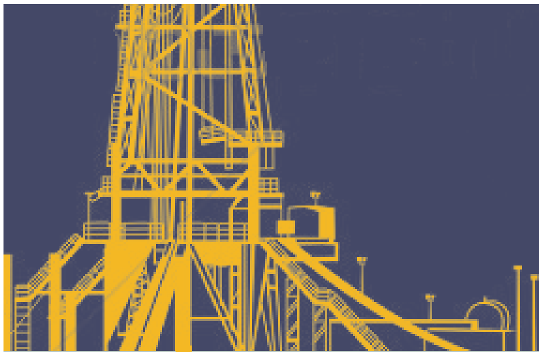


UNIVERSITY OF MICHIGAN

Overview + Glossary

HYDRAULIC FRACTURING IN THE STATE OF MICHIGAN

Participating University of Michigan Units

Graham Sustainability Institute

Erb Institute for Global Sustainable Enterprise

Risk Science Center

University of Michigan Energy Institute

THIS PUBLICATION IS A RESULT OF WORK SPONSORED BY THE UNIVERSITY OF MICHIGAN

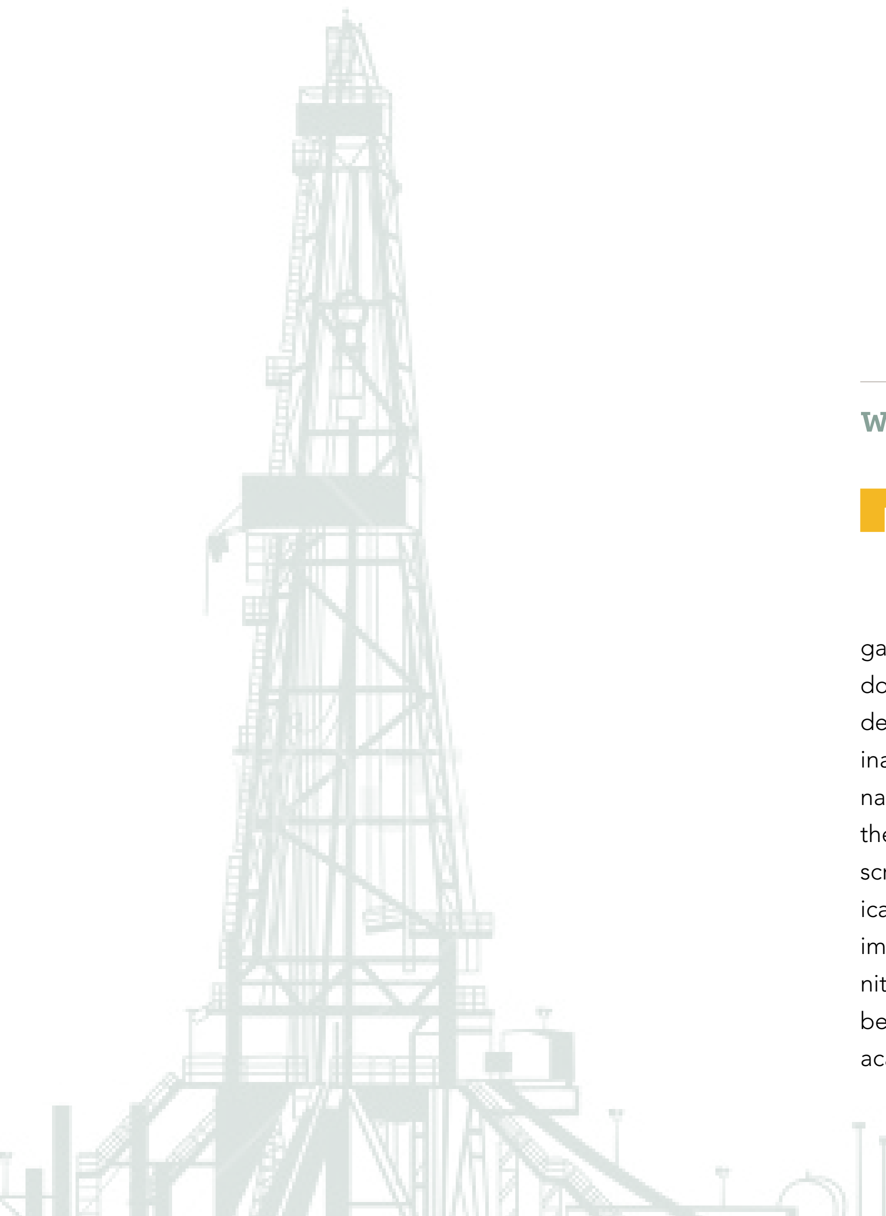
Direct questions to **grahaminstitute-ia@umich.edu**

GRAHAM SUSTAINABILITY INSTITUTE INTEGRATED ASSESSMENT REPORT SERIES
VOLUME II, REPORT 1

HYDRAULIC FRACTURING IN THE STATE OF MICHIGAN

Overview + Glossary

SEPTEMBER 3, 2013



WHAT IS THE ISSUE?

There is significant momentum behind natural gas extraction efforts in the United States, with many individual states embracing it as an opportunity to create jobs and foster economic strength. Natural gas extraction has also been championed as a way to move toward domestic energy independence and a cleaner energy supply. First demonstrated in the 1940's, hydraulic fracturing is now the predominant method used to extract natural gas in the U.S. As domestic natural gas production has accelerated in recent years, however, the hydraulic fracturing process has come under increased public scrutiny. Concerns include perceived lack of transparency, chemical contamination, water availability, waste water disposal, and impacts on ecosystems, human health, and surrounding communities. Consequently, numerous hydraulic fracturing studies are being undertaken by government agencies, industry, NGO's, and academia, yet none have a particular focus on Michigan.

What is Happening in Michigan?

Recent interest from energy developers, lease sales, and permitting activities suggest increasing activity around deep shale gas extraction in Michigan.

- Roughly 9,800 Antrim Shale wells are currently in production and hydraulic fracturing was used as part of the completion activity in virtually every one of these wells without incident. Most of these wells were drilled and completed in the late 1980s and early 1990s. Some new activity will still take place, and a very small number of the old wells may be hydraulically fractured in the future, but this is a "mature" play and is unlikely to be repeated.
- The hydrocarbon resources in the Utica and Collingwood Shales in Northern Michigan will likely require hydraulic fracturing.
- A May 2010 auction of state mineral leases brought in a record $178 million—nearly as much as the state had earned in the past 82 years of lease sales combined. Most of this money was spent for leases of State-owned mineral holdings with the Utica and Collingwood Shales as the probable primary targets.
- Some ground water zones in Michigan are closer to gas zones than in other shale gas regions. It is significant that the Antrim Formation is only about 100 to about 1000 feet below the potential fresh water zones, and approximately 9,800 wells have been completed with no known contamination of fresh water zones to date. The Utica and Collingwood Shales are 3,000 to 10,000 feet below the fresh water zones.
- State representatives have proposed packages of bills to regulate hydraulic fracturing, and state officials are reviewing existing regulations.

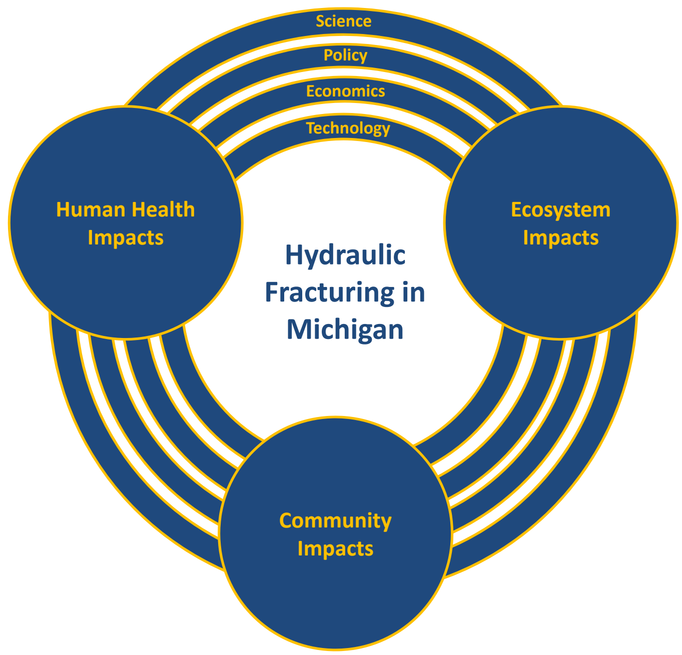
Recognizing this context and that future hydraulic fracturing treatments will likely be of very high volume suggests a need for Michigan to be as well prepared as possible to manage this trend.

What is being Done?

Through a research-based partnership of University of Michigan (U-M) institutes, centers, and faculty, we are holistically evaluating the impacts of hydraulic fracturing in Michigan. Hydraulic fracturing has the potential to touch issues that all Michigan residents care about - drinking water, air quality, Great Lakes health, water supply, local land use, energy security, economic growth, tourism, and natural resource protection. This project's technical analysis, stakeholder engagement, and proposed approaches to minimize negative impacts will be important outcomes that guide future decision making on this issue and hopefully help state decision makers avoid some of the pitfalls encountered in other states. The project is based on the premise that natural gas extraction pressures will likely increase in Michigan due to a desire for job creation, economic strength, energy independence, and cleaner fuels.

What is Our Approach and Expertise?

This project is using Integrated Assessment (IA) (http://graham.umich.edu/knowledge/ia), which is a useful method for analyzing environmental, social, and economic dimensions of challenging sustainability problems. The IA process achieves significant impact by leveraging interdisciplinary faculty expertise and engaging decision makers and stakeholders outside of academia to affect policy analysis and decision making.



The figure above illustrates an IA framework focusing on hydraulic fracturing and its impact on Michigan's communities, human health, and ecosystems. The project is:

- Leveraging and building upon U-M's existing relationships to facilitate successful partner and stakeholder engagement.
- Drawing on key studies and regulatory approaches from across the country. Because hydraulic fracturing is thus far less contentious in Michigan, this project can be a platform to consider multiple stakeholder perspectives.
- Acknowledging that hydraulic fracturing is likely to be part of Michigan's future while providing analysis to address concerns and determine what strategies may be needed to improve the process.

Currently identified U-M partners with relevant expertise include:

- The Graham Environmental Sustainability Institute is a boundary organization connecting academics and policy-makers to address challenging sustainability problems.
- The Risk Science Center is an interdisciplinary research and communication center in the School of Public Health that supports science-informed decision making on health risks.
- The Energy Institute seeks to chart the path to a clean, affordable and sustainable energy future through multi-disciplinary research.
- The Erb Institute for Global Sustainable Enterprise is committed to creating a socially and environmentally sustainable society through the power of business.

How Long Will it Take?

IA's typically involve a 2 year timeline, the approach allows for flexibility and interim deliverables based on partners' needs.

PROCESS

Phase 1: Technical Reports

An effective IA in this context first requires compiling technical reports to provide a solid foundation of information for decision makers and stakeholders, and upon which the policy analysis can be built. These reports cover key issues within each topic related to hydraulic fracturing, and conclude with Michigan-specific questions/issues for later analysis in Phase 2. Below are the primary topics which were identified for the technical reports and the lead authors for each report:

- **Technology**: Johannes Schwank, Chemical Engineering; John Wilson, U-M Energy Institute
- **Geology/hydrogeology**: Brian Ellis, Civil and Environmental Engineering
- **Environment/ecology**: Allen Burton, School of Natural Resources & Environment; Knute Nadelhoffer, Department of Ecology and Evolutionary Biology
- **Human health**: Nil Basu, School of Public Health
- **Policy/law**: Sara Gosman, Law School
- **Economics**: Roland Zullo, Institute for Research on Labor, Employment, & the Economy
- **Social/public perception**: Andy Hoffman and Kim Wolske, Erb Institute for Global Sustainable Enterprise

Each report considers a range of impacts/issues related to the primary topic. There may be overlaps of impacts/issues analyses as many of the items connect to multiple topics. Below is a non-exhaustive list of possible impacts/issues which may be considered in the technical reports. While the IA has been developed to focus on High Volume Hydraulic Fracturing (HVHF) in Michigan (defined by the Michigan Department of Environmental Quality as hydraulic fracturing activity intended to use a total of more than 100,000 gallons of hydraulic fracturing fluid), data and analyses may cover a range of activity depending on topic or issue.

Groundwater Impacts	Health Impacts
Surface Water Impacts	Community Benefits/Impacts
Risk Assessment	State Economy Impact
Air Quality Impacts	Indirect Impacts (noise, traffic, roads)
Fracturing Materials	Catastrophic Events
Federal-State-Local Policy Nexus	Emergency Preparedness
Process Innovations	Public Perception
Life Cycle Assessment	Communications and Messaging
Non-regulatory Strategies	Local Land Use Policy
Terrestrial and Aquatic System Impacts	Lease Agreements/Good Neighbor Models
Hydraulic Fracturing in Oil Production	Management and Reuse of Flowback Water
Methane Gas Releases	On-site Diesel Emissions

Phase 2: Integrated Assessment

The IA will build from the technical reports, focus on identifying strategic policy options, and work to address the following guiding question:

What are the best environmental, economic, social, and technological approaches for managing hydraulic fracturing in the State of Michigan?

The IA will likely be formed around topics identified in the technical reports and faculty authors from Phase 1 will likely be involved with the IA as leaders of topic specific analysis teams. However, new faculty may also become engaged at this point.

Key aspects of the IA that will distinguish it from the technical reports include:

- focus on the identification of key strategies and policy options,
- collaboration and coordination across analysis teams to identify common themes and strategies,
- regular engagement with decision makers, and
- robust stakeholder engagement process to gauge public concerns and perceptions.

Steering Committee

The following steering committee has been assembled to guide project efforts including the configuration and structure of the IA during Phase 2:

- Mark Barteau, Director, U-M Energy Institute
- Valerie Brader, Senior Strategy Officer, Office of Strategic Policy, State of Michigan
- John Callewaert, Int. Assessment Program Director, U-M Graham Sustainability Institute
- James Clift, Policy Director, Michigan Environmental Council
- John De Vries, Attorney, Mika Meyers Beckett & Jones; Michigan Oil and Gas Association
- Hal Fitch, Director of Oil, Gas, and Minerals, Michigan Department of Environmental Quality
- Gregory Fogle, Owner, Old Mission Energy; Michigan Oil and Gas Association
- James Goodheart, Senior Policy Advisor, Michigan Department of Environmental Quality
- Andy Hoffman, Director, U-M Erb Institute for Global Sustainable Enterprise
- Drew Horning, Deputy Director, U-M Graham Sustainability Institute
- Andrew Maynard, Director, U-M Risk Science Center
- Tammy Newcomb, Senior Water Policy Advisor, Michigan Department of Natural Resources
- Don Scavia, Director, U-M Graham Sustainability Institute
- Tracy Swinburn, Managing Director, U-M Risk Science Center
- Grenetta Thomassey, Program Director, Tip of the Mitt Watershed Council
- John Wilson, Consultant, U-M Energy Institute

The role of the steering committee is to provide broad stakeholder input and guidance to the overall IA process and to ensure the scope of study is relevant to key decision makers. Committee members may also provide data and input to research teams throughout the process, but decisions regarding content of project analyses and reports are determined by the researchers.

Engagement

The IA will be informed by semi-annual meetings with analysis teams and the steering committee for project updates and discussions. Twice during the IA, these meetings will involve a larger group of decision makers and stakeholders. An online comments/ ideas submission site has been established to direct public input to the steering committee and analysis teams: http://graham.umich.edu/knowledge/ia/hydraulic-fracturing

Funding

At present, the IA is entirely funded by the University of Michigan. The project is expected to cost at least $600,000 with support coming from the University of Michigan's Graham Institute, Energy Institute and Risk Science Center. Current funding sources are limited to the U-M general fund and gift funds, all of which are governed solely by the University of Michigan. As the project develops, the Graham Institute may seek additional funding to expand stakeholder engagement efforts. All funding sources will be publicly disclosed.

Timeline

- Mid May 2013: steering committee and technical report leads meet to discuss technical reports and plans for the Integrated Assessment
- Early September 2013: technical reports are released with 30 day public comment period for ideas and questions for the Integrated Assessment
- Early Fall 2013: plans are developed for the Integrated Assessment
- Mid 2014: final Integrated Assessment report released (tentative)

Direct comments or questions to: **grahaminstitute-ia@umich.edu**

HYDRAULIC FRACTURING GLOSSARY OF COMMONLY USED TERMS[1]

AIR QUALITY. A measure of the amount of pollutants emitted into the atmosphere and the dispersion potential of an area to dilute those pollutants.

AQUIFER. A body of rock that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs.

BASIN. A closed geologic structure in which the beds dip toward a central location; the youngest rocks are at the center of a basin and are partly or completely ringed by progressively older rocks.

BIOGENIC GAS. Natural gas produced by living organisms or biological processes.

CASING. Steel piping positioned in a wellbore and cemented in place to prevent the soil or rock from caving in. It also serves to isolate fluids, such as water, gas, and oil, from the surrounding geologic formations.

COAL BED METHANE/NATURAL GAS (CBM/CBNG). A clean-burning natural gas found deep inside and around coal seams. The gas has an affinity to coal and is held in place by pressure from groundwater. CBNG is produced by drilling a wellbore into the coal seam(s), pumping out large volumes of groundwater to reduce the hydrostatic pressure, allowing the gas to dissociate from the coal and flow to the surface.

COMPLETION. The activities and methods to prepare a well for production and following drilling. Includes installation of equipment for production from a gas well.

CONVENTIONAL NATURAL GAS. Natural gas comes from both 'conventional' (easier to produce) and 'unconventional' (more difficult to produce) geological formations. The key difference between "conventional" and "unconventional" natural gas is the manner, ease and cost associated with extracting the resource. Exploration for conventional gas has been almost the sole focus of the oil and gas industry since it began nearly 100 years ago. Conventional gas is typically "free gas" trapped in multiple, relatively small, porous zones in various naturally occurring rock formations such as carbonates, sandstones, and siltstones.

CORRIDOR. A strip of land through which one or more existing or potential utilities may be colocated.

DISPOSAL WELL. A well which injects produced water into an underground formation for disposal.

DIRECTIONAL DRILLING. The technique of drilling at an angle from a surface location to reach a target formation not located directly underneath the well pad.

DRILL RIG. The mast, draw works, and attendant surface equipment of a drilling or workover unit.

EMISSION. Air pollution discharge into the atmosphere, usually specified by mass per unit time.

ENDANGERED SPECIES. Those species of plants or animals classified by the Secretary of the Interior or the Secretary of Commerce as endangered pursuant to Section 4 of the Endangered Species Act of 1973, as amended. See also Threatened and Endangered Species.

EXPLORATION. The process of identifying a potential subsurface geologic target formation and the active drilling of a borehole designed to assess the natural gas or oil.

FLOW LINE. A small diameter pipeline that generally connects a well to the initial processing facility.

FORMATION (GEOLOGIC). A rock body distinguishable from other rock bodies and useful for mapping or description. Formations may be combined into groups or subdivided into members.

FRACTURING FLUIDS. A mixture of water and additives used to hydraulically induce cracks in the target formation.

GROUND WATER. Subsurface water that is in the zone of saturation; source of water for wells, seepage, and springs. The top surface of the groundwater is the "water table."

HABITAT. The area in which a particular species lives. In wildlife management, the major elements of a habitat are considered to be food, water, cover, breeding space, and living space.

1. General sources include:
- "Modern Shale Gas Development," a Department of Energy Report: www.eogresources.com/responsibility/doeModernShaleGasDevelopment.pdf
- The Canadian Association of Petroleum Products: www.capp.ca/CANADAINDUSTRY/NATURALGAS/CONVENTIONAL-UNCONVENTIONAL/Pages/default.aspx
- The Union of Concerned Scientists: www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/how-natural-gas-works.html

HIGH VOLUME HYDRAULIC FRACTURING. High volume hydraulic fracturing well completion is defined by the State of Michigan as a "well completion operation that is intended to use a total of more than 100,000 gallons of hydraulic fracturing fluid."[2]

HORIZONTAL DRILLING. A drilling procedure in which the wellbore is drilled vertically to a kickoff depth above the target formation and then angled through a wide 90 degree arc such that the producing portion of the well extends horizontally through the target formation.

HYDRAULIC FRACTURING. Injecting fracturing fluids into the target formation at a force exceeding the parting pressure of the rock thus inducing a network of fractures through which oil or natural gas can flow to the wellbore.

HYDROSTATIC PRESSURE. The pressure exerted by a fluid at rest due to its inherent physical properties and the amount of pressure being exerted on it from outside forces.

INJECTION WELL. A well used to inject fluids into an underground formation either for enhanced recovery or disposal.

LEASE. A legal document that conveys to an operator the right to drill for oil and gas. Also, the tract of land, on which a lease has been obtained, where producing wells and production equipment are located.

NORM (Naturally Occurring Radioactive Material). Low-level, radioactive material that naturally exists in native materials.

ORIGINAL GAS IN PLACE. The entire volume of gas contained in the reservoir, regardless of the ability to produce it.

PARTICULATE MATTER (PM). A small particle of solid or liquid matter (e.g., soot, dust, and mist).PM10 refers to particulate matter having a size diameter of less than 10 millionths of a meter (micrometer)and PM2.5 being less than 2.5 micro-meters in diameter.

PERMEABILITY. A rock's capacity to transmit a fluid; dependent upon the size and shape of pores and interconnecting pore throats. A rock may have significant porosity (many microscopic pores) but have low permeability if the pores are not interconnected. Permeability may also exist or be enhanced through fractures that connect the pores.

2. Department of Environmental Quality, Supervisor of Wells Instruction 1-2011 (2011), available at www.michigan.gov/documents/deq/SI_1-2011_353936_7.pdf (effective June 22, 2011). Michigan.

PRIMACY. A right that can be granted to state by the federal government that allows state agenciesto implement programs with federal oversight. Usually, the states develop their own set of regulations. By statute, states may adopt their own standards, however, these must be at least as protective as the federal standards they replace, and may be even more protective in order to address local conditions. Once these state programs are approved by the relevant federal agency (usually the EPA), the state then has primacy jurisdiction.

PRODUCED WATER. Water produced from oil and gas wells.

PROPPING AGENTS/PROPPANT. Silica sand or other particles pumped into a formation during a hydraulic fracturing operation to keep fractures open and maintain permeability.

PROVED RESERVES. That portion of recoverable resources that is demonstrated by actual production or conclusive formation tests to be technically, economically, and legally producible under existing economic and operating conditions.

RECLAMATION. Rehabilitation of a disturbed area to make it acceptable for designated uses. This normally involves regrading, replacement of topsoil, re-vegetation, and other work necessary to restore it.

SETBACK. The distance that must be maintained between a well or other specified equipment and any protected structure or feature.

SHALE GAS. Natural gas produced from low permeability shale formations.

SLICKWATER. A water based fluid mixed with friction reducing agents, commonly potassium chloride.

SOLID WASTE. Any solid, semi-solid, liquid, or contained gaseous material that is intended for disposal.

SPLIT ESTATE. Condition that exists when the surface rights and mineral rights of a given area are owned by different persons or entities; also referred to as "severed estate".

STIMULATION. Any of several processes used to enhance near wellbore permeability and reservoir permeability.

STIPULATION. A condition or requirement attached to a lease or contract, usually dealing with protection of the environment, or recovery of a mineral.

SULFUR DIOXIDE (SO_2). A colorless gas formed when sulfur oxidizes, often as a result of burning trace amounts of sulfur in fossil fuels.

TECHNICALLY RECOVERABLE RESOURCES. The total amount of resource, discovered and undiscovered, that is thought to be recoverable with available technology, regardless of economics.

THERMOGENIC GAS. Natural gas that is formed by the combined forces of high pressure and temperature (both from deep burial within the earth's crust), resulting in the natural cracking of the organic matter in the source rock matrix.

THREATENED AND ENDANGERED SPECIES. Plant or animal species that have been designated as being in danger of extinction. See also Endangered Species.

TIGHT GAS. Natural gas trapped in a hardrock, sandstone or limestone formation that is relatively impermeable.

TOTAL DISSOLVED SOLIDS (TDS). The dry weight of dissolved material, organic and inorganic, contained in water and usually expressed in parts per million.

UNCONVENTIONAL NATURAL GAS. Natural gas comes from both 'conventional' (easier to produce) and 'unconventional' (more difficult to produce) geological formations. The key difference between "conventional" and "unconventional" natural gas is the manner, ease and cost associated with extracting the resource. However, most of the growth in supply from today's recoverable gas resources is found in unconventional formations. Unconventional gas reservoirs include tight gas, coal bed methane, gas hydrates, and shale gas. The technological breakthroughs in horizontal drilling and fracturing are making shale and other unconventional gas supplies commercially viable.

UNDERGROUND INJECTION CONTROL PROGRAM (UIC). A program administered by the Environmental Protection Agency, primacy state, or Indian tribe under the Safe Drinking Water Act to ensure that subsurface emplacement of fluids does not endanger underground sources of drinking water.

UNDERGROUND SOURCE OF DRINKING WATER (USDW). 40 CFR Section 144.3 An aquifer or its portion:
(a) (1) Which supplies any public water system; or
(2) Which contains a sufficient quantity of ground water to supply a public water system;
and
(i) Currently supplies drinking water for human consumption; or
(ii) Contains fewer than 10,000 mg/l total dissolved solids; and
(b) Which is not an exempted aquifer.

WATER QUALITY. The chemical, physical, and biological characteristics of water with respect to its suitability for a particular use.

WATERSHED. All lands which are enclosed by a continuous hydrologic drainage divide and lay upslope from a specified point on a stream.

WELL COMPLETION. See Completion.

WORKOVER. To perform one or more remedial operations on a producing or injection well to increase production. Deepening, plugging back, pulling, and resetting the liner are examples of workover operations.