsest to finest), Hydrologic Unit Code watersheds that is supported by GIS technology and databases. It is a defensible and scalable management and research framework that can be extrapolated for predictive and comparative analyses. Issues (e.g., air, water, habitat) and their potential primary impacts (e.g., decrease in surface and ground water quality and quantity, habitat fragmentation), and associated stressors (e.g., sediments, chemical compounds, nutrients) should be considered for all environmental disturbances. Preliminary results indicate that surface coal mining, urbanization, logging, and agricultural disturbances have an overall greater potential for primary environmental impacts in the Level IV ecoregions of eastern Ohio, western West Virginia, and southwestern Pennsylvania than conventional and unconventional oil and gas development.

- **Surface Water Quality.** Developing and applying effective methods to monitor exposure to not only hydraulic fracturing waste water but to other effluents produced by energy-related resource extraction operations (e.g., coal mining) in surface waters is crucial for understanding and mitigating the potential risks of these technologies. Teleost fish bio-accumulate metals from the aquatic environment into their otoliths throughout their life history and thus represent potentially valuable tools for tracking metal exposures associated with energy-related resource extraction processes.

  On-going research is accessing this exposure history through trace element analysis of the otolith using laser ablation inductively coupled plasma mass spectrometry. This methodology will be used to reconstruct the exposure histories of fish from watersheds that contain various energy-related resource extraction activities. Otolith microchemistry will be compared between fish sampled from watersheds with no resource extraction activity and those from watersheds with resource extraction activities to determine a baseline presence/absence signal for trace element exposure. Additionally, otolith microchemistry will be compared between fish in watersheds that have either hydraulic fracturing or coal mining activity in an attempt to discriminate between the signatures associated with each set of processes.

- **Biological Parameters.** The blacklegged tick *(Ixodes scapularis* (Isc)) is the vector responsible for transmitting the pathogen *Borrelia burgdorferi* (Bb), the causative agent of Lyme disease. The spread and prevalence of Isc and Bb is tied to the ecology of their mammalian hosts, which in turn, is determined by habitat and predator-prey dynamics. However, testing how ecological model predictions affect the prevalence of Lyme disease in the real world has been difficult due to the diverse species involved and the nuances of landscape configurations. A detailed Study Design, Data Generation and Acquisition Plan was developed that contained a site sampling plan, subject(s), laboratory materials, methods, and personnel necessary for completion of habitat fragmentation study were developed before the MWCD site was withdrawn.

- **Groundwater.** The original focus of work was divided into two distinct USEEL projects: the characterization of the subsurface aquifer(s) within the study area in terms of the geological framework defined by stratigraphy, natural fractures, and other subsurface pathways of fluid migration; and the characterization of the groundwater chemistry that included the chemistry of dissolved gases and salts in the water. Brines and gases associated with hydrocarbon migration (including noble gases and hydrocarbons) in groundwater were to be specifically fingerprinted for use as tracers of fluid migration. Analyses were to be performed throughout the entirety of the project (prior to, during, and after drilling) to monitor any potential fluid migration associated with the process of completing a hydraulically fractured well. Characterizing the baseline chemistry of the groundwater prior to any activity is critical to differentiating the presence of natural gases/brines in water and those introduced through anthropogenic activity.

  Numerous activities were initiated/completed for the study area before the project was terminated, including an extensive literature search of the subsurface geology, hydrology/hydrogeology, and environmental concerns; compilation of water and oil/gas wells of the study; and coordination with local and state agencies to compile an inventory of wells in eastern Ohio that penetrate the Utica Shale and have accessible geophysical well log data. Perhaps the most significant deliverable was the extensive sampling and analysis protocol QAPP for groundwater and produced gases/brines. This elaborate document combines sampling and analytical methods from the USGS, EPA and OSU laboratory protocols and serves as a complete guide for sampling and analysis in environmental and energy-related studies. While this protocol was developed specifically for USEEL research objectives, the standard operating procedures it details can be used in any study that targets the sample types and analytes discussed within it.

- **Drilling Fluids**. The broad objective of this research was to advance technology and engineering practices to increase safety and decrease environmental impact during and after hydraulic fracturing. Environmental impact-mitigation technologies that have been developed with DOE support were to be demonstrated at the end of the project term. However, the project was terminated before the proposed end-date.

  A prototype (hybrid microchannel-nanochannel proof-of-concept device), based on the novel physics that govern nanoscale water transport, was designed. This device would (a) extract useful water from flowback that would facilitate water recycling and potentially mitigating deep-well injection, and (b) be capable of separating volatile organic compounds from water found during shale gas production. In the process, a fundamental understanding of water transport was investigated in order to design novel membranes with enhanced flux and selectivity, thereby improving the state-of-the-art technologies for membrane based filtration. (It should be noted, that nearly all existing membranes are optimized for treating solutions up to seawater salinity.) Although shale flowback water was never collected from the USEEL project well, flowback water was collected from two different wells in the Utica play and one from the Marcellus play and used in prototype fabrication and surface modification experiments to evaluate desalination and solvent separation.

- **Borehole Geophysics.** In some areas of the Appalachian Basin the Utica and Point Pleasant formations are under extremely high pore pressure. The processes responsible for generating this high pore pressure and how it is maintained is poorly understood. The highest initial production rates from the Utica and Point Pleasant shale plays have been observed in wells that have targeted these areas of high pore pressure, suggesting that there is a relationship between high pore pressure and production. If high pore pressure existed in the proposed USEEL well, the cause of high pore pressure could have been investigated and a more accurate pore pressure prediction model developed. An accurate pore pressure prediction model is important for drilling and well completion to identify and quantify high pressure zones.

  If completed, the study would have been conducted using a combination of geophysical well logs from the planned USEEL well and 19 previously drilled Marcellus wells in Greene County, plus two additional Utica wells; and a 3-D seismic volume acquired by ECA. Based upon the pore pressure prediction analysis conducted on the two public wells that had adequate data to run the analysis, it appears that the Utica and Point Pleasant formations are significantly over pressured in southwestern Pennsylvania. A Bowers plot indicates that the overpressure is caused by a combination disequilibrium compaction and fluid expansion mechanisms. More public data is being acquired across the Appalachian Basin to confirm the results of the pore pressure prediction observed in the wells used in this study. This study provided insight into where high pore pressures are located within the Utica and Point Pleasant formations and what mechanisms are responsible for generating these high pore pressures.

ACRONYMS

DAS – Distributed Acoustic Sensing

DOE-NETL – Department of Energy-National Energy Technology Laboratory

DTS – Distributed Temperature Sensing

EARS – Eastern Agricultural Research Station

ECA – Energy Corporation of America

EFD – Environmentally Friendly Drilling

GIS – Geographical Information System

GRA – Graduate Research Associate

GSI - General Synfuels International

HARC – Houston Advanced Research Center

HF – Hydraulic Fracturing

HVHHF - High Volume Horizontal Hydraulic Fracturing

HUC – Hydrologic Unit Code

ICP-MS - Inductively-Coupled Plasma Mass Spectroscopy

LA-ICP-MS – Laser Ablation Inductively Coupled Plasma Mass Spectrometry

MWCD – Muskingum Watershed Conservancy District

MS – Master of Science

MWD – Measurement-While-Drilling

NCTL - Normal Compaction Trend Line

NGO – Non-governmental Organization

NORM – Naturally Occurring Radioactive Material

OSU – The Ohio State University

OSUE – Ohio State University Extension

PCL – Pipe Conveyed Logging

PhD – Doctor of Philosophy

PMP – Project Management Plan

PRM - Participatory Risk Mapping

QAPP – Quality Assurance Project Plan

STRIPES – Strategic Integrated Procurement Enterprise System

UOG – Unconventional Oil and Gas

USEEL – Utica Shale Energy and Environment Laboratory

USEPA – United States Environmental Protection Agency

USGS – United States Geological Survey

WVU – West Virginia University