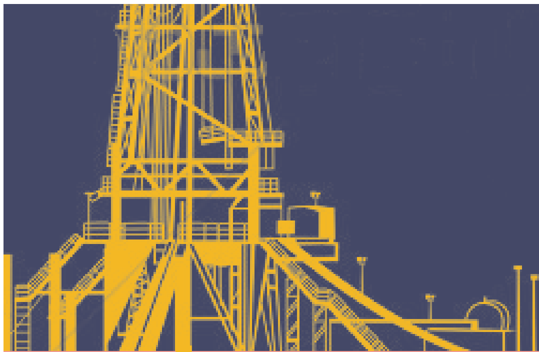
UNIVERSITY OF MICHIGAN



Environment/ Ecology Technical Report

HYDRAULIC FRACTURING IN THE STATE OF MICHIGAN

ABOUT THIS REPORT

This document is one of the seven technical reports completed for the **Hydraulic Fracturing in Michigan Integrated Assessment** conducted by the University of Michigan. During the initial phase of the project, seven faculty-led and student-staffed teams focused on the following topics: **Technology**, **Geology/Hydrogeology**, **Environment/Ecology**, **Human Health**, **Policy/Law**, **Economics**, and **Public Perceptions**. These reports were prepared to provide a solid foundation of information on the topic for decision makers and stakeholders and to help inform the Integrated Assessment, which will focus on the analysis of policy options. The reports were informed by comments from (but do not necessarily reflect the views of) the **Integrated Assessment Steering Committee**, expert peer reviewers, and numerous public comments. Upon completion of the peer review process, final decisions regarding the content of the reports were determined by the faculty authors in consultation with the peer review editor. These reports should not be characterized or cited as final products of the Integrated Assessment.

The reports cover a broad range of topics related to hydraulic fracturing in Michigan. In some cases, the authors determined that a general discussion of oil and gas development is important to provide a framing for a more specific discussion of hydraulic fracturing. The reports address common hydraulic fracturing (HF) as meaning use of hydraulic fracturing methods regardless of well depth, fluid volume, or orientation of the well (whether vertical, directional, or horizontal). HF has been used in thousands of wells throughout Michigan over the past several decades. Most of those wells have been shallower, vertical wells using approximately 50,000 gallons of water; however, some have been deeper and some have been directional or horizontal wells. The reports also address the relatively newer high volume hydraulic fracturing (HVHF) methods typically used in conjunction with directional or horizontal drilling. An HVHF well is defined by the State of Michigan as one that is intended to use more than 100,000 gallons of hydraulic fracturing fluid. The reports indicate if the text is addressing oil and gas development in general, HF, or HVHF.

Finally, material in the technical reports should be understood as providing a thorough hazard identification for hydraulic fracturing, and when appropriate, a prioritization according to likelihood of occurrence. The reports do not provide a scientific risk assessment for aspects of hydraulic fracturing.

Participating University of Michigan Units

Graham Sustainability Institute
Erb Institute for Global Sustainable Enterprise
Risk Science Center
University of Michigan Energy Institute

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HYDRAULIC FRACTURING IN THE STATE OF MICHIGAN

Environment/Ecology Technical Report

SEPTEMBER 3, 2013

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EXECUTIVE SUMMARY

As hydraulic fracturing operations expand, we seek to scientifically assess the potential impacts of hydraulic fracturing operations on ecosystems of varying scales and compositions. Generally, the closer geographical proximity of the "susceptible" ecosystem to a drilling site or a location of related industrial processes, the higher the risk of that ecosystem being impacted by the operation. Although the actual "hydraulic fracturing" process targets geologic formations well below surface level, potential impacts of infrastructure development and drilling operations (including groundwater withdrawals and wastewater processing) associated with hydraulic fracturing on surface terrestrial and aquatic ecological systems are great. This review of potential ecological effects applies to high volume hydraulic fracturing (HVHF) and also shallow/low volume fracturing. Both types of fracturing operations have similar "footprints", where the greatest potential for ecosystem impacts exists. This study is not a risk assessment but rather is identifying potential hazards associated with HVHF that may pose a risk to the environment. This study is also not a comparison of HVHF to other energy and oil, gas or coal extraction technologies, which is beyond the scope of the University of Michigan study.

Michigan's dense, interconnected aquatic ecosystems (e.g., streams, rivers, lakes, inland and coastal wetlands) and the hyporheic zones and aquifers with which they exchange water, chemicals, and organisms are of particular concern. Hydrologic connectivity of these aquatic networks to lowland and upland landscape features and associated plant, microbial and animal communities (including wildlife) can lead to impacts on terrestrial ecosystems as well. The landscape-scale connectivity, therefore, which is mediated by hydrologic flows across through watersheds and between surface and ground water bodies, can lead to impacts distant from, as well close to drilling sites.

Building the necessary roads, product transportation lines, power grid, and water extraction systems, together with the siting of drilling equipment and increased truck traffic, produces varying site-specific environmental externalities. Potential effects include: increased erosion and sedimentation, increased risk of aquatic contamination from chemical spills or equipment runoff, habitat fragmentation and resulting impacts on aquatic and terrestrial organisms, loss of stream riparian zones, altered biogeochemical cycling, and reduction of surface and hyporheic waters available to aquatic communities due to lowering groundwater levels.

In December 2012, the US Environmental Protection Agency (EPA) panel on the potential impacts of hydraulic fracturing on drinking water resources suggested that the impact of hydraulic fracturing on aquatic resources is heavily influenced by the proximity of the well site location to water resources (http://epa.gov/hfstudy/pdfs/hf-report20121214.pdf). Also of note is the EPA's suggestion that the density of wells in a specific geographic region strongly correlates to the potential for degradation of a particular ecosystem.

Michigan is fortunate to have a Wetland Protection Program and also a Water Withdrawal Assessment Tool (WWAT). These could allow for effective evaluations of potential ecological impacts from fracturing operations by considering their proximity and density in relation to sensitive and vulnerable wetlands and fisheries, such as trout streams. The focus of the WWAT is on long term groundwater withdrawal impacts to surface waters. However, questions have been raised about the ability of the tool to address short-term intensive withdrawals such as those associated with hydraulic fracturing operations and the need for periodic revisions to better account for important considerations such as streamflow, streamflow gaging, and rare ecosystems[1,2]. This tool, moreover, cannot assess the potential impacts of establishing the infrastructure and operations on habitat, wildlife, and nearby waters receiving site runoff. A surface water ecosystem relies upon a myriad of factors for its proper function. While the groundwater-surface water interchange is a key factor, other very important ecological considerations are: amount and timing of precipitation and runoff. For example, the water withdrawal tool will not measure potential changes in surface runoff patterns due to the clearing of land and road construction for fracturing operations. However, GIS-based modeling and site monitoring could allow for these potential impacts to be evaluated by ensuring proper siting and operational controls are established.

1.0 INTRODUCTION

Shale oil and gas development, if not properly managed, could adversely affect water quality due to surface water and groundwater contamination as a result of 1) spills and releases of produced water, chemicals, and drill cuttings, 2) erosion from ground disturbances, or 3) underground migration of gases and chemicals. Oil and gas development, whether conventional or from fracturing to extract shale oil and gas, can contribute to erosion, carrying varying loads of sediments and /or chemicals of concern pollutants into surface waters[3–14]. Spills into surface waters can result from spills or releases of toxic chemicals and waste that occur as a result of tank ruptures, blowouts, equipment or impoundment failures, overfills, vandalism, accidents (including vehicle collisions), ground fires, or operational errors. For example, tanks storing toxic chemicals or hoses and pipes used to convey wastes to the tanks could leak, or impoundments containing wastes could overflow as a result of extensive rainfall[3,4]. Wastewater impoundments are not allowed in Michigan for these operations.

In addition to the hazards of the leaks of natural gas itself, the fluids used in the hydraulic fracturing fluids can be toxic in their own right. Hydraulic fracturing fluids are composed of proppants, gelling agents, solvents, and biocides. The proppants, generally silica-based sand, are necessary to prop open the hydraulic fracturing cracks in the rock. In order for the proppants to seep into these cracks, a gel must first be formed that is then removed using solvents. The biocide added to hydraulic fracturing chemicals keeps the cracks from being clogged by bacterial growth and biofilm formation. Around 30 different chemicals are still used for hydraulic fracturing of tight gas and conventional gas reservoirs, but result in a mass fraction of approximately 0.5% chemicals in hydraulic fracturing fluid[15].

The chemical additives in fracturing fluid, if not properly handled, pose risks to water quality if they come into contact with surface water or groundwater. Some additives used in fracturing fluid are known to be toxic, but toxicological data are limited for other additives, Michigan law does not require disclosure of all additives (See Table 4 in the Technical Report on Policy & Law), and not all end products of reacting additives injected in shale formations are known.

2.0 STATUS AND TRENDS

2.1 Factors of Potential Concern

The industrial nature of shale oil and gas development requires operators to undertake a number of earth-disturbing activities, such as clearing, grading, and excavating land to create a pad to support the drilling equipment[3], or other necessary industrial process materials. One specific example of this equipment used in fracturing operations is the implementation of small rigs to "flare" excess gas into the atmosphere. While this practice is declining, it still occurs. These are particularly utilized when the market demand for gas is low, contributing to low natural gas prices, and thus operators' hesitance to spend capital selling gas. If necessary, operators may also construct access roads to transport equipment and other materials to the site. In general, these pads and roads are not paved, thus increasing the potential for sediment erosion on and off location[9,10,16,17]. If sufficient erosion controls to contain or divert sediment away from surface water are not established then surfaces exposed to precipitation and runoff could carry sediment and other harmful pollutants into nearby rivers, lakes, and streams. Sediment clouds water, decreases photosynthetic activity, and destroys organisms and their habitat[3]. In addition, nutrients and other chemicals tend to sorb to sediments where they accumulate and can contaminate overlying waters and biota .

Construction of the well pad, access road, and other drilling facilities requires substantial truck traffic. Up to 96% of the fleet of on-road and off-road vehicles employed in a particular hydraulic fracturing operation are diesel trucks and trailers; however, many of these trucks are being converted to natural gas resulting in reduced emissions. These trailers function to transport equipment and chemicals on-site, transport product or waste by-products off-site, and power the massive fracturing operation itself[16]. The increased traffic creates a risk to air quality as engine exhaust that contains air pollutants such as nitrogen oxides (which react to form ground-level ozone) and particulate matter that are of concern to human, environmental, and ecological health[3].

According to the EPA's National and Environmental Effects Research Laboratory, defining ecosystem health can be a nebulous effort. However, it can be equated to human health, or rather, the environment in which a human would be healthy. The Research Laboratory points out that, "Most people envision instinctively a 'healthy' ecosystem as being pristine, or at least minimally altered by human action[19]." Thus, an ecosystem with extended human impacts from industrial processes could be an unhealthy ecosystem. The vast infrastructure requirements for fracturing operations —from individual well bores, to pipeline networks—imply enormous industrial processes, and consequent significant impacts on ecosystems. Particular ways in which ecosystems may be affected are discussed later in this paper.

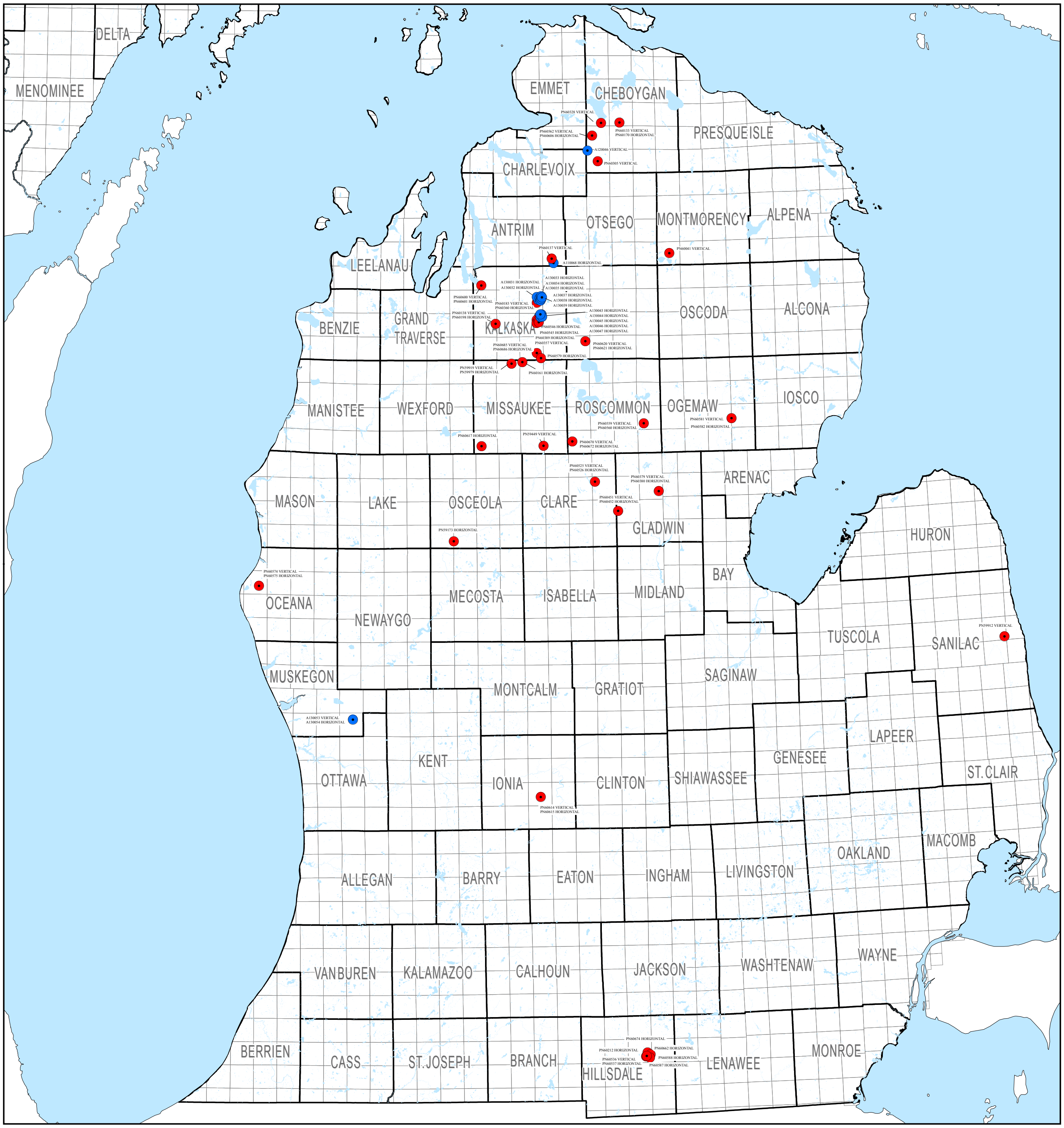
Increased networks of pipelines must be constructed to move product to storage and/or processing facilities[20,21]. Much of Michigan's shale play activity is in the northern region of the lower peninsula (Figure 1). This should be kept in mind while considering the potential ecosystems at risk.

Hydraulic fracturing chemicals are transported to drilling sites in tank trucks, and are stored and mixed at the sites. More than 750 distinct chemicals, ranging from benign to toxic, have been used in hydraulic fracturing solutions; however, usually only several are used in each operation. Although these additives are approximately 0.5 % by volume of the total fracturing fluid, hydraulic fracturing is a water-intensive process and at least 13,000 gallons of chemicals would be used for a typical 2.6 million gallon hydraulic fracturing project. Chemical and wastewater transport vehicles can potentially be involved in traffic accidents, and it is estimated that a 30 ton tank truck will have an accident every 207,000 miles. And while this does not necessarily mean that chemical emissions will occur each time, they can potentially occur nonetheless. Moreover, truck accidents that occur on public roads could result in chemicals

HIGH VOLUME HYDRAULIC FRACTURING

ACTIVE APPLICATIONS AND ISSUED PERMITS - SINCE 2008*

AS OF 5/09/2013



HIGH VOLUME (>100,000 gallons) HYDRAULIC FRACTURING SINCE 2008 - ACTIVE PERMITS

#	Permit #	Company Name	Well Name	Well No	County	Wellhead T R S	comments	target formation	Well type	Well status	Confidential
1	59112	BEACON EXPLORATION AND PRODUCTION CO LLC	SCHULTZ	1-36	SANILAC	12N 15E 36	well completed Feb. 2012	A1 Carbonate	Oil	Shut-in	NO
2	59173	CIMAREX ENERGY CO	SOPER	1-25 HD1	OSCEOLA	17N 10W 25	well completed Aug. 2008	Antrim	Gas	Plugging complete	NO
3	59449	O I L NIAGARAN LLC	HENKEL	D4-24	MISSAUKEE	21N 6W 24	proposed deepening of Antrim permit	Utica-Collingwood	Dry Hole	Plugging complete	NO
4	59979	ENCANA OIL AND GAS USA INC	PIONEER	1-3 HD1	MISSAUKEE	24N 7W 3	well completed Feb 2010	Utica-Collingwood	Gas	Shut-in	NO
5	60041	MERIT ENERGY COMPANY	HUBBEL	2-22 HD1	MONTMORENCY	29N 1E 22	well completed June, 2011	Niagaran	Oil	Producing	NO
6	60133	ENCANA OIL AND GAS USA INC	KENDALL	1-33	CHEBOYGAN	35N 2W 33	permit for vertical well	Utica-Collingwood	Dry hole	Well complete	NO
7	60137	ATLAS RESOURCES LLC	STATE MANCELONA	1-28	ANTRIM	29N 5W 28	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Dry Hole	Temporarily abandoned	NO
8	60138	ATLAS RESOURCES LLC	LUCAS	1-13	KALKASKA	26N 8W 13	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Dry Hole	Plugging complete. HD permitted	NO
9	60161	ATLAS RESOURCES LLC	STATE NORWICH	1-6 HD1	MISSAUKEE	24N 6W 6	permit for horizontal well	Utica-Collingwood	Dry Hole	Temporarily abandoned	NO
10	60170	ENCANA OIL AND GAS USA INC	STATE KOEHLER & KENDALL	1-27 HD1	CHEBOYGAN	35N 2W 33	well completed Oct 2010	Utica-Collingwood	Oil	Temporarily abandoned	NO
11	60183	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	1-24	KALKASKA	27N 6W 24	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Dry Hole	Plugging complete. HD drilled	NO
12	60198	ATLAS RESOURCES LLC	LUCAS	1-13 HD1	KALKASKA	26N 8W 13	permit for horizontal well (60138)	Utica-Collingwood	Not available	Temporarily abandoned	NO
13	60212	CONTINENTAL RESOURCES INC	KELLY ET AL	1-26 HD1	HILLSDALE	6S 2W 26	well completed Sept. 2011	Black River (Van Wert)	Oil	Producing	NO
14	60305	ENCANA OIL AND GAS USA INC	STATE WILMOT	1-21	CHEBOYGAN	33N 3W 21	well completed July 2011	Utica-Collingwood	Oil	Plugging complete	NO
15	60328	ENCANA OIL AND GAS USA INC	STATE TUSCARORA	1-34	CHEBOYGAN	35N 5W 34	permit for vertical well	Utica-Collingwood	Location	Permitted Well	YES
16	60357	ENCANA OIL AND GAS USA INC	STATE OLIVER	1-1	KALKASKA	26N 6W 1	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Dry Hole	Well complete. HD drilled	NO
17	60360	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	1-13 HD1	KALKASKA	27N 6W 24	well completed Nov 2011	Utica-Collingwood	Gas	Producing	NO
18	60379	DEVON ENERGY PRODUCTION COMPANY LP	CRONK	1-24 P	GLADWIN	19N 1W 24	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Dry Hole	Well Complete	NO
19	60380	DEVON ENERGY PRODUCTION COMPANY LP	CRONK	1-24 HD1	GLADWIN	19N 1W 24	permit for horizontal well	A1 Carbonate	Gas	Well Complete	NO
20	60389	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	1-25 HD1	KALKASKA	26N 6W 1	well completed Nov 2011	Utica-Collingwood	Gas	Producing	NO
21	60451	DEVON ENERGY PRODUCTION COMPANY LP	WILEY	1-18 P	GLADWIN	18N 2W 18	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Other	Well Complete	NO
22	60452	DEVON ENERGY PRODUCTION COMPANY LP	WILEY	1-18 HD1	GLADWIN	18N 2W 18	well completed may/june 2012	A1 Carbonate	Gas	Temporarily abandoned	NO
23	60525	DEVON ENERGY PRODUCTION COMPANY LP	SCHICK	1-7P	CLARE	19N 3W 7	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Other	Well Complete	NO
24	60526	DEVON ENERGY PRODUCTION COMPANY LP	SCHICK	1-7HD1	CLARE	19N 3W 7	well not hydraulic fractured	A1 Carbonate	Other	Well Complete	NO
25	60536	CONTINENTAL RESOURCES INC	MCNAIR ET AL	1-26 P	HILLSDALE	6S 2W 26	permit for vertical well	Black River (Van Wert)	Other	Plugging complete	NO
26	60537	CONTINENTAL RESOURCES INC	MCNAIR ET AL	1-26 HD1	HILLSDALE	6S 2W 26	permit for horizontal well	Black River (Van Wert)	Oil	Producing	NO
27	60545	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	2-25 HD1	KALKASKA	26N 6W 1	permit for horizontal well	Utica-Collingwood	Gas	Drilling complete	NO
28	60546	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	3-25 HD1	KALKASKA	26N 6W 1	permit for horizontal well	Utica-Collingwood	Location	Drilling complete	NO
29	60559	DEVON ENERGY PRODUCTION COMPANY LP	STATE RICHFIELD	1-27P	ROSCOMMON	22N 1W 27	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Other	Well Complete	NO
30	60560	DEVON ENERGY PRODUCTION COMPANY LP	STATE RICHFIELD	1-34 HD1	ROSCOMMON	22N 1W 27	permit for horizontal well (60559)	Collingwood	Gas	Well Complete	NO
31	60562	ENCANA OIL AND GAS USA INC	STATE MENTOR	1-17	CHEBOYGAN	34N 3W 17	permit for vertical well	Utica-Collingwood	Location	Permitted Well	YES
32	60574	ALTA ENERGY OPERATING LLC	RILEY	1-22	OCEANA	15N 18W 22	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Other	Plugged back	NO
33	60575	ALTA ENERGY OPERATING LLC	RILEY	1-22 HD1	OCEANA	15N 18W 22	permit for horizontal well (60574)	A1 Carbonate	Location	Drilling complete	NO
34	60579	ENCANA OIL AND GAS USA INC	STATE GARFIELD	1-25 HD1	KALKASKA	25N 6W 36	permit for horizontal well	Utica-Collingwood	Location	Drilling complete	NO
35	60581	DEVON ENERGY PRODUCTION COMPANY LP	DAVID'S ACRES, LLC	1-19 P	OGEMAW	22N 4E 19	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Other	Well Complete	NO
36	60582	DEVON ENERGY PRODUCTION COMPANY LP	DAVID'S ACRES, LLC	1-19 HD1	OGEMAW	22N 4E 19	well not hydraulic fractured	A1 Carbonate	Other	Well Complete	NO
37	60587	COUNTRYMARK ENERGY RESOURCES LLC	ARNO	1-25 HD1	HILLSDALE	6S 2W 25	permit for horizontal well	Black River (Van Wert)	Location	Permitted Well	NO
38	60588	COUNTRYMARK ENERGY RESOURCES LLC	ARNO & TIMMONS	1-24 HD1	HILLSDALE	6S 2W 24	permit for horizontal well	Black River (Van Wert)	Location	Permitted Well	NO
39	60600	ENCANA OIL AND GAS USA INC	WESTERMAN	1-29	KALKASKA	28N 8W 29	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Location	Permitted Well	YES
40	60601	ENCANA OIL AND GAS USA INC	WESTERMAN	1-32 HD1	KALKASKA	28N 8W 29	permit for horizontal well	Utica-Collingwood	Location	Permitted Well	YES
41	60606	ENCANA OIL AND GAS USA INC	STATE MENTOR	1-17 HD1	CHEBOYGAN	34N 3W 17	permit for horizontal well (60562)	Utica-Collingwood	Location	Permitted Well	YES
42	60614	ROSETTA RESOURCES OPERATING LP	CHRISTENSEN	1-21 P	IONIA	6N 6W 21	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Location	Permitted Well	YES
43	60615	ROSETTA RESOURCES OPERATING LP	CHRISTENSEN	1-21 HD1	IONIA	6N 6W 21	permit for horizontal well	A1 Carbonate	Location	Permitted Well	YES
44	60617	DEVON ENERGY PRODUCTION COMPANY LP	YOUNKMAN	1-29 HD1	MISSAUKEE	21N 8W 29	permit for horizontal well	Utica	Location	Permitted Well	YES
45	60620	ENCANA OIL AND GAS USA INC	STATE BEAVER CREEK	C3-11	CRAWFORD	25N 4W 11	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Location	Permitted Well	YES
46	60621	ENCANA OIL AND GAS USA INC	STATE BEAVER CREEK	1-23 HD1	CRAWFORD	25N 4W 11	permit for horizontal well	Utica-Collingwood	Location	Permitted Well	YES
47	60662	COUNTRYMARK ENERGY RESOURCES LLC	STIVERSON & FRENCH	1-25 HD1	HILLSDALE	6S 2W 24	permit for horizontal well	Black River (Van Wert)	Location	Permitted Well	NO
48	60670	ENCANA OIL AND GAS USA INC	STATE ROSCOMMON	D1-17	ROSCOMMON	21N 4W 17	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Location	Permitted Well	YES
49	60672	ENCANA OIL AND GAS USA INC	STATE ROSCOMMON	1-7 HD1	ROSCOMMON	21N 4W 17	permit for horizontal well	Utica-Collingwood	Location	Permitted Well	YES
50	60674	MUZYL OIL CORPORATION	BURNS	A1-23 HD1	HILLSDALE	6S 2W 23	permit for horizontal well	Black River (Van Wert)	location	Permitted Well	NO
51	60685	ENCANA OIL AND GAS USA INC	STATE GARFIELD	1-26	KALKASKA	25N 6W 26	permit for vertical well	PILOT - Not to be Hydraulic Fractured	Location	Permitted Well	YES
52	60686	ENCANA OIL AND GAS USA INC	STATE GARFIELD	1-23 HD1	HILLSDALE	25N 6W 26	permit for horizontal well	Utica-Collingwood	Location	Permitted Well	YES

HIGH VOLUME (>100,000 gallons) HYDRAULIC FRACTURING PROPOSALS - ACTIVE APPLICATIONS

#	App #	Company Name	Well Name	Well No	County	Wellhead T R S	target formation	comments
1	A110068	MERIT ENERGY COMPANY	STATE MANCELONA	8-33	ANTRIM	29N 5W 33	Utica-Collingwood	application for horizontal well
2	A120046	ENCANA OIL AND GAS USA INC	STATE WILMONT	1-6	CHEBOYGAN	33N 3W 6	Utica-Collingwood	application for vertical well
3	A130031	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	1-14 HD1	KALKASKA	27N 6W 24	Utica-Collingwood	application for horizontal well
4	A130032	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	1-12 HD1	KALKASKA	27N 6W 24	Utica-Collingwood	application for horizontal well
5	A130033	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	1-11 HD1	KALKASKA	27N 6W 24	Utica-Collingwood	application for horizontal well
6	A130034	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	2-14 HD1	KALKASKA	27N 6W 24	Utica-Collingwood	application for horizontal well
7	A130035	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	2-12 HD1	KALKASKA	27N 6W 24	Utica-Collingwood	application for horizontal well
8	A130037	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	3-12 HD1	KALKASKA	27N 6W 24	Utica-Collingwood	application for horizontal well
9	A130038	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	4-12 HD1	KALKASKA	27N 6W 24	Utica-Collingwood	application for horizontal well
10	A130039	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	5-12 HD1	KALKASKA	27N 6W 24	Utica-Collingwood	application for horizontal well
11	A130043	ENCANA OIL AND GAS USA INC	STATE OLIVER	3-13 HD1	KALKASKA	26N 6W 1	Utica-Collingwood	application for horizontal well
12	A130044	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	4-25 HD1	KALKASKA	26N 6W 1	Utica-Collingwood	application for horizontal well
13	A130045	ENCANA OIL AND GAS USA INC	STATE OLIVER	2-13 HD1	KALKASKA	26N 6W 1	Utica-Collingwood	application for horizontal well
14	A130046	ENCANA OIL AND GAS USA INC	STATE OLIVER	1-13 HD1	KALKASKA	26N 6W 1	Utica-Collingwood	application for horizontal well
15	A130047	ENCANA OIL AND GAS USA INC	STATE EXCELSIOR	5-25 HD1	KALKASKA	26N 6W 1	Utica-Collingwood	application for horizontal well
16	A130053	ROSETTA RESOURCES OPERATING LP	SWANSON TRUST	1-1 P	MUSKEGON	9N 14W 1	A1-Carbonate	application for pilot - not to be hydraulically fractured
17	A130054	ROSETTA RESOURCES OPERATING LP	SWANSON TRUST	1-1 HD1	MUSKEGON	9N 14W 1	A1-Carbonate	application for horizontal well

Legend

ISSUED ACTIVE PERMITS (52)

PENDING ACTIVE APPLICATIONS (17)

NOTE: PERMIT NUMBER AND APPLICATION NUMBER CAN BE CROSS REFERENCED BETWEEN THE MAP AND SPREADSHEET.

* HIGH VOLUME HYDRAULICALLY FRACTURED WELL COMPLETIONS ARE DEFINED IN SUPERVISOR OF WELL INSTRUCTION 1-2011 AS A 'WELL COMPLETION OPERATION THAT IS INTENDED TO USE A TOTAL OF MORE THAN 100,000 GALLONS OF HYDRAULIC FRACTURING FLUID'. WE MADE ALL EFFORTS TO TRACE BACK THE WELL COMPLETION RECORDS THRU 2008 TO COMPLILE THIS MAP AND LIST. THIS INFORMATION PROVIDED HEREIN IS ACCURATE TO THE BEST OF OUR KNOWLEDGE AND IS SUBJECT TO CHANGE ON A REGULAR BASIS, WITHOUT NOTICE. WHILE THE DEPARTMENT OF ENVIRONMENTAL QUALITY - OFFICE OF OIL, GAS, AND MINERALS (DEQ-OOGM) MAKES EVERY EFFORT TO PROVIDE USEFUL AND ACCURATE INFORMATION, WE DO NOT WARRANT THE INFORMATION TO BE AUTHORITATIVE, COMPLETE, FACTUAL, OR TIMELY. IT IS SUGGESTED THAT THIS INFORMATION BE COMBINED WITH SECONDARY SOURCES AS A MEANS OF VERIFICATION. INFORMATION IS PROVIDED "AS IS" AND AN "AS AVAILABLE" BASIS. THE STATE OF MICHIGAN DISCLAIMS ANY LIABILITY, LOSS, INJURY, OR DAMAGE INCURRED AS A CONSEQUENCE, DIRECTLY OR INDIRECTLY, RESULTING FROM THE USE, INTERPRETATION, AND APPLICATION OF ANY OF THIS INFORMATION.

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Department of Environmental Quality PURE MICHIGAN

Figure 1: Locations of High Volume Hydraulic Fracturing in Michigan according to Michigan Department of Environmental Quality[22].

being spilled on unpaved areas and draining into surface and groundwaters[16].

Evaluations of fracturing operations in central Arkansas found that surface water quality violations at site operations were due to erosion (22%), illegal discharges (10%) and spills (10%)[5]. Impacts to receiving water streams and their biota were significantly linked to well and pad densities, rate of installations, inverse flow path length, pipeline density, and a combination of roads-pasture and well density proximity[5]. These recent findings were presented at the annual meeting of the Society of Environmental Toxicology and Chemistry in November 2012 and support concerns that have previously been identified by Entrekin and others[7–14]. One critical factor is that gas wells are often located adjacent to rivers and streams. In shale basins with a high density of operations, numerous well pads may be located within the same watershed, thus compounding the cumulative impacts of industrial activity within that particular watershed. To date most research focusing on environmental concerns of hydraulic fracturing focus on contamination of groundwater and contamination of drinking water sources. However, fewer data are available to address concerns associated with surface water and terrestrial ecosystems.

The ongoing studies of Entrekin[5,7] represent one of the best and most comprehensive scientific evaluations of the impacts of fracturing operations on receiving waters and should be considered as applicable for Michigan in regards to runoff issues associated with site development. Although Entrekin's report focuses on the Fayetteville Shale in Arkansas, it is applicable to basins in Michigan if site development increases as it has in Arkansas. The comparison can be made in the broad similarities of vegetation percentage, surface cover type, moisture availability, and amount of runoff. Both Arkansas and Michigan are prone to high amounts of precipitation, and have slightly rolling topography with high percentages of vegetation cover.

Produced water will be a significant waste stream during the production phase, requiring extensive trucking to offsite injection wells. Regulations govern the disposal of this waste stream; most is disposed of by underground injection either in disposal wells or, in mature producing fields, in enhanced oil recovery wells (i.e., wells through which produced water and other materials are injected into a producing formation in order to increase formation pressure and production)[23].

In locations where naturally occurring radioactive materials (NORM)-bearing produced water and solid wastes are generated, mismanagement of these wastes can result in radiological contamination of soils or surface water bodies[24–26]. In some locations, produced water may carry NORM to the surface. Typically, the NORM radionuclides (primarily radium-226, radium-228, and their progeny) are dissolved in the produced water[25]. Proper management of NORM-bearing produced water and solid wastes are critical to prevent both occupational and public human health risks and environmental contamination. NORM waste problems are generally associated with long-term operations of oil gas fields. The NORM Technology website (http://norm.iogcc.state.ok.us/reg/dsp_statereg.cfm) provides information about the regulation of NORM bearing wastes on a state by state basis as generated by the petroleum industry[25].

Exposure of wildlife to light and noise is an additional concern, and impacts on wildlife will likely vary among types of wildlife and species (e.g. game species, migratory birds, amphibians). The main sources of noise during the production phase would include compressor and pumping stations, producing wells (including occasional flaring), and vehicle traffic. Compressor stations produce high noise levels. Use of remote telemetry equipment would reduce daily traffic and associated noise levels within the oil and gas field area. The primary impacts from noise would be localized disturbance to wildlife, livestock, recreationists, and residents. Flooding an ecosystem with excessive light can disrupt feeding, breeding, and rest patterns in micro- and mega- flora and fauna, providing a potential for ecosystem degradation.

The risks that hydraulic fracturing poses to susceptible ecosystems were studied in the adjacent Marcellus Shale region[5]. This is applicable to Michigan as models describing cumulative probability and contamination volume per well are developed. The Marcellus Shale region studies point to the need for monitoring[8–11]. A useful way to assess the potential impacts of hydraulic fracturing operations is through geographic information system (GIS)-based models that incorporate ecological, political, and fracturing features[6]. The USEPA estimates that 5 million gallons of fracturing solution is consumed per month, along with 1.5 million pounds of proppant. In the Marcellus, the EPA undertook a biological assessment of the Allegheny and Monongahela Rivers. To design their study, they first evaluated conditions via probabilistic survey for the following: fish, fish habitat, macro-invertebrates (such as mussels), water chemistry, plankton, and sediment. Data assisted in risk assessment from potential stressors, as well as aided in analyzing the potential seasonal and yearly variability. In these formations, process waters may be discharged to wastewater treatment plants; however, that will not occur in Michigan where these waters are deep-well injected.

Another tool used by the EPA in their 2008 Marcellus study was "RAIN," or, River Alert Information Network (http://www.3rain.org/). RAIN integrates information from water treatment, source water protection, and distribution system maintenance into a multiple barrier approach. The goal of RAIN is to employ protection measures to form a first barrier to a multiple-barrier approach to drinking water protection. This includes providing information and tools to aid water suppliers in making decisions, and improving communication between water suppliers about water quality events. RAIN implements these goals by installing monitoring equipment at appropriate locations and providing operational training. The EPA RAIN administrators will develop a secure website to share information about water quality, as well as improve communication between water suppliers, the US Army Corps of Engineers (USACE) and emergency responders.

RAIN covers the areas of the Allegheny, Monongahela, Youghiogheny, and headwaters of the Ohio River. The particular communication system is governed on spill alerts, alarm notifications, and water supplier roundtables. RAIN's monitoring systems are based on-line, continuous monitoring equipment, and operator training. The RAIN website employs water quality data, both historical and current, and provides links to other applicable websites that provide monitoring data such as the US Geological Survey (USGS), National Oceanic and Atmospheric Administration, National Weather Service, and the USACE. The RAIN's Monongahela Total Dissolved Solids Project Monitoring Effort is composed of ten RAIN facilities that measure conductivity, pH and temperature. Additionally, RAIN has four remote tributary sites with data readings. The remote sites measure conductivity, pH and temperature. RAIN has proposed 11 more 15-member monitoring facilities. Monitoring efforts will focus on the environmental constituents of concern: nitrate, ammonia, dissolved oxygen, UV organics, suspended solids and turbidity, as well as ORP.

As a tandem effort to RAIN, the EPA initiated a waste characterization study to measure TDS, metals, organics and TENORM. The study is dual-phased, with Phase I focusing on site-specific characteristics across the region. In Pennsylvania, the rapid pace of Marcellus Shale drilling has outstripped Pennsylvania's ability to document pre-drilling water quality, even with some 580 organizations focused on monitoring the state's watersheds. More than 300 are community-based groups that take part in volunteer stream monitoring. Unlike the Marcellus Shale region, there will not be discharges of process waters to wastewater treatment plants or surface impoundments in Michigan; however, there is a need for similar surface water monitoring programs as described above, both pre- and post-drilling operations.

2.2 State of Michigan Programs

State specific regulations concerning surface waters and hydraulic fracturing operations in Michigan are driven by the Michigan Department of Environmental Quality (DEQ) (drilling permit) and Michigan Department of Natural Resources (DNR) (Well-site permit for State of Michigan owned surface lands) (see the Technical Report on Policy & Law for details). Before permits are issued, DNR and DEQ personnel evaluate any potential sensitive ecosystems, considering endangered and threatened species, streams and fisheries, and other relevant issues.

The State permitting process dictates that all hydraulic fracturing operations reduce their potential impact on-site through a variety of measures. These include construction of the well-pad at least 1320 feet from the nearest stream for State leases. For private properties, the DEQ requires optimal location that protects surface water while considering a host of other property and environmental issues. The State's considerations also include land elevations, avoiding hillsides, and always using silt curtains. All pervious site grounds are covered in plastic to capture any potential spillage. Permitted sites are for a drilling unit (a tract which the DEQ has determined can be efficiently drained by one well), which is generally a minimum of 80 acres in size but often much larger, while the working pad area is usually less than 5 acres regardless of unit size. Lined-berms are put in place to contain tank or pipe spills. The DEQ (and the DNR where State acreage is involved) also evaluates where roads may be constructed. Well operators are required to have spill pollution prevention plans. After site operations cease, the owners are required to reclaim the site using native species of vegetation. All of these procedures are encouraging if implemented and if monitored routinely by State personnel. The primary hazard of operations appears to be that of trucking production brine waters from the fracturing process. This leads to the possibility of vehicle related accidents, and increased dust and erosion from dirt roads. Some of the public health issues related to this are covered in a subsequent chapter.

Michigan DEQ has developed a fairly robust Wetlands Protection program, stemming from Part 303 of the Natural Resources and Environmental Protection Act (NREPA), PA 451 of 1994 (NREPA). The statute requires protection of wetlands under private and public land, without respect to zoning or ownership. However, with respect to wetland protection, it is important to remember that even though the acreage sizes of wetlands may be small, they are generally interconnected systems. Even very small wetlands can still be important surface water sources and reserves. With this scenario in mind, when considering the accidental spills or unintentional impacts of any hydraulic fracturing operations, it is important to remember that there is a connection between water quantity and quality. Taking water from a small stream concentrates any contaminants in the stream water. If stream flow is reduced by groundwater withdrawals, the lower dilution rate of any solids loadings or other contaminants from the watershed can damage ecosystems and harm aquatic life.

Michigan's WWAT[2] is designed to estimate the likely Adverse Resource Impact of a water withdrawal on nearby streams and rivers (http://www.miwwat.org/). Use of the WWAT is required of anyone proposing to make a new or increased large quantity withdrawal (over 70 gallons per minute) from the waters of the state, including all groundwater and surface water sources, prior to beginning the withdrawal. The Michigan Senate and House enacted new legislation to manage large water withdrawals in the state using science as the basis for policy development, including a water withdrawal assessment process for high capacity wells. These Public Acts became part of Michigan Compiled Laws and amended Part 327 (Great Lakes Preservation) of the NREPA and the Safe Drinking Water Act (SDWA), PA 399 of 1976. Fracturing operations will be assessed during the permit review process by the WWAT to determine if a proposed withdrawal is likely to cause an Adverse Resource Impact. This system allows for an evaluation of potential impacts to many sensitive ecosystems but has limitations, as discussed below.

Currently the State is not maintaining a registry of the hydraulic fracturing operation water withdrawals or entering them into the water withdrawal accounting system to be subtracted from the available water balance. However, the DEQ does account for prior withdrawals for hydraulic fracturing. The hydraulic fracturing withdrawals are kept in a separate database and included in later assessments on a case-by-case basis. After the WWAT analyses is conducted and approved for a hydraulic fracturing operation permit, the withdrawals are no longer considered in relation to other applications or operations in the area. Given that fracturing operations can be dense and adjacent to each other, this creates the possibility for negative cumulative impacts from high volume water withdrawals. Indeed recent operations will be in the tens of millions of gallons extracted for each operation. It can take months to years for groundwater aquifers to replenish after large extractions, therefore the impacts of multiple operations within the same aquifer with not be assessed by the WWAT.

Some of the State's surface waters most sensitive to groundwater withdrawals are classified as cold transitional and cold waters. Streams whose headwaters are shallow are particularly at risk during drought and low flow periods. The WWAT may not fully account for the shallow stream morphology. Based on a limited analysis, Jocks and Bzdok (2010) question using the tool in its current form for analyzing the impacts of withdrawals on small streams and rivers[28]. In addition, this tool does not account for water withdrawal impacts to wetlands and lakes. The WWAT estimates surface water flows across the state from fewer than 150 USGS river and stream gauges, which tend to be located on medium and large sized streams. Sensitive headwaters are rarely monitored; therefore the WWAT model has high associated uncertainties. It was primarily designed to account for long term withdrawals, such as agricultural irrigation. However, questions have been raised about the ability of the tool to address short-term intensive withdrawals such as those associated with hydraulic fracturing operations[1]. It is also a concern that the massive quantities being removed from the aquifer are not being replaced, but rather deep-well injected.

Some relevant questions that arise from the hydraulic fracturing operations that the current version of WWAT cannot answer are: Will local hydrologic cycles be altered? How long before they recover? How do water withdrawals during winter conditions impact fish during this sensitive time for their survival? Are stream base flow estimates accurate? What are base flows for critical headwater streams? When the Legislature approved the WWAT, the authors of the approach stressed that "Any implementation […of the recommended WWAP] must include a plan for ongoing, periodic field testing and review and revision of the process and tool."[2] The WWAT has never been updated and remains as Version 1. There is a critical need to update the model to better account for wetlands, shallow streams, and high volume water withdrawals.

The prospects of a changing regulatory environment that could result in shifting priorities from protection of resources to production of renewable and non-renewable commodities impact risks to ecological systems. For example, Michigan Senate Bill 78[29] recently passed by the state Senate and headed for a vote in the House of Representatives would modify Michigan's Natural Resources and Environmental Protection Act to explicitly prohibit state agencies from designating or classifying an area of land for the purpose of achieving or maintaining biological diversity. In addition, the bill redefines the goals of biological conservation to be more aligned with managing public lands for economic interests, eliminates text about managing forests for sustainability, and eliminates text saying that biodiversity loss is primarily caused by humans. While biodiversity is not one of the specific criteria used by the DNR for nondevelopment lease classification[30], this bill raises questions about the likelihood that hydraulic fracturing operations could be allowed in natural/wild/wilderness areas. The associated well-pad and road construction, habitat loss, and associated human activities would undoubtedly pose threats to sensitive ecosystems that have historically been protected. Further analysis is needed regarding the potential impact of this legislation.

3.0 CHALLENGES AND OPPORTUNITIES

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 fracturing operation sizes, pad densities and quality control measures. Additionally, as multiple well sites are established within watersheds, there is potential for the ecological effects of these fracturing operations to interact. Upstream wells, for example, could impact water flows, turbidity or nutrient and TDS loadings of aquatic communities far downstream, particularly if impacts of downstream wells are additive or synergistic.

Another challenge lies in the examination of the effects of fracturing operations before, during, and after the actual hydraulic fracturing occurs. Typically wells will only be actively fractured in a one to two month time frame. However, the ecological effects of the fracturing begin as soon as infrastructure construction is initiated, and last through the fracturing phase, and for an un-established period of time after fracturing is finished. Related to this is the inability to assess whether an actual ecological impact has occurred due to the lack of monitoring. Very few sites exist across the nation where baseline (reference condition) environmental monitoring has occurred prior to hydraulic fracturing operations commencing. From both scientific and practical perspectives it is difficult to establish "impacts" if the baseline is unknown, particularly if these operations are occurring in human dominated watersheds. It is essential that at least a subset of hydraulic fracturing operations have pre- and post-monitoring of environmental conditions to establish whether or not detrimental impacts are occurring.

One example of an ongoing effort to characterize the effects of the development of shale gas resources through hydraulic fracturing is by a forest conservation organization, called the Pinchot Institute for Conservation[31]. The Pinchot Institute is in the process of implementing non-partisan research on the future of sustainable resource management. Their interdisciplinary workshop in 2011 outlined ways in which scientific methods are being established to cumulatively assess the various facets of shale gas development that impact any ecosystem[32]. Three specific key factors analyzed by this report are: the location planning for water withdrawals, timing of water withdrawals, and the centralization of infrastructure. Presumably, if the timing of water withdrawals could be initiated during a time of groundwater recharge, the effect to surface water ecosystems would be diminished. Additionally, if the location of groundwater withdrawals could be located at a feasible distance from ecologically susceptible biodiversity, possible harm to surface water ecosystems could also be diminished. And, lastly, if the infrastructure utilized to perform the withdrawals could be centrally located, the infrastructure operator could reduce the potential area for ecological impact[31].

Although chemical spills are less frequent than chronic habitat disturbance and erosion, it is important to begin to understand the toxicity of the wide-range of hydraulic fracturing chemicals and combinations of these chemicals that may be released in produced waters, in addition to any pure chemical products stored on-site.

Full assessment of the complex task of determining whether ecological systems are at risk from hydraulic fracturing operations requires a comprehensive, watershed-based research and management approach. An appropriate analogy that may be useful is the Total Maximum Daily Loading (TMDL) program, used widely by EPA and the States, which offers a useful watershed-based framework for this task and accounts for the cumulative contributions of multiple sources to receiving waters. Although oil and gas operations are not granted surface water discharges, the idea of considering environmental and groundwater "loadings or use" on a watershed by watershed basis is appropriate. The TMDL is a useful tool in establishing particular watersheds, water bodies, or water basins that may be impaired. The TMDL was developed under section 303(d) of the Clean Water Act that requires states or territories to develop lists of waters that are "impaired" or otherwise too degraded to meet water quality standards[32]. The TMDL actually calculates a maximum amount of pollutant that a body of water can maintain, while still adhering to the approved water quality standards[32]. The TMDL tool provides curves that aid in a calculation of the duration that a particular pollutant or chemical of concern can last in a certain water body. Thus, an industrial operator, or monitoring agency, could use this approach to evaluate how to assess the potential terrestrial and surface water impacts of multiple HVHF operations within a watershed. The WWAT must be modified to consider cumulative withdrawal impacts from operations drawing on the same aquifer, at extremely high volumes, during biologically sensitive seasonal periods.

There are extensive studies ongoing to determine the environmental and ecological impacts of hydraulic fracturing. For example, EPA provided a progress report on their study of the potential impacts of hydraulic fracturing on drinking water resources in December 2012 (http://www.epa.gov/hfstudy/). In January of this year, Glenn Paulson, EPA's science advisor, was hopeful that the agency's nationwide project examining natural gas hydraulic fracturing and potential drinking water impacts will provide comprehensive guidelines. The report will be released in 2014. EPA, DOE and DOI signed a MOU in April 2012 to align their research in 2013. They are also including CDC, NIOSH and other HHS agencies to be engaged on their steering committee.

Michigan is fortunate to have a Wetland Protection Program and also a WWAT and a comprehensive permitting program by the DNR and DEQ that consider the local environmental impacts and source controls. These could allow for effective evaluations of potential ecological impacts from fracturing operations by considering their proximity and density in relation to sensitive and vulnerable wetlands and fisheries, such as shallow trout streams and cold transitional waters. The focus of the WWAT is on long-term, growing season, groundwater withdrawal impacts to surface waters but may require updating to address questions associated with short-term extremely high volume extractions, multiple operations in the same watershed, shallow streams, and headwater base flow conditions[1,2]. This screening tool, currently designed, may not identify ecologically sensitive situations. This tool will also not assess the potential impacts of establishing the infrastructure and operations on habitat, wildlife, and nearby waters receiving site runoff. Routine site inspections will be required to ensure site erosion is minimal and spill prevention plans are being followed. GIS-based modeling and site monitoring will allow for these potential impacts to be evaluated ensuring proper siting and operational controls are established and followed.

4.0 PRIOTIZED PATHWAYS FOR PHASE 2

- Establish a decision-matrix that guides decision making on establishing hydraulic fracturing operations in "sensitive/susceptible" ecosystems.
- Establish baseline (reference condition) ecosystem monitoring in susceptible areas that continues through post-operation periods to establish whether or not detrimental impacts occur.
- Assess the cumulative impacts of multiple hydraulic fracturing operations within a watershed for downstream surface waters and groundwater. Update the WWAT Version 1 to reduce critical uncertainties identified above.
- Establish to what degree other likely stressors in watershed, unrelated to fracturing operations, impact aquatic communities.
- Identify areas for improved quality control / best practices in fracturing operations, especially near riparian zones, surface waters and shallow aquifers.
- Establish a publically available database for HVHF studies and data.
- It is important that close attention be paid to the findings published in the "peer-reviewed" scientific literature in the coming months to years to improve decision-making.
- Any assessment of ecological health impacts from this energy-driven activity, should in turn, evaluate how these potential impacts compare to the environmental impacts of energy-related activities, such as coal mining, that it may be replacing.

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