State Oil and Gas Agency Groundwater Investigations

And Their Role in Advancing Regulatory Reforms

A Two-State Review: Ohio and Texas






Ground Water Protection Council

August 2011

Groundwater investigations can be complex endeavors involving trained and experienced specialists who exercise their technical skills in fields such as geology, hydrogeology, geophysics, and chemistry, while evaluating possible causes of contamination, including the full range of diverse oil and gas exploration and production activities. Specialists collect, analyze, and evaluate evidence to develop a “diagnosis”, a testable hypothesis regarding causation. The photographs on the cover depict specialists with the Ohio Department of Natural Resources, Division of Mineral Resources Management participating in the investigation process.

State Oil and Gas Agency Groundwater Investigations

And their Role in Advancing Regulatory Reforms

A Two-State Review: Ohio and Texas

Prepared for: the Ground Water Protection Council

Prepared by: Scott Kell, Professional Geologist

August 2011

Acknowledgements: This project was funded by the Groundwater Protection Research and Education Foundation (GWPREF). The GWPREF is a not-for-profit 501 (c) 3 corporation dedicated to conducting research and education related to the protection of groundwater. The foundation is comprised of a board made up of volunteers from state regulatory agencies who serve as members of the GWPC Board of Directors.

The author thanks and acknowledges assistance from the following individuals:

Mike Paque, Executive Director, GWPC

Mike Nickolaus, Special Projects Director, GWPC

Richard Simmers, Statewide Enforcement Manager, Ohio DNR, DMRM

Thomas Tomastik, Geologist, Ohio DNR, DMRM

Leslie Savage, Chief Geologist, Texas RRC, Oil and Gas Division

Bill Renfro, Senior Technical Coordinator, Texas RRC, Operator Cleanup Program

About the Author: Scott Kell has thirty years of state regulatory experience with the Ohio Department of Natural Resources, Division of Mineral Resources Management (DMRM), including over 25 years conducting or overseeing agency groundwater investigations. He served DMRM as a geologist and administrator overseeing a variety of regulatory programs including technical services, field enforcement, underground injection, and orphaned well plugging. He provided training to other states on methods for investigating oilfield-related groundwater contamination incidents at the request of the Interstate Oil and Gas Commission and U.S. EPA Region V. Kell served ten years as a member of the Board of Directors of the Ground Water Protection Council, including two years as President of the Board of Directors. He earned a BS in Geology from Mount Union College (1975) and a MS in Geology from Kent State University (1979).

FOREWORD

State oil and gas regulatory agencies place great emphasis on protecting groundwater resources. Agencies typically have broad authority to promulgate regulations, establish field rules, issue orders or directives, inspect permitted activities, enforce regulatory standards, require reports, and order corrective action for all phases of oil and gas exploration and production (E&P) activities from site preparation through eventual plugging, and final site reclamation. Oil and gas statutes typically include broad performance-based standards that establish the necessary authority to protect human health, safety, and the environment, while prohibiting contamination of surface and groundwater. State regulatory agencies also issue permits that establish site-specific terms and conditions for site development, drilling, and well construction that may be tailored to address site or region-specific groundwater resource protection concerns.

In addition to regulatory requirements, state agencies employ a variety of non-regulatory processes to supplement existing standards such as:

1. Developing standard operating procedures;
2. Creating industry guidance documents;
3. Training and certifying inspectors;
4. Establishing risk-based inspection priorities;
5. Managing inspection and compliance history records;
6. Utilizing enhanced data management systems; and
7. Sponsoring and conducting research.

These regulatory and non-regulatory processes are designed to collectively manage risk and provide the regulated industry with a framework for successful development of oil and gas resources while protecting public safety and the environment. A central objective of every state oil and gas agency is to prevent groundwater contamination.

A report published in May 2009 by the Ground Water Protection Council (GWPC), *State Oil and Gas Regulations Designed to Protect Water Resources*, recognized a number of factors that have shaped the evolution of state oil and gas regulations that protect groundwater resources including: (1) the passage of federal environmental laws beginning in the 1970s; (2) peer reviews conducted by the GWPC for state-administered Class II Underground Injection Control (UIC)

Programs; (3) state reviews conducted by multi-stakeholder teams applying guidelines developed by the State Review of Oil and Natural Gas Environmental Regulations, Inc. (STRONGER); and (4) heightened public environmental awareness. In addition, state agencies have strengthened their regulatory standards based on the findings of investigations that have identified groundwater contamination or disruption as the result of specific oilfield activities.

A typical state groundwater investigation combines the experience of field inspectors, who evaluate current and historic oil and gas exploration activities, with the technical expertise of other specialists, such as geologists and engineers. These experts then draft reports that summarize their findings and conclusions. Each report includes a "diagnosis" that identifies the activity that caused the incident, if an investigation concludes that oilfield activity has contaminated groundwater. Agencies then evaluate these incident reports over time to discern and address patterns and/or common causation factors. These "diagnoses" have played a significant role in advancing statutory and regulatory amendments, developing permit conditions, and implementing other actions that refine and enhance groundwater protection.

This study categorizes state determinations regarding causes of groundwater contamination resulting from the oil and gas industry E&P activities based on a review of agency records and discussions with agency personnel in two selected states: Ohio and Texas. This study also evaluates how those findings have contributed to the evolution of state regulatory authority and improvement of standard industry practices.

The GWPC provides a forum for state groundwater protection officials to meet and discuss groundwater resource issues and policies with the regulated community, Non-Governmental Organizations (NGOs), and the public. The GWPC advocates development of policies and regulations that are supported by "sound science". To determine the cause of contamination, incident investigations must be supported by sufficient facts and data collected according to standard methods and protocols. The data must then be interpreted and analyzed by qualified experts who apply accepted scientific principles within their specialized fields, including hydrogeology, petroleum engineering, aqueous chemistry, and geophysics. This report describes how these two state agencies have utilized the findings of groundwater investigations to prioritize and implement regulatory reforms.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

State agencies are responsible for investigating and addressing complaints about groundwater contamination that may be caused by oilfield activities. State agency directors generally have the authority to suspend oilfield operations, order corrective action, and order remediation or replacement of disrupted groundwater supplies when the responsible parties have been identified. State agencies identify the activities that cause groundwater contamination incidents and evaluate contributory patterns over time. These investigations can be an important diagnostic tool for supporting regulatory reform and prioritizing inspections of specifically identified higher-risk oilfield activities. States evaluate the overall effectiveness of their current regulatory schemes by monitoring groundwater incident trends over a given time period. This report evaluates agency groundwater investigation findings in two states, Ohio and Texas.

Groundwater resources are crucially important in both Ohio and Texas. In 2005, Texas ranked second nationwide in fresh groundwater withdrawals, while Ohio ranked nineteenth; both states rank in the top ten for fresh groundwater withdrawals for public or private water supplies. Accordingly, their long-term commitments to protecting their groundwater resources are evidenced through a cumulative examination of investigation findings and resultant regulatory reforms.

The Texas Railroad Commission (RRC) began conducting groundwater investigations related to oil and gas operations in the 1950s, while the Ohio Division of Mineral Resources Management (DMRM) began in 1983. In a number of cases, agency investigators have identified case-specific causes of oilfield-related groundwater contamination. There are both similarities and differences in agency findings regarding the causes of groundwater contamination incidents. Dissimilarities in the scope and scale of regulated activities, land uses, population densities, and climatic and geologic factors have contributed to the unique evolution of their respective regulatory programs.

There were significant levels of oil and gas E&P in both states during their respective study periods. In Ohio, over 33,000 oil and gas wells were drilled and nearly 28,000 wells were plugged from 1983 through 2007. The number of producing wells increased by 29 percent from a low of 50,342 in 1983 to a high of 64,830 in 1991. Over 222 million barrels of crude oil and 3.2 trillion cubic feet (tcf) of natural gas were produced. Nearly 202 million barrels of produced water was disposed. In Texas, 187,788 oil and gas wells were drilled and 140,818 wells were plugged from 1993 through 2008. During the 16 year study period the number of producing wells increased 6.7 percent from 237,136 to 253,090. Texas operators produced nearly 6.7 billion barrels of crude oil and 93.7 tcf of natural gas. Over 5.1 billion barrels of produced water was disposed by injection annually.

During the 25 year study period (1983-2007), Ohio documented 185 groundwater contamination incidents caused by historic or regulated oilfield activities. Of those, 144 groundwater contamination incidents were caused by regulated activities, and 41 incidents resulted from orphaned well leakage. Seventy-six of the incidents caused by regulated activities (52.7 percent) occurred during the first five years of the study (1983-1987). When viewed in five year increments, the number of incidents caused by regulated activities declined significantly (90.1 percent) during the study period. Seventy-eight percent (113) of all documented regulated activity incidents were caused by drilling or production phase activities. Improper construction or maintenance of reserve pits was the primary source of groundwater contamination, which accounted for 43.8 percent of all regulated activity incidents (63) in Ohio.

During the 16 year study period (1993-2008), Texas documented 211 groundwater contamination incidents. More than 35 percent of these incidents (75) resulted from waste management and disposal activities including 57 legacy incidents caused by produced water disposal pits that were banned in 1969 and closed no later than 1984. Releases that occurred during production phase activities including storage tank or flow line leaks resulted in 26.5 percent of all regulated activity incidents (56) in Texas.

During the study period, over 16,000 horizontal shale gas wells, with multi-staged hydraulic fracturing stimulations, were completed in Texas. Prior to 2008, only one horizontal shale gas well was completed in Ohio. During their respective study periods, neither the RRC or the DMRM identified a single groundwater contamination incident resulting from site preparation, drilling, well construction, completion, hydraulic fracturing stimulation, or production operations at any of these horizontal shale gas wells.

Identifying state-specific activities and patterns of failures has allowed Ohio and Texas to implement regulatory reforms and to strategically apply resources to improve groundwater protection. Both states, for example, have established deep injection of produced water and drilling wastes as the preferred disposal option. Since 1983, Ohio has eliminated earthen pit storage of produced water, developed permit conditions for the construction, maintenance, and reclamation of reserve pits, and established one of the first orphan well plugging programs in the Appalachian Basin. Texas has banned earthen disposal pits, tightened standards for rule-authorized and permitted pits, and established an Oil Field Cleanup Program (OFCP) to remediate contamination at both regulated and legacy sites. Although both states have made improvements in their regulations and standards, the process is a continual evolution.

Neither state has documented a single occurrence of groundwater pollution during the site preparation or well stimulation phase of operations. Despite this, Ohio has implemented more detailed notification, inspection, record keeping, and reporting requirements in response to the national debate on the process of hydraulic fracturing. Texas is currently placing summary data online for new completions, has implemented new disposal well requirements in the Barnett Shale play, and recently enacted statutes requiring public disclosure of hydraulic fracturing chemicals.

Class II injection accounts for the disposal of more than 98 percent of all produced water in both states. Accordingly, implementing effective regulations for injecting oilfield wastes and produced water has significantly improved produced water management. Over the past 25 years, Ohio has not identified a single incident of groundwater contamination from subsurface injection at a permitted Class II disposal well. Texas has identified six contamination incidents directly caused by Class II injection operations; however, documented groundwater contamination incidents dropped significantly after subsurface injection replaced earthen pit disposal as the primary method of produced water management. In summary, Class II injection has been a significant improvement compared to previous waste management methods.

Ohio and Texas both have extensive petroleum production histories that predate state permitting and regulatory agencies or current regulatory standards. A significant number of groundwater contamination incidents, known as “legacy issues”, have been directly linked to abandoned wells and sites. Legacy issue incidents cannot be addressed through simple regulatory reform for a number of reasons; specifically, they are often directly linked to insolvent or defunct operators and pre-regulated practices. Both states however, have established funding mechanisms and programs to oversee plugging of orphaned wells and/or reclamation of abandoned sites. Since 2000, both states have passed legislation that increased spending levels for orphan well and site cleanup funds through increased industry fees. They also have developed prioritization processes that expedite responses when orphaned wells have contaminated, or pose a threat to groundwater resources.

BACKGROUND, PURPOSE, AND SCOPE

Background: Every land use activity, including resource extraction and energy development, poses some degree of environmental risk. Those risks associated with oil and gas E&P are managed through an extensive, perpetually evolving framework of federal, state, and local regulations. Every oil and gas producing state has an oil and gas permitting and regulatory program that manages risks associated with various phases of the oil and gas development process that begins with site preparation and ends with well plugging and site reclamation. All state oil and gas agencies recognize the protection of groundwater as a mission-critical objective (GWPC, 2009).

Improving environmental protection through regulatory change is a continuous process. States may enhance existing regulations and environmental protection by:

1. Restructuring and improving waste management practices;
2. Upgrading quality standards for materials used in various practices;
3. Increasing monitoring and testing obligations;
4. Requiring increased inspector notifications; and
5. Improving reporting and data management in order to document and verify compliance.

The ultimate goals of regulatory change are to prevent environmental contamination, protect public safety, and to promote early detection and corrective action when prevention fails.

In 1993, the U.S. Department of Energy and Interstate Oil and Gas Compact Commission (IOGCC) released the results of a 17 state study that evaluated the evolution of state regulations since the mid-1980s. The study concluded that “state regulatory programs have undergone major improvements to increase environmental protection since the mid-1980s, and the pace of change appears to be accelerating” (ICF Resources, Inc., 1993). While acknowledging that regulatory change may be prompted by a variety of stimuli, the review concluded that “the greatest number of modifications to regulatory requirements appear to stem from areas identified by the States themselves as necessary for the protection of the different environmental settings within their state” (ICF Resources, Inc., 1993). The report noted several encouraging regulatory trends including: (1) an increased leadership role at the state level; (2) better cooperation between the oil and gas industry and environmental and public interest groups; and (3) greater state focus on environmental protection for regulated industry activities (ICF Resources, Inc., 1993).

Purpose: The purposes of this report are to:

1. Summarize and characterize the findings of state groundwater investigations in two states relative to the various phases and activities associated with oil and gas E&P operations over time;
2. Evaluate and chronicle the history and evolution of regulations in relation to lessons learned through groundwater contamination investigations; and
3. Evaluate, when possible, whether regulatory enhancements actually reduce groundwater contamination incidents over time.

Scope: The scope of this review is limited to the evaluation of two oil and gas producing states. Ohio and Texas were selected as the project states because of the differences in climate, geology, demographics as well as the scope and scale of regulated E&P activities. These variables are summarized in Table 1. The progression of regulatory developments in both states differ significantly due to differences in climate, demographics, hydrogeology, groundwater usage, land usage, the history and scale of industry activities, and differences in industry activities. These differences provide each state agency with specific challenges that have shaped their respective regulatory programs. Hence, the state evaluations are presented separately.

Table 1 Variables

Category	Variables Within Areas of Oil and Gas Development
Climate	• Arid versus net precipitation
Demography	• Population density • Groundwater dependence
Hydrogeology	• Prevalence of confined versus unconfined aquifers • Relative reliance on shallow unconfined aquifers
Groundwater Usage	• Prevalent types of groundwater usage • Confined versus unconfined aquifer development by user category
Oil and Gas Industry History and Activities	• History and scale of pre-regulatory practices • Prevalence of legacy issues • Scale of regulated industry activities • Waste volumes associated with various industry activities • Waste characteristics (salinity, toxicity, etc.) • Standard industry practices • Evolving drilling and well completion practices associated with new plays

Each state description includes a general characterization of groundwater usage, state hydrogeology, and an historical overview of the development of its oil and gas industry. In addition, there is a general description of the origins and development of each state's regulatory authority. These foundations provide context to help understand the evolution of state efforts to protect their groundwater resources.

INTRODUCTION

State Approaches: Ohio and Texas have developed different, yet effective approaches for initiating, assessing, and resolving groundwater contamination incidents that reflect the variables listed in Table 1. In Ohio, the DMRM initiates investigations primarily in response to citizen complaints or inspection findings. It then resolves verified incidents determined to be caused by regulated oilfield activities by requiring treatment or replacement of the contaminated water supply (Figure 1). Depending on the nature and persistence of contamination, water supply replacement may be temporary or permanent. The RRC initiates investigations as a response to contaminant detections at monitored wells, citizen complaints, or through environmental assessments conducted during property transactions. Verified incidents are resolved through aquifer remediation projects conducted by a variety of programs including: the Operator Cleanup Program (OCP) when a responsible owner can be identified, the state OFCP for orphaned wells or contaminated sites, or the Voluntary Cleanup Program (VCP) that provides remediation incentives for parties that did not cause groundwater contamination. A timely and effective response to citizen complaints alleging groundwater contamination is essential to both their resolution and to the progress and evolution of state regulatory programs.

Figure 1
Ohio DMRM investigators use a downhole camera to document conditions in a water well
Source: Ohio DMRM

For the purposes of this report, an incident is any reported or detected event associated with upstream development of oil and gas resources and management or disposal of associated wastes that caused contamination of groundwater, or disrupted water supply usage. This includes contaminant detections in monitor well samples or groundwater used for any legitimate purpose including: public or domestic water supplies, livestock, irrigation, aquaculture, industry, mining, or thermoelectric power. The report does not include incidents that may be associated with downstream, off-lease activities after custodial change. The RRC has broader authority than most states and regulates a variety of downstream activities including: intrastate crude oil and natural gas distribution pipelines, associated compressor and booster stations, gas dehydration and scrubber facilities, as well as gas processing plants. However, in most states these activities are regulated by other federal or state agencies, and therefore were excluded from the scope of this report.

The DMRM began conducting groundwater investigations in 1983. In Ohio, oil and gas law requires agency personnel to respond to citizen complaints about suspected groundwater contamination, and delegates remedial authority to the agency director. Section 1509.32 of the Ohio Revised Code (ORC) mandates that the DMRM complete an investigation of every citizen complaint alleging pollution or contamination by an oil and gas E&P activity, and to then provide the complainant with a report summarizing their findings. Furthermore, ORC Section 1509.22(F), enacted in 1985, requires oil and gas well owners to replace any water supply used for domestic, agricultural, industrial or other legitimate use, if the agency determines that the supply was "substantially disrupted by contamination, diminution, or interruption proximately resulting from the owner's oil or gas operation" (DMRM, 2011).

The RRC began conducting groundwater investigations in the 1950s. The RRC's complaint policy requires a state response to citizen complaints within 24 hours, unless other mutually agreeable arrangements are made with the complainant (STRONGER, 1993). The RRC also identifies groundwater contamination through monitor wells that are required at certain commercial oilfield E&P waste disposal facilities such as land farms, or other monitoring wells required for regulatory or research purposes. In 2007, Texas had over 56,000 monitor wells in use. Operators also identify groundwater contamination issues while reviewing monitor well or environmental data during environmental assessments conducted in preparation for mergers, divestitures, or acquisitions of oilfield properties. Therefore, many documented incidents do not involve wells used for drinking water or any other legitimate purpose (RRC, personal communication: Bill Renfro).

In 1991, the Texas Legislature established the Oil Field Cleanup Fund (OFCF)(SB 1103) with an expanded balance cap of $10 million. The bill increased industry fees and provided funds for the RRC to conduct investigations of contaminated sites. According to Sections 91.112 and 91.113 of the Texas Natural Resources Code (TNRC), the RRC may use Oil and Gas Cleanup Fund (OGCF) monies to conduct site investigations or environmental assessments in order to determine the nature and extent of contamination caused by oil and gas wastes or other substances regulated by the RRC if:

1. The responsible party has failed or refused to control or clean up wastes after notice and an opportunity for a hearing;
2. The responsible party cannot be found; or
3. The wastes are causing surface or groundwater contamination.

TNRC Section 91.112 specifically authorizes RRC employees to enter properties in order to conduct site investigations and environmental assessments, as well as to oversee the clean up of oil and gas wastes. The RRC may seek penalties or other forms of relief from any person who is required by laws, rules, or orders to control or clean up oilfield contaminants. Furthermore, the RRC may file civil actions or issue orders requiring reimbursement of the OFCF. Although the RRC assumes the lead role in conducting these investigations, it often coordinates work with other state and local authorities, such as the Texas Commission on Environmental Quality (TCEQ), local health departments, and local Groundwater Conservation Districts when findings indicate non-oilfield sources of contamination (RRC, 2011-a.).

When RRC investigators conclude that oilfield contaminants are present as the result of current or former operations, cases are referred to the OCP for resolution. Owner(s) of oilfield operations identified as liable for contributing to specific groundwater contamination incidents are directed to take appropriate actions to address the contaminants. Operator cleanups are typically complex assessment and remediation projects. Based upon site-specific factors, an OCP project may include:

1. Installation of one or more monitoring wells;
2. Scheduled groundwater sampling and analyses;
3. Plume delineation using sample analyses and/or geophysical methods;
4. Evaluation of contaminant migration direction and extent;
5. Design and implementation of in situ remediation projects;
6. Contaminant recovery and disposal; and/or
7. Water supply replacement.

Every new case is assigned an OCP number during the calendar year the RRC determines oilfield contaminants are present. The RRC then tracks project progress and requires periodic status updates until it determines no further action is necessary.

Texas law requires members of the Texas Groundwater Protection Committee (TGPC), including the RRC and nine other agencies, to publish an annual report on documented groundwater contamination incidents “reasonably suspected of having been caused by activities regulated by state agencies” (Section 26 of the Texas Water Code). Accordingly, since 1993, the *Joint Groundwater Monitoring and Contamination (JGWMC) Report* is published each June and summarizes the previous calendar years’ investigations by describing each newly documented case of groundwater contamination (TGPC, 1993-2008). The report further describes all previously-reported incidents that have yet to be resolved through remedial action, or if requirements of an enforcement action remain incomplete at the time of report issuance.

The Investigation Process: Groundwater investigations are exercises in applied science. When an agency responds to a citizen complaint, the investigators first evaluate whether there is sufficient evidence to conclude that groundwater is actually contaminated by substances or chemicals that may be associated with oilfield activities. This process typically begins with preliminary citizen interviews and water quality evaluations. The investigation process ultimately leads to a “diagnosis”, a testable hypothesis regarding causation.

The investigation process has many parallels to the differential diagnosis method employed in modern medicine. In modern medicine, a team of diagnosticians, representing a range of medical specialties, work to identify the cause of a particular ailment by systematically evaluating symptoms, listing possible causes, and dismissing possible etiologies by using rigorous tests that should yield different results. The team persists through the process of elimination until the most plausible explanation is evident. After making their diagnosis, the team prescribes treatment and monitors the patient’s results to confirm or falsify their diagnosis. This process often requires the team to reconsider their preliminary assumptions and observations. Incomplete information or patient misrepresentations about symptoms, circumstances, or personal histories often further complicate the process. The team is ultimately able to arrive at the singular and correct diagnosis and its correlative treatment by faithfully adhering to the scientific method.

In a similar manner, state agencies conduct investigations with a team of specialists that deploy the differential diagnosis method in order to identify the specific cause of a contamination incident. Teams must consider the full range of plausible explanations such as: natural occurrence, local land use practices, domestic practices, local industrial activities, and the presence of both current and historic oilfield activities. A variety of investigative tests and methods narrow the list of plausible causes before reaching a “diagnosis”. The “diagnosis” may be tested through ongoing monitoring of groundwater quality after removing the source, peer review by other qualified specialists, the administrative appeals process, or through the court hearings.

When an agency determines that specific oilfield activities have disrupted a water supply, it typically requires remedial action and/or water replacement (temporary, permanent, or both). These actions can be implemented cooperatively with a consent agreement, through an adjudication order, or by civil action. To secure consensual corrective action or to enforce an order, an agency must compile evidence sufficient in scope and quality to withstand judicial scrutiny in court, before an appeals commission, or a less formal review process. As part of this evidentiary responsibility, the agency typically identifies the specific operational phase and activity(s) that resulted in the release of contaminants into groundwater. In other words, investigators must compile and defend evidence that supports the state's specific finding or "diagnosis" regarding causation.

Experts must follow established protocols while collecting evidence, and then apply sound scientific principals when interpreting and analyzing that data. There is often a dynamic tension between the need to expeditiously address legitimate citizen concerns, particularly when the public safety is at risk, while proceeding methodically to ensure evidence is defensible, and conclusions are objective when identifying the actual cause of contamination. Consequently, investigatory conclusions may be subject to review and testing by legal counsel and other experts representing the defense, plaintiffs, or both. The agency specialists who participate in the investigative process must be able to establish their credentials as experts by virtue of their education, training, and experience.

In environmental litigation, case law has led to the development of standards that assess opposing "expert" opinions to screen out testimony based on conjecture and speculation. The Federal Rules of Evidence, effective in 1975, govern the admissibility of evidence in federal court; they are also applied in some state courts. In 1993, the United States Supreme Court enhanced admissibility standards for screening conflicting scientific testimony in Daubert vs. Merrell Dow Pharmaceuticals, Inc. (Foster, Bernstein, and Huber, 1993). Under the enhanced standards, known as the "Daubert Rule", the judge or hearing officer acts as a gatekeeper, and evaluates whether the data, inferences, reasonings, and methodologies used to support expert testimony are scientifically valid and reliable based on accepted principles and standards. Although only a small percentage of cases actually reach court hearings, agency officials must conduct investigations with sufficient attention to detail when collecting, analyzing, and interpreting data; as any findings set forth in an administrative order may someday face scrutiny under appeal. When presenting an agency "diagnosis" to an operator or hearing officer, the agency must establish its expertise by demonstrating its investigation: (1) was conducted by qualified personnel; (2) is based upon sufficient facts and data; (3) is the product of generally accepted and reliable principles and methods; and (4) has reliably applied those principles and methods to the facts in a particular case (Foster, Bernstein, and Huber, 1993). The successful resolution of a case ultimately hinges on agency credibility as demonstrated through a commitment to the factors listed above.

Agency experts review records, observe site conditions, conduct tests, and collect environmental data before arriving at a "diagnosis" as to causation. Groundwater investigations vary significantly in their scope and complexity, but every investigation involves the collection and interpretation of evidence pertaining to at least five elements as follows:

1. Natural groundwater quality/chemistry;
2. Potential contaminant composition/chemistry;
3. Potential contamination sources;
4. Hydrogeologic framework including: groundwater flow directions, permeabilities of vadose zone materials, aquifers and confining strata, contaminant migration pathways, travel times, and driving mechanisms; and
5. Chronologic considerations.

Thus, the investigation process can be lengthy, but groundwater contamination caused by different activities generally manifest different symptoms. This enables agency experts to distinguish oilfield from non-oilfield causes, and to differentiate contamination incidents caused by various types of oilfield activities.

Inferences or conclusions reached without consideration of these elements may be subject to challenge as conjecture or speculation. For example, the analytical detection of chemical compounds that may be present in some oilfield fluids or waste products is insufficient to infer a source without further evaluation. The investigators must determine whether there are natural or non-oilfield, anthropogenic sources for the same compounds within the investigation area; evaluate alternative explanations for the presence of those compounds in groundwater; and in some cases, use chemical "fingerprinting" methods and other tools to arrive at the best hypothesis explaining the occurrence, concentration, and distribution of these compounds. For example, chloride concentrations may be elevated in groundwater due to the release of oilfield produced water, but they may also naturally exceed U.S. Environmental Protection Agency (EPA) standards, or may be caused by upconing of deeper brackish groundwater due to excessive pumping of the aquifer, the spreading of salt to deice roads, or the discharge of water softener recharge brines through septic systems (GWPC, 2002). When multiple potential sources of chloride are present, investigators may use well-established fingerprinting methods that plot bromide to chloride weight ratios in groundwater samples against chloride concentration (Figure 2). When the bromide to chloride ratio of a groundwater sample is compared to binary mixing curves that characterize possible sources, investigators can distinguish various sources of chloride in groundwater (Whittemore, 1988; Knuth, Jackson, and Whittemore, 1990; GWPC, 2002). Investigators also may employ geophysical testing methods such as electromagnetic conductivity or resistivity surveys to map the extent and relative salinity of groundwater relative to possible contaminant sources.

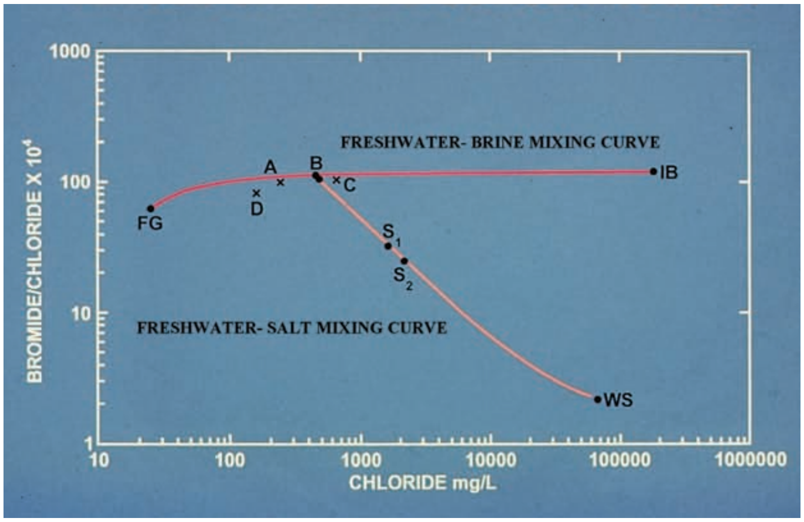


Figure 2
Bromide: chloride weight ratios can be used to distinguish sources of saline contaminants
Source: Ohio DMRM

In a similar manner, natural gas may naturally occur in developed aquifers and Underground Sources of Drinking Water (USDW), and can also originate from organic shale or coal deposits, abandoned or active underground coal mines, the decomposition of buried organic materials in glacial sediments, or landfills. Stable isotopic signatures for natural gas components such as methane and ethane can help discern the origins of natural gas in water wells (Breen, Revesz, Baldessare, and McAuley, 2007). Isotopic signatures and compositional analyses can distinguish shallow biogenic gas from deeper thermogenic gas, as well as thermogenic gases from different hydrocarbon reservoirs or sources. When used in concert with other sources of information compiled as part of a thorough investigation, isotopic along with compositional gas analyses can help determine whether the source of natural gas in groundwater is caused by oilfield activities.

Table 2 summarizes the categories (evidentiary elements) that are typically evaluated during the course of an agency investigation, and the potential sources of data that may be collected for evaluation and synthesis into a testable hypothesis. A thorough and objective investigation will include all of these elements.

Table 2 Evidence Categories and Data Sources

Element	Evidence Categories	Potential Evidence Sources
Water Quality	Ambient or background water quality/conditions	Pre-drilling survey well water analyses, USGS monitoring network well water analyses, EPA ambient groundwater well analyses, resident surveys, pre-existing water treatment and filtration systems, water treatment company water analyses, analysis of water from wells with similar construction adjacent to the investigation area, water well driller interviews, state groundwater resource maps, down-hole video surveys of water wells of similar vintage and construction in areas adjacent to the investigation, published theses and dissertations
	Quality of the allegedly impacted water supply	Resident surveys, down-hole video surveys, analysis of water well/spring samples
Contaminant Composition	Chemical composition of potential contaminants	Produced water analyses, natural gas composition analyses, natural gas isotopic analyses, drilling fluid additive records, well stimulation additive records, hydrocarbon analyses
Potential Contamination Sources	Oilfield (historic)	Historic well-spot maps, orphan well files, metal detector surveys, 3-D electromagnetic conductivity surveys, historic newspaper accounts, geologic survey publications, aerial magnetometer surveys, long-term resident surveys, resistivity surveys, electromagnetic conductivity surveys, aerial photographs, well plugging records, vegetative stress
	Oilfield (present)	Inspection records, digital images, surveillance film, cement tickets, job logs, well completion records, electric logs, invoices, casing pressure test/BOP test results, geolographs, drilling fluid additive records, treatment pressure/rate charts, rig and service company employee interviews, resistivity surveys, electromagnetic conductivity surveys, annular pressure tests, produced water and/or solid waste transport and disposal, reuse, or treatment records, vegetative stress, soil condition
	Non-oilfield	Water softener salt usage surveys, county/state road salt records, septic tank samples, resident surveys to evaluate chemical use/disposal practices, inspection of fuel-oil and other hydrocarbon storage tanks, pre-complaint water treatment systems, down-hole video surveys, source rock/aquifer chemistry, other industrial or agricultural activities
Hydrogeologic Framework	Aquifer properties	Water well logs, down-hole videos, pump tests, groundwater resource maps, stratigraphic section descriptions, local outcrop measurements and observations, electric logs, relative porosity/permeability of aquifers and confining strata
	Contaminant transport pathway(s)	Joint measurements, lineament analyses, down-hole videos, local outcrop measurements and observations, soil maps, glacial geology maps
	Contaminant transport driving mechanism	Static water level measurements, annular pressure readings
Chronology	Temporal sequence of events	Sequence of activities related to all potential contamination sources

To determine if oilfield activities have disrupted or caused contamination of a water supply, an agency must first establish that the groundwater was degraded by a release from an oil and gas operation. For these purposes, the groundwater incident determinations are based on each state's unique criteria, definitions, and action levels. State oil and gas statutes may define the terms "pollution" or "contamination" differently, or not at all; they also may establish different action levels to guide administrative actions. Ohio oil and gas law [Section 1509.22 (A) ORC] prohibits the placement of brine (produced water including hydraulic fracturing fluids recovered during the flowback process), crude oil, natural gas or any other fluid associated with oil and gas E&P activities into surface or groundwater "in such a manner as actually causes or could reasonably be anticipated to cause water used for consumption by human or domestic animals to exceed the standards of the Safe Drinking Water Act" (40 CFR Parts 140-149). The EPA establishes Primary Maximum Contaminant Levels (PMCLs) as health-based standards for public drinking water supplies and Secondary Maximum Contaminant Levels (SMCLs) as aesthetic standards for public drinking water supplies (U.S.EPA, 2002-a. and b.). DMRM applies these federal standards developed for public water systems to non-public systems including private and agricultural wells. Furthermore, DMRM can order replacement of water supplies based on violations of aesthetic standards (SMCLs) that are unrelated to public health or safety (DMRM, 2011).

The Chief of the DMRM may order the owner of an oil and gas operation to replace any water supply used for public, private and agricultural, industrial or any other legitimate use if it is determined that the operation "substantially disrupted" a water supply. The term "disruption" is broader than "pollution or contamination" and provides the Chief discretionary authority to require corrective action for impacts that limit water usage, but do not necessarily have associated PMCLs, SMCLs, or known adverse health effects. For example, some oilfield parameters of interest, particularly natural gas, do not have any known adverse health effects when ingested, and therefore are not subject to PMCLs or SMCLs under the Safe Drinking Water Act (SDWA). However, the Office of Surface Mining Reclamation and Enforcement (OSMRE) within the U.S. Department of Interior has developed investigation and mitigation measures for fugitive methane hazards associated with coal mining that can be applied to stray natural gas incidents (Eltschlager, Hawkins, Ehler, and Baldessare, 2001). For the sake of this report, natural gas is deemed to have disrupted or interrupted domestic or public use of a water supply when:

1. Dissolved methane levels exceed background concentrations and are sufficiently high to necessitate venting of water wells or installation of methane removal systems;
2. Gas pressure causes artesian flow resulting in water use disruptions;
3. Gas bubbles cause gas lock of water well pumps;

4. Gas perturbation results in persistent turbidity issues, including line pressure drops due to sediment-clogged filters; or
5. Gas releases cause persistent, ignitable spurting at the spigot.

Under Chapter 27 of the Texas Water Code, pollution means “the alteration of the physical, chemical, or biological quality of, or the contamination of, water that makes it harmful, detrimental, or injurious to humans, animal life, vegetation, or property or to public health, safety, or welfare, or impairs the usefulness or the public enjoyment of the water for any lawful or reasonable practice”. Similar to Ohio, Texas law empowers the RRC to address contamination incidents that could potentially affect public health, impair use or enjoyment, or make water use unsafe (RRC, 2011-a.).

To determine if there is a significant, measurable impact on groundwater, agency investigators must compare the aqueous chemistry and condition of groundwater in the allegedly impacted water supply to ambient or background conditions for the aquifer(s) in the vicinity of the complainant’s water supply. The agency should then compare the condition and aqueous chemistry of the allegedly affected supply to a baseline in order to conclude that there is a measurable impact. “Ambient conditions” refer to the natural or undegraded condition and chemistry of groundwater in aquifers in the region. In some cases, ambient groundwater quality does not meet federal SDWA standards. Aquifers may be naturally saline, or may have naturally occurring concentrations of certain heavy metals, dissolved methane, or petroleum hydrocarbons. Various dissolved chemical constituents may naturally exceed U.S. EPA PMCLs and/or SMCLs; these naturally occurring conditions must be identified and factored into agency determinations.

The agency also should evaluate water quality relative to “background conditions”. Background refers to the condition and chemistry of groundwater in the immediate vicinity of the complaint including the affects of other sources of degradation that predate or are wholly unrelated to local oilfield operation(s). For example, groundwater may be saline locally as a result of salt spreading for road deicing or the release of water softener discharges via septic systems. Petroleum products, surfactants, methane, and other chemicals or compounds that are not unique to oil and gas E&P activities may enter groundwater from a variety of sources. When evaluating specific complaints, agency experts strive to factor and evaluate local background conditions in their determinations. As a result, in some investigations, agency experts may conclude that groundwater supplies are degraded or fail to meet U.S. EPA or state standards for public water supplies, but that oil and gas E&P activities were not the proximal cause.

Geologists play a vital role in the investigatory process. Geologists must typically collect and evaluate information regarding the site-specific, three-dimensional, hydrogeologic framework in order to develop an understanding of potential contaminant migration pathways and the driving mechanisms associated with activities of concern where there were potential or documented releases to the environment. In addition to defining a source of contaminant release, the diagnosis must scientifically demonstrate how released contaminants traveled from the source to affected water supplies. Geologists also collect and evaluate data to assess the relative permeability of soils, materials in the vadose zone, underlying aquifers, and the intervening confining strata to understand the three-dimensional framework of groundwater movement and contaminant migration. Potentiometric surface maps may be necessary to explain the direction and rate of dissolved contaminant migration, whereas structural contour maps may explain the migration of free gases within the subsurface.

Geologists must develop determinations that are chronologically coherent. While cause and effect dictates that the alleged contaminant release must precede the alleged effect, simple chronology is insufficient to establish causality. The arrival time for alleged changes in groundwater quality must be consistent with reasonable groundwater or gas migration rates based on evaluation of geologic conditions, or pressure gradients between the alleged source and the impacted water supply.

This report proposes a framework or classification scheme, to categorize groundwater contamination incidents caused by oilfield operations that are typically regulated by state agencies by phase and activity (Appendix A). Each oil and gas E&P phase may include one or more activities that pose potential risks to groundwater resources. Some states may have restrictions on the use of listed activities, and industry practice may vary significantly from one state to another or depending on the conditions present in any one field. Appendix A lists potential activities by phase, potential contaminants associated with each activity, and possible contaminant release mechanisms. This table was used to guide consistent classification of groundwater contamination incidents identified by state agencies, but is not intended to be an exhaustive list.

It is important to recognize that if a release occurs as described in Appendix A, measurable groundwater contamination is possible, but not inevitable. To contaminate an aquifer, a release would have to occur in sufficient volume to cause measurable or detectable water quality degradation in a hydrogeologic setting susceptible to infiltration. A susceptible route to contamination requires permeable pathways from the point of release into an aquifer.

Furthermore, the volume and concentration of released contaminant must exceed an aquifer's capacity to mitigate adverse affects through natural attenuation processes, such as dilution, dispersion, adsorption, dissolution, and biodegradation.

As with any "diagnosis", an accurate assessment of causation is critical in prescribing an appropriate cure. In the realm of medicine, misdiagnosis results in further deterioration, delayed remedy, and wasted and ineffective use of resources. Likewise, misdiagnosis of groundwater contamination results in the misdirection of regulatory reforms, misdirection of agency inspection and enforcement priorities, and misapplication of compliance resources. Therefore, agencies and the public have a vested interest in the accurate "diagnosis" of water supply contamination incidents.

State groundwater incident findings and determinations are important risk management tools. By identifying, assessing, and prioritizing risks, states can apply resources and amend standards to minimize, monitor, and reduce the probability and/or impact of future activities. Prompt responses to citizen complaints require sufficient numbers of well-trained, qualified personnel to properly collect and review relevant evidence in a professional manner. Site inspection and complaint investigations are two of the most resource-intensive components of any regulatory oversight program. Agencies strive to maintain adequate levels of environmental protection in the most cost-effective manner. The examination of groundwater contamination incidents and their common risk factors and trends provides an important tool for targeting inspections at higher-risk oilfield activities. By identifying, assessing, and prioritizing risks, states can enhance regulations and target inspections in order to reduce the number, frequency, and severity of incidents over time while improving the efficient allocation and focus of agency resources (Belieu, Kell, Lowther, and Gillespie, 2007).

Oilfield operations may affect resources other than groundwater. Agency resources therefore need to be allocated to address other competing priorities including: ensuring the public safety, conserving oil and gas resources, and protecting soil and surface water resources. However, protecting groundwater from contamination should be regarded among the highest priorities due to the potential impacts on public health, the inconvenience and hardship imposed on affected citizens and businesses who rely on groundwater, the cost and duration of remediation or recovery, and the cost and challenges associated with supply remediation and replacement.

METHODS

The following methods were used to develop this report:

1. Development of an Incident Classification Scheme: The report uses a classification scheme that categorizes groundwater contamination incidents by oil and gas E&P phases (Figure 3). Phases one through six involve activities that are typically subject to state permitting and regulatory requirements. Phases one through four are sequential, while the production, on-lease transport, and storage (phase four) and waste management and disposal (phase five) continue simultaneously throughout the productive life of a well, prior to the plugging and site reclamation (phase six). In addition to these sequential phases, the scheme also includes a phase seven for legacy issues caused by orphaned wells and sites, which generally preceded state bonding or regulatory standards. While state regulations aim to reduce incidents caused by permitted and regulated activities, legacy issues can only be identified and remediated on a site-by-site basis over time.

2. Selection of States: This report evaluates documented contamination incidents for two participating states: Ohio and Texas. The report provides a framework that could be used in other states to perform further similar evaluations.

3. Characterization of State Context: The report provides state profiles for participating state groundwater use and resource availability; the history, scale, and nature of oil and gas industry activities; and an overview of oil and gas regulatory evolution.

4. Defining State Timeframe: Using the incident classification scheme and agency definitions for contamination and disruption, groundwater incident determinations were categorized by calendar year over a period of time determined by the participating state.

5. Classifying Incidents: Incident investigation determinations were derived from agency records and discussions with agency personnel. These determinations were sorted by oilfield operation phase and activity.

6. Statistical Analysis: Groundwater contamination incidents were categorized by phase and activity, evaluated for trends over time, compared to activity levels when appropriate, and presented as a percent of total incidents.

7. Characterizing Regulatory Evolution: The author evaluated statute and rule amendments, other regulatory program enhancements, and research that occurred in response to documented incidents based upon a review of agency documents and interviews with agency personnel.

Figure 3 Regulated Oil and Gas E&P Phases

1.) Site Preparation

Roads are constructed to access the well site. Well pads are constructed to safely locate the drilling rig and associated equipment during the drilling process. Pits may be excavated to contain drilling fluids and cuttings.

2.) Drilling and Completion

The well is drilled in stages and multiple layers of steel pipe, called casing, are placed into the borehole and cemented in place. The casing protects freshwater aquifers and isolates deeper oil and gas reservoirs. Drill cuttings, mud, and fluids encountered while drilling are circulated into the reserve pit or tanks.

3.) Well Stimulation, including Hydraulic Fracturing

Fluid is pumped under pressure into the permitted oil and gas reservoir. The fluid usually consists of water along with a proppant, usually sand, and chemical additives. This treatment process creates fractures in the oil and gas reservoir allowing crude oil and natural gas to flow into the well. Once the fractures are created, pressure is released and fracturing fluids commingled with connate formation fluids flow to surface where they are temporarily stored in steel tanks or lined pits prior to recycling or disposal.

4.) Production, On-lease Transport, and Storage

Once the well is placed into production, oil, natural gas, and/or produced water are brought up the well and separated as needed. Oil and produced water are temporarily stored in tanks. Operators may perform workover operations to clean, repair, and maintain the well for the purposes of increasing or restoring production. States may also allow or permit a variety of types of pits for waste segregation, temporary storage, or disposal.

5.) Waste Management and Disposal

Solid and liquid wastes are often transported from the production site for treatment, recycling, or disposal by truck or pipeline. This includes: landfarming, landspreading, road application, or disposal via injection at Class II injection wells.

6.) Plugging and Site Reclamation

Once a well has reached its economic limit, it is plugged according to state standards. The disturbed areas are reclaimed back to the native vegetation and contours, or to conditions requested by the surface owner.

STATE ASSESSMENTS

Each state's findings should be understood in the context of a number of variables including: climate, population density, geology, hydrology, topography, land usage, groundwater usage, history of the oil and gas industry, industry activity levels, and evolving state regulatory structures. For this reason, the report includes a state profile to provide a quick-glance summary of the key variables depicting differences between Ohio and Texas (Table 3). Each state evaluation is preceded by introductory discussions on groundwater hydrogeology and water usage, the history of its oil and gas industry, and a chronological overview of its oil and gas regulatory programs for protecting groundwater.

A number of similarities and significant differences between Ohio and Texas have contributed to the unique evolution of regulatory programs and approaches to addressing groundwater contamination. Although both states regard groundwater as a vital resource, Texas groundwater users withdrew eight to ten times as much groundwater annually as did Ohio users during the study period. In Texas, groundwater is primarily withdrawn for irrigation, while in Ohio most groundwater is withdrawn for consumption and domestic usage.

Ohio and Texas have substantially different climates. Ohio is a net precipitation state with average annual precipitation ranging from 29 to 44 inches per year (Ohio Division of Water, 2011-a.). In Texas, annual precipitation ranges from over 55 inches per year in the coastal areas to less than ten inches per year in southwest Texas. Average annual gross lake surface evaporation ranges from less than 45 inches in east Texas to more than 90 inches in the far west. Evaporation exceeds precipitation throughout most of Texas, which results in a semiarid climate that shifts to arid in the west (Texas Water Development Board, 2007).

Both Ohio and Texas have extensive histories of oil and gas E&P predating the twentieth century, and the advances in environmental awareness that typically began in the 1970s. The Ohio industry began commercially producing natural gas and crude oil in the mid-1800s before Texas. Both states have significant legacy issues created by the abandonment of wells and/or facilities that continue to threaten groundwater resources. As a result, both states have implemented programs to plug orphaned wells and remediate contamination at legacy sites.

Both states have had to address significant groundwater contamination issues caused by the percolation of produced water from earthen pits into shallow unconfined aquifers. Prior to 1969, earthen pits and discharge into surface water were the primary means to dispose large volumes of produced water in Texas (STRONGER, 1993). Ohio allowed “storage” of produced water in earthen pits prior to 1986 (STRONGER, 1995). While produced water volumes are significantly less than those in Texas, most produced water in Ohio is extremely saline, often exceeding 200,000 milligrams per liter (mg/L) chloride (Knapp and Stith, 1989). Today, Ohio and Texas manage produced water by injection into Class II wells, which annually accounts for the disposal of over 98 percent of all produced water in both states.

The current scale of oil and gas industry activities also differs significantly between the states. On an average annual basis, the Texas oil and gas industry drilled nearly nine times as many wells (11,737) as the Ohio industry (1,332). On an average annual basis during the study period, the Texas industry produced 47 times as much crude oil as Ohio and over 800 times the volume of produced water.

There appear to be significant differences in the persistence of groundwater contamination issues being addressed in Ohio and Texas. According to the RRC, contamination problems created by pre-1969 earthen pit disposal practices have persisted for decades after pit closures (STRONGER, 2003). In Ohio, regulatory enhancements that addressed waste management practices have been rewarded with relatively rapid declines in associated incidents. These differences are likely the result of climate and geologic factors that affect aquifer recharge and discharge rates, as well as contaminant attenuation processes.

Collectively, these differences explain why Ohio developed a program that emphasizes replacement of affected domestic water supplies, while Texas has emphasized long-term monitored aquifer remediation projects. The following chapters, describe in greater detail the findings of state investigations, and summarize the state regulatory responses to the identified issues. Both states have made exemplary progress reducing and managing the risks associated with E&P activities by eliminating unacceptable waste management practices and improving regulatory standards.

Table 3 State Profiles

Category	Topic	Ohio	Texas
Demographics	Population (2000 census)	11,353,140	20,851,820
	Square miles	44,828	268,601
	Population density (persons per sq. mi. 2000)	277.3	79.6
	Population density national rank	9	28
Groundwater Usage	Fresh groundwater withdrawal (2005) (gallons per day in 2005)	946,000,000	8,020,000,000
	National rank	19	2
	Primary usage and percent of total	Public water (51.6%)	Irrigation (76.3%)
	Percent used for public water supply	51.6%	15.1%
	Percent used for private water supply	15.4%	3.2%
Oil and Gas Industry	First year of natural gas production	1850	1872
	First year of commercial oil production	1861	1866
	Total number of wells drilled (through 2007)	275,000	1,074,718
	Number and percent of counties with E&P activity (2007)	88 (64%)	254 (88%)
	Wells drilled during study period	33,304	187,788
	Producing wells (2007)	63,937	241,534
	Average wells drilled annually during study period	1,332	11,737
	Average annual gas production during study period (Mcf)	128,869,878	5,858,575,998
	Average annual oil production during study period (bbls)	8,896,479	418,302,687
	Average annual produced water volume during study period (bbls)	8,088,054	6,455,474,300
	Maximum number of Class II EOR wells operating during study period	194 (1993)	39,511 (1996)
Regulatory Authority	Permitting/regulatory agency	Ohio Division of Mineral Resources Management	Texas Railroad Commission
	Enabling legislation	Chapter 1509. Ohio Revised Code	Title 3. Texas Natural Resources Code
	Year enacted	1965	1917
	Year groundwater investigations initiated	1983	1950
	Years evaluated by the study	25 (1983-2007)	16 (1993-2008)
	Class II Program Primacy	1983	1982

OHIO

Groundwater Usage

Abundant fresh groundwater resources have played a vital role in Ohio's development. According to the United States Geological Survey, Ohio's water users withdrew 946 million gallons of groundwater per day, which accounts for 1,060,000 acre feet of withdrawal per year. In 2005, Ohio ranked 19th among states in total fresh groundwater withdrawals (USGS, 2005). Figure 4 depicts 2005 groundwater withdrawals by user category.

Ohio Fresh Groundwater Withdrawals by User Category (Million Gallons per Day)

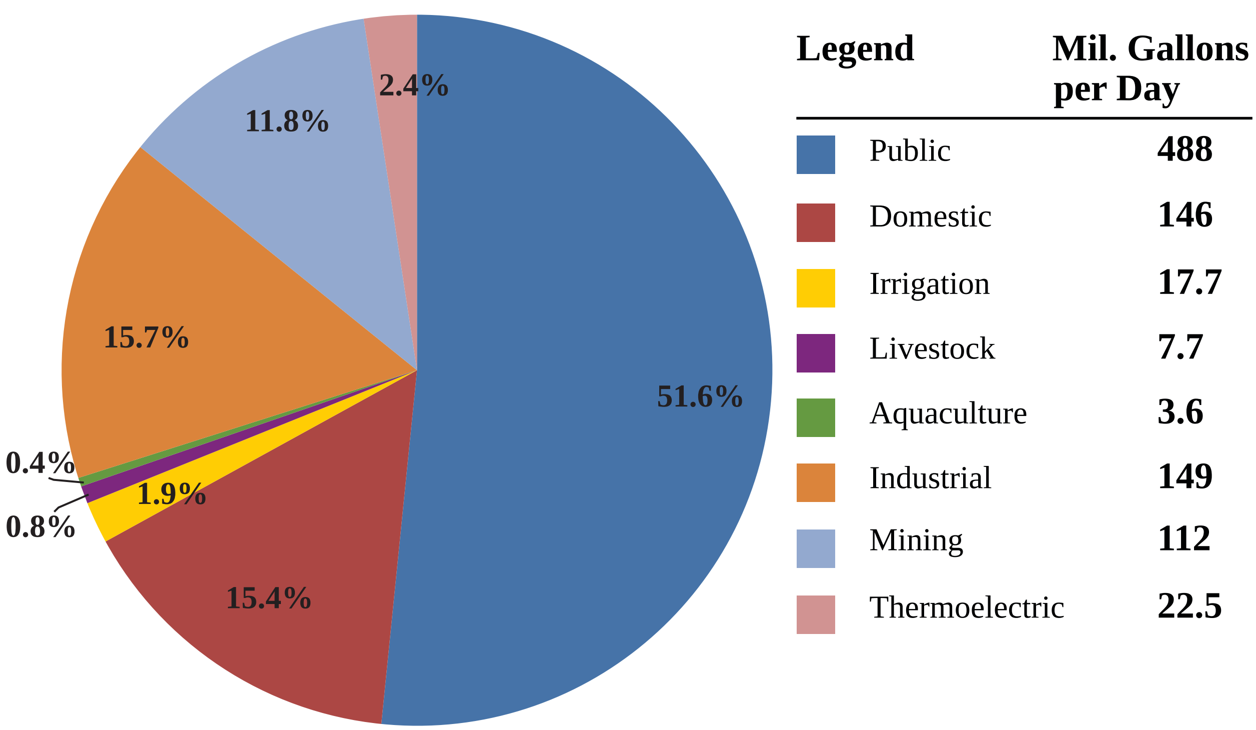


Figure 4
Groundwater withdrawals by user category

Sixty-seven percent of fresh groundwater withdrawals provide drinking water, including public (51.6%) and private (15.4%) water supplies (USGS, 2005). Approximately 95 percent of public water systems use groundwater as their source of drinking water, and more than 700,000 households use groundwater to meet domestic needs (Ohio Division of Water, 2011-b.).

Figures 5 and 6 are maps depicting groundwater availability in unconsolidated alluvial or glacial and bedrock aquifers. Approximately 70 percent of Ohio is blanketed with glacial deposits. The most productive aquifers in Ohio are sand and gravel deposits in buried valleys. Water wells developed in these sand and gravel deposits are capable of producing 500 gallons per minute, and are the source of many municipal water supplies (Ohio Division of Water, 2011-b.).

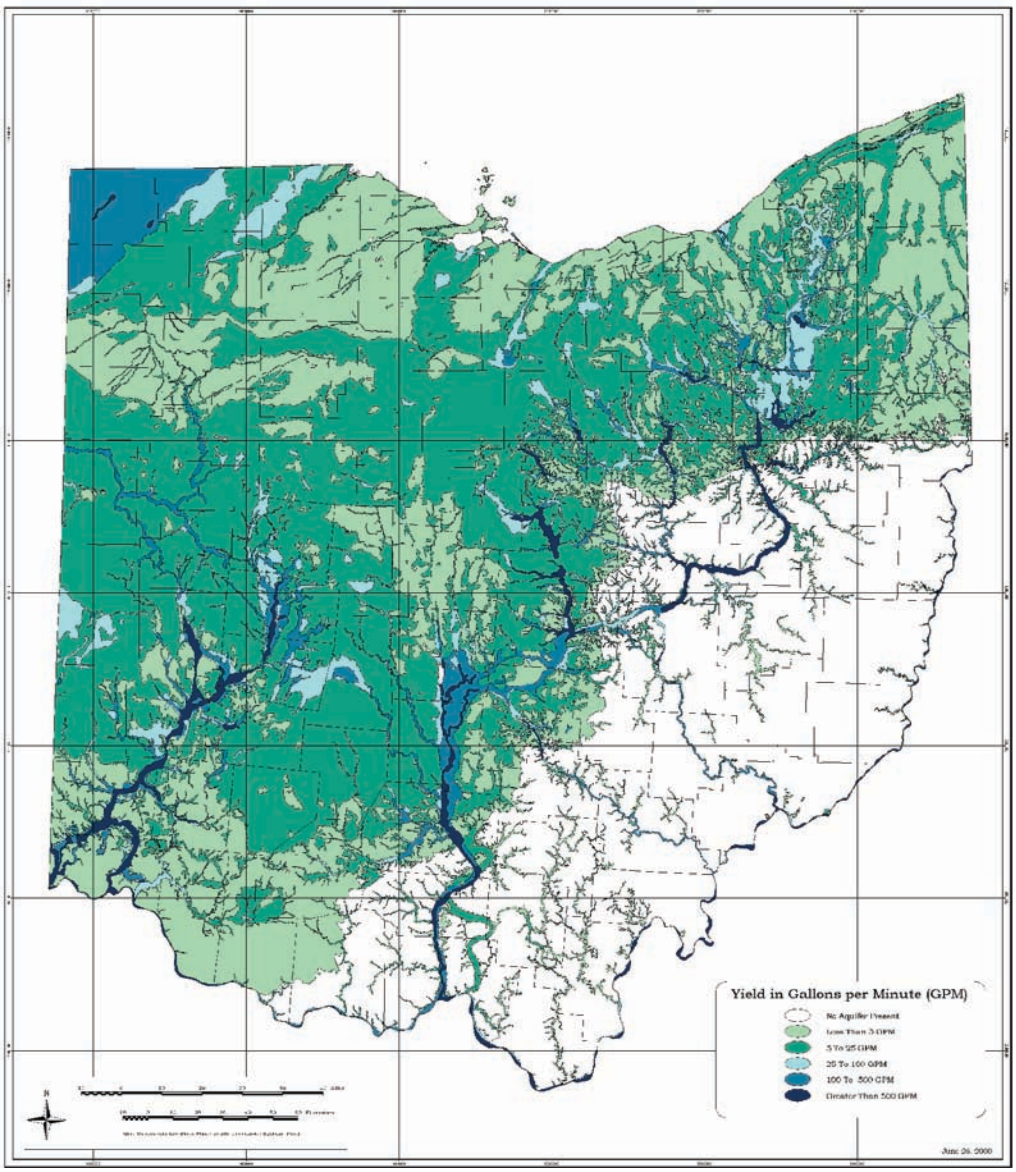


Figure 5
Yields of unconsolidated aquifers in Ohio
Source: Ohio DNR Division of Water

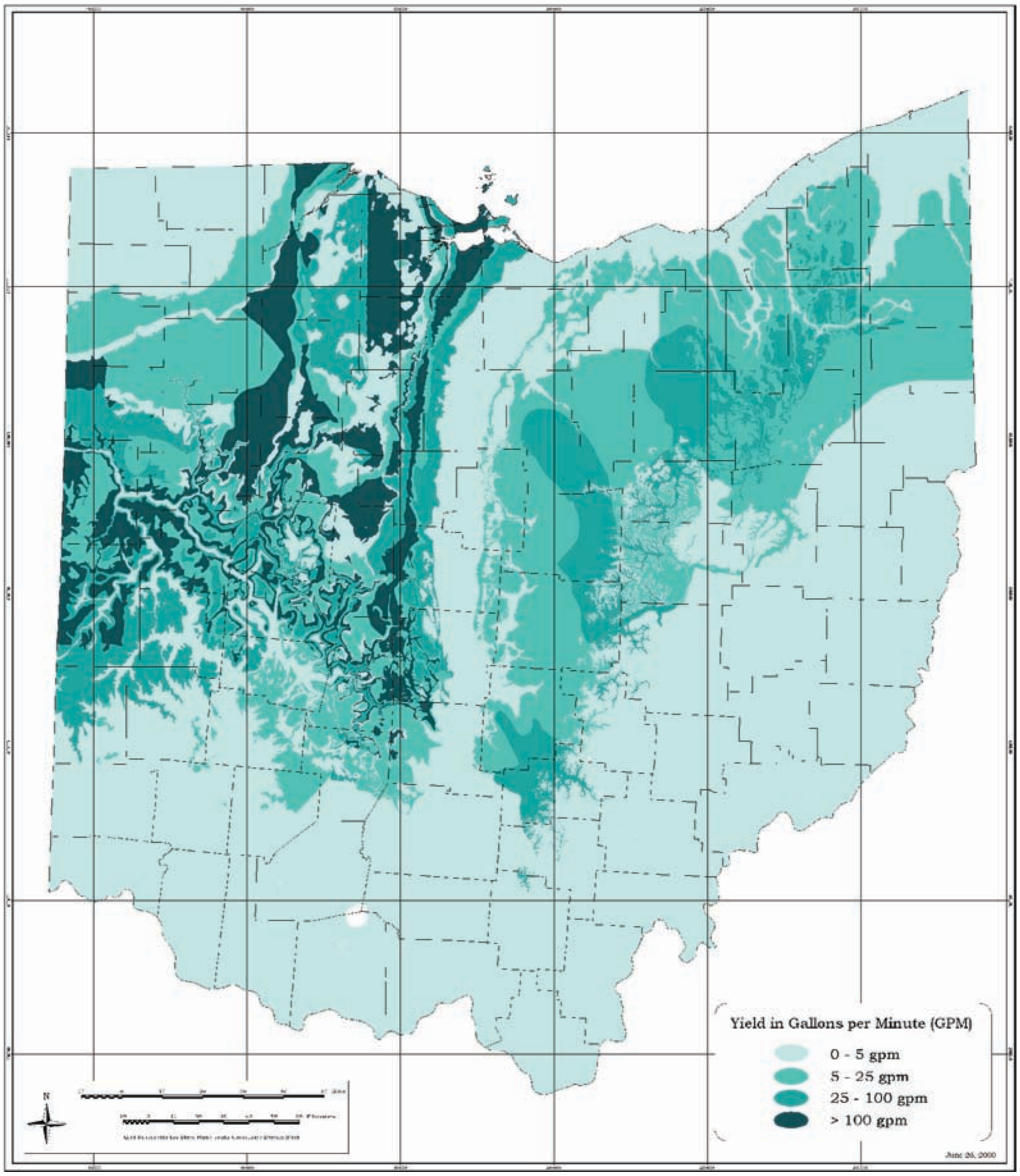


Figure 6
Yields of uppermost bedrock aquifers in Ohio
Source: Ohio DNR Division of Water

Water wells developed in the fractured carbonate aquifers of northwestern Ohio reliably yield 25 to 100 gallons of water per minute. Clastic aquifers including sandstones and conglomerates of northeastern Ohio provide reliable yields of 5 to 100 gallons per minute. In southeast Ohio, bedrock primarily consists of clay shale and laterally discontinuous lenses of siltstone, sandstone, or limestone. Private water supplies may be developed with general yields of less than three gallons per minute. In these areas, domestic water wells are typically less than 100 feet deep (Ohio Division of Water, 2011-b.).

Some portions of Ohio's aquifers are protected by a thick blanket of glacial till, where sufficient clay protects the underlying aquifers. However, in many areas domestic wells are developed in shallow, unconfined aquifers near the surface and are therefore relatively vulnerable to contamination from surface sources (Ohio Division of Water, 2011-b.).

In 1981, the DMRM commissioned the Ohio Department of Natural Resources (ODNR) Division of Water (DoW) to collect samples from wells in the regional consolidated aquifers of eastern Ohio. The project sought to define the down-gradient interface of potable versus saline groundwater based on the 10,000 mg/L Total Dissolved Solids (TDS) threshold used by the EPA (40 CFR § 146.3) to define USDWs (USEPA, 2002-c.). Using the maps generated by DoW, the DMRM defined the basal elevation of these USDWs based upon a review of gamma ray logs throughout eastern Ohio on a quarter township basis. Consequently, the DMRM established standardized surface casing programs for oil and gas wells using glacial drift thickness maps prepared by the ODNR Division of Geological Survey (DoGS), and quarter township data for the bedrock aquifers. In 2002, DMRM commissioned DoGS to prepare structural contour maps for the base of several regional bedrock aquifers in Ohio (Riley, 2001). These maps help ensure that surface casing is installed through the deepest USDW at oil and gas wells drilled in Ohio, as required by permit.

History of Oil and Gas Exploration and Development

Ohio has an extensive history of oil and gas E&P predating the turn of the twentieth century. Nearly 275,000 oil and gas wells have been drilled in Ohio, at depths ranging from less than 100 to over 11,500 feet. E&P activities have focused on the flanks of two major sedimentary basins: the northwestern Michigan Basin and the eastern Appalachian Basin (McCormac, 1983-2007). The Ohio oil and gas fields map (Figure 8) illustrates that drilling activity has primarily occurred in the three of four quadrants. As of 2007, the Ohio oil and gas industry has produced over one billion barrels of crude oil and over eight tcf of natural gas (McCormac, 1983-2007). Figure 7 illustrates crude oil and natural gas production trends from 1876 through 2007, and depicts boom and bust cycles experienced by the industry as the result of new discoveries, emerging technologies, commodity price fluctuations, and varying national tax policies.

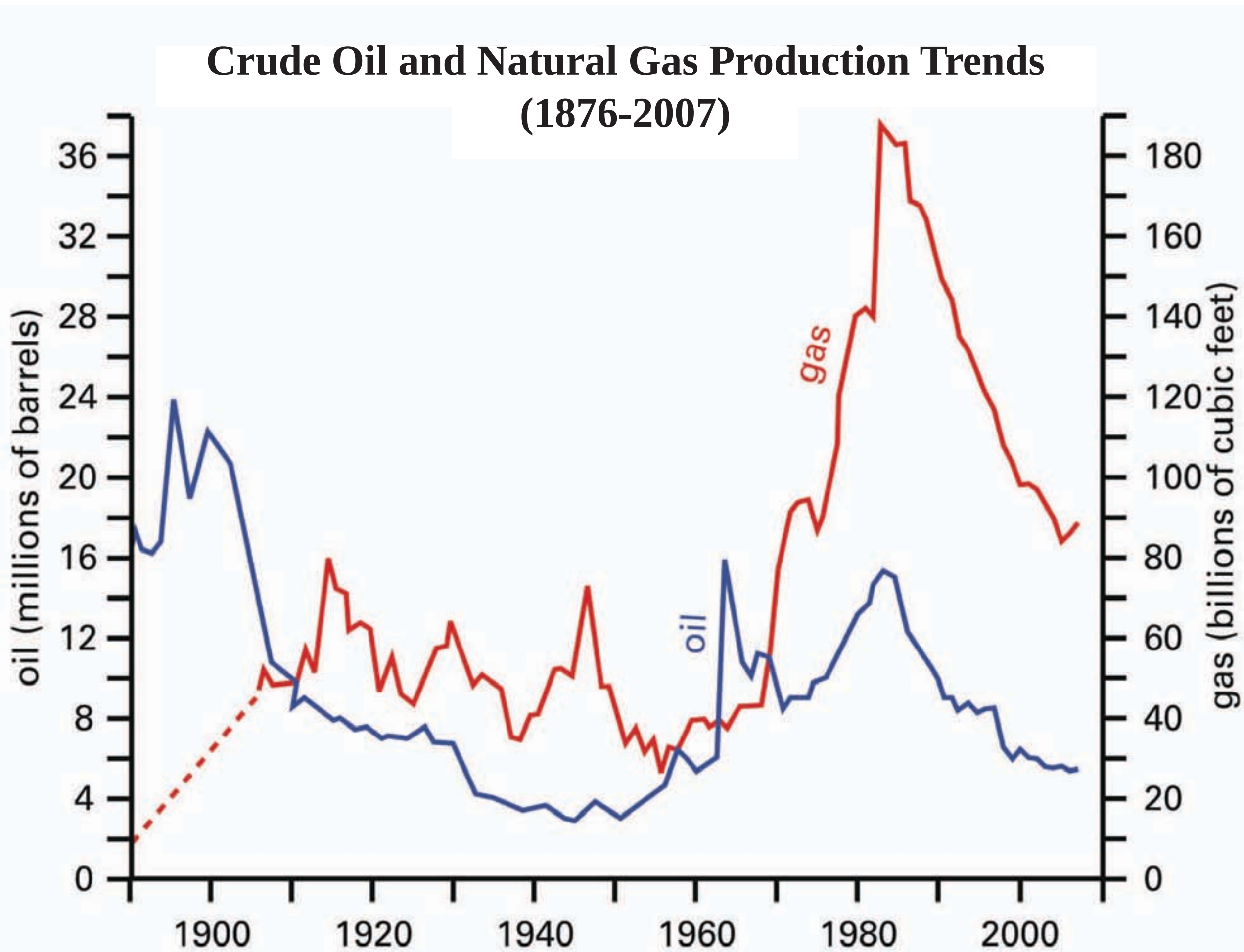


Figure 7
Crude oil and natural gas production trends (1876-2007)
Source: Ohio DNR Division of Geological Survey

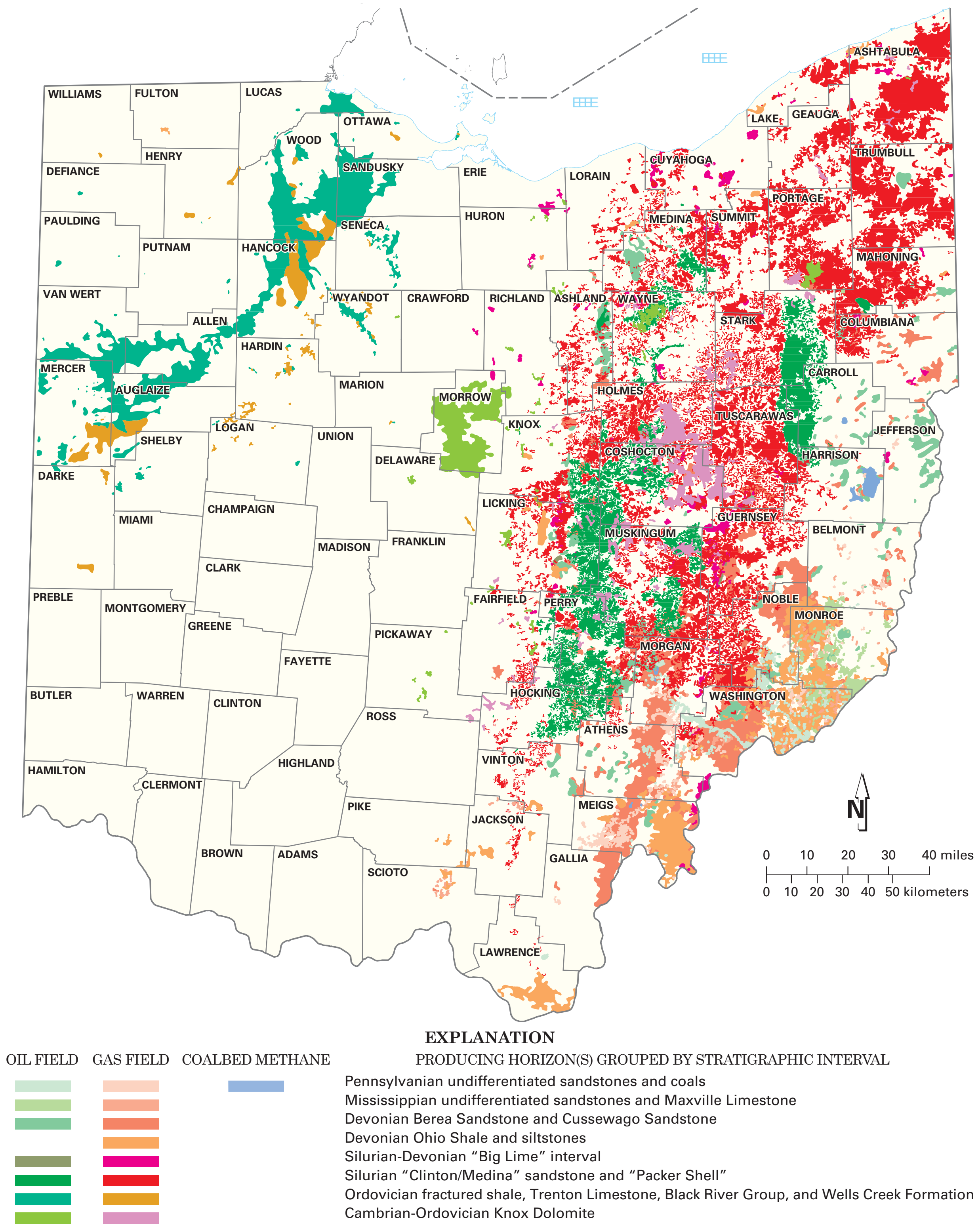


Figure 8
Oil and gas fields map of Ohio
Source: Ohio DNR Division of Geological Survey

Scouts and early settlers of southeastern Ohio discovered crude oil and natural gas flowing from natural seeps and springs. While exploring the Ohio River Valley in 1770, a pre-statehood surveyor named George Washington recorded the discovery of burning springs in his field notes. In 1814, Silas Thomas and Robert McKee made the first drilling discovery of crude oil in Ohio while exploring for salt water in Noble County. Initially, crude oil was viewed as a nuisance and a hindrance to extraction of salt water needed to preserve meat (McKain, 1994).

The first natural gas wells were drilled in the Ohio River Valley near Steubenville as early as 1850 to supply gas for domestic and manufacturing purposes. The first commercial production of oil occurred in Macksburg, Washington County (southeastern Ohio), only one year after Colonel Edwin Drake's famous discovery well was completed in Titusville, Pennsylvania. From 1861 until the early 1890s, shallow Pennsylvanian sandstone reservoirs were extensively developed in southeastern Ohio (Norling, 1970; Van Doren, 2004; Vogt and Wells, 2007; STRONGER, 2005).

In 1884, the giant Lima Oil Field was discovered in northwestern Ohio, which made Ohio the world's largest oil producer (Figure 9). Over 70,000 wells were drilled to the northwestern Ordovician Trenton Limestone between 1888 and 1937 and by the late 1800s the Trenton Play was annually yielding over 24 million barrels of oil (Wickstrom, Gray, and Stieglitz, 1992). However, production declined rapidly due to poor conservation practices, and by 1910 state production dropped to less than 8 million barrels per year.

Figure 9
Drilling practices in the Lima Oil Field in 1885
Source: Ohio DNR Division of Geological Survey

In 1887, natural gas was discovered at the up-dip pinch out of the Silurian "Clinton sandstone" in Fairfield County of south-central Ohio. Since its discovery, over 74,000 wells have been completed in the "Clinton sandstone" throughout eastern Ohio (McCormac, 1983-2007; STRONGER, 1995). As oil production from the Trenton Limestone declined after the turn-of-the-century, exploration activity increasingly focused on reservoirs in the upslope region of the Appalachian Basin in eastern Ohio.

Although Ohio authorized waterflooding in 1939, Enhanced Oil Recovery (EOR) has not played a significant role in Ohio oil production. Waterflooding operations peaked in 1943 when they accounted for almost 16 percent of Ohio's oil production. By 1998, there were fewer than 150 Class II EOR injection wells, and waterflooding accounted for less than one percent of annual oil production (Tomastik, 1999).

Hydraulic fracturing became a routine well stimulation method for many, but not all, oil and gas reservoirs in 1951. Prior to the advent of hydraulic fracturing, wells were stimulated by detonating nitroglycerine that had been lowered down a borehole adjacent to the petroleum reservoir. Hydraulic fracturing technology enabled the oil and gas industry to extend the down-dip, commercial viability of "tight" (low-permeability) reservoirs, including the "Clinton sandstone", Berea Sandstones, and the Ohio Shale Formation. From 1951 through 2007, over 78,000 oil and gas wells were completed in reservoirs that typically required hydraulic fracturing in order to be commercially productive (McCormac, 1983-2007). From 1983 to 2007, there was only one horizontal well completed in Ohio using a multi-staged stimulation (McCormac, 2007). A typical hydraulic fracturing operation in Ohio lasts five hours or less and uses approximately 50,000 to 200,000 gallons of water. Some operators prefer nitrogen or carbon dioxide (CO_2) foam over more conventional polymer-based or slickwater stimulations (DMRM, personal communication: Steve Opritza).

In 1961, the discovery of crude oil in central Ohio's Morrow County sparked a drilling boom. Production peaked at nearly 16 million barrels in 1964, but by 1970, annual production declined to 10 million barrels. In 1978, the federal Natural Gas Policy Act established price incentives for production of natural gas from "unconventional sources", including "tight [low-permeability] formations". The Devonian Ohio Shale formation, "Clinton sandstone", and Second Berea Sandstones met federal criteria for designation as "tight formations". During the 1980s, high prices and attractive "take or pay" contracts triggered a drilling boom that resulted in a 73 percent increase in the number of oil and gas wells from 37,296 to 64,590. Over 3,000 oil and gas wells were annually drilled between 1978 and 1985. In 1981 alone, over 6,000 oil and gas wells were drilled. Figure 10 illustrates drilling activity trends from 1983 through 2007. The collapse in crude oil prices in the mid-1980s brought this boom to a halt though, and by 1992 fewer than 1,000 wells were drilled annually for the next fifteen years (McCormac, 1983-2007).

Although produced water to crude oil production ratios are low, many reservoirs produce highly-saline water. Since Ohio law first required reporting of produced water volumes in 1985, the average ratio has ranged from 0.96-1.05 barrels of oil per barrel of produced water, including water generated during drilling and stimulation operations (Figure 11). On an annual basis, 70 to 75 percent of all wells drilled in Ohio penetrate the top of the Devonian Onandaga Limestone (McCormac, 1983-2007). The salinity of produced waters from reservoirs below the top of the Onandaga Limestone typically ranges from 170,000 to 220,000 mg/L chloride (Knapp and Stith, 1989).

During the 25 year study period (1983-2007), over 33,000 wells were drilled, and nearly 28,000 wells were plugged. The number of producing oil and gas wells increased 29 percent, from a low of 50,342 in 1983 to a high of 64,830 in 1991. Over 222 million barrels of oil and over 3.2 tcf of natural gas were produced over this period, and nearly 202 million barrels of produced water was disposed (McCormac, 1983-2007). Appendix D summarizes Ohio industry activity levels by year during the study period.

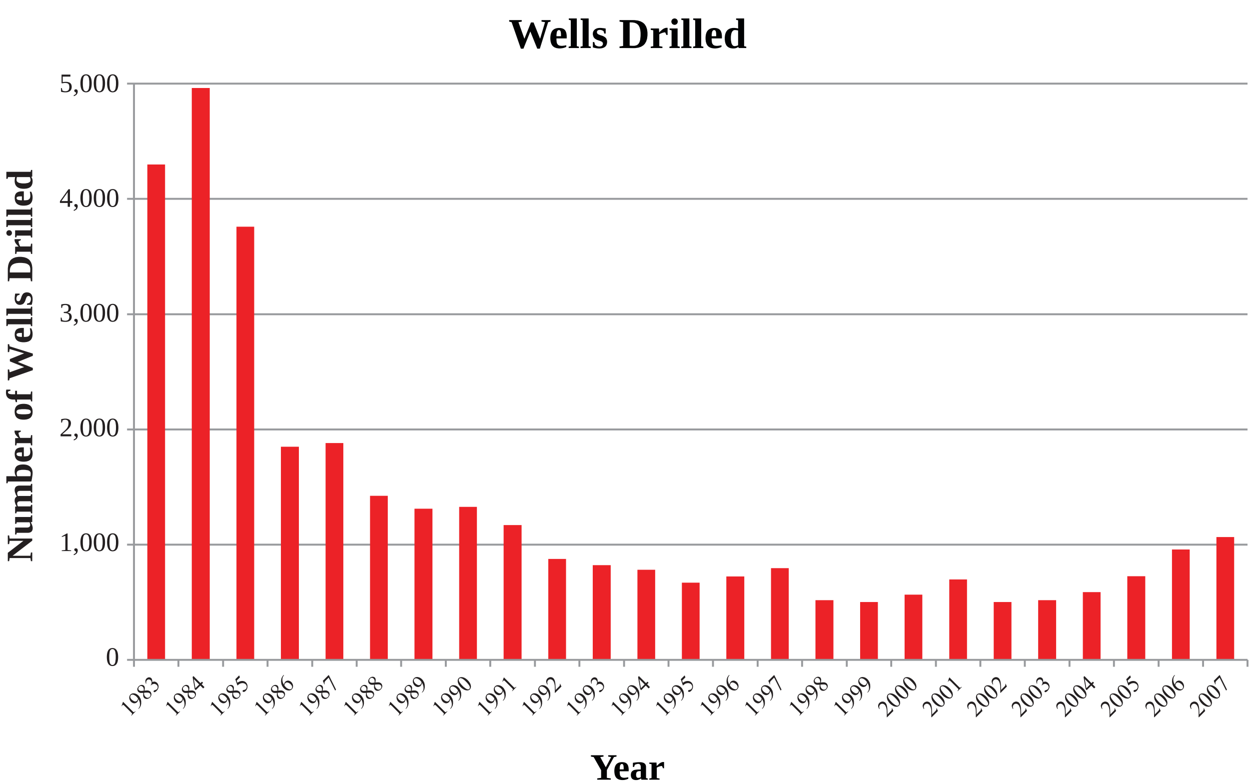


Figure 10
Drilling operations (1983-2007)

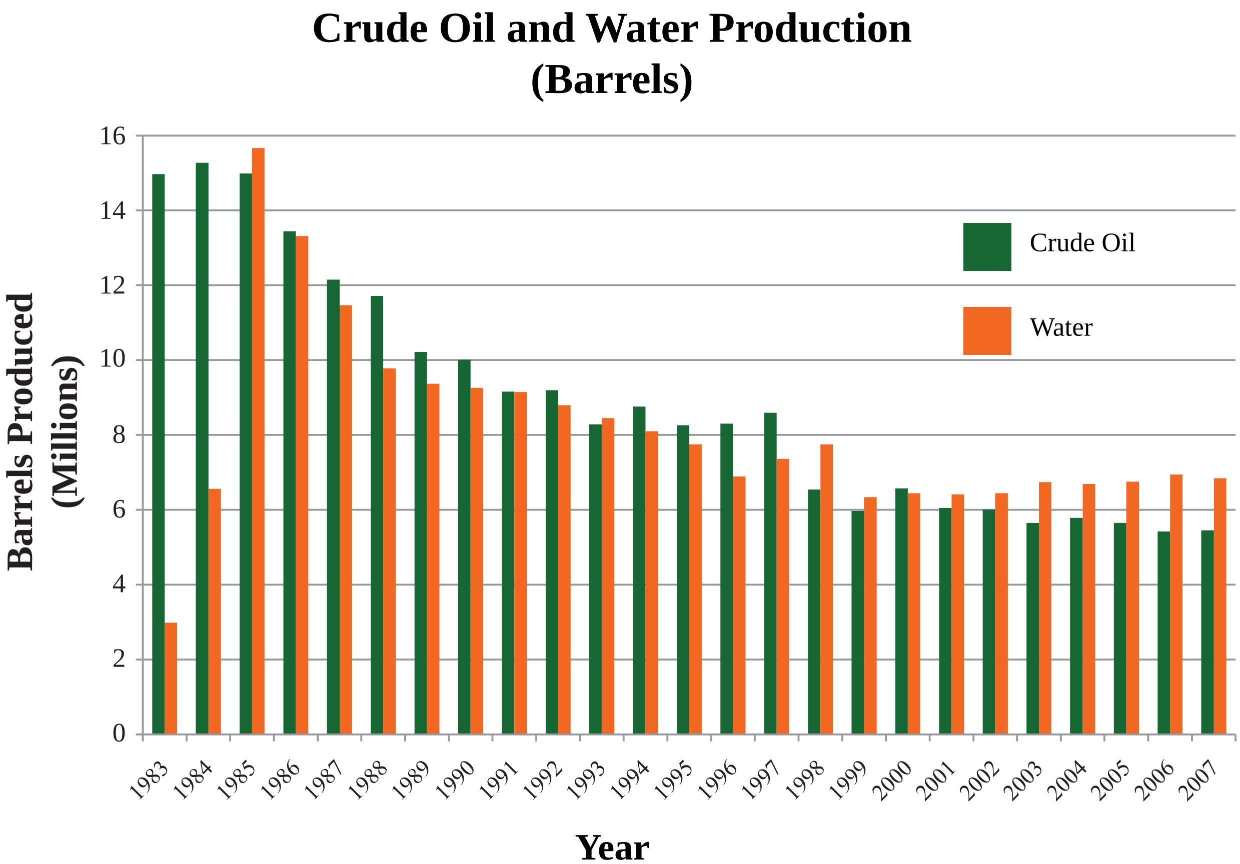


Figure 11
Crude oil and produced water volumes (1983-2007)

History of Oil and Gas Regulation Pertaining to Groundwater Protection (1883-1983)

Ohio enacted its first oil and gas statute in 1883, approximately 25 years after its first commercial oil production from the shallow Pennsylvanian sandstones in southeastern Ohio, and one year before the discovery of the major Lima-Indiana oil field in northwestern Ohio. The law required the installation of casing while drilling wells, and that wells be plugged upon abandonment to protect oil-bearing reservoirs from invasions of fresh water. The primary purpose of the legislation was oil conservation, but these nominal well construction requirements provided a measure of protection for fresh groundwater (Glosser, 1965).

In 1898, the Ohio General Assembly passed legislation requiring a map to be filed with the Chief of the Division of Mines that showed the location of all wells on coal-bearing lands in eastern Ohio. The law's passage marked the beginning of requirements to maintain location information for drilled oil and gas wells despite the fact that it was intended to protect coal miners. Subsequent legislation in 1917 and 1927 expanded the Division of Mines' authority by requiring a map and permit application prior to drilling a well in a coal-bearing township, as well as submission of a post-drilling well completion report. In 1933, the General Assembly enacted legislation requiring well completion records for all oil and gas wells, regardless of the presence of coal. Well location, depth, and construction records benefit current groundwater resource protection by providing the data necessary to: (1) evaluate wells and require corrective action within the Area of Review of future Class II injection wells or EOR projects, and (2) to design well-specific plugging plans (Glosser, 1965).

In 1964, emergency rules were enacted that established bonding and well spacing standards because of chaotic drilling activity in the Morrow County oil boom. One year later the General Assembly passed House Bill (HB) 234, which created the Division of Oil and Gas within the ODNR. This legislation established Chapter 1509 of the ORC and entrusted the Division of Oil and Gas with a threefold mission:

1. To assure the protection of public health, safety, and the environment;
2. To allow the orderly and efficient development of oil and gas reserves; and
3. To assure conservation of other natural resources.

The new law expressly forbade groundwater contamination, and authorized the Chief of the Division of Oil and Gas to promulgate rules necessary to enforce Chapter 1509 ORC (Glosser, 1965). In 2000, the Division of Oil and Gas was merged with the Division of Mines and Reclamation, which created the new DMRM. For the sake of simplicity, this report refers to both the pre-and-post merger agency as the DMRM.

While the 1965 statute authorized injection of produced water and other oilfield wastes, as of 1965, only 20 injection wells were operational in Ohio and all were located in Morrow County (central Ohio). The statute also authorized the "storage" of produced water in unlined earthen pits; these pits became the standard method of "storing" produced water onsite. Over the following decade, no significant legislation or rules clarified or enhanced existing measures for protecting fresh groundwater resources.

In 1974, Ohio enacted preliminary and final restoration requirements to address soil erosion issues that also included closure timeframes (five months) for reserve pits. The state next established an orphan well program to plug orphaned wells and reclaim legacy sites in 1977. The primary purpose was to address the public safety risks posed by improperly abandoned wells, and some had been identified as sources of groundwater contamination.

The DMRM began to focus attention on improving waste management practices, particularly the storage and disposal of produced water, in 1980. That year, the Ohio Water Development Authority commissioned a report by Elmer Templeton and Associates, Inc. to estimate the volume of "salt brines" (produced water) generated annually by Ohio E&P activities and to recommend environmentally acceptable disposal options (Templeton, 1980). This report provided the foundation for:

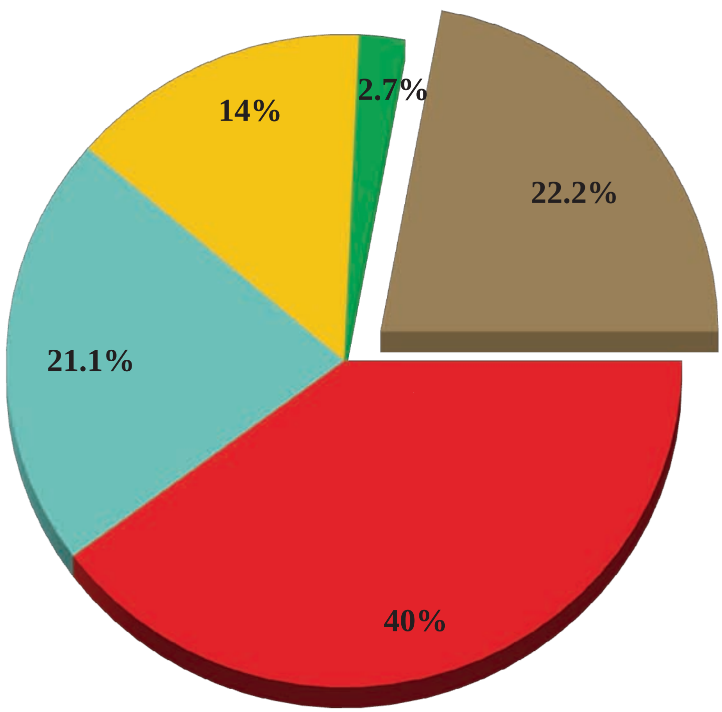
1. Enforcement actions to eliminate earthen pit produced water storage;
2. Shifts in DMRM policy towards establishing deep injection as the preferred method of disposal;
3. DMRM's pursuit of Class II primacy; and
4. Statewide debates that led to the passage of comprehensive produced water management legislation (Am.Sub. HB 501) enacted in 1985.

Regulatory enhancements and research projects focused on waste management practices were enacted or initiated nearly annually after 1980. Appendix B is a chronological summary of program enhancements that have improved groundwater protection since the mid-1970s.

Analysis of Documented Incidents and Regulatory Enhancements by Phase

Introduction: In the 25 year study period (1983-2007), the DMRM documented 185 groundwater contamination incidents caused by historic or regulated oilfield activities. Nearly all documented incidents (184) involved a temporary disruption of private water supplies. In 2007, investigators deemed a single non-consumption public water supply as "likely affected". The DMRM did not document any further incidents involving contamination or disruption of wells used for municipal, industrial, irrigation, agricultural, aquacultural, or any other legitimate purpose. Twenty-two percent of the 185 incidents (41) were caused by abandoned sites (orphaned wells). The remaining 78 percent (144) were caused by violations at permitted or regulated activities (Figure 12).

Total Incidents by Phase



Phases	Number of Incidents
Orphaned Wells & Sites	**41**
Site Preparation	**0**
Drilling & Completion	**74**
Well Stimulation	**0**
Production, On-lease Transport, & Storage	**39**
Waste Management & Disposal	**26**
Plugging & Site Reclamation	**5**

Figure 12
Total incidents by phase

The DMRM rendered determinations identifying contaminated private water supplies in each of the 25 years reviewed by this study. The number of incidents per year ranged from one (1994, 1999, 2003, 2004, and 2007) to 23 (1985, 1986). Fifty-three percent of all documented incidents caused by regulated activities (76) occurred during the first five years of the study (1983-1987), and 69.4 percent of all incidents caused by regulated activities (100) occurred within the first ten years. Viewed in five-year increments, the number of incidents from regulated activities declined significantly (90.1 percent) over the course of the study (Figure 13).

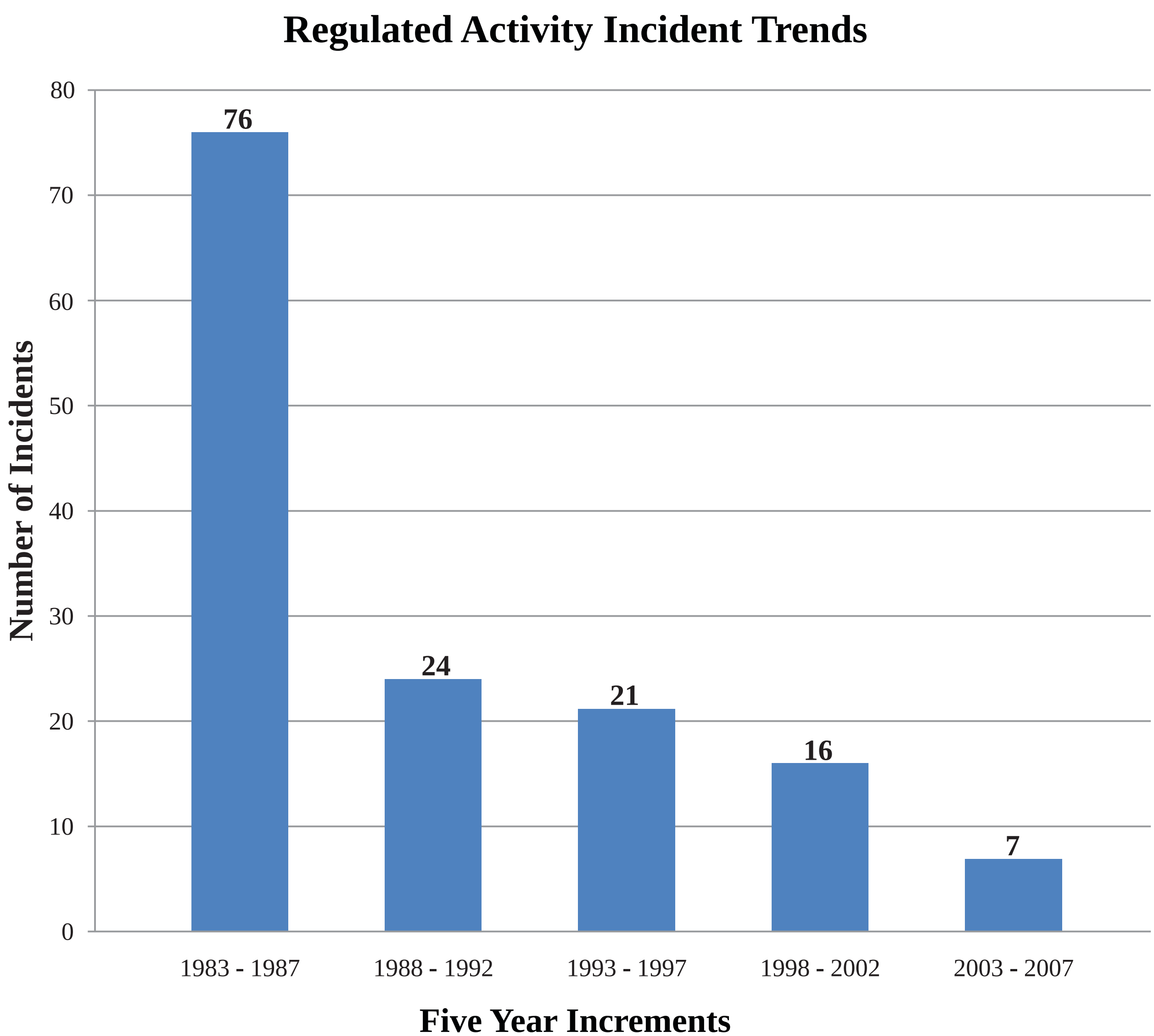


Figure 13
Regulated activity incident trends

The DMRM has initiated numerous regulatory reforms and participated in numerous research projects in response to issues identified through investigations of citizen water supply complaints. Figure 14 depicts temporal incident trends alongside some of the most significant regulatory reforms from 1983 to 2007. The following discussion depicts the evolution of Ohio's oil and gas E&P regulatory standards in response to documented incidents by their respective phase and activity. Appendix B is a chronological summary of significant regulatory reforms and actions.

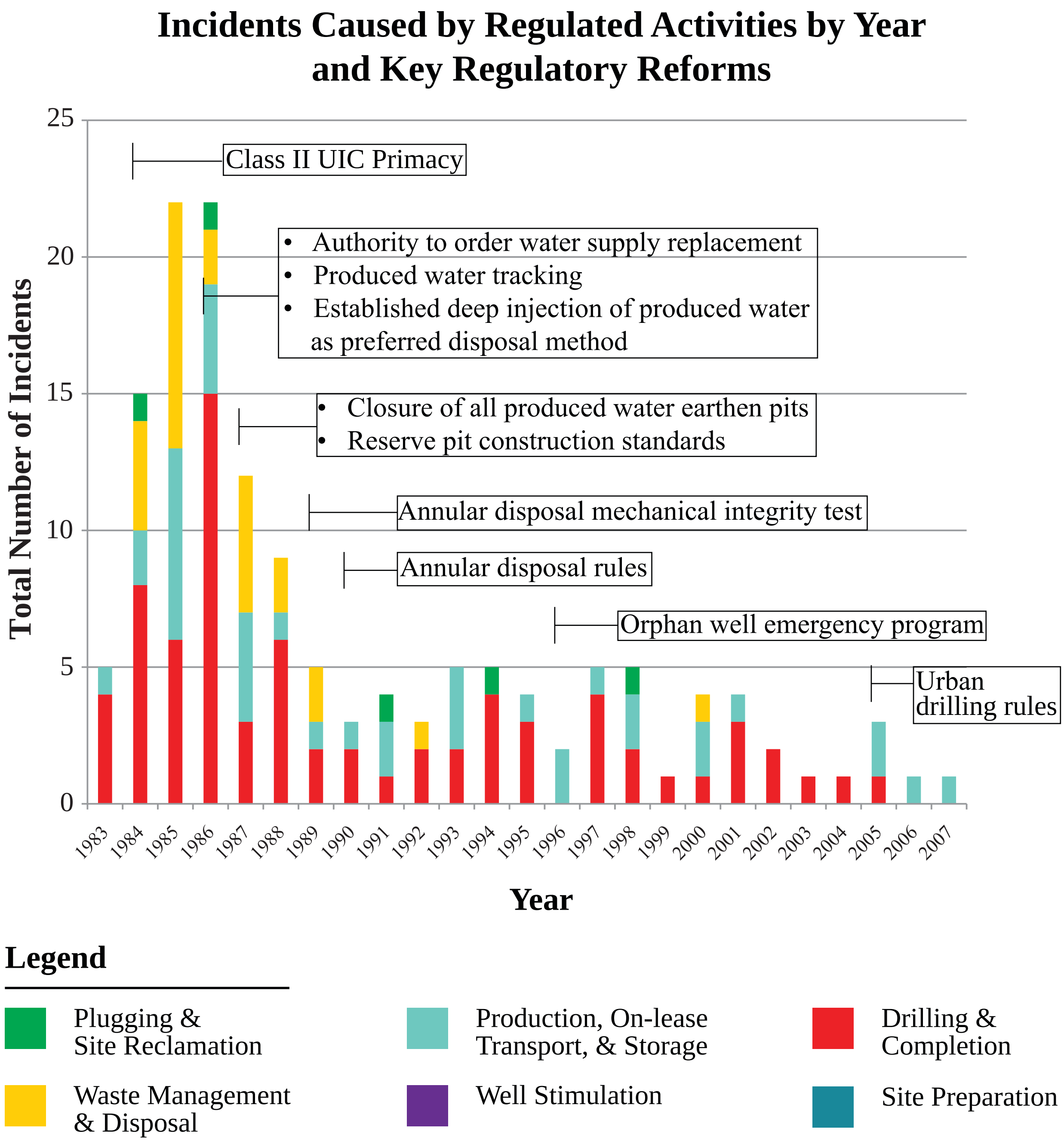


Figure 14
Incidents caused by regulated activities by year

Phase 1: Site Preparation

Phase Overview: Phase one involves construction of a well pad, access road, and excavation of reserve pits by diesel-powered equipment. In Ohio, less than one acre is typically disturbed during well pad construction for vertical completions. During the study period, 33,304 drilling pads were constructed (McCormac, 1983-2007).

Phase Incident Summary: Between 1983 and 2007, the DMRM did not identify a single incident of groundwater contamination caused by the accidental release of fuels or fluids from mobile powered equipment during site preparations. Figure 15 depicts the preparation of a drilling site and excavation of its reserve pit.

Figure 15
Site preparation and reserve pit excavation, Geauga County, Ohio 2008
Source: Ohio DMRM

Phase Regulatory Enhancements: The DMRM began to implement special permit conditions in 1985 that required operators to notify local inspectors prior to excavation of reserve pits at sensitive sites. HB 278 (2005) required operators to notify inspectors prior to commencement of site preparation, primarily to ensure installation of storm water runoff controls in urban areas. As a result of these notification requirements, DMRM inspectors are on location to witness phase one activities more frequently. Previously, the first inspection of a drilling site was to witness installation and cementing of conductor or surface casing.

Under the Federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), an operator is required to report any release of fuels, lubricants, transmission fluids, or antifreeze, to a variety of federal, state, and local authorities that exceeds Reportable Quantities (RQ), or impacts navigable water. The RQ for a gasoline, diesel fuel, transmission fluid, or any other refined petroleum product release is 25 gallons, or any quantity that causes a visible sheen upon the surface of navigable water. The RQ for antifreeze is 5000 pounds. Furthermore, under the Resource Conservation and Recovery Act (RCRA), an operator is prohibited from mixing any released non-exempt substance with RCRA-exempt waste (40 CFR Part 261.3).

ORC Section 3750.06 (1993) requires that operators report the release of any regulated chemical into the environment that exceeds the established RQ. Under rules promulgated by the State Emergency Response Commission, the operator must notify the Ohio EPA, the Local Emergency Planning Agency, and the jurisdictional fire department when such releases occur. Furthermore, if released fluids cause a visible sheen on “navigable waters”, which includes rivers, lakes, ponds or wetlands, the operator must additionally notify the National Response Center. If wildlife has been affected by a release, the operator must then notify the ODNR Division of Wildlife.

Phase 2: Drilling and Completion

Phase Overview: During the study period, 33,304 oil and gas production wells were drilled in Ohio. Most wells are drilled using fluid or air rotary systems. In areas where the target reservoir is relatively shallow (<3000 feet), some wells are still drilled with cable tools. Cable tool drilling operations declined from over one hundred per year to less than 30 from 1995 to 2007. The average depth of wells drilled in Ohio ranged from 3,745 to 4,745 feet deep during the study; the deepest historical well reached a depth of 10,200 feet in 1989. Rotary drilling operations typically last five to eight days (Figure 16). Only one horizontal well was drilled between 1983 and 2007 (McCormac, 1983-2007).

Figure 16
Typical rotary drilling operation using a freshwater mud system,
Geauga County, Ohio 2008
Source: Ohio DMRM

Phase Incident Summary: During the 25 year study period, the DMRM identified 74 incidents caused by activities during the drilling and completion phase. These incidents accounted for 51.4 percent of all documented incidents caused by regulated activities. Forty-nine incidents (66.2 percent) occurred within the first ten years of the study (1983-1992) and sixty-three of the incidents (85.1 percent) were caused by inadequate construction or maintenance of reserve pits. Eleven drilling operation incidents occurred prior to installation and cementing of protective surface casing. The DMRM did not identify any contamination incidents associated with steel tanks, emergency pits, blowouts, or fuel spills during the study.

1) Activity- Surface-Hole Drilling: The surface borehole is typically drilled using fresh water, fresh water mixed with clay (bentonite), or compressed air as a fluid media to circulate cuttings out of a borehole. If lost-circulation zones are anticipated or encountered, drillers may add non-toxic, biodegradable materials such as cellophane strips or cottonseed hulls to the drilling fluid in order to seal off permeable sections of the borehole and thus prevent migration of drilling fluids into aquifers. When drilling with compressed air, surfactants may be added to the system to both reduce the weight of the column of fluid in the borehole and to create foam that assists the removal of borehole cuttings. While drilling the surface hole, the drilling bit penetrates deeper aquifers that may be more saline than the shallow aquifers. If uncased, shallow lost-circulation zones are present while drilling the surface hole, drilling fluids may enter freshwater aquifers prior to installation and cementing of the surface casing. Despite this potential risk, contamination incidents are not common due to the brief duration of exposure, which is typically less than 24 hours.

   Activity Incident Summary: The DMRM determined that there were eleven incidents of private water supply contamination or disruption by surface-hole drilling fluids during the study, which accounted for 14.9 percent of drilling and completion phase incidents. All eleven incidents occurred while drilling the surface hole on compressed air. Three incidents involved contamination by surfactants, and another four involved increased salinity causing groundwater to temporarily exceed the SMCL for chloride (250 mg/L). The other three disruptions were turbidity issues attributed to agitation of scale, sediment, and biofilms in poorly maintained water wells, oxidation (aeration) causing a precipitation of naturally occurring iron, or of lost circulation of cement.

Activity Regulatory Enhancements: In 1982, the DMRM began to require 60 feet of “conductor casing” when drilling surface holes on air. This requirement has undoubtedly protected some, but not all, shallow water supplies. Beginning in the mid-1980s, the DMRM began to require operators to drill with freshwater systems in mapped contamination-sensitive areas, or areas where naturally occurring methane can be expected while drilling through or immediately below the deepest USDW.

2) Activity- Reserve Pits: Reserve pits are constructed at most drilling operations in Ohio. These pits are excavated to contain the cuttings and fluids that are circulated out of the borehole while drilling below surface casing. While drilling the production hole, drilling bits sometimes penetrate brine-bearing aquifers, salt deposits, and sub-commercial accumulations of crude oil; fluids from these zones are also circulated into the reserve pit. Reserve pits should therefore be constructed to sufficiently contain these fluids prior to their removal for disposal and site reclamation. Steel tanks may be required when drilling in flood plains or in areas where the base of the pit would intersect the water table. During the 25 year study period, there were 33,304 drilling operations; most involved construction of a reserve pit (McCormac, 1983-2007).

Activity Incident Summary: The DMRM identified 63 incidents of private water supply contamination from the infiltration of saline fluids from unlined or inadequately constructed reserve pits (Figure 17). Forty-four (70 percent) of these incidents occurred prior to 1990. Over the 25 year study period, inadequately constructed or maintained reserve pits were the number one cause

Figure 17
Poorly constructed and maintained reserve pit showing naturally fractured bedrock exposed to reserve pit fluids,
Columbiana County, Ohio 1986
Source: Ohio DMRM

of oilfield-related groundwater contamination, accounting for 43.7 percent of all incidents regardless of their phase. Incidents per 1,000 drilling operations peaked at 8.1 in 1986, but remained at 0.0 for the final five years of the study (2003-2007).

Activity Regulatory Enhancements: Ohio oil and gas law authorizes the use of reserve pits to contain cuttings and fluids, including the brine circulated out of the borehole during drilling operations. While the law requires that operators construct and maintain pits to prevent the escape of brine or other waste substances, neither current laws nor rules establish specific construction standards. During water supply complaint investigations in the 1980s, DMRM geologists began to document a pattern of groundwater contamination incidents within shallow, unconfined aquifers in several distinct hydrogeologic settings in northeastern and north-central Ohio. Drilling pits were being constructed in, or over, shallow, contamination-sensitive, unconfined aquifers, without liners or with thin (3-mil.), low-density, polyethylene that often tore during drilling operations. Contamination-prone aquifers included the sand and gravel beach deposits of the Lake Plain Region bordering Lake Erie, and the fractured sandstone, ridge-top aquifers overlain by thin deposits of glacial till.

DMRM geologists mapped these contamination-sensitive areas in the 1980s. In 1985, the General Assembly provided the DMRM with authority to issue permits subject to special terms or conditions in areas where there is a “substantial risk” of violations that could cause “damage to the environment” as part of Sub. HB 501. The DMRM developed and implemented special permit conditions that were applied to the mapped sensitive aquifer areas, including standards for:

- Inspector notification prior to excavation of the reserve pit;
- Reserve pit grading;
- Subliner preparation and soil sealants;
- Synthetic liners and seams;
- Maintenance and free-board requirements;
- Rapid removal and disposal of free liquids; and
- Cutting solidification and expedited reclamation.

Since the implementation of these standards, the DMRM has not documented an incident of groundwater contamination caused by infiltration of brine or fluids from reserve pits within a mapped area subject to permit conditions (Figure 18).

Figure 18
Reserve pit constructed according to new standards, Geauga County, Ohio 2008
Source: Ohio DMRM

The standards applied to the mapped contamination-sensitive aquifers have increasingly become standard industry practice throughout Ohio. As a result, the DMRM has not documented any groundwater contamination incidents attributed to faulty construction or maintenance of a reserve pit in the final five years of the study, during which time 3,858 wells were drilled.

General site restoration standards adopted in 1974 allowed up to five months for reclamation of the reserve pit. HB 501, enacted in 1985, authorized the Chief of the DMRM to order reclamation of pits within five months if there was evidence of integrity failure, such as a slumped liner. Beginning in the 1980s, the reclamation timeframe for all reserve pits in mapped sensitive areas subject to special reserve pit conditions was reduced to 14 days. Senate Bill (SB) 165, enacted in 2010, required the closure of reserve pits within 14 days for all urban drilling sites, regardless of the drilling location's contamination sensitivity.

Phase 3: Well Stimulation

Phase Overview: Stimulation by hydraulic fracturing has been a routine part of completing most oil and gas wells in Ohio since 1951. During the study period (1983-2007), the DMRM estimated that 27,969 oil and gas wells were stimulated by hydraulic fracturing. A typical hydraulic fracturing operation in Ohio lasts five hours or less, and approximately uses between 50,000 to 200,000 gallons of water (Figure 19). Most hydraulic fracturing stimulations use polymer-based systems or slickwater, though some use nitrogen or CO_2 foam.

Figure 19
Typical "Clinton sandstone" hydraulic fracturing operation,
Geauga County, Ohio 2008
Source: Ohio DMRM

Phase Incident Summary: During the 25 year study period, the DMRM did not identify any groundwater contamination incidents caused by hydraulic fracturing.

Phase Regulatory Enhancements: The DMRM has not identified hydraulic fracturing as a significant threat to fresh groundwater resources. Regardless, SB 165 (2010) establishes notification and reporting requirements to improve documentation of the process and the composition of stimulation fluids including additives. Among other provisions, SB 165 establishes clear well construction performance objectives that require the isolation of all USDWs behind cemented surface casing, and the isolation of petroleum reservoirs prior to, during, and after well stimulation operations. SB 165 further requires:

1. Inspector notification prior to the commencement of stimulation operations;
2. Immediate notification of an inspector upon detection of defective cement or casing during stimulation operations;
3. Submission of additional records, including job logs, pumping and pressure charts, and invoices listing additives by volume; and
4. Disposal of produced water generated during the post-stimulation flowback process at Class II injection wells.

Phase 4: Production, On-lease Transport, and Storage

Phase Overview: During the study period, the number of producing wells increased from 50,342 to a high of 64,830 in 1991. The number of active oil and gas wells has exceeded 62,000 each year thereafter through 2007. Most wells in Ohio are combination wells, producing both crude oil and natural gas. During the study period, over 222 million barrels of crude oil and 3.2 tcf of natural gas were produced (Appendix D). Typical production facilities include the well, a distribution line from the well to the storage facility, a fluid separator, one or more steel tanks for storage of crude oil and produced water, and a spill contaminant dike. Prior to 1985, earthen pits were commonly used to store produced water. Over 200 million barrels of produced water were generated during the study period.

Phase Incident Summary: The DMRM identified 39 incidents that occurred during the production phase of operations, which accounted for 27.5 percent of all regulated activity incidents. Documented incidents resulted from leaking storage tanks (12), leaking distribution lines (5), produced water pits (10), and well construction issues (12). Fifty-nine percent (23) of these incidents occurred within the first ten years of the 25 year study period. The DMRM did not identify any incidents caused by workover operations. The Ohio oil and gas industry does not use skimming/settling pits, percolation pits, evaporation pits, blowdown pits, basic sediment pits, or on-lease gas treatment systems; accordingly, there were no documented incidents associated with these activities.

1) Activity- Produced Water Pits: Although the 1965 Conservation statute (Chapter 1509 ORC) prohibited pollution and contamination of groundwater, earthen pits remained a standard industry practice for "storage" until 1985. Drainage

of produced water (brine) from tanks into lined or unlined earthen pits was the standard method of "storage" prior to 1985. The storage capacity of these earthen pits ranged from less than ten to over 32,000 barrels. The estimated number of earthen pits ranged from 2,500 to over 10,000 prior to 1985. Rules required earthen pits to be "liquid tight", but there were no construction or liner standards, or prescribed tests for "liquid-tightness" (Figure 20). Although the rule was intended to prevent contamination, enforcement actions were almost always remedial in nature.

Figure 20
Produced water pit, Morrow County, Ohio 1982
Source: Ohio DMRM

Activity Incident Summary: Ten of the 39 production phase incidents (25.6 percent) were caused by the failure of unlined water pits, all of which occurred within the first five years of the study period and were caused by pits that had been banned in 1985.

During the late 1960s, several studies were completed in Morrow and Delaware Counties (central Ohio) that documented groundwater contamination associated "with infiltration of produced water from earthen pits" (Shaw, 1966; Boster, 1967; Lehr, 1968; and Pettijohn, W.A., 1971). These studies documented eight water wells, including a municipal water well, where two year chloride concentrations averaged over 250 mg/L. The village of Cardington, located in the center of the Morrow County oil boom of the 1960s, was forced to abandon their municipal water well due to a chloride concentration exceeding 3,700 mg/L. This shallow water well had been developed in an unconfined glacial sand and gravel aquifer 150 feet away from an unlined earthen produced water pit. The Morrow County case is the only documented incident involving contamination of municipal water well by oilfield activities in Ohio. Researchers subsequently concluded that "unlined evaporation pits in humid areas where fresh groundwater may be contaminated by brines should be prohibited" (Lehr, 1968). From 1983 to 1986, the DMRM identified ten additional earthen pits that had contaminated one or more private water supplies.

Activity Regulatory Enhancements: In 1982, the DMRM began to focus field enforcement efforts on the identification and elimination of non-liquid tight earthen pits based on site-by-site field observations. During the first year, 1,685 pits were eliminated. A three year debate over produced water management practices in Ohio ensued, during which time DMRM geologists and field staff advocated for the elimination of all earthen pit storage of produced water. As a result, Am. Sub HB 501 (1985), required closure of all earthen pits storing produced water by July 1986. Two remnant groundwater contaminations incidents were identified in 1986. However, between 1987 to 2007, there has not been a single additional contamination incident involving earthen pit storage.

2) Activity- Storage Tanks and Distribution Lines: Storage tanks and fluid separation equipment are installed and connected to the well by distribution lines, if a well is completed as productive. In accordance with federal spill control regulations (CFR 40, Chapter 112), spill control containment structures, usually dikes, should be constructed around the storage facility. During the study period, the number of producing wells increased 28.8 percent from 50,342 to 64,830 in 1991, the peak year (McCormac, 1983-2007).

   Activity Incident Summary: The DMRM identified 17 incidents resulting from leaks at storage tanks or distribution lines. These incidents accounted for 43.6 percent of production phase incidents throughout the study period. On average, there were 0.76 incidents per year caused by failures at storage tanks or distribution lines. Incident rates ranged from 0.0 during 14 of the 25 years, and reached a high of 0.032 incidents per 1,000 production operations in 1986. In all tank releases that resulted in contamination, the surface storage facilities was not in compliance with federal spill control regulations.

   Activity Regulatory Enhancements: The storage of crude oil at onshore facilities, including crude oil storage tanks, is subject to federal regulations and liability provisions. Specifically, Section 311 of the Clean Water Act (CWA) requires operators to prepare and implement facility Spill Prevention Control and Countermeasure (SPCC) plans that address prevention and response to accidental releases of crude oil and other hazardous substances. In 1994, the DMRM acquired primacy (authority) to enact state spill control, reporting, and cleanup regulations to supplement federal regulations. The DMRM has drafted, but not enacted state regulations for spill control. The proposed regulations establish containment system standards and require operators to notify the DMRM if there is an unplanned release of any fluid or gas, including, but not limited to crude oil, within or outside of the containment structure.

3) Activity- Well Construction: During the course of drilling a well, multiple layers of coupled steel pipe (casing) are placed and cemented in the borehole. Wide-diameter conductor pipe is typically installed for borehole stabilization, to prevent the collapse of unconsolidated materials, and to isolate shallow glacial sand and gravel aquifers. Locally, the DMRM may require installation conductor pipe in order to protect vulnerable, shallow bedrock aquifers before drilling through deeper USDWs. Ohio requires that surface casing be installed through the deepest USDW for the protection of all used and/or potentially treatable groundwater. For all rotary drilled wells, surface casing must be cemented to the surface. However, prior to 2010, it was a common and lawful practice to seal surface casing in cable tool drilled wells with circulated prepared clay. From 1995 to 2007, fewer than 30 wells per year were drilled with cable tools (McCormac, 1983-2007).

   Activity Incident Summary: The DMRM identified 12 incidents caused by well construction deficiencies. Eleven of the twelve incidents were caused by the corrosion of surface casing over time, after the well had been completed. One incident in 2007 was the result of a deficient primary cement job on the production casing caused by a deep thief zone, which had been created by local faulting. As a result, the cement did not seal or isolate a sub-commercial gas-bearing zone above the targeted petroleum reservoir. Compounded by operator error, the annulus was shut in and overpressurized resulting in gas migration into local aquifers.

   Of the eleven incidents caused by corrosion of surface casing, six operations (55 percent) involved surface casing sealed with clay rather than cement in cable tool-drilled wells. Two were caused by the migration of hydrogen sulfide in the surface-production casing annulus, in an area of southeastern Ohio where hydrogen sulfide concentrations in a non-commercial gas-bearing zone, above the target hydrocarbon reservoir, may be atypically high. The corrosive, hydrogen sulfide-bearing zone was not sealed or isolated by cemented casing. All twelve incidents resulted in migration of natural gas into aquifers causing disruption of usage at one or more domestic water wells.

Activity Regulatory Enhancements: In 1988, the DMRM implemented permit conditions that require corrosive, hydrogen sulfide-bearing zones to be isolated with cement behind the production casing. SB 165 (2010) updates well construction requirements by:

- Establishing performance objectives for well construction activities;
- Mandating cementing of all surface casings;
- Requiring isolation of corrosive zones;
- Prohibiting annular over pressurization; and
- Requiring immediate agency notification upon detection of defective pipe, cement, or any other well construction component.

Permit conditions for new wells in northeastern Ohio require surface casing valves to be above grade and readily accessible. They must further be equipped with a pressure gauge and properly functioning pressure relief valve that has been set to release gas into the atmosphere if necessary to prevent annular overpressurization. The operator must immediately notify the DMRM if a pressure relief valve releases.

Phase 5: Waste Management and Disposal

Phase Overview: In 1983, U.S. EPA delegated U.I.C. regulatory authority to the DMRM for the Class II Program. The Ohio Class II Program regulates three types of wells: conventional Class II brine disposal wells, injection for EOR, and annular disposal of produced water. Ohio also allows the spreading of produced water for dust or ice control if authorized by the relevant local jurisdictional authority. Between 1985 and 2007, produced water production declined from 15,056,651 to 6,842,115 barrels per year. Because the volume released to the environment through unlined earthen pits cannot be estimated, data regarding produced water volumes prior to the closure of earthen pits in 1986 is unreliable. Landspreading of and treatment of saline solids and bioremediation of oily solids is allowed under certain circumstances, but in fact rarely occurs. The vast majority of saline and oily solids are excavated and disposed of at Ohio EPA approved solid waste landfills. Ohio does not practice roadspreading of heavy hydrocarbons for dust control, or annular disposal of drilling solids.

Phase Incident Summary: The DMRM documented 27 incidents (19 percent) caused by waste management and disposal activities. Over half of these incidents (14) were caused by annular disposal of produced water prior to the enactment of more stringent construction and mechanical integrity testing standards in 1988 and 1990. Eighty-nine percent of the incidents (23) occurred within the first ten years of the study period (1983-1992).

1) Activity- Annular Disposal: Produced water can be gravity fed into the annular space between the surface and production casing of a producing oil and gas well, if authorized by permit. When an annular disposal well functions properly, the produced water enters permeable saline reservoirs below the base of the surface casing, which extends through the deepest USDW. This produced water disposal practice has been used by the Ohio oil and gas industry since the mid-1960s, and is limited to disposing of water produced on or at a lease adjacent to where it was produced. Produced water may not be hauled to an annular disposal well by truck. Furthermore, operators may only dispose a maximum of ten barrels per day on average, and pressure at the wellhead is restricted to the natural force of gravity (Tomastik and Kell, 1987).

   Even with these volume and pressure restrictions, many federal and state officials were concerned with the practice of annular disposal as implemented in Ohio because the surface casing was the sole casing string protecting USDWs. This casing string was typically sealed with clay rather than cement. Prior to 1988, there was no practical method to test the mechanical integrity of the surface casing. Potential for aquifer contamination exists if the surface casing loses mechanical integrity and the hydrostatic head in the annulus exceeds the hydrostatic pressure in the adjacent USDW (Tomastik and Kell, 1987).

   Annular disposal regulations adopted in 1982 required that all operators demonstrate the mechanical integrity of surface casings at least once every five years. Therefore, owners of over 7,000 wells that were being used for annular disposal prior to adoption of the rules were required to demonstrate casing mechanical integrity by June 1987. However, because there was no practical method to test mechanical integrity, the Ohio General Assembly extended the test deadline until September 1988 (Tomastik and Kell, 1987).

Activity Incident Summary: Between 1983 and 1985, the DMRM documented fourteen annular disposal operations that had contaminated one or more private water supplies.

Activity Regulatory Enhancements: In 1987, the DMRM completed a systematic study evaluating annular disposal of produced water in order to assess the environmental, public health, and safety risks associated with annular disposal as practiced (Tomastik and Kell, 1987). Surface casing conditions and clay sealant quality were evaluated at 100 oil and gas wells as the casing string was extracted from the well during plugging operations. Hydrogeologic investigations were conducted within a quarter-mile radius of wells which had exhibited evidence of mechanical integrity failure (holes, severe corrosion, splits, partings, and lack of sealant).

The study determined that only three percent of the inspected wells were constructed and maintained in a manner consistent with the EPA's twofold requirements for demonstrating mechanical integrity. Eighty percent of the total recovered surface casing was rated as being in "fair to poor" condition. Surface casings extracted from 29 wells had observable mechanical integrity failures. Specifically, the study documented a total of 150 holes in surface casings withdrawn from these 29 wells (Figure 21). Fifty-four percent of the wells had no clay sealant on any portion of the recovered surface casing. Annular fluid levels were measured above the basal elevation of the deepest

Figure 21
Badly corroded surface casing extracted from a well used for annular disposal,
Perry County, Ohio 1987
Source: Ohio DMRM

USDW in 88 percent of the 41 wells tested (Tomastik and Kell, 1987).

In 1988, the DMRM developed a mechanical integrity test for annular disposal wells and the EPA's National Technical Workgroup approved Ohio's proposal for the Positive Differential Test in April 1988. The DMRM subsequently established a test schedule and revoked every well's authorization that failed to conduct or, if conducted, to pass the new test by a scheduled deadline.

The DMRM adopted amended rules concerning annular disposal operations on June 19, 1989. These rules required the isolation and protection of USDWs by cemented surface casing and verification of mechanical integrity before new annular disposal operations could begin. Operators are further required to repeat the test every five years to ensure a surface casing's continued mechanical integrity.

Since the new well construction and mechanical integrity test standards were implemented in 1989, the number of annular disposal operations declined from an estimated 7,500 in 1983 to 94 in 2007 (UIPC, 1989; DMRM, 2000-2007). The DMRM did not subsequently identify a single case of groundwater contamination caused by annular disposal for the remaining 17 years of the study.

2) Activity- Enhanced Oil Recovery: Ohio authorized waterflooding as a method of EOR in 1939; however, EOR has not played a significant role in oil production or produced water injection. During the study period, the maximum number of EOR injection wells was 194 in 1993. Since 1998, fewer than 150 wells have injected produced water at Ohio waterflooding operations. EOR currently accounts for less than seven percent of produced water disposal (Tomastik, 1999).

   Activity Incident Summary: The DMRM documented two contamination incidents of private water supplies attributed to historic EOR injection operations in Medina County of north-central Ohio. The oil reservoir was the Mississippian Berea Sandstone where the depth to the pay zone ranged from 242 to 494 feet below surface. These two incidents were remnant problems created by poor well construction and operational practices allowed from 1939 to 1983, prior to the adoption of SDWA regulations.

Prior to 1983, injection wells in Medina County were typically constructed without protective surface casing and minimal cement behind the base of injection tubing. Compounding the problem was the fact that many injection wells were operated at pressures exceeding formation-parting pressure (Tomastik, 1999). The Ohio DoW's Water Resource Map for Medina County delineates the areas in two townships where substandard practices were employed from 1939 to 1983 as areas where water wells typically encounter "oil residue and salt water resulting from [historic] petroleum exploration" (Schmidt, 1978). The two incidents involved private water supplies developed in these historically contaminated areas.

Activity Regulation Enhancements: The practices that resulted in the extensive contamination of Medina County aquifers were terminated in 1983. Rather than grandfathering existing EOR wells into their Class II Programs, Ohio mandated that all injection wells meet or exceed the new construction standards or terminate injection by 1983. Most Medina County EOR project operators elected to abandon their projects rather than meet the new standards for well construction, operation, monitoring, mechanical integrity verification, and reporting. Between 1993 and 2007, the DMRM did not identify any further incidents from injection for EOR or EOR-associated surface facilities

3) Activity- Class II D Injection Well Surface Facilities: Class II injection facilities typically include bermed unloading pads, fluid segregation impoundments, storage tanks and their associated spill containment dikes, pump houses, and disposal lines. During the study period, the number of Class II disposal wells nearly doubled, from 79 (1983) to 154 (2007).

Activity Incident Summary: The DMRM documented five groundwater incidents caused by inadequate surface facilities at Class II produced water injection wells, all prior to 1989. In those cases, contamination resulted from either corroded distribution lines or concrete deterioration in the buried vaults that capture produced water spillage at unloading pads.

Activity Regulatory Enhancements: In 1989, the DMRM chartered a task force of agency, public, and industry representatives to define Best Management Practices (BMPs) for construction of surface facilities. As a result, new BMPs have been established for unloading pads, storage tanks, distribution lines, and runoff-collection vaults, which are implemented through permitting requirements. The DMRM did not subsequently identify any further incidents from deficient produced water management at Class II injection well surface facilities after the new standards were established (Figure 22).

Figure 22
Class II injection well surface facility, Ohio 2008
Source: Ohio DMRM

4) Activity- Dumping: Dumping produced water has been illegal in Ohio since 1965.

   Activity Incident Summary: The DMRM identified four incidents caused by illegal dumping of transported produced water at abandoned mines during the mid-1980s.

   Activity Regulatory Enhancements: The 1980s were a transitory period for produced water management. An estimated 10,000 earthen pits were eliminated while the DMRM and the oil and gas industry more than doubled the number of Class II injection wells to meet demand for increased produced water disposal capacity. HB 501 (1985) established deep injection at Class II wells as the preferred method of brine disposal. HB 501 also provided the DMRM with authority to revoke the registration of any brine hauler that had established a pattern of violations that threatened public health, safety, or the environment. Injection wells have since become geographically distributed throughout eastern Ohio, and the DMRM has not documented a single additional groundwater incident caused by illegally dumped produced water.

5) Activity- Brine Spreading: Ohio has allowed controlled spreading of produced water (brine) for road deicing and dust control since the 1960s.

   Activity Incident Summary: Brine spreading caused a single documented case of groundwater contamination. In that case, the DMRM determined that spreading produced water at excessive frequencies and volumes on a parking lot and industrial work yard in violation of existing standards was to blame for the contamination.

   Activity Regulatory Enhancements: HB 501(1985) established minimum standards for brine spreading and established local jurisdiction controls to enforce them. Brine spreading is allowed when authorized through resolution by local governments with authority over road maintenance. Local authorities may: establish standards that exceed statewide minimum standards; rescind previously-granted authorization; and are required to annually report the source, volume, and location of all brine spreading to the DMRM. Local authorities may not, however, authorize spreading of flowback or drilling fluids.

   HB 501 also established the Brine Management Research Special Account (BMRSA) to fund research regarding potential environmental impacts associated with brine spreading. Between 1989 and 1991, the DMRM funded four research projects on brine spreading through the BMRSA (Bair, Digel, and Springfield,1989; Corbett,1990; Springfield,1988; Digel,1988).

Phase 6: Plugging and Site Reclamation

Phase Overview: During the study period, 20,374 oil and gas wells were plugged in Ohio (McCormac, 1983-2007). The very first Ohio laws regarding oil and gas wells, enacted in 1893, recognized the critical importance of plugging wells to prevent flooding of oil and gas zones by fresh or salt water after casing was withdrawn during the plugging process. In 1982, the DMRM enacted plugging rules providing more specific standards and elaborating on the generalized well plugging objectives listed in the statute. These plugging rules require well owners to notify an inspector before commencement of plugging operations. DMRM inspectors must approve plugging materials, methods, and a plugging plan for each well based on site-specific geology and well construction records. Wells must be plugged in a manner that confines oil, gas, and water in the reservoir rocks in which they originate. Cement plugs must be placed across and above the reservoir rock, across all other petroleum-bearing zones, at the top of the Onandaga Limestone, across mineable coal seams, across the surface casing shoe, and at surface to effectively isolate USDWs.

Phase Incident Summary: The DMRM identified four groundwater incidents prior to 1992 caused by plugging and site reclamation operations. Three of the incidents were caused while circulating saline or oily fluids out of the borehole after removing mudded surface casing at cable tool drilled wells. The fourth incident involved naturally occurring crude oil in the deepest USDW that had been confined behind surface casing until the casing was pulled during plugging. The DMRM study did not document any further incidents related to temporary storage pits, decommissioned tanks, or pipelines removed during site reclamation.

Phase Regulatory Enhancements: The DMRM amended its plugging rules in 1992. The new rules require all brine and crude oil to be circulated out of the borehole prior to pulling mudded surface casing during plug jobs for cable tool wells. Furthermore, these amendments establish cement quality standards and require use of sulfate-resistant cements across hydrogen sulfide-bearing zones. Prior to 2004, jurisdictional oversight of plug jobs had been split between the Department of Industrial Relations' Division of Mine Safety for wells in coal-bearing townships, and the DMRM for all other wells. That authority was centralized under the DMRM in 2004 when harmonized standards for protection of groundwater, the public, and underground miners were adopted. SB 165 (2010) requires surface casing to be cemented in all wells, including those drilled by cable tools, thereby eliminating potential problems that can occur when non-cemented surface casing is pulled during plug jobs.

Phase 7: Orphaned Wells and Sites

Phase Overview: From 1978 to 2008, the DMRM spent over $20 million plugging 1,870 orphaned wells and reclaiming abandoned sites without recorded owners. The DMRM Idle and Orphan Well Program is funded by a portion of the severance tax on oil and gas production and forfeited bonds. This program was established to: respond to public complaints, research well ownership records so as to determine eligibility, contract with well plugging services, and monitor well plugging and restoration work to ensure contractual compliance.

Phase Incident Summary: The DMRM has identified 41 sites where fluid leaked from orphaned wells and disrupted private water supplies. Orphaned wells accounted for 22.2 percent of all recorded incidents.

Phase Regulatory Enhancements: Ohio was one of the first states in the Appalachian Basin to establish an Idle and Orphan Well Program (Figure 23). "Idle and orphaned wells" are those that have been abandoned, and have no legally responsible party to assume plugging or cleanup costs. In 1994, SB 182 authorized the Chief of the DMRM to spend oil and gas well fund monies in order to address imminent public health and safety risks without delays caused by competitive bidding requirements or State controlling board authorization. As a result, the DMRM can expedite corrective action at orphaned wells which are threatening or contaminating water supplies without the inherent delays of bid advertisement and contract processes. SB 165 (2010) requires the DMRM to spend 14 percent of its annual revenue on orphaned well plugging contracts, and is projected to raise annual expenditures to approximately one million dollars.

Figure 23
Orphaned well plug job at a site between two homes in suburban Cleveland
Source: Ohio DMRM

TEXAS

Groundwater Usage

Groundwater continues to be an important source of water for Texas. Texas ranks second nationally in fresh groundwater withdrawals. In 2005, Texas withdrew over eight billion gallons of groundwater per day, which translated to 8,990,000 acre feet of total withdrawal that year and 34 percent of all fresh water used in 2005 (USGS, 2005). Farmers used 76.3 percent of this groundwater to irrigate crops, and 18.3 percent was withdrawn for public and private drinking water supplies. Figure 24 depicts 2005 groundwater withdrawals by user type.

Texas Fresh Groundwater Withdrawals by User Category (Million Gallons per Day)

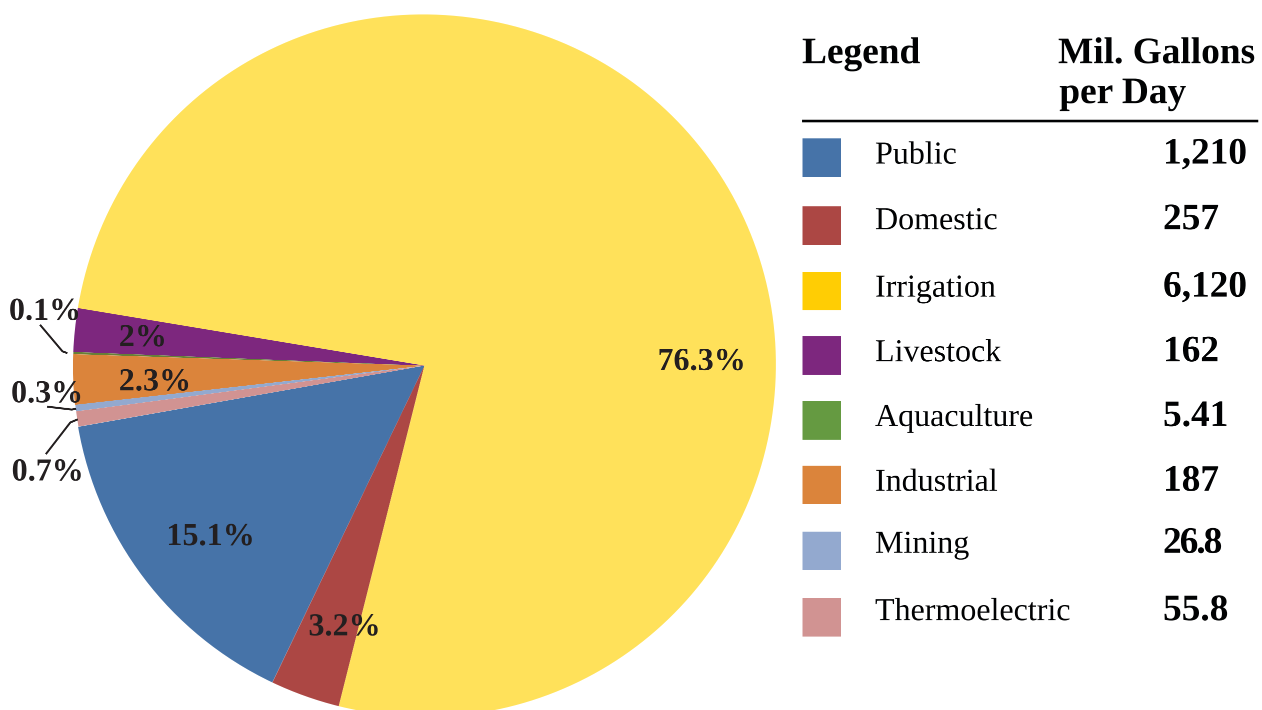


Figure 24
Groundwater withdrawals by user category

Groundwater production has increased nearly tenfold above 1940 levels since the drought of the 1950s (Texas Water Development Board, 2006-a.). Prior to 1940, groundwater provided Texans less than 1 million acre feet of water per year; it has provided approximately 10 million acre feet per year since the drought.

The Texas Water Development Board (TWDB) monitors and manages the quality and quantity of groundwater. In 2003, the TWDB recognized that nine major and twenty-one minor aquifers provided approximately 59 percent of all fresh water used in Texas that year. Major aquifers produce large volumes of groundwater over large areas, while minor aquifers produce minor amounts of groundwater over large areas, or large amounts over small areas. Figures 25 and 26 depict the outcrop and subcrop areas of major and minor aquifers in Texas (TWDB, 2006-a. and b.).

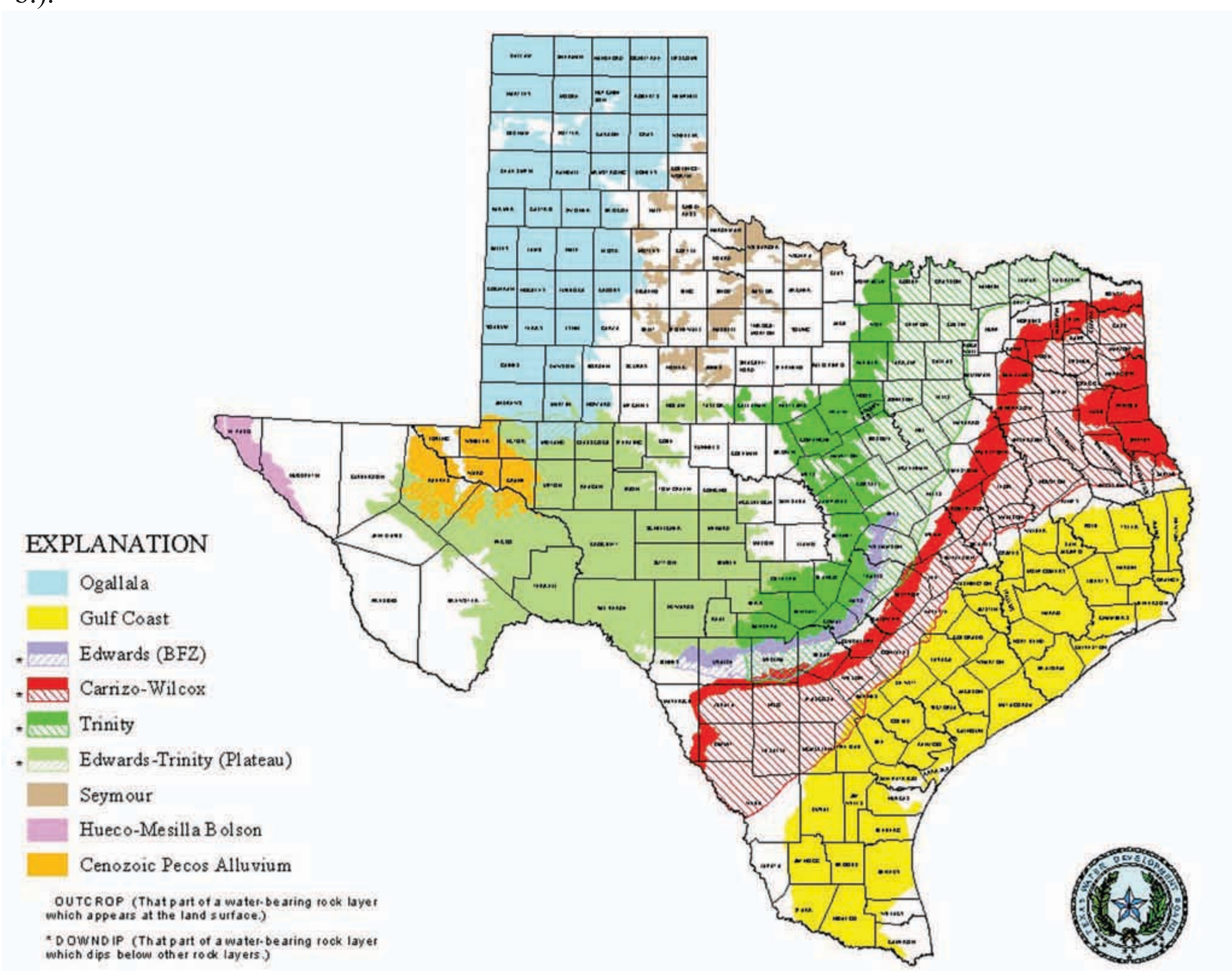


Figure 25
Major aquifers in Texas
Source: Texas WDB

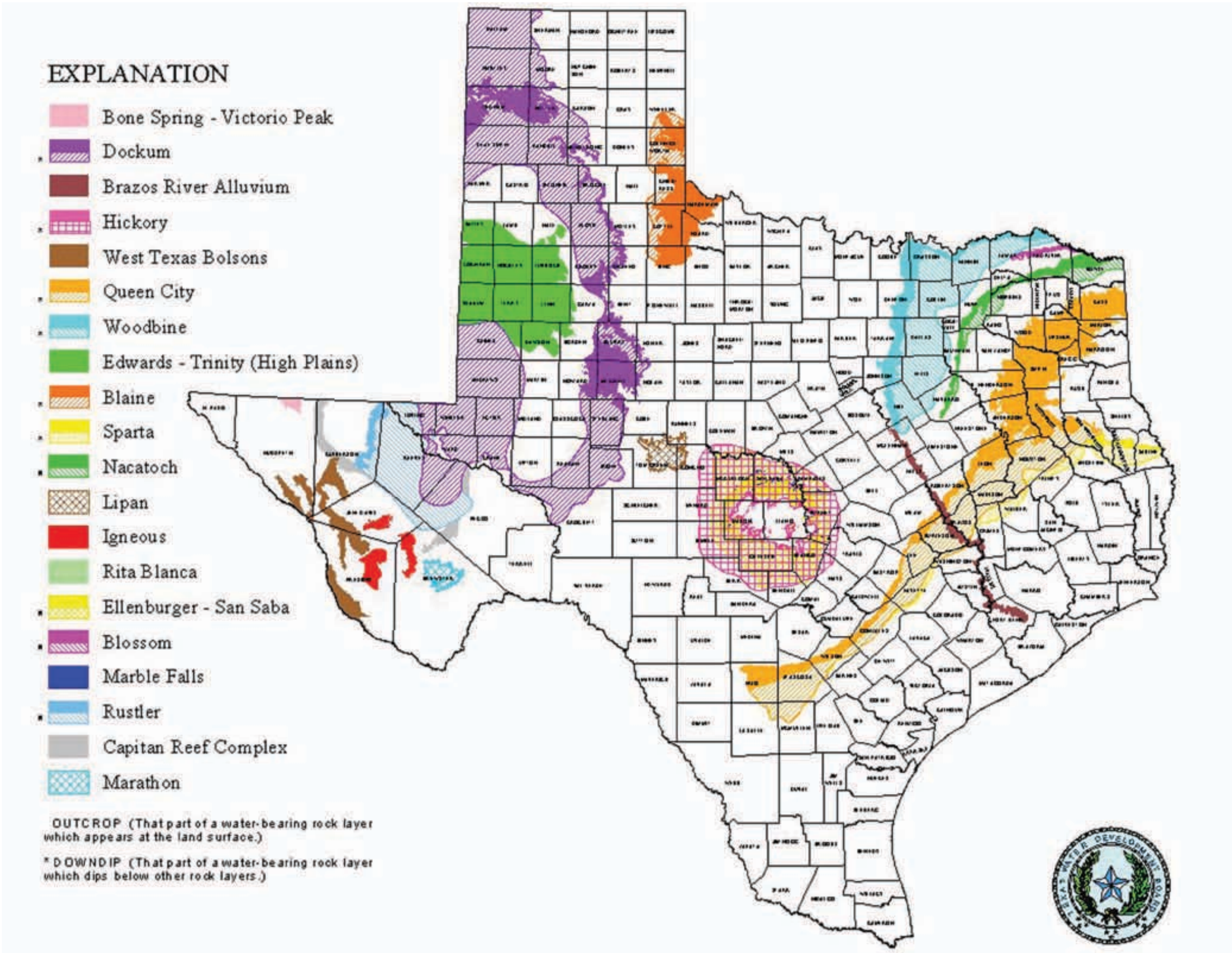


Figure 26
Minor aquifers in Texas
Source: Texas WDB

The TWDB has mapped the downdip boundaries that delineate the areas where these aquifers contain groundwater with dissolved solids concentrations low enough to meet an aquifer's primary use. The quality limit for most protected aquifer groundwater is 3,000 mg/L TDS; others are limited to 1,000, 5,000, or 10,000 mg/L TDS depending on whether the aquifers are currently being used or have been identified for desalination. The TWDB delineated these downdip water quality boundaries using a combination of sources including: geophysical logs, driller's logs, water quality sample analyses, and the results from earlier groundwater studies and reports conducted by TWDB staff and others agencies (TWDB, 2007).

The RRC requires that oil and gas operators set and cement surface casing through the deepest "useable-quality" groundwater aquifer at a depth determined by the TCEQ. The TCEQ bases its determinations on geological interpretations that identify freshwater zones and the base of useable-quality water. The TCEQ then makes protection depth recommendations to the RRC for oil and gas drilling operations, shot holes created during seismic surveys, and cathodic protection wells. The geological interpretation also may require protection of lower quality groundwater based on potential hydrological connectivity to useable-quality water. For recommendations regarding injection into non-producing zones, the TCEQ provides geological interpretations on the base of the deepest USDW, defined as an “aquifer or its portions: (1) which supplies drinking water for human consumption; or (2) in which the groundwater contains fewer than 10,000 mg/L TDS; and (3) which is not an exempted aquifer” (40 CFR Part 156.3).

History of Oil and Gas Exploration and Development

Texas' cultural and economic development is intertwined with the history of oil and gas E&P. Petroleum began to displace agriculture as the principal engine driving the state economy at the turn of the ninetieth century. Texas ranked first nationwide in drilling and production of both oil and gas throughout most of the twentieth century (IPAA, 2009).

Over 1,074,000 wells have drilled in Texas since 1866 (IPAA, 2009). Oil and gas reservoirs have been developed at depths from 100 to over 30,000 feet. As of 2007, 68,947 million barrels of crude oil and 426,094 billion cubic feet (bcf) of natural gas have been produced. The Texas oil and gas fields map (Figure 27) illustrates that drilling has occurred in virtually all of the state's 254 counties (Texas Bureau of Economic Geology, 2005). In 2007, 223 counties (88 percent) had oil and/or natural gas production (IPAA, 2009).

In 1866, less than a decade after Colonel Edwin Drake completed the first commercial oil well in Titusville, Pennsylvania, L.T. Barret struck oil at a depth of 106 feet below surface at Oil Springs, in East Texas. While the presence of natural oil seeps in Texas had been known for centuries before the arrival of European explorers, this was the first purposeful attempt to drill for crude oil. Since production could not economically compete with Appalachian production in Ohio and Pennsylvania, the well was subsequently abandoned (RRC, 1991).

The first major oil discovery in Texas occurred in 1894 at Corsicana, southeast of Dallas. However, it was the Lucas No.1 discovery at Spindletop in 1901 that jump-started the Texas oil industry, when the well blew the drilling pipe, mud, gas, and crude oil out of the borehole. The well was completed over one of the many gentle mounds that can be found in the Texas and Louisiana Gulf Coast reflecting the presence of subsurface salt domes. Beginning with Spindletop Dome, early explorers realized that these reservoirs contained prolific quantities of crude oil. Initial production from the Lucas No. 1 well was approximately 100,000 barrels per day, which flooded the market and collapsed the price of oil to $0.03 per barrel. Within two years of this discovery, 1,200 oil wells were drilled over the 200 acre Spindletop salt dome (Figure 28). Texas production dominated the market after Spindletop, leading to a drastic decrease in drilling and production in Ohio and Pennsylvania (STRONGER, 1993).

Between 1902 and 1920, new fields were discovered in north-central Texas at Petrolia, Electra, Burkburnett, Breckenridge, and Desdemona. During these early years, gushers were celebrated as signs of success. In the infancy of the oil and gas industry, wellhead controls were primitive, and reservoir pressure was so great that it often took days to halt uncontrolled flow. With each new well, oil saturated the ground, flowing into nearby creeks and gullies. Even when captured, oil was typically stored in unlined earthen pits or open tanks, resulting in surface and groundwater contamination (RRC, 1991).

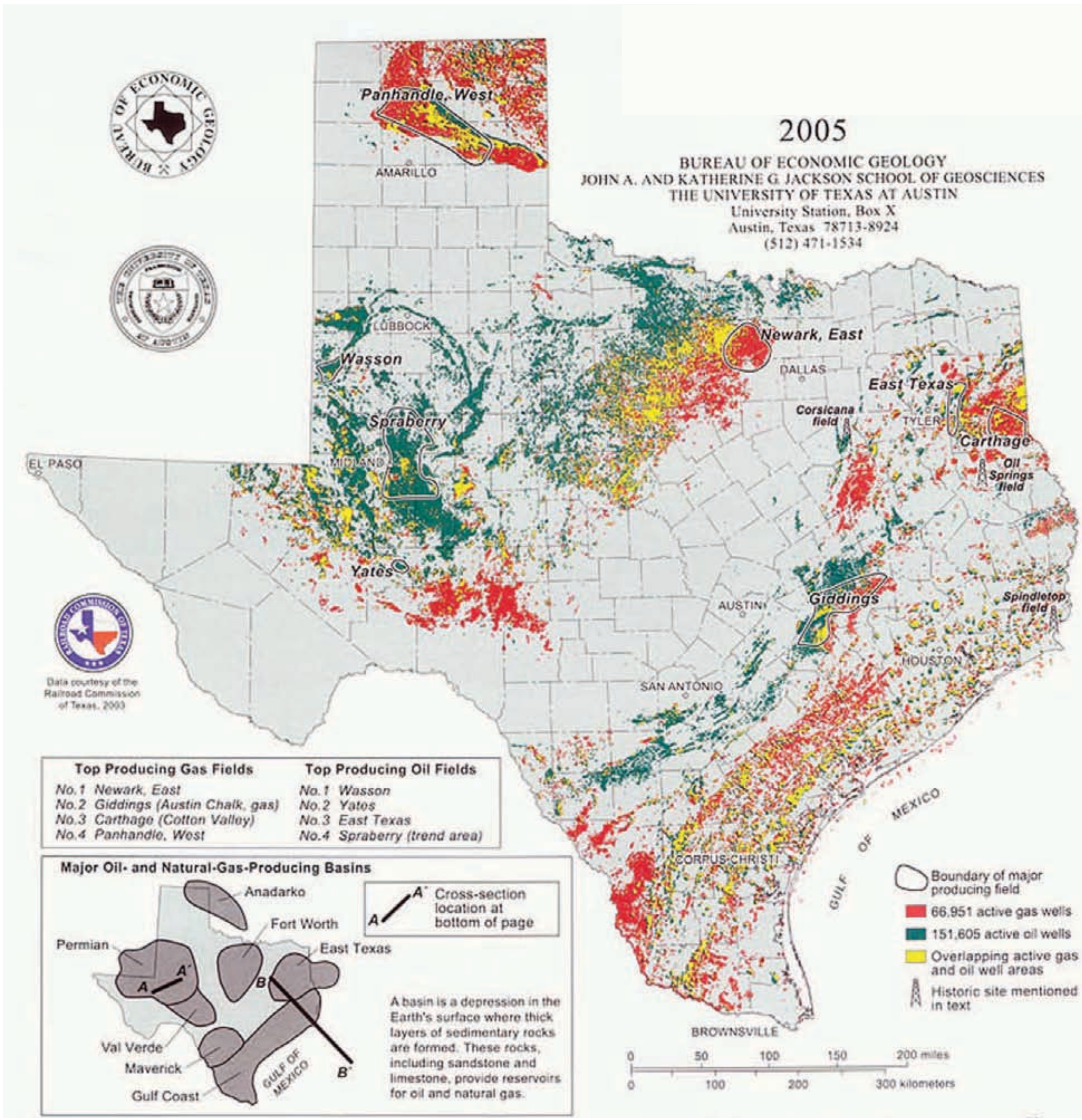


Figure 27
Oil and gas fields map of Texas
Source: University of Texas Library

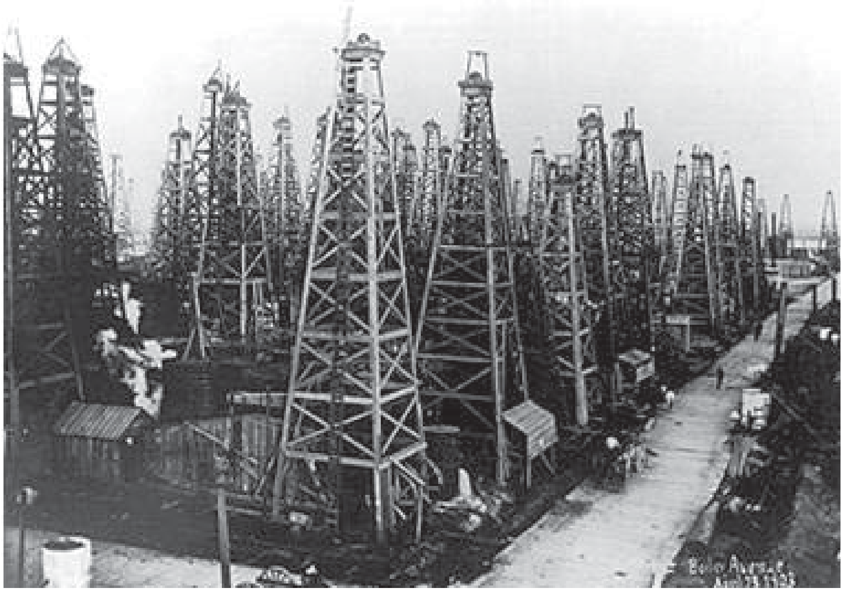


Figure 28
Standard rigs on Spindletop Dome
Source: Texas RRC

Texas' largest oil field, the East Texas Field, was discovered in 1930. Like the other booms, non-existent spacing and conservation regulations resulted in excessive drilling and over production. Without spacing controls, competing companies constructed drilling derricks in the shadows of neighboring derricks. Each well was produced wide open, resulting in lost production as the natural subsurface reservoir pressures prematurely dissipated. On August 17, 1931, Governor Sterling placed the area under martial law until legal battles over production proration and well spacing could be resolved (Ramos, 2001).

World War II led to the creation of the world's then largest (24 inch diameter) and longest oil transport pipeline, which stretched 1,400 miles from East Texas to refineries in Philadelphia. Oil was historically transported by sea, but German submarines made reliable transport by ship impossible (Beach, 2011). Today, the state hosts an extensive network of pipelines that transport crude oil from fields to refineries along its Gulf Coast.

State oil production peaked in 1972 at 1,263,412,000 barrels (bbls) when operators were allowed to continuously produce maximum efficient rates from 167,223 wells in response to the Arab oil embargo. October 1973 marked the first time that Texas production was unable to make up for world shortages. Natural gas tax incentives under the federal Natural Gas Policy Act resulted in new record levels of drilling activity in 1982. However, by 1986, falling crude oil prices led to steep declines in exploratory drilling and production (RRC, 2011-b.). Figure 29 shows oil and gas well completion trends in Texas from 1960 to 2010 (RRC, 2011-c.).

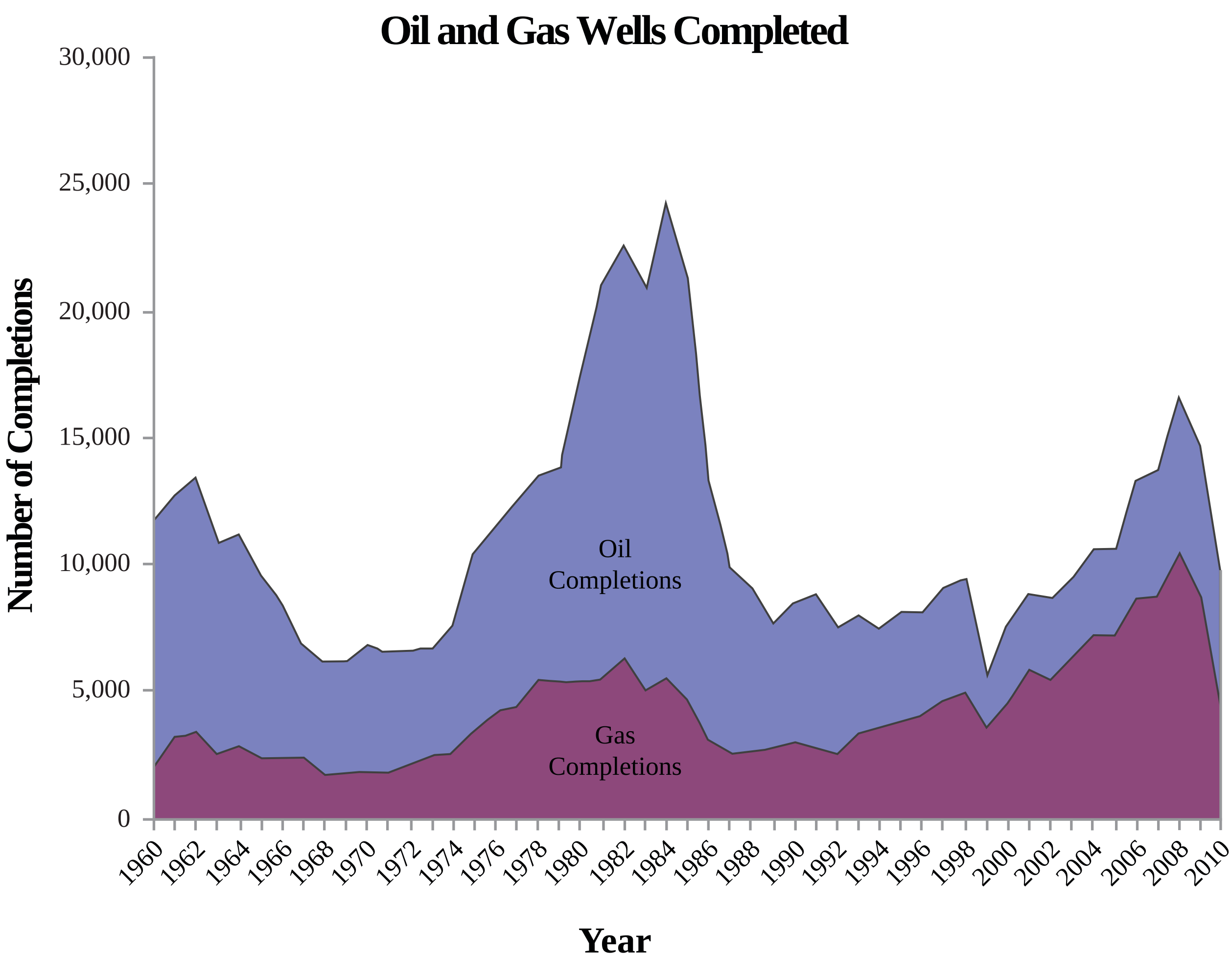


Figure 29
Oil and gas wells completed (1960-2010)
Source: Texas RRC

Texas has always been a national leader in waterflooding and developing advanced EOR technologies. The injection of produced water to restore reservoir driving pressure and to sweep oil towards producing wells has been practiced in Texas since 1938. Texas has the largest number of EOR injection wells in the nation, with over 38,000 in operation annually during the study period (Appendix G). Texas also leads the nation in produced water generation, accounting for between 35 to 43 percent of all nationally reported produced water volumes in 1995 and 2002 (Veil, Puder, Elcock, and Redweik, 2004). During the study period, the volume of injected produced water ranged from 5,077,990,191 to 7,452, 248, 595 bbls. The ratio of produced water to crude oil generally exceeded 12:1 and reached a high of 21.5:1 in 2008 (Figure 30). Since 1969, over 98 percent of produced water has been reinjected, including 60 percent for EOR. Annually, approximately 50 percent of Texas crude oil comes from enhanced production (RRC, personal communication: Leslie Savage).

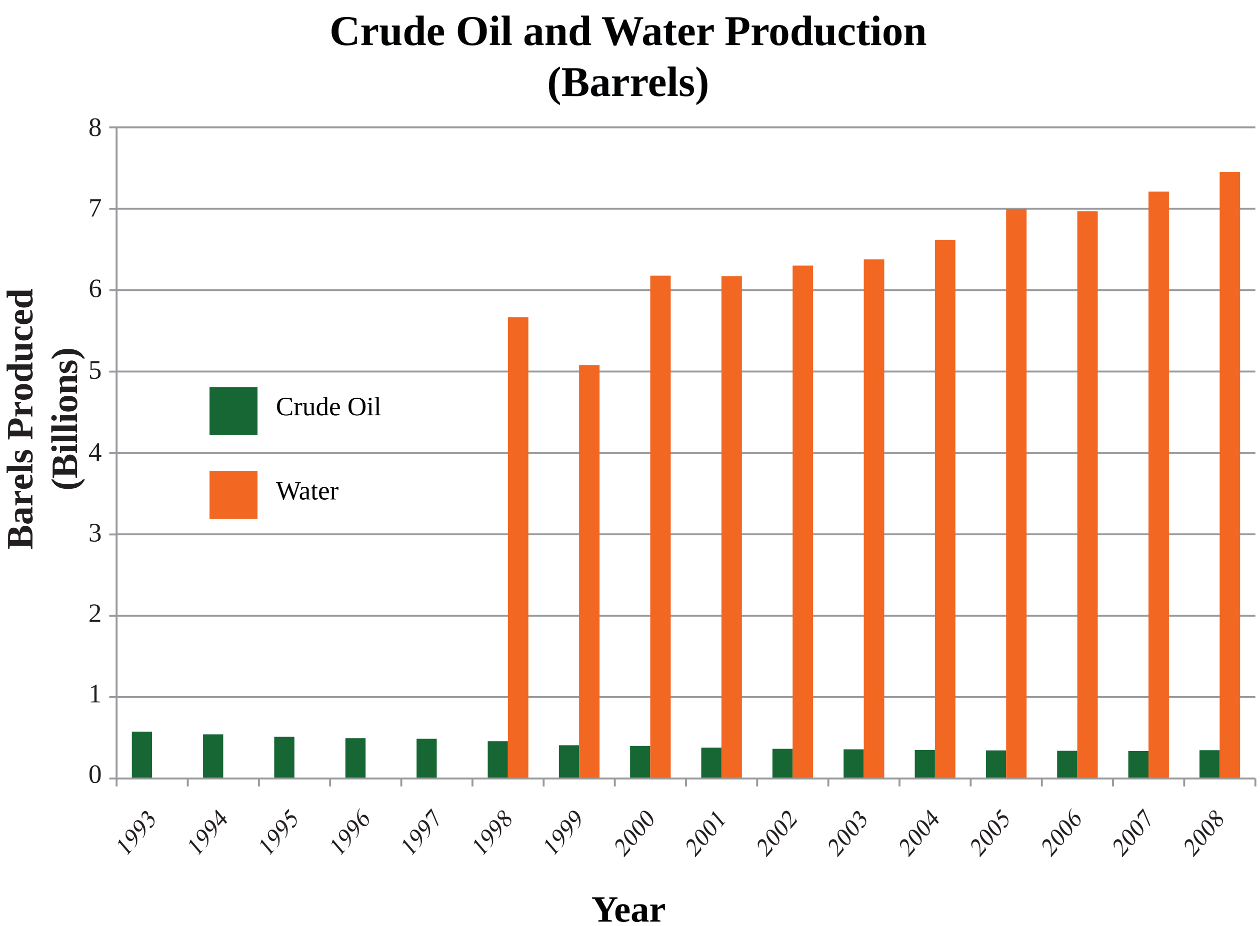


Figure 30
Crude oil and produced water volumes (1993-2008)

Texas also is a world leader in CO_2 injection for EOR. Texas has over forty years of experience in CO_2-based EOR, and has permitted more than 11,000 wells for CO_2 injection. Currently, the Permian Basin in west Texas is the world's largest market for CO_2 EOR (Future Gen Texas, 2010).

During the past decade, Texas has become a leader in the development of shale gas resources. Texas has used reservoir stimulation by hydraulic fracturing since the 1950s. Advances in horizontal drilling technology and the use of high volume, multi-stage, hydraulic fracturing stimulations have contributed to the economic potential of shale gas (GWPC and ALL Consulting, 2009). Six significant shale gas basins are located, partially or solely, within Texas' boundaries. The Barnett Shale, for example, accounts for six percent of all natural gas produced in the lower 48 states. The first large-scale fracturing of the Barnett Shale occurred in 1986. Since 1986, over 13,000 wells have been stimulated in the Barnett Shale alone (GWPC and ALL Consulting, 2009).

During the 16 year study period (1993-2008), 187,788 oil and gas wells were drilled and 140,818 wells were plugged. The number of producing wells increased 6.7 percent from 237,136 to 253,090. Texas operators produced nearly 6.7 billion barrels of crude oil and 93.7 tcf of natural gas. Figure 31 shows trends in oil and natural gas production from 1993 through 2008 (Appendix G). Crude oil production declined by 39.7 percent during the study period, from 574,568,000 to 346,632,000 bbls. Conversely, natural gas production increased 29.7 percent during the same period, from 5.61 to 7.27 trillion cubic feet. Over 5.1 billion barrels of produced water was disposed by injection annually. Appendix G summarizes Texas oil and gas industry activity levels by year during the study period.

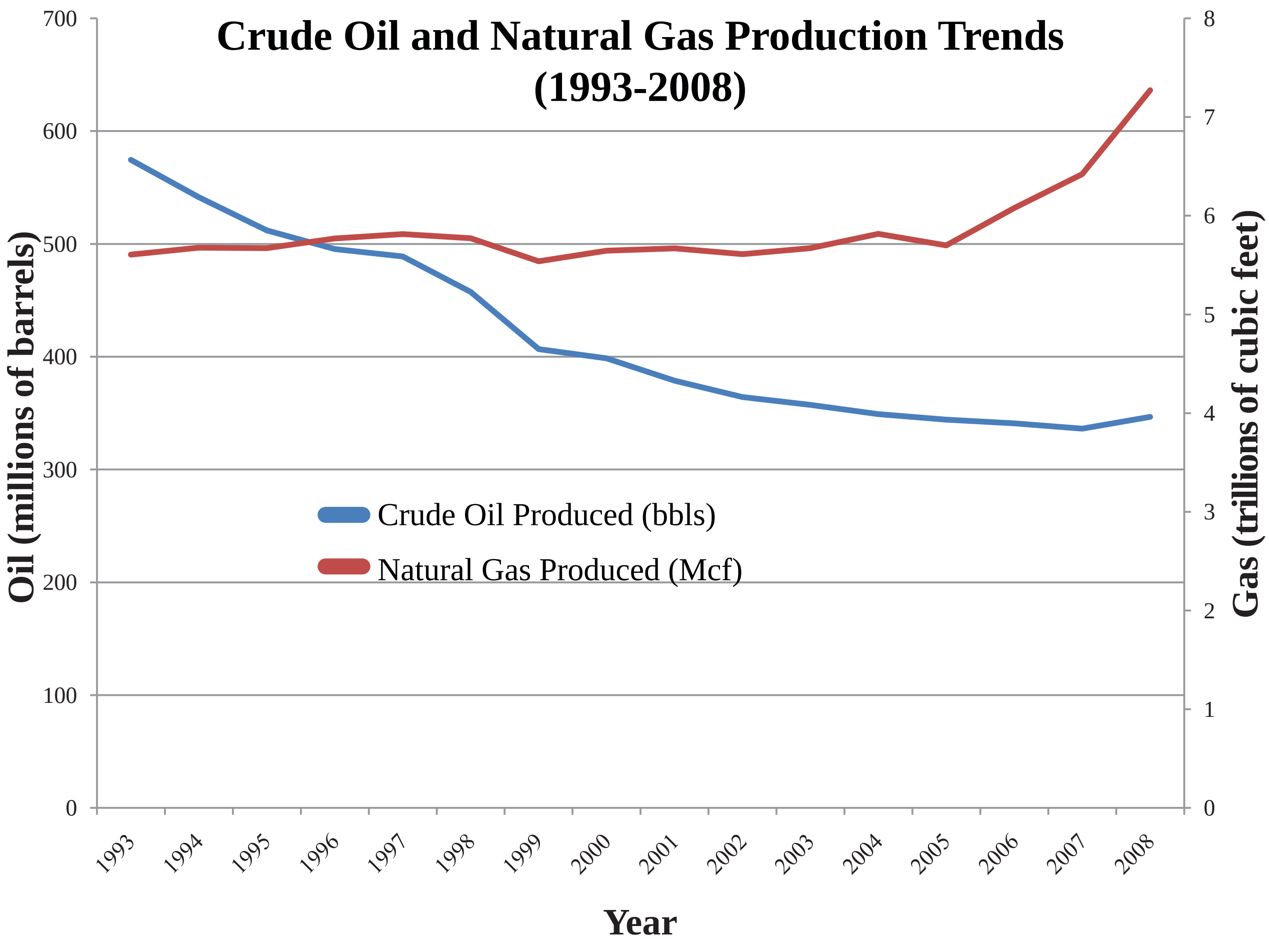


Figure 31
Crude oil and natural gas production trends (1993-2008)

History of Oil and Gas Regulation Pertaining to Groundwater Protection

Resource Conservation Challenges: The Texas Legislature (Legislature) created the Texas RRC in 1891 to correct abuses and prevent unjust discrimination and extortion in railroad freight rates and passenger tariffs. In 1919, the Legislature created the Oil and Gas Division (OGD) within the RRC. The OGD is charged with regulating oil and gas E&P to protect correlative rights and prevent waste and pollution of surface and groundwater. The RRC was given authority to regulate the oil and gas industry in February 1917, when the state Legislature declared oil pipelines as "common carriers" due to the fact that the pipeline operators had the same control over well operators that the railroads formerly had over farmers and ranchers who had to transport their goods to market (RRC, 1991).

Similar to all other states, early oil and gas legislation focused on the conservation of petroleum resources. Although the Legislature passed several bills governing use and conservation of the state's oil and gas resources in the late 1800s and early 1900s, these laws were not enforced, and there was no specific agency charged with bringing order to the oil field. In 1905, the Legislature declared a state of emergency over the drilling, operation, and abandonment of oil, gas, and water wells. Other laws were subsequently enacted to prevent waste, but the continued absence of an enforcement body rendered them impotent (STRONGER, 1993).

The same 1919 bill that created the OGD further established well-spacing standards, prohibited waste, and provided the OGD with broad enforcement powers. Rule 20, for example, was one of the nation's first regulations that sought to protect water while allowing continued development of oil and gas resources. These rules persist in Texas' regulatory program today, and cover every phase of oil and gas operations (STRONGER, 1993). For the sake of simplicity, the OGD will be referred to as the RRC for the remainder of this report.

Regulation did not truly take hold until the 1930s when the East Texas Oil Field was discovered. Governor Sterling's declaration of martial law signified the first state effort to level control over oil and gas production. However, it was still several years before the courts and the Legislature granted the RRC the right to prorate production to conserve the oil and gas resources, protect correlative rights, and prevent pollution. A 1932 law authorized the RRC to limit production based on market demand; in 1935, a comprehensive oil and gas statue was finally enacted to prevent wasteful production (Ramos, 2001).

Waste Management Challenges: Protecting groundwater has always been one of the RRC's greatest responsibilities. The RRC amended Rule 20 in 1931, requiring the protection of fresh water during produced water disposal. During 1964 rule revisions, Rule 20 was combined with Rule 55, a regulation on exploratory wells, to create Rule 8 (16 Texas Administrative Code §3.8). The new Rule 8's primary purpose was to protect water supplies by:

1. Prohibiting pollution of surface or groundwater;
2. Prohibiting any method of disposal not expressly authorized by rule or permit;
3. Establishing permit requirements for pits; and
4. Establishing allowable management practices for various waste streams.

Texas' varied climate, topography, geology, hydrology, and wide spectrum of toxicity in various waste streams are just a few of the factors that make water protection on a statewide basis a complex challenge (STRONGER, 2003).

State E&P waste regulation historically focused on management of large volumes of produced water. Beginning in the 1950s, groundwater pollution prompted the RRC to selectively ban disposal of produced water in earthen pits in specific counties and fields; the RRC virtually eliminated the practice altogether in 1969. The RRC further tightened regulations on all oil and gas wastes in 1984 (STRONGER, 1993).

Virtually all produced water has been reinjected for EOR or disposal since the elimination of disposal pits. The minute volume of remaining produced water is discharged in accordance with federal National Pollutant Discharge Elimination System (NPDES) permits and RRC Rule 8 discharge permits. These discharges include those from four freshwater-bearing formations in Texas that have been authorized by the EPA (STRONGER, 2003).

The first documented injection of produced water for EOR occurred in 1938. It was not until the 1950s though, that the RRC began to permit and regulate injection of produced water as a result of pit closures. The number of Class II injection wells, including disposal and EOR injection wells exceeded 49,000 annually throughout the study period, and the volume of injected produced water increased 31.5 percent from 1998 to 2008 (Appendix G).

U.S. EPA awarded the RRC Class II Primacy in 1982. In 1983, the RRC created an Environmental Services Section in order to administer the UIC and Waste Management Programs. The Waste Management Program was responsible for source reduction, hazardous waste management, and pollution prevention. The RRC was recently further reorganized to create the Technical Permitting Section (TPS). The TPS possesses all of the authority and responsibilities of the old Environmental Services Section, and processes drilling permits and performs engineering reviews. The RRC's Field Operations Section is responsible for conducting field inspections, ensuring field compliance, well plugging, and cleanup activities (RRC, 2011-d.).

Over the past sixty years, tens of thousands of wells have been hydraulically fractured, primarily to develop unconventional gas resources. The RRC regulates the practice of hydraulic fracturing through:

1. Well construction regulations;
2. Management of associated produced flowback waters through permitted water recycling facilities; or
3. Disposal by injection at Class II wells.

Operators are further required to submit summary data as part of their well completion records, including the volumes and types of fluids used during fracturing.

In 2001, the RRC enacted pipeline safety regulations (Chapter 8 of Title 16 of the TAC). These rules establish minimum testing standards for a variety of pipelines including onshore, intrastate, crude oil and natural gas transmission pipelines. Texas became one of the first states in the nation to require pipeline operators to participate in a Pipeline Integrity Management Program (PIMP), effective April 30, 2001 and predating federal requirements by more than two years. PIMP requires liquid petroleum transmission pipeline operators to verify the integrity of their pipelines by either hydrostatic testing or other approved inline inspection tools. Regulations establish a schedule for testing all lines based on risk-based criteria. Federal regulations require testing of lines only in "high consequence areas", whereas RRC regulations require integrity testing and verification for all lines regardless of locality (RRC, 2011-e.).

The RRC is a certified agent in partnership with the U.S. Department of Transportation Pipeline and Hazardous Material Safety Administration. The RRC's Pipeline Safety Division investigates pipeline-related accidents and complaints, and conducts roughly 2,500 inspections per year using a risk-based evaluation model (RRC, 2011-d.). RRC regulations currently meet or exceed all federal pipeline safety regulations.

Today, the RRC is responsible for preventing pollution that could result from activities associated with the exploration, development, and production of oil and gas resources. The RRC's environmental and safety programs regulate the following:

1. Well drilling, operating, and plugging of wells;
2. Separating and treating produced fluids in the field or at natural gas processing plants;
3. Storage of pre-refined crude oil;
4. Hydrocarbon storage in salt caverns or depleted natural gas reservoirs;
5. Transportation of crude oil or natural gas by pipeline;
6. Drilling, operation, and plugging of brine wells; and
7. Storage, hauling, reclamation, or disposal of wastes generated by these activities.

Regulations and programs covering these activities have been developed over the years. The RRC has revised and strengthened most major environmental standards within the past 20 years; it has also adopted regulations for management of hazardous oil and gas wastes. Additionally, the RRC has developed a nationally recognized Waste Minimization Program that encourages and helps the oil and gas industry reduce the amount and toxicity of generated waste (RRC, 2011-f.).

Legacy issues including orphaned wells and sites polluted by produced water releases from pre-1969 earthen pits continue to affect groundwater resources. In 1984, the Legislature clarified the RRC's authority to regulate all oil and gas wastes and established the Well Plugging Fund to plug orphaned wells. The program was funded by a variety of fees and taxes collected from oil and gas development. The Legislature enhanced this program in 1991, and again in 2001, by creating the OFCF, further expanding the RRC's authority, and increasing the fund balance cap. As a result, the RRC now has authority and enhanced funding to: investigate citizen complaints about contamination, remediate contaminated sites, manage a VCP, and an OCP. The VCP encourages lenders, developers, and landowners, to remediate environmental damage, while the OCP oversees long-term cleanup projects conducted by operators deemed responsible by the RRC for contamination. In 2001, the OFCF's balance cap was raised from \$10 to \$20 million. From 1984 to 2009, the RRC has plugged over 30,000 orphaned wells at a cost of \$172.4 million, and restored, assessed, or investigated over 4,300 sites with OFCF monies (RRC, 2011-a.). Appendix E is a summary of regulatory enhancements enacted between 1982 and 2010 to both improve groundwater protection and remediate contaminated groundwater.

Analysis of Documented Incidents and Regulatory Enhancements by Phase

Introduction: During the 16 year study period (1993-2008), the RRC documented 211 groundwater contamination incidents caused by historic or regulated oilfield activities, only some of which involved domestic or public water supplies. Some incidents were reported as a result of contaminants detected at monitor wells, or contamination detections during environmental assessments, rather than citizen water supply complaints. More than 35 percent of these incidents (75) resulted from waste management and disposal activities including 57 legacy incidents caused by produced water disposal pits that were banned in 1969 and closed no later than 1984. Releases that occurred during production phase activities including storage tank or flow line leaks resulted in 26.5 percent of all incidents (56). Thirty incidents (14.2 percent) were caused by orphaned wells or sites. Figure 32 depicts incidents by E&P phase from 1993 to 2008.

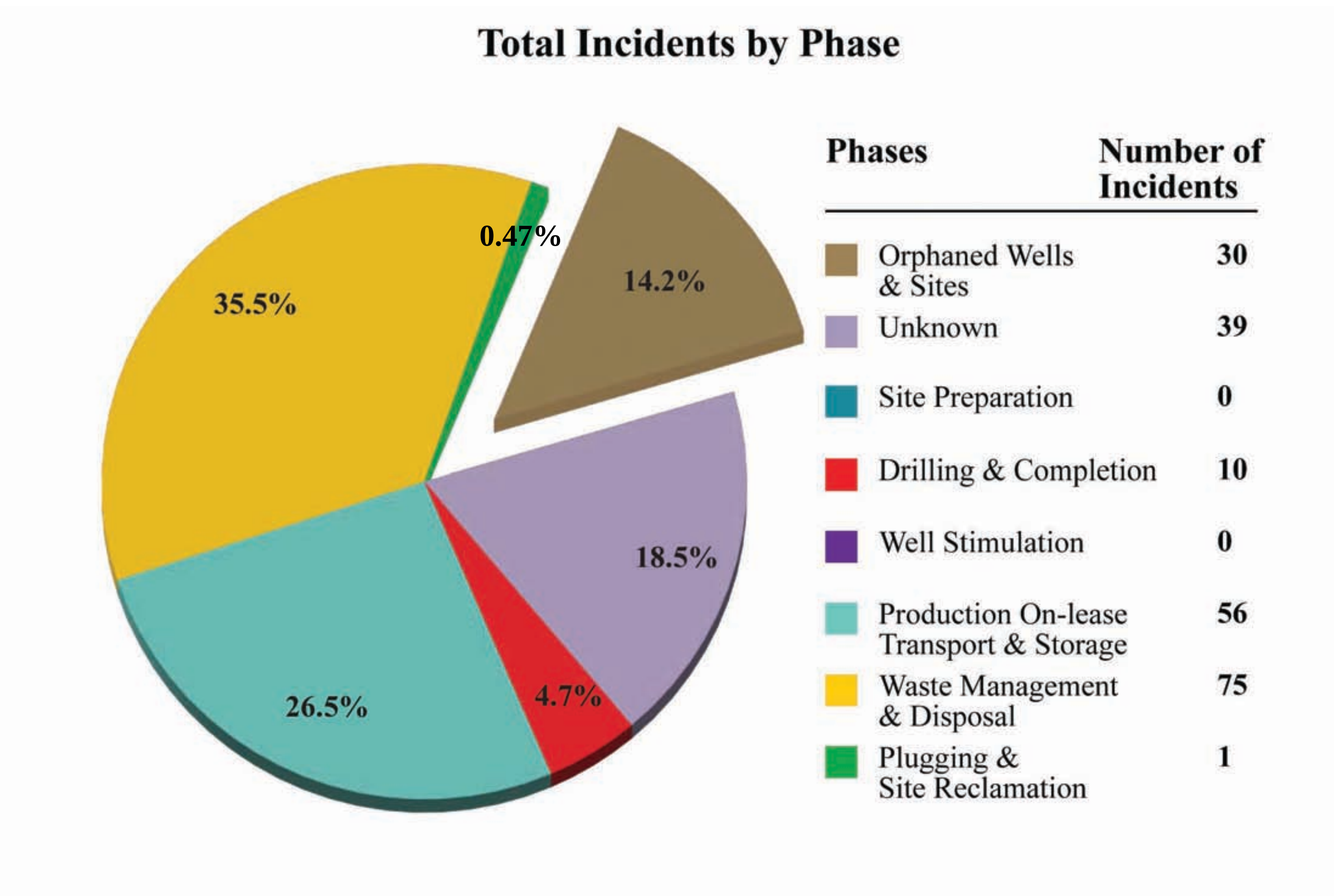


Figure 32
Total incidents by phase

The RRC tracks contamination incidents and publishes a yearly summary of its active investigations in the annual *Texas Joint Groundwater Monitoring and Contamination (JGWMC) Report* (TGPC, 1993-2008). The JGWMC provides a table summary of all groundwater contamination incidents representing the full-range of activities regulated by the RRC. This report focuses on those incidents that are typically permitted and regulated by state oil and gas agencies, consistent with the scope of the classification scheme (Appendix A).

The JGWMC Report describes each newly documented case of groundwater contamination from the previous calendar year, along with earlier, unresolved cases during previous years when remedial action or requirements of an enforcement action remain incomplete at the time of report issuance. This report summarizes the RRC's determinations regarding the type and source of each incident by the year that it was first included in the annual report.

The RRC identified new incidents caused by oil and gas activities within the scope of this study in each of the study's 16 years. Annually, the number of new incidents ranged from six (1997) to a high of 32 (2005). There is no discernable correlation between the number of new documented incidents and current E&P activity levels over the course of the study (Appendix F). The RRC attributes the 2005 spike (32 incidents) to several factors including: improvements in the complaint tracking processes, improved due diligence by operators performing environmental assessments during property transactions, and an administrative determination to include incidents that had previously been excluded from the list because the affected groundwater was classified as unusable (RRC, personal communication: Bill Renfro).

The following discussion depicts the evolution of Texas' oil and gas E&P regulatory standards in response to documented incidents by their phase and activity. Appendix E summarizes significant regulatory reforms and actions undertaken by the RRC during the study.

Phase 1: Site Preparation

> Phase Overview: Phase one activities include construction of a well pad, access road, and excavation of water storage and reserve pits. In Texas, the surface area disturbed during well pad construction typically ranges from 0.5 to 2.0 acres based on rig size, drilling depth, the number of wells to be drilled from a common pad, and the volume of requisite fluids to be managed during stimulation operations. The first large scale hydraulic fracturing of a horizontal well in the Barnett Shale occurred in 1992. Between 1992 and 2007, over 13,000 wells were subsequently drilled to the Barnett Shale (GWPC

and ALL Consulting, 2009). In rural areas where multiple horizontal wells may be drilled from a single pad, it is common practice to construct a large lined impoundment to hold between one and three million gallons of fresh water for drilling and large volume, multi-staged hydraulic fracturing operations. Even at sites without impoundments, a larger pad is necessary to accommodate the number of water storage tanks and pumps necessary to perform large volume hydraulic fracturing operations. Multi-well pads typically require two to three acres. Multiple horizontal wells can be drilled from a single larger pad; this can reduce habitat fragmentation and surface disturbance by reducing the number of pads, access roads, pipeline routes, and production facilities that accompany conventional operations. Four to eight wells drilled from a single pad can efficiently drain the same natural gas reservoir that would require up to 16 vertical completions (GWPC and ALL Consulting, 2009). During the study period, 187,788 oil or gas wells were drilled (RRC, 2011-c.). Since the practice of drilling multiple wells from a single pad covers the study period (1993-2008), the number of pads constructed will be slightly less than the drilling total.

Phase Incident Summary: Between 1993 and 2008, the RRC did not identify a single incident of groundwater contamination caused by the accidental release of fuels or fluids from mobile powered equipment during site preparation.

Phase Regulatory Enhancements: The federal Oil Pollution Act (OPA) of 1990 amended Section 311 of the CWA, and established procedural and equipment standards to prevent oil and fuel discharges from onshore facilities. Operators are obligated to report oil discharges, including refined motor oil, diesel fuel, or transmission fluid if the release exceeds the RQ (25 gallons) or creates a visible sheen on navigable waters. Surface facilities that store over 1,320 gallons of fuel on location are subject to SPCC regulations.

Phase 2: Drilling and Completion

Phase Overview: During the study, 187,788 wells were drilled with fluid or air rotary systems, including dry holes and completions. In 2007, average well depth was 8,258 feet below the surface (IPAA, 2009). Texas' deepest well reached a depth of 29,670 feet in 1983. Out of the 162,989 wells drilled and completed during the study, 16,819 (10 percent) were horizontal wells (Figure 33).

Figure 33
Active rig drilling a horizontal well in the Barnett Shale Play
Source: Gas Drilling Rig in Texas by Wendy Lyons Sunshine

Phase Incident Summary: Drilling and completion phase activities were identified as the source of ten groundwater contaminations during the study. This translates to one incident per every 18,789 drilling operations and accounted for 4.7 percent of all incidents. Six of the incidents involved natural gas contamination of groundwater from subsurface blowouts, and four were caused by releases of drilling fluids from reserve pits.

Phase Regulatory Enhancements: Since the 1984 Rule 8 amendments, new reserve, mud circulation, and fresh makeup water pits have been rule authorized by the RRC. Rule 8 establishes performance objectives, restricts fluid content, and establishes timeframes for removal of fluids and pit reclamation. Pits must be constructed and restored in a manner that prevents pollution of surface or groundwater. No wastes are allowed in the freshwater makeup pits, and they must furthermore be backfilled within one year after cessation of drilling operations. Reserve and mud circulation pits can contain drilling fluids, cuttings, rig wash, drill stem test fluids, and blowout preventer test fluids. Pit contents must be dewatered within 30 days after completion of drilling operations prior to reclamation, if the chloride concentration of drilling fluids is greater than 6100 mg/L. Placement of any other type of fluid, oil, or waste into a reserve pit or mud circulation pit is strictly prohibited. Operators have one year to dewater and backfill a pit, if the chloride concentration of drilling fluids is less than 6100 mg/L. The RRC director may order pit closure sooner than the standard timeframes if there are indications that fluid is likely to escape or the pit is being used improperly for storage of unauthorized fluids or wastes. Closed loop-circulation tank systems are encouraged in sensitive areas, and are required in areas adjacent to wetlands (STRONGER, 2003).

Similar to Ohio, Texas rules do not include detailed standards for construction, maintenance, or operation of rule authorized pits used during drilling operations. However, the RRC publishes a Surface Waste Management Manual, most recently updated in 2010, that provides guidance for industry consideration when designing and constructing pits (RRC, 2011-g.). This guidance addresses factors such as:

1. Geologic and hydrologic conditions that affect relative susceptibility to contamination;
2. Distance to nearby water supplies;
3. Water table depth;
4. Soil and subsoil characteristics;
5. Berms to prevent storm water discharges;
6. Subliners including geomembrane liners;
7. Synthetic liner properties; and
8. Installation and maintenance considerations.

Rule 13, adopted in 1976 and amended most recently in 2003, establishes performance objectives and standards for well construction, mechanical integrity, and control. Texas well construction and integrity standards are amongst the most thorough in the nation. Operators must pressure test each cemented casing string prior to continuation of drilling operations. Surface casing must be installed and cemented at a depth sufficient to isolate useable groundwater, and must be in place before the drilling operation can encounter natural gas or abnormally pressurized zones. A blowout preventer or control head must be installed after surface casing is cemented to maintain well control while drilling below the surface casing seat. Drilling must cease if tests indicate the blowout prevention or diverter system is unable to function or operate as designed. According to Rule 20, an operator must immediately notify the RRC if there is a blowout (RRC, 2011-e.).

Phase 3: Well Stimulation

Phase Overview: Hydraulic fracturing has been practiced in Texas for over sixty years at tens of thousands of wells. Hydraulic fracturing plays a key role in the development of unconventional gas resources, including shale gas and tight (low-permeability) formations. However, until the development of the Eagle Ford formation, oil wells were typically developed without hydraulic fracturing stimulation in the state. During the study period, 161,383 oil or gas wells were completed, 91,783 (56.9 percent) of which were natural gas wells (RRC, 2011-e.).

Hydraulic fracturing of a vertical well can use over 1.2 million gallons (28,000 barrels) of water; fracturing a horizontal well can use over 3.5 million gallons (over 83,000 barrels). Wells may be, and often are, refractured multiple times after producing for several years (RRC, personal communication: Leslie Savage).

Since 1986, over 13,000 wells have been drilled to the Barnett Shale, the largest shale gas play in Texas (GWPC and ALL Consulting, 2009). The Barnett Shale was first hydraulically fractured with vertical wells in 1986, and with horizontal wells in 1992. The target reservoir ranges in thickness from 100 to 600 feet, and lies between 6,500 and 8,500 feet below the surface. The intervening zone, the stratigraphic interval between the base of the lowest useable water and the top of the Barnett Shale Play is typically over a mile thick, ranging from 5,300 to 7,300 feet (GWPC and ALL Consulting, 2009). As a result of continued improvements in drilling, well construction and hydraulic fracturing technology, shale gas development has accelerated since the late 1990s. The combination of horizontal well completions, with sequenced, multi-staged, hydraulic fracture stimulations has dramatically increased production and recoverable reserve estimates (GWPC and ALL Consulting, 2009). Figure 34 shows a high volume (3.5 million gallons) stimulation operation in the Barnett Shale.

Figure 34
Hydraulic fracturing job in the Barnett Shale
Source: XTO Energy, a subsidiary of ExxonMobil

Since 1983, the RRC has required operators to submit summary data on stimulation operations, including the depth of the target reservoir and hydraulic fracturing fluid volumes. Fracturing stimulations in shale gas reservoirs typically use water-based (slickwater) fluids, which consist of water, sand proppant, and a variety of other additives selected to reduce friction, prevent microorganism growth, and prevent pipe corrosion or scale deposition. The additives generally represent less than 0.5 percent of total fluid volume (GWPC and ALL Consulting, 2009).

Phase Incident Summary: Between 1993 and 2008, the RRC did not identify a single incident of groundwater contamination caused by hydraulic fracturing. Significantly, no incidents have been identified after nearly two decades of large volume, multi-staged hydraulic fracturing operations in over 13,000 Barnett Shale stimulations.

Phase Regulatory Enhancements: In 2003, the RRC began to issue permits for mobile produced water treatment facilities. In December 2006, the RRC adopted new regulations on commercial recycling facilities (RRC, 2011-e.). These facilities treat the produced waters generated by post-stimulation flowback, by filtering solids and removing organics through a thermal distillation process that allows the water to be reused at subsequent hydraulic fracturing operations. Rule 4 requires operators of all mobile or stationary commercial recycling facilities to have a permit, subject to public notice and hearing requirements. Any hauler transporting waste to a stationary facility also must be permitted. Permit applicants must submit plans with all geologic and engineering data deemed necessary to demonstrate that the facility will not contaminate surface or groundwater, or endanger public safety. Subchapter B, Chapter 4 of Title 16 establishes requirements for information that must be included as part of a complete application, and specifies minimum standards for siting, design, construction, operation, monitoring, and closure.

As of September 2009, the RRC began to post summary well completion and stimulation information online. Well completion records including Form G-1 (Gas Well Back Pressure Test, Completion or Recompletion Report, and Log) and Form W-2 (Oil Well Potential Test, Completion or Recompletion Report, and Log) are available online (RRC, 2011-h.).

Phase 4: Production, On-lease Transport, and Storage

Phase Overview: Texas had more producing oil wells, gas wells, total wells, oil production, and natural gas production than any other producing state during the study period. The total number of wells declined slightly (6.5 percent) during the first eight years (1993-2000), but then increased to a high of 253,090 producing wells in 2008. Figure 35 shows trends in oil wells, gas wells, and total producing wells from 1993 to 2008. The number of producing oil wells declined by 20 percent, from 186,342 (1993) to 156,588 (2008). The number of gas wells, however, increased 90 percent from 50,794 (1993) to 96,502 (2008) (RRC, 2011-c.).

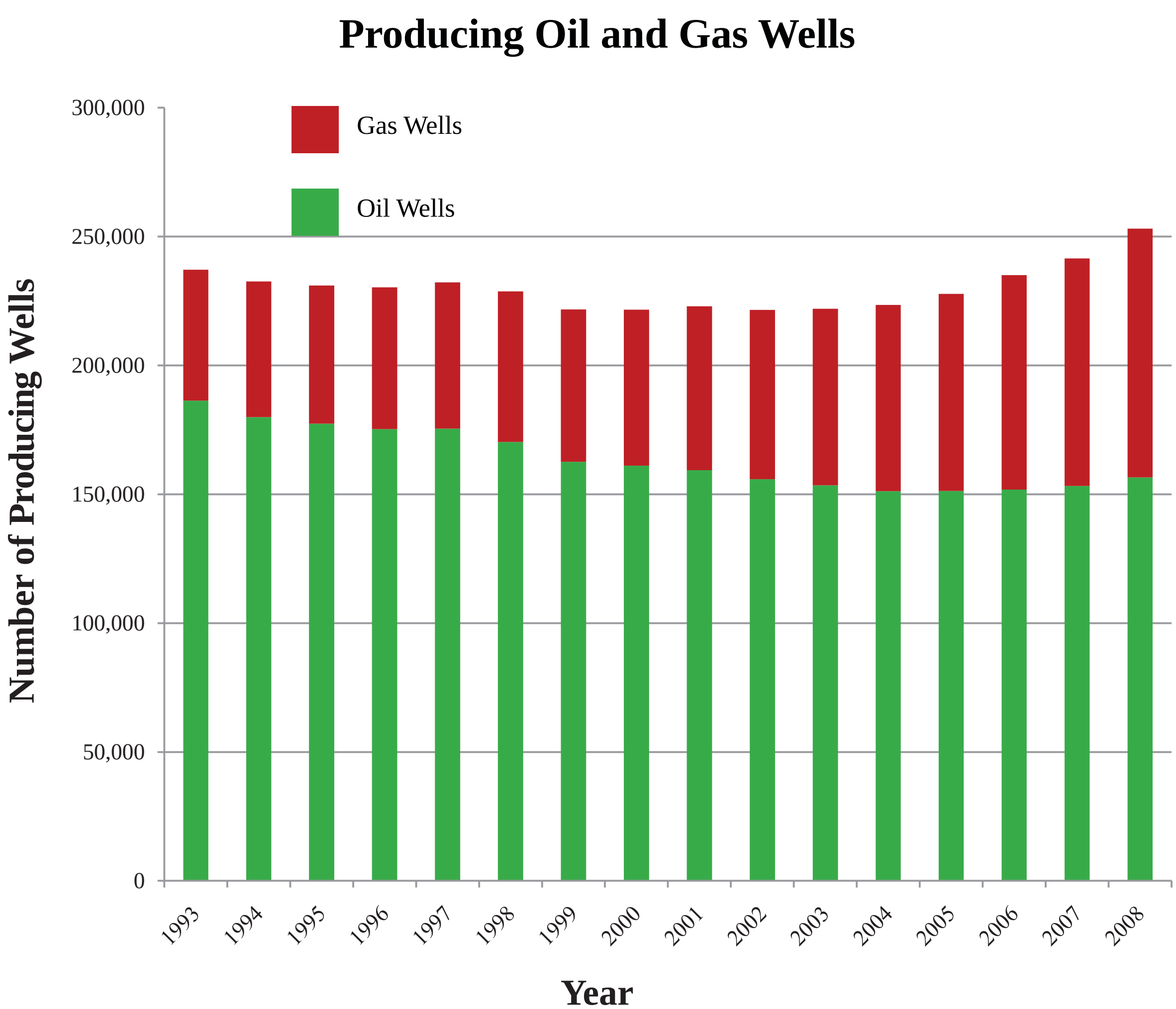


Figure 35
Producing oil and gas wells

Crude oil production declined 39.7 percent from 574,568,000 (1993) to 346,632,000 barrels (2008). Natural gas production increased 29.7 percent from 5,606,497,721 Mcf (1993) to 7,271,814,561 Mcf (2008) (Appendix G).

Similar to other state regulatory agencies, the RRC has jurisdiction over production wells, on-lease flow lines, fluid separators, and storage tanks. Furthermore, the RRC permits and regulates natural gas processing plants, distribution of crude oil and natural gas by intrastate pipeline, including associated compressor and booster stations, and permitted temporary waste storage pits. In addition to 253,090 producing wells (2008), the RRC oversees approximately 1,275 dehydration, scrubber, compressor, separator, and drip facilities. There are almost 170,000 miles of RRC-regulated pipelines in the state (RRC, 2011-d.). This report only evaluates groundwater contamination incidents caused by releases during on-lease production, transport, fluid separation, and storage activities.

Since the 1969 “No Pit Order”, any new pit must be rule-authorized or authorized by permit. The RRC requires pits intended to contain wastes for any extended period of time (greater than 48 hours) to be lined and inspected. Rule-authorized E&P pits that may be constructed at production sites include basic sediment pits and completion/workover pits. These pits are authorized without a permit only if they are operated and backfilled according to the requirements of Rule 8 so as not to cause pollution (RRC, 2011-e.).

Pits that require individual permits at production sites include emergency saltwater storage pits and skimming pits. Permits specify notification, operating, and closure criteria (STRONGER, 2003). The RRC tracks the number and disposition of permitted pits and provides summary data in the annual JGWMC Report. During the study period, the number of permitted pits declined by 24.2 percent from a high of 5,406 in 1994 to 4,100 in 2008. Forty-eight percent of those pits were authorized for short-term (24 to 72 hours) storage of E&P wastes (TGPC, 1993-2008).

<u>Phase Incident Summary</u>: The RRC identified 56 incidents (26.5 percent of the total) caused by activities associated with on-lease production, flow line transport, fluid separation, and product or waste storage activities. Of the incidents caused by phase four activities, 35 (62.5 percent) were caused by releases from storage tanks. Releases from flow lines and wellheads caused eight and four incidents, respectively.

Remnant groundwater contamination, caused by historic earthen oil storage pits, banned in 1939, was found at seven sites. The waste oil that had accumulated in these clay-lined pits was typically buried in place during the reclamation of these facilities. Two incidents were attributed to deficient well construction practices, including one incident caused by short surface casing that did not adequately isolate all useable groundwater. Deficient surface casing allowed natural gas to migrate from the surface-production casing annulus into the unprotected basal section of the aquifer.

Phase Regulatory Enhancements: All production facilities are subject to the Rule 8 prohibition against contamination and unauthorized releases. The RRC further addresses unauthorized releases from wells, flow lines, separators, and storage tanks through: (1) spill notification requirements; (2) waste hauler standards; and (3) remediation standards based upon that type of fluid released and the sensitivity of the environment where the release occurred. Furthermore, the State OFCF (1991 and 2001) authorizes and provides funds for the RRC to immediately respond to any spill that threatens human safety or the environment. The RRC has the authority to seek reimbursement of these expended funds from responsible parties.

Statewide Rule 20 (amended 2003) requires an operator to immediately report any oil spill into surface water, or any release of oil on land greater than five barrels to the RRC. Statewide Rule 91 (1993) establishes reporting and remediation standards for crude oil releases in “non-sensitive areas”. The remediation standards apply to all spills, regardless of volume. According to Rule 91, verbal notification must be followed by submittal of a report (Form H-8) describing the surface area, depth, and volume of soil contaminated with greater than 1.0 percent by weight of Total Petroleum Hydrocarbons (TPH), and a detailed description of the plan for disposal or remediation method used for clean up of the site. Any unauthorized release of oil or associated production is a violation, and an enforcement action is undertaken when operators fail to properly notify the RRC or remediate a contaminated site.

Rule 91 (1993) authorizes onsite remediation of crude oil (not including hydrocarbon condensate) from spills in non-sensitive areas, but requires removal of oil spilled at sensitive sites followed by offsite treatment or disposal. “Sensitive sites” are defined in Rule 91 as areas that are relatively vulnerable to contamination based on factors including: shallow groundwater, pathways into deeper groundwater, proximity to surface water, wildlife areas, commercial, or residential areas. In non-sensitive areas, onsite remediation is subject to the following cleanup requirements:

1. All free oil must be removed immediately for reclamation or disposal;
2. Contaminated areas (all soils containing more than 1.0 percent TPH) must be delineated;
3. All soil exceeding the 1.0 percent TPH standard must be excavated and brought to surface for remediation or disposal; and
4. Storm water controls must be implemented for all excavated soils containing over 5.0 percent TPH.

Within one year after the release, treated soil must attain a final cleanup level of less than 1.0 percent TPH. For crude oil spills exceeding 25 barrels, the operator must submit analyses of soil samples representative of the site to verify that the target cleanup concentration has been achieved (RRC, 2011-e.).

The RRC requires that all condensate spills or crude oil spills in sensitive areas be removed from location, transported by a permitted waste hauler, and remediated or disposed in accordance with Rule 91 (1993). Remediation standards for these types of spills are determined by the RRC on a case-by-case basis. Offsite treatment typically occurs at permitted commercial land farms or reclamation plants. Statewide Rule 57 amendments (1991) established bonding requirements for reclamation plants to ensure that plants are operated and closed in accordance with RRC rules. Amendments to Statewide Rule 8 (1984) require waste generators to maintain records of generated waste and disposition. Waste haulers must track the types and volumes of waste, and the disposal facility to which they haul the waste. Waste management facilities are required to maintain records relating to the type, volume, and source of the waste they receive. Amendments to Rule 20, enacted in 2003, clarify the circumstances that require an operator to report natural gas or associated liquid hydrocarbon releases. That same year, the RRC issued guidelines for the assessment and remediation of soil or groundwater that has been contaminated with condensate (RRC, 2011-i.).

Phase 5: Waste Management and Disposal

Phase Overview: In Texas, oil and gas E&P waste streams include: produced water, drilling mud, cuttings, completion/workover wastes, as well as basic sediment and other oily solids such as contaminated soils. Produced water remains the largest volume waste stream. During the study period, 5.1 to 7.5 billion barrels of produced water were generated annually, the vast majority of which were injected into Class II wells. The EPA granted the RRC primary enforcement authority to permit and regulate Class II injection wells in 1982 (STRONGER, 1993).

Drilling mud and cuttings are primarily disposed of by onsite burial in rule-authorized drilling and reserve pits after dewatering. The RRC also regulates landspreading of solids, annular disposal of drilling fluids, as well as Class II injection of drilling mud. Rule 8 allows rule-authorized landspreading of low-chloride (<3000 mg/L) drilling fluids and cuttings on the same lease where the waste was generated with written permission from the surface owner, provided that there is no runoff or pollution. The RRC also may permit non-commercial disposal of drilling fluid into a dry hole, or into the surface-production casing annulus of an oil and gas well. In order to receive authorization to dispose of drilling fluid, surface casing must be set at least 500 feet deeper than the base of useable-quality groundwater, or there must be at least 250 feet of impermeable formation between the surface casing shoe and the base of useable water. The operator also must demonstrate the mechanical integrity of the surface casing prior to beginning injection, monitor the injection pressure during injection, and install a pop-off valve to prevent exceeding the permitted injection pressure. Dewatered drill cuttings can be disposed at municipal landfills pursuant to a Memorandum of Understanding (MOU) between the RRC and the TCEQ (Statewide Rule 30). The RRC also regulates treatment or disposal of oily solids at land farms or reclamation plants (RRC, 2011-e.).

The RRC's 1992 *Waste Minimization in the Oil Field* manual advocates recycling, product substitution, and source reduction as the preferred waste management alternatives to disposal (RRC, 2011-f). The manual is complemented by the RRC's waste minimization training program, which has been presented at workshops nationwide. Furthermore, the RRC sponsors an annual Oil and Gas Regulatory Expo that showcases new waste minimization technologies and strategies. The RRC has authority to regulate recycling practices and issues permits to recycle the produced water collected during post-stimulation flowback.

In 1991, SB 1103 (72nd Texas Legislature, Regular Session) established the OFCF. The OFCF included the RRC's well plugging program and provided specific funding for the RRC to investigate groundwater contamination. When the RRC identifies groundwater contamination at a site, including legacy contamination from abandoned disposal pits, the RRC requires the responsible party to remediate the groundwater to acceptable levels. The RRC may initiate legal action if the responsible party does not volunteer remedial action. The remediation process continues until the RRC has determined that site conditions satisfy public health, safety, and environmental standards, at which point it issues a “no further action” letter to the responsible operator. The RRC can use the OFCF to perform any necessary remediation, if the responsible party is no longer a viable entity or is unable to perform the necessary remediation. Figures 36 and 37 show a site investigated with OFCF monies, and remediated through the OCP.

Figure 36
Produced water contaminated soil and dead vegetation,
Howard County, Texas
Source: Texas RRC

Figure 37
Finished recovery trench with withdrawal wells,
Howard County, Texas
Source: Texas RRC

Under Rule 8, oily wastes, such as tank bottoms, can be managed by roadspreading if authorized by a minor permit. The RRC may issue these minor permits for county roads provided the appropriate County Commissioners provide written authorization. The RRC developed a guidance document that addressed standards in order to assist Commissioners in deciding whether to allow roadspreading.

Phase Incident Summary: During the study period, the RRC identified 75 incidents (35.5 percent of total incidents) caused by waste management and disposal activities. Fifty-seven incidents (76 percent of phase five incidents) were remnant groundwater contamination incidents caused by legacy (pre-1984) produced water releases from unlined earthen disposal (percolation) pits at oil production facilities. The RRC also identified groundwater contamination caused by Class II disposal wells or surface facilities, as well as permit violations at two commercial landfarming facilities. The RRC did not identify any incidents associated with the landspreading of saline solids, annular disposal of drilling fluids, or other waste management practices.

1) Activity- Earthen Produced Water Disposal Pits: Prior to January 1, 1969, most produced water was disposed of in unlined earthen percolation pits. Produced water characteristics vary considerably from field to field, but most produced water is saline or brackish, and typically contains small percentages of dissolved and/emulsified hydrocarbons.

   Activity Incident Summary: In many areas of Texas, the impacts from historic earthen pit produced water disposal practices persist today (STRONGER, 1993 and 2003; and RRC, personal communication: Bill Renfro). Pit disposal and discharge practices led to widespread groundwater contamination, particularly within the outcrop areas of shallow, unconfined aquifers that were vulnerable to contaminants released at the surface. As a result, in 1969, the RRC issued its “No Pit Order” prohibiting the continued use of pits for disposal of produced water without RRC authorization. Although all earthen produced water disposal pits were eliminated by 1984, the RRC identified 57 remnant incidents caused by historic earthen disposal pits during the study period. Figure 38 shows an abandoned earthen pit that was used for produced water disposal prior to 1984. While the pit is currently filled with rain water, elevated concentrations of chloride and benzene are still found in groundwater samples collected from nearby monitor wells that were required by the OCP.

Figure 38
Abandoned earthen dispoal pit
Source: Texas RRC

Activity Regulatory Enhancements: The RRC issued Order No. 20-804 on July 21, 1939, which prohibited storage of oil in open pits. The RRC issued its “No Pit Order” in 1969, which prohibited continued use of pits for the disposal of produced water without RRC authorization. Following the order, the RRC received over 13,000 applications for exceptions from owners of produced water percolation pits. In 1969, the RRC issued exceptions for pits in select fields in Loving and Upton Counties, believing that the pits posed no threat of contamination. The Legislature subsequently amended the statute, authorizing earthen disposal pits only if the applicant could conclusively demonstrate that use of the pit could not contaminate surface or groundwater. The RRC implemented the mandate when it amended Rule 8 (1984), which required that a variety of pits be repermitted under the new standards, including earthen disposal pits. The RRC denied permit renewals in the two previously excepted counties after finding evidence that some of its pits may have caused contamination, and that local operators could not conclusively meet their new evidential burden.

Since elimination of pit disposal, over 99 percent of produced water, workover, and completion fluids has been injected into permitted Class II injection wells for EOR or disposal. As a result, intentional discharges of produced water into surface or groundwater have been virtually eliminated. The RRC issues permits that authorize surface discharges of fresh produced waters from stripper wells with low salinity (<3000 mg/L TDS), which accounts for the remainder of this waste stream (STRONGER, 2003).

The RRC historically only regulated produced water haulers. However, the 1984 Rule 8 Amendments expanded RRC permitting authority to include all waste haulers. Waste haulers are now only authorized to transport waste to specific permitted facilities. Permitted waste haulers also are required to maintain daily transport records that detail the type and volume of hauled water, as well as its pickup and delivery points.

2) Activity- Class II Injection: During the study period, the yearly number of operational Class II injection wells ranged from 49,503 (2007) to 51,821 (1998). Operators drilled 5,743 new injection wells between 1993 and 2008. During the study period, between 5.1 and 7.5 billion barrels of produced water were injected annually (Appendix G).

Activity Incident Summary: During the study period, the RRC identified fourteen incidents associated with Class II injection operations. Eight of these incidents resulted from produced water releases from surface storage facilities, including pits at Class II disposal wells or Class II waterflood projects. Five incidents were caused by mechanical integrity failures at Class II disposal wells. One incident was caused by leakage from historic, improperly plugged wells that penetrated the producing zone that had been repressurized by produced water injection at an EOR project.

Activity Regulatory Enhancements: Since 1984, the RRC has managed storage of all E&P waste streams through rule-authorizations, permits, or facility registrations. Individual permits are required to store liquid wastes in pits at centralized and commercial facilities including oil skimming pits at Class II injection well surface facilities. Each permit application must include a well's plans for construction, operation, monitoring, and closure. Local topographic and geologic conditions are evaluated as part of the permit application review. The RRC issues permits for all pits at commercial facilities that contain design, construction, and operational requirements including:

material specifications, dike standards, liner material and thickness standards, installation procedures, inspection schedules, overflow warning devices, leak detection system standards, and fencing requirements (RRC, 2011-e.).

The RRC also attaches special permit conditions for tanks at commercial Class II disposal facilities that address construction materials, dikes, catch basins, gauges, and alarms. Tanks must be maintained in a leak-free condition and must be emptied and repaired or replaced when there are integrity issues.

In 1998, the RRC amended Rules 9 and 46 to expand public notice requirements for Class II injection wells permit applications. The amendments require notice to additional persons for commercial disposal well applications, and any additional notice deemed necessary by the RRC. These amendments also codified requirements and standards for conducting mechanical integrity tests (RRC, 2011-e.).

3) Activity- Landfarming: Basic sediment and other oily solids are primarily disposed of by on-lease treatment in non-sensitive areas or offsite treatment at permitted commercial land farms or reclamation plants. Landfarming of oily solids involves spreading a thin layer of oily solids onto a plot of land, and tilling the waste into the soil. Bulking agents and nutrients are typically added to the mixture within the incorporation zone to stimulate the feeding activity of microbes to expedite the degradation, transformation, and immobilization of hydrocarbons. The application of waste is subject to permitting standards that limit spreading rates to prevent surface runoff, avoid groundwater contamination, and facilitate rapid degradation of the waste. Unlike storing waste by burial at landfills, land treatment uses natural chemical and biological processes to transform hydrocarbons into various by-products, primarily water and CO_2.

   Activity Incident Summary: Permit violations at commercial land farms caused two incidents during the study term.

   Activity Regulatory Enhancements: Rule 91(1993) authorizes onsite remediation of crude oil from spills in non-sensitive areas. Any other spill of crude oil into sensitive environments, spills of hydrocarbon condensate, or any spill into water must be remediated in accordance with a RRC-approved plan. Rule 8 establishes permitting requirements for all land treatment sites including commercial land farms. In addition to general requirements, commercial facilities are subject to public notice requirements. Applicants must submit all information listed in the Surface Waste Management Manual including, but not limited to:

- Tract dimensions and coordinates;
- Land contour map and identification of all water courses and drainage ways;
- Depth to shallowest groundwater and distance and depth of domestic water wells within one mile;
- Groundwater flow direction;
- Map showing cells, dikes, access roads, along with perpendicular cross-section views;
- Storm water management plans based on a 25 year maximum 24 hour rainfall event;
- Proposed liner specifications;
- List of anticipated types and volumes of wastes to be treated;
- Waste application method and proposed loading rate;
- Estimated duration of the land treatment operation; and
- Closure plans.

Land treatment operations cannot be permitted in 100 year floodplain areas. The landfarming permit specifies allowable waste streams and defines the operating and monitoring standards for the site including: storm water management, soil monitoring, groundwater monitoring, record keeping and reporting, closure standards, and future land-use restrictions. Waste analyses including electrical conductivity, soluble salts, and TPH must be submitted for non-commercial bioremediation of RCRA exempt crude oil contaminated soils. Additional parameters are required for other types of waste. Before a new facility is permitted, treatment tests are performed to identify site-specific operating measures to optimize waste degradation and immobilization. Furthermore, commercial facilities must install monitor wells to compare upgradient and downgradient groundwater chemistry immediately adjacent to the treatment area to identify and correct any contamination found within the boundaries of the permitted facility (RRC, 2011-g.).

Phase 6: Plugging and Site Reclamation

Phase Overview: During the study period, 140,818 oil or gas wells were plugged in Texas. The RRC first enacted rules for plugging wells in accordance with SB 350 (1919) requiring that every "dry or abandoned well be plugged in such a way as to confine oil, gas, and water in the strata in which they are found and prevent them from escaping into other strata". In 1934, the RRC issued specific plugging instructions that required a producing formation be sealed with cement. It further required that surface casing be set through the deepest usable water aquifer and cemented from casing shoe to surface. When a well is abandoned, an operator is required to set a cement plug between 50 feet below and 50 feet above the zone. The RRC amended Rule 14 in 1966 to upgrade plugging standards by establishing many of the current rule's requirements. Figure 39 shows the number of wells plugged each year since 1993 (RRC, 2011-e.).

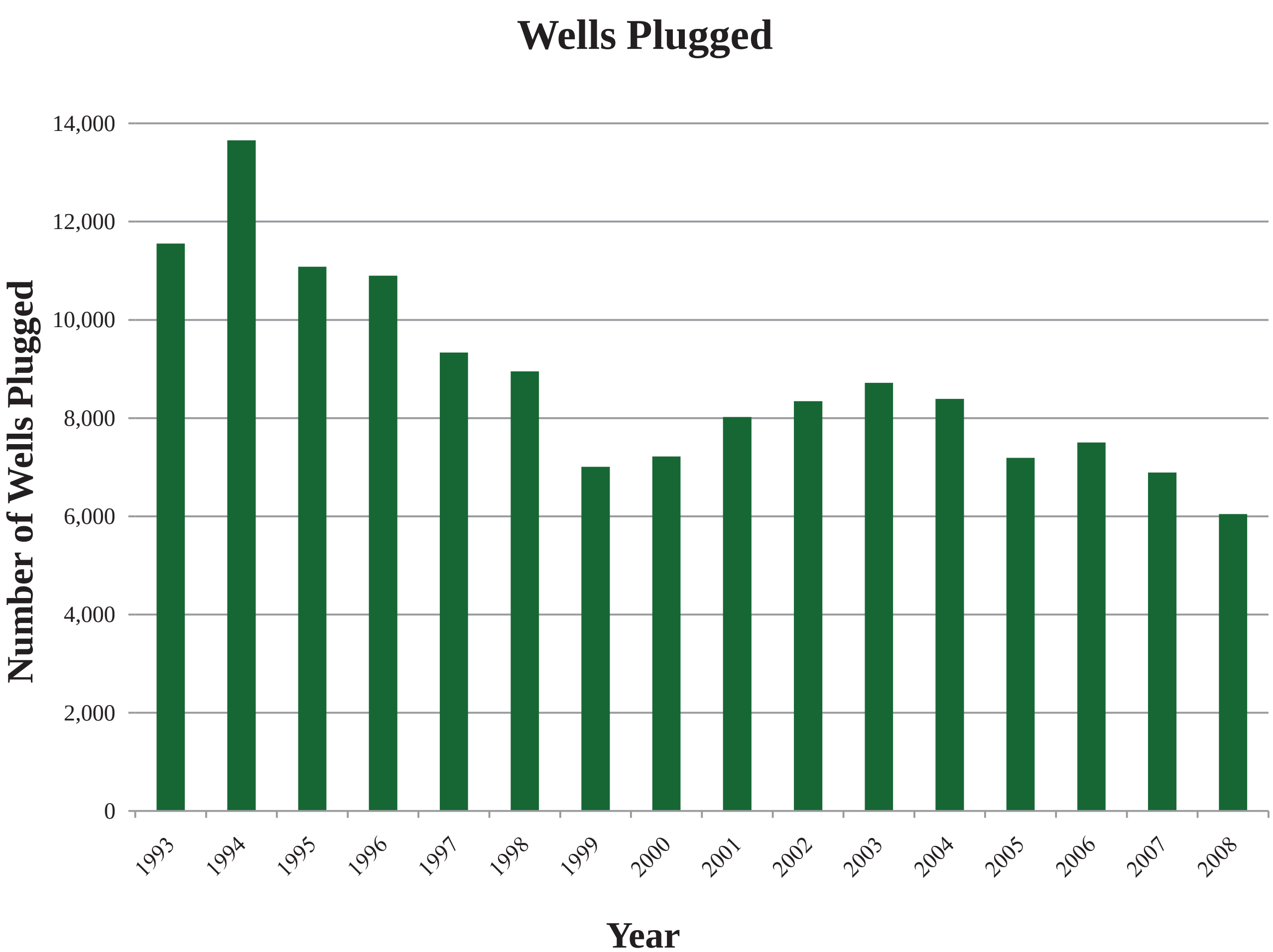


Figure 39
Number of wells plugged (1993-2008)

Phase Incident Summary: Phase six incidents occur when contaminants are released into groundwater during plugging operations, or by an operator's failure to comply with temporal plugging standards. Wells plugged according to temporal rules and standards that subsequently allowed vertical fluid migration into useable groundwater are assigned to phase seven (orphaned wells and sites). There was one incident caused by deficient plugging practices that violated prescribed standards accounting for 0.47 percent of all incidents.

Phase Regulatory Enhancements: In 1992, the RRC began requiring testing for older wells to determine whether they were eligible for plugging extensions. Annular fluid level tests are required for inactive wells over 25 years old. An operator must conduct a test to verify mechanical integrity in order to qualify for a plugging extension, if fluid in the surface-production casing annulus is near or above the base of fresh water. Wells over 25 years old that have been inactive for more than ten years must be tested for mechanical integrity every five years.

In 2003, the RRC revised Rule 14 to require that the operator verify the placement of the plug required at the base of the deepest useable-quality water stratum by tagging with tubing or drill pipe. Rule 14 requires an operator to plug wells that are no longer productive, and to empty all tanks, vessels, their related piping, and flow lines that will not be actively used within 120 days after plugging is completed.

Phase 7: Orphaned Wells and Sites

Phase Overview: From 1984 to 2009, the RRC plugged 30,335 orphaned wells at a cost of $172.4 million. It has further remediated, assessed, or investigated 4,306 sites using the OFCF and other state and federal funds. The OFCP is funded by oil and gas industry fees including drilling permit applications and organizational report fees. It is further supplemented by forfeited bonds, penalties, and proceeds from the sale of salvaged equipment (RRC, 2011-a.).

The RRC continually tracks the status of all oil and gas wells including compliant temporarily inactive wells that are owned by operators with Active Organization Reports that meet all bonding and financial assurance requirements, and wells owned by operators in non-compliance with RRC plugging rules. The RRC defines a well as “orphaned” when:

1. The well has not been plugged within the time prescribed by the RRC;
2. The operator fails to provide the required financial assurance for the well(s);
3. The RRC cannot locate the operator; and
4. The operator is not financially able to, or simply refuses to plug the well.

The number of orphaned wells is dynamic and updated regularly. The RRC tracks monthly changes in the number of orphaned wells and prepares an annual report for the General Assembly (RRC, 2011-a.).

Phase Incident Summary: The study noted 30 incidents involving contaminant releases from orphaned wells and sites accounting for 14.2 percent of all incidents. Vertical migration of fluids through inadequately sealed boreholes was the cause of 28 incidents (93 percent of phase seven incidents); most of these incidents involved wells characterized as “old” or “historic”. Many of the wells were subsequently referred for plugging through the State Well Plugging Fund. The remaining two sites that required clean up with state funds involved historic releases from orphaned earthen pits.

Phase Regulatory Enhancements: During its 2003 follow-up program review, the STRONGER team concluded that “Texas has been extremely proactive in addressing the issues relating to existing orphaned wells and sites, as well as taking action to stem the growth of this problem”. Appendix E includes a summary of the actions taken by the Legislature and the RRC to address the threats to safety and the environment posed by orphaned wells. Specifically, the RRC has diligently worked to reduce the number of potential wells and sites that could be added to the inventory since 1991 by amending rules that:

1. Increase state funds available to plug orphaned wells and remediate abandoned sites;
2. Access other federal and private sources of funding, including establishment of a VCP;
3. Progressively strengthen bonding standards;
4. Prohibit the transfer of wells to operators who do not meet current financial assurance requirements;
5. Limit the number of time extensions an operator can receive before plugging a well;
6. Provide tax incentives to restore inactive wells;

7. Require financial security for reclamation plants and commercial E&P waste disposal facilities to ensure their proper closure; and
8. Create a prioritization scheme that includes groundwater contamination risk assessment as a tool to direct OFCF expenditures.

Texas first established a Well Plugging Fund in 1965 to address orphaned wells that pose a pollution hazard. Initially, the fund was supplied by limited funds that had been appropriated from the state's general revenue. In 1983, a new Well Plugging Fund was established that was primarily supported by a $100 per well drilling fee, as well as administrative and civil penalties. These combined revenues provided approximately $3 million of annual income dedicated solely to plugging orphaned wells. Well Plugging Fund receipts dropped sharply when the 1980s collapse in oil prices forced the oil and gas industry to cut back drilling operations, resulting in a spike of inactive wells.

It became apparent by 1990 that the Well Plugging Fund was no longer adequate to address the growing number of orphaned wells and their cleanup costs. Texas SB 1103 (1991) rolled the remaining monies from the Well Plugging Fund into the OFCF. The OFCF expanded the RRC's authority to investigate and remediate contaminated sites, and to plug orphaned wells. The fund was a dedicated account of $10 million per year. Figure 40 depicts the number of orphaned wells plugged from Fiscal Year (FY)92 to FY09 with OFCF monies.

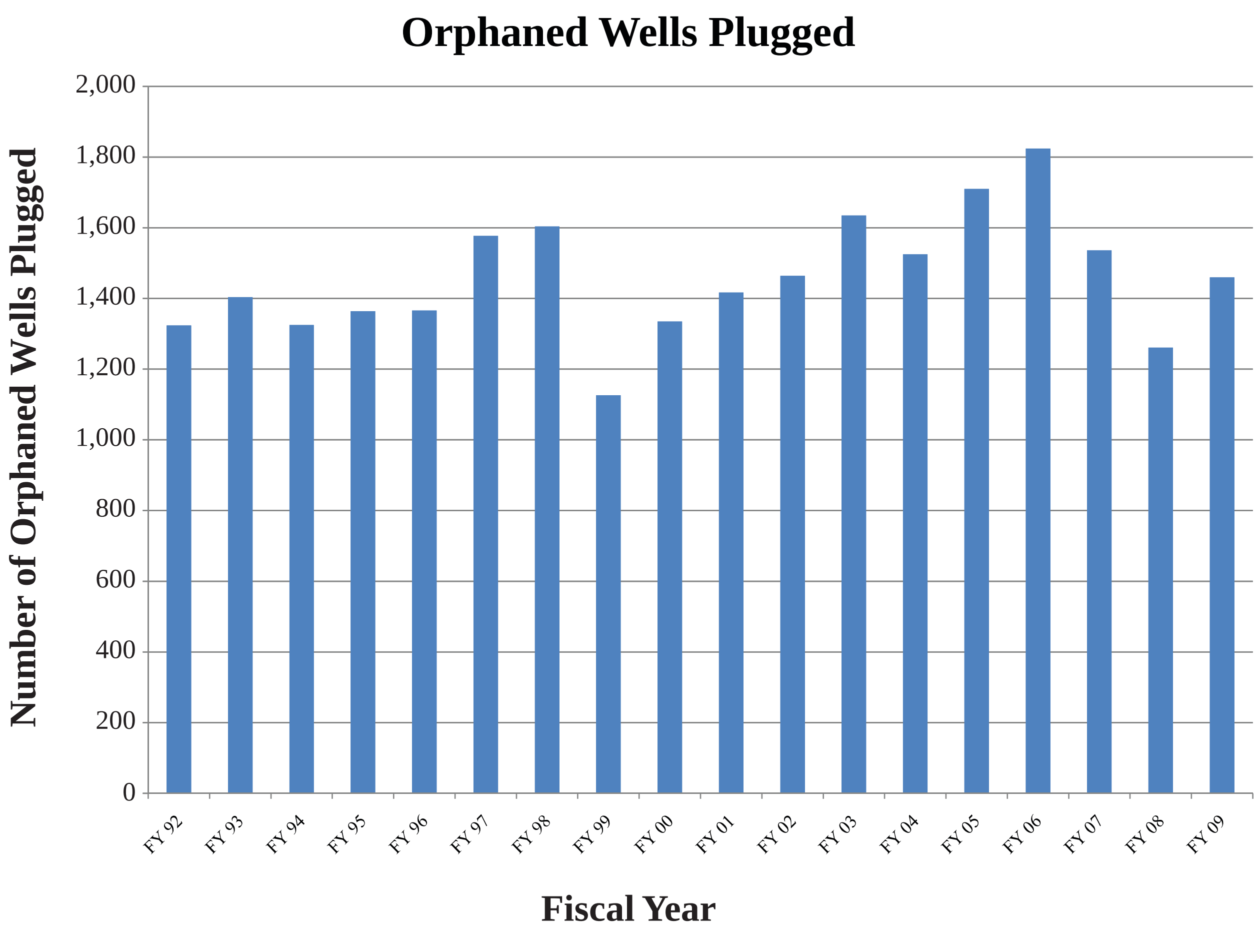


Figure 40
Orphaned wells plugged (FY92-FY09)
Source: Texas RRC

SB 310 (2001) expanded the annual fund balance cap to $20 million by increasing the severance tax on oil and gas production and increasing other fees. The RRC spends approximately 50 percent of available OFCF funds to plug orphaned wells; the remaining 50 percent is utilized through state-funded cleanup operations that remediate orphaned sites with surface and groundwater contamination. Table 4 illustrates the average number of orphaned wells plugged, and the average annual plugging expenditures under each bill since 1983.

Table 4 Average Annual Orphan Well Plugging Activity and Expenditure

Senate Bill	Years	Orphaned Wells Plugged (Annual Average)	Plugging Expenditures (Average Annual)
729	1984-1991	510	$2,021,426
1103	1992-2001	1,248	$6,158,349
310	2002-2009	1,552	$11,836,575

The RRC also pursues other sources of private sector and federal funding to address the problems posed by orphaned wells. For example, the Oil Spill Contingency Liability Trust Fund (OSCLTF) has been a source of federal funding for the removal of imminent threats to the waters of the U.S. from leaking oil wells and facilities. The OSCLTF was enacted through the OPA of 1990. The EPA authorizes program expenditures either directly through federally managed clean up, removal, and plugging operations, or through a Pollution Removal Funding Agreement with the state or other relevant entities.

The federal Coastal Impact Assistance Program (CIAP) also has been a source of state cleanup funds. The CIAP authorizes funds to states that produce oil and gas on the outer continental shelf for the conservation, protection, and preservation of coastal areas. The RRC has received $3,024,050 to plug abandoned wells in state coastal waters, and $1,914,420 to remediate a number of abandoned sites in coastal counties.

SB 310 (2001) authorized the RRC to establish a VCP. The VCP incentivizes site remediation by removing liability to the state for lenders, developers, owners, and operators who are not responsible for contamination, but nonetheless wish to remediate sites with RRC oversight. The VCP places formerly contaminated oil field properties into productive use and reduces the number of sites that would otherwise have to be remediated with OFCF funds. Participants pay for the both clean up and RRC oversight costs.

In 1988, the RRC established a Well Plugging Priority System to ensure that wells posing the greatest threat of pollution or risk to public safety are plugged first (RRC, 2011-a.). The priority system includes a number of factors to address groundwater contamination potential including:

1. Well completion factors such as: wells without surface casing, wells with surface casing that do not isolate all aquifers with useable groundwater, and wells that penetrate corrosive or abnormally pressurized zones;
2. Well condition factors such as: a pressurized annulus, fluid levels above the base of the deepest protected aquifer, or demonstrated mechanical integrity failure;
3. Well location factors such as proximity to domestic water wells; and
4. Other unique factors such as: proximity to an active waterflood project or Class II disposal wells.

The benefits of the OFCF, increased funding, and other rule enhancements have been demonstrated by increased plugging of orphaned wells, a general decrease in the number of orphaned wells, and the number of sites that have been investigated, assessed, or remediated. The RRC tracks the constantly changing number of orphaned wells, as wells are placed in and out of compliance. These changes are reported on a monthly and annual basis. Figure 41 depicts the total number of orphaned wells from FY03 through FY09. The number of orphaned wells decreased 56 percent from 17,971 (2003) to 7,900 (2009). A total of 10,969 orphaned wells were plugged during this seven year period. Since 2003, 78,867 wells were removed from the RRC inventory when they were either: returned to active status (1,451), transferred to a bonded owner (12,639), as the result of an Organizational Report renewal (53,458), and for various other reasons (350). Collectively, these reductions protect the citizenry and significantly reduce threats to groundwater resources (RRC, 2011-a.).

Abandoned oilfield sites are also prioritized based on the present or possible future impact to the environment and public safety. Surface sites are classified as Priority A (high), Priority B (medium), and Priority C (low). Priority A sites are those that require emergency clean up due to: active or imminent pollution; a threat to public health, safety, or sensitive environmental areas; or greater anticipated cleanup costs if action is delayed. In determining priority ranking for other sites, the RRC considers such factors as: type of contaminant and the media contaminated; the number of potentially affected people; the potential for releases, leaks, or seeps; the need for repeated inspections; the distance to surface water, municipal or domestic water wells, and known aquifers; annual precipitation; and type of native soil (RRC, 2011-a.).

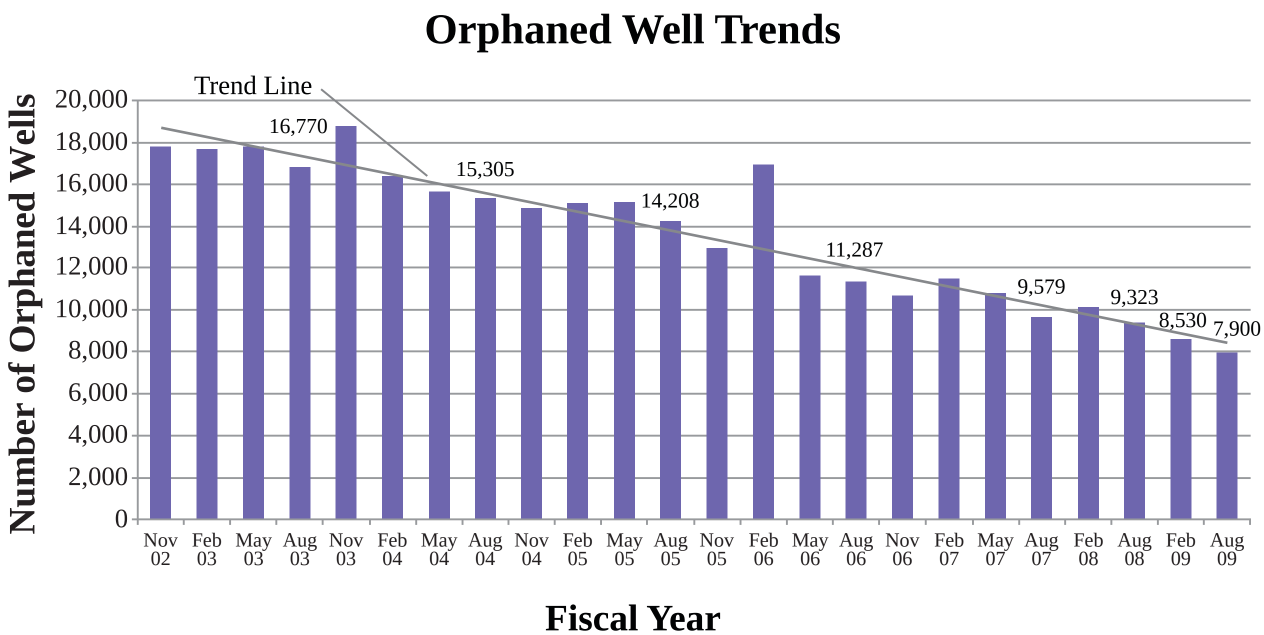


Figure 41
Total orphaned wells (FY03-FY09)
Source: Texas RRC

With larger, more complex sites, the greatest challenges are to distinguish whether a source of pollution is natural, and which type of remediation will be most effective. To answer these questions, the RRC conducts specialized investigations with contractors who conduct site assessments, propose cost-effective cleanup techniques, and conduct cleanup activities in the field. The RRC also occasionally contracts with the Texas Bureau of Economic Geology (the University of Texas at Austin) to participate in such investigations. State managed remediation activities include: site assessment investigation, routine remediation operations, and emergency operations (RRC, 2011-a.).

Key Messages

1. Investigation Findings are Drivers of Regulatory Reform: All land use and energy development activities present some level of associated environmental and public safety risk. There are no risk-free energy development options. State agencies use groundwater investigation findings as an important tool for identifying risks and deficiencies in their regulatory schemes. The findings and determinations of state agency groundwater investigations are important drivers of regulatory reform and improved industry practice. By identifying activities and patterns of failure resulting in groundwater contamination, state agencies prioritize regulatory reforms and strategically apply resources to improve standards that reduce risk associated with state-specific compliance issues. Over time, both Ohio and Texas have strategically enhanced regulatory standards for state-specific oil and gas E&P activities that have been found to cause groundwater contamination incidents. Dissimilarities in the scope and scale of regulated activities, land usage, groundwater usage, population densities, climatic, and geologic factors have contributed to the unique evolution of their respective regulatory programs.

2. Investigations are Applied Science: Groundwater investigations are exercises in applied science. An agency determination regarding the cause of groundwater contamination is a testable hypothesis. Investigations are typically conducted by a team of specialists including inspectors and geo-scientists. Determinations must be supported by sufficient facts and data, that are collected and analyzed according to standard methods and protocols. Data and evidence must be interpreted and analyzed by specialists that apply scientific principles that are generally accepted within fields including: geology, hydrogeology, aqueous chemistry, geophysics, and petroleum engineering. Investigation findings and determinations are subject to review and testing, informally or formally through contested legal proceedings. Agency specialists must be able to establish their credentials as experts in order to present evidence and professional opinions during these review processes. This testing process, that is foundational to science, serves to filter and discard conclusions that are based on speculation, conjecture, or insufficient evidence.

3. Sound Science is Foundational to Good Public Policy: Regulatory proposals and policy should reflect sound science. Speculative conclusions and opinions about possible groundwater contamination incidents that are based solely upon anecdotes, innuendo, and oversimplified chronologies are not a sufficient foundation to advance national or state regulatory reforms or policies. While state investigation findings should not be viewed as inerrant, they are typically conducted by experienced and qualified personnel who recognize that their evidence, findings, and conclusions may face scrutiny under appeal, or peer review. Accordingly, state agency investigation findings and determinations, associated rulings by commissions that hear appeals, and court decisions should be valued and taken seriously when amending regulatory schemes and establishing new policies.

4. Incidents are Caused by Diverse Activities: In addition to contamination caused by legacy practices and orphaned sites, Ohio and Texas investigators have identified groundwater contamination caused by a wide range of regulated industry practices. Appropriately, Ohio and Texas have focused regulatory attention on those activities that have caused the majority of groundwater contamination incidents. In recent years, the national debate on natural gas E&P has been focused nearly exclusively on a single, brief, yet essential activity, hydraulic fracturing. Neither state has identified hydraulic fracturing as the cause of a single documented groundwater contamination incident. However, it has become increasingly apparent that in much of the popular literature, the term "hydraulic fracturing" has become synonymous with any and every E&P activity that can impact groundwater. When developing public policy, it is critical to differentiate activities that can contribute to groundwater contamination in order to accurately target and prioritize reforms. As in the practice of medicine, the physician must accurately diagnose the specific cause of an ailment, in order to prescribe the appropriate remedy. Although many states, including Ohio and Texas, have implemented or are considering new regulations that significantly improve documentation of hydraulic fracturing operations, including public disclosure of chemical additives in fracturing fluids, it is critical that states maintain an appropriate focus on activities and practices that are actually found to cause groundwater contamination.

5. Regulatory Evolution is a Continuing Process: Both Ohio and Texas have demonstrated a commitment to the protection of groundwater resources as evidenced by the scope of regulatory amendments that have been advanced since the early 1980s. While these regulatory efforts are commendable, both states should continue to evaluate, update, and amend regulations in response to new technologies, evolving effective management practices, peer review recommendations such as those provided through the STRONGER process, and groundwater investigation findings and determinations. The goal should be to prevent contamination to the extent reasonably possible.

ACRONYMS

bbls	barrels, petroleum (42 gallons)
bcf	billion cubic feet
BMP	Best Management Practices
BMRSA	Brine Management Research Special Account (Ohio)
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CIAP	Coastal Impact Assistance Program
CO_2	Carbon dioxide
CWA	Clean Water Act
DMRM	Division of Mineral Resources Management (within ODNR)
DoGS	Division of Geological Survey (within ODNR)
DoW	Division of Water (within ODNR)
E&P	Exploration and Production
EOR	Enhanced Oil Recovery
EPA	Environmental Protection Agency (United States)
FY	Fiscal Year
GWPC	Ground Water Protection Council
HB	House Bill (Ohio General Assembly)
IOGCC	Interstate Oil and Gas Compact Commission
IPAA	Independent Producers of America Association
JGWMC	Joint Groundwater Monitoring and Contamination (Texas report)
Mcf	Thousand cubic feet
mg/L	milligrams per Liter
MMcf	Million cubic feet
NGO	Non-Governmental Organization
NPDES	National Pollutant Discharge Elimination System
OCP	Operator Cleanup Program (within Texas RRC)
ODNR	Ohio Department of Natural Resources
OFCF	Oil Field Cleanup Fund (within Texas RRC)
OFCP	Oil Field Cleanup Program
OGD	Oil and Gas Division (within Texas RRC)
OPA	Oil Pollution Act

OSCLTF	Oil Spill Contingency Liability Trust Fund
OSMRE	Office of Surface Mining Reclamation and Enforcement
ORC	Ohio Revised Code
PIMP	Pipeline Integrity Management Program (Texas)
PMCL	Primary Maximum Contaminant Level
ppm	parts per million
RCRA	Resource Conservation and Recovery Act
RQ	Reportable Quantity
RRC	Railroad Commission (Texas)
SB	Senate Bill (Ohio General Assembly)
SDWA	Safe Drinking Water Act
SMCL	Secondary Maximum Contaminant Level
SPCC	Spill Prevention Control and Countermeasures
STRONGER	State Review of Oil and Natural Gas Environmental Regulations
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
tcf	trillion cubic feet
TDS	Total Dissolved Solids
TGPC	Texas Groundwater Protection Committee
TNRC	Texas Natural Resources Code
TPH	Total Petroleum Hydrocarbon
TPS	Technical Permitting Section (Texas)
TWDB	Texas Water Development Board
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
USGS	United States Geological Survey
VCP	Voluntary Cleanup Program (within Texas RRC)

DEFINITIONS

A

Adjudication: An enforcement action subject to the legal process by which an arbiter or judge reviews evidence and reasoning presented by opposing parties.

Ambient water quality: The natural or non-degraded condition and chemistry of groundwater in aquifers within a defined area.

Annular disposal: The disposal of waste products, such as drilling mud or produced water, between the surface and/or intermediate casing shoe and production casing strings into permeable zones above the cemented portion of the production casing.

Annular overpressurization: A condition where the pressure of fluids in the surface-production casing annulus exceeds hydrostatic pressure at the surface (water protection) casing shoe.

Aquifer: A geological formation, group of formations, or part of a formation that is capable of yielding useable quantities of groundwater to a well or spring.

Area of Review: An area prescribed by regulations, surrounding a proposed injection well where permit reviewers examine records to evaluate the presence and condition of other boreholes that may penetrate the target injection zone.

B

Background water quality: The condition and chemistry of groundwater, including contaminants that may be present, in the immediate vicinity of an activity that could potentially alter the condition or chemistry of groundwater.

Barrel: A measure of volume for crude oil equivalent to 42 U.S. gallons.

Basic sediment: The sediment and other extraneous material present in crude oil.

Basic sediment pit: A lined pit used for temporary storage of production wastes during removal or replacement of storage tanks.

Basin: A geologic structure in which strata dip, and generally thicken, toward a central location known as the axis.

Biocide: A chemical substance used to kill or render harmless microorganisms in water.

Biogenic gas: A natural gas produced by living organisms or biological processes.

Bioremediation: The natural or enhanced process of breaking down crude oil or other contaminants entrained in soil into by-products by the action of living things, such as microorganisms.

Blowdown pit: A pit constructed to temporarily contain waste fluids resulting from depressurizing a vessel or well.

Blowout: An uncontrolled flow of pressurized fluid (natural gas, crude oil, or water) that can occur during drilling or completion operations if subsurface formation pressure exceeds the pressure applied by the column of drilling or well control fluid in the borehole.

Blowout preventer: An assemblage of specialized safety valves installed on a wellhead to control subsurface fluid pressure during drilling and completion operations.

Brackish water: Water that contains relatively low concentrations of soluble solids. Brackish water has more total dissolved solids than fresh water, but considerably less than sea water. While classification schemes differ, brackish water typically contains 5,000 to 30,000 mg/L total dissolved solids.

Brine: Water that has a large concentration of dissolved salts, especially sodium chloride. While classification schemes differ, brine typically contains more than 30,000 mg/L total dissolved solids.

C

Casing: The steel pipe installed in a well to maintain structural integrity, control the flow of pressurized fluids, and isolate water zones from injection or oil and gas production zones.

Clean Water Act (CWA): The act that sets the basic structure for regulating discharges or pollutants to surface waters of the United States, establishing contaminant limitations or guidelines for all discharges of wastewater into the nation's waterways.

Coal bed methane: A natural gas produced by coal seams.

Condensate: A low-density mixture of liquid hydrocarbons that may be present in raw (untreated) natural gas and separates from the gaseous phase as a result of pressure and temperature changes during production or transportation processes.

Conductor pipe: The first and broadest-diameter string of casing installed in a well, generally to prevent collapse of unconsolidated sediments, such as sand and gravel, while drilling the deeper portions of the borehole.

Confined aquifer: An aquifer that is completely saturated and overlain by impermeable strata.

Contamination: The introduction of pollutants into a media, such as groundwater, causing measured concentrations of chemical parameters of interest to exceed maximum concentrations permitted by regulation, or to exceed "background" levels by designated amounts.

Completion operations: The work performed in an oil or gas well after the well has been drilled to total depth. This work includes but is not limited to, setting the casing, perforating, production testing, and equipping the well for production of oil or gas in paying quantities, or in the case of an injection or service well, prior to when the well is plugged and abandoned.

Correlative rights: The legal doctrine that provides owners of subsurface mineral rights a reasonable share of the value of an extracted resource, typically based on the amount of land owned by the respective parties of a developed tract or unit.

Crude oil: Unrefined liquid petroleum.

D

Dip: The angle that strata tilts relative to a horizontal plane.

Directional drilling: The technique of drilling at an angle to reach a target not located directly underneath the well pad.

Disposal well: A Class II well permitted through the UIC program under the SDWA which is used for the injection of produced water and certain exploration and production wastes into an underground formation.

Disruption: Any physical condition, in addition to contamination or diminution, that prevents reasonable, uninterrupted use of a water well.

Dissolved solids: Salts and minerals that dissolve in water.

Drill cuttings: The fragments of rock that are created by drilling bit during the drilling process.

Drilling fluid: The circulating fluid used during rotary drilling of wells to clean and condition the hole and counterbalance the pressure of fluids in the subsurface.

Drill stem test: A procedure for isolating and testing petroleum reservoir properties by measuring pressure behavior at the drill pipe.

Drip gas: Synonymous with condensate.

E

Effective management practices: Practices that are effective in achieving process objectives, including but not limited to Best Management Practices that continually evolve.

Emergency pit: A pit constructed in the event of an emergency, to contain the unanticipated release of fluids.

Enhanced Oil Recovery (EOR): A generic term for processes that improve the amount of crude oil that can be extracted from an oil reservoir or field.

Evaporation pit: A lined pit used in arid regions to allow evaporation of water-based waste by-products generated during drilling, production, or treatment operations.

Exploration: The process of identifying a potential subsurface geologic target and the drilling of the borehole designed to access the petroleum reservoir.

F

Flowback fluids: The produced water recovered after the release of pressure at the end of hydraulic fracturing operation, consisting of hydraulic fracturing fluids commingled with connate brines or water from the stimulated zone.

Flow line: A small diameter pipeline that conveys fluids from a well to the initial separation and storage facility.

Foam frac: A hydraulic fracturing fluid consisting of gaseous foam typically using nitrogen or carbon dioxide.

G

Gas compressor station: A facility that helps transport natural gas moving through a transmission line by boosting in-line pressure.

Gas processing plant: A facility that removes marketable liquid hydrocarbons, as well as water and waste by-products from natural gas before it is placed into a transmission line.

Groundwater: The subsurface water within the zone of saturation.

Groundwater table: The upper surface of the zone of water saturation.

H

Hazardous waste: A waste with properties that make it dangerous or capable of having a harmful effect on human health and the environment. Under the Resource Conservation and Recovery Act, hazardous wastes are specifically defined as wastes that meet a particular listing description or that exhibit a characteristic of hazardous waste.

Horizontal drilling: A drilling procedure in which the wellbore is drilled vertically to a planned kick off depth above the target formation and then angled through a 90 degree arc such that the producing part of the well extends horizontally through the target formation.

Hydraulic fracturing: A method of stimulating production by increasing the permeability of the producing formation. Under hydraulic pressure, a fluid is pumped down the well and out into the formation. The fluid enters the formation and parts or fractures it.

Hydraulic fracturing fluids: The fluids, liquid or gas, used to fracture rock to increase the permeability of a target zone to enhance injection or extraction of fluids.

Hydrocarbon: An organic compound consisting of hydrogen and carbon that includes natural gas and crude oil.

Hydrostatic pressure: The natural pressure exerted by the weight of a column of groundwater in the subsurface.

I

Incident: An event resulting in the pollution, contamination, or disruption of water well usage.

Injection well (Class II): A well used to inject fluids into an underground formation to enhance recovery of petroleum or disposal of oilfield waste fluids.

Intermediate casing: A casing string that may be installed and cemented in a wellbore, after surface casing but before production casing, to control pressurized zones or stabilize the borehole.

L

Landfarming: An engineered, controlled process that incorporates small volumes of oily waste into soil where bacteria and microorganisms decompose and immobilize hazardous components.

Landspreading: A method of treatment and disposal of low-toxicity, typically saline solid wastes in which wastes are spread upon and mixed into soil to promote dilution of salts and attenuation of metals.

Lost circulation: During drilling operations, circulation is deemed lost when it flows into a permeable, subsurface zone rather than returning up the annulus to surface.

M

Mechanical integrity: A condition in which the casing, mechanical, and cement components of a well are effectively isolating specific zones, effectively preventing fluid movement into protected groundwater.

N

Natural gas: A naturally occurring mixture of hydrocarbon and non-hydrocarbon gases found in geologic formations beneath the earth's surface. The principal hydrocarbon constituent is methane.

O

Operator: The person or company, proprietor, contractor, or lessee, actually operating a well, lease, or disposal facility.

Orphaned well: An abandoned well that no longer has a legally responsible owner.

Outcrop: The area in which a stratigraphic unit is exposed at land surface.

P

Percolation pit: A pit used to dispose waste liquids through the base or sides of the pit into surrounding soils.

Permeability: The capacity of rock to transmit fluids, depending on the size, shape, and interconnectivity of pore spaces.

Plugging: The placement of plugging materials, generally cement, into a well in order to restrict vertical movement of fluids after site reclamation.

Primacy: The right granted by federal government authorizing states to implement federal regulations subject to oversight agreements.

Produced water: The water brought up from the hydrocarbon-bearing strata during the drilling, well completion, post stimulation flowback process, and/or production of oil and/or gas.

Production: The phase of the petroleum industry that deals with bringing the well fluids to the surface, separating them, and storing, gauging, and otherwise preparing the product for sale.

Production casing: The last, and narrowest, casing string cemented in a well to isolate the oil and gas producing zone from the remainder of the borehole.

Proppant: The silica sand or other articles pumped into a target zone during a hydraulic fracturing operation to keep fractures open and maintain permeability after pressure is released.

Proration: The regulatory practice of limiting oil production to promote efficient resource development.

R

Reclamation: The process of returning a site or contaminated soil to an appropriate state of environment acceptability.

Reserve pit: A temporary pit used to contain drill cuttings and drilling fluids during drilling operations that is reclaimed after completion of the well.

Reservoir: A subsurface, porous, permeable rock body in which oil and/or gas are stored. Most reservoir rocks are limestones, dolomites, sandstones, or a combination of these.

Roadspreading: The authorized placement on roads of specific exploration and production wastes that exhibit properties similar to commercial road oils, dust suppressants, road compaction, or deicing materials.

Rule-authorized: The establishment of standards by regulation, rather than by permit term or condition, directive, or order.

S

Safe Drinking Water Act (SDWA): The act designed to protect the nation’s drinking water supply by establishing national drinking water standards and by regulating UIC wells.

Salinity: The quantitative level of salt in an aqueous medium.

Salt dome: A structural feature caused by the intrusion of deep, subsurface salt deposits upwards into overlying strata, as a result of salts relative low density and plasticity. Salt domes create impermeable traps for hydrocarbons migrating upward through permeable strata.

Skimming pit: A lined pit, tank, or constructed impoundment to allow gravity segregation and removal of free oil before disposing aqueous waste.

Slickwater: A water-based fluid consisting primarily of water mixed with friction reducing agents that is used in hydraulic fracturing operations.

Spent materials: The materials that have been used and can no longer serve the purpose for which they were produced without processing.

Spill Prevention Control and Countermeasures (SPCC): Federal regulations establishing spill prevention procedures for certain above-ground storage facilities including crude oil tanks, pursuant to the Clean Water Act.

Stimulation: A process used to enhance near wellbore permeability, including hydraulic fracturing.

Storage tank: A storage vessel at a producing well to store crude oil and/or produced water prior to offsite transportation to market or disposal.

Structure contour map: A map depicting the surface elevation of a geologic formation of interest relative to sea level.

Subcrop: The area where a stratigraphic unit occurs in the subsurface.

Surface casing: A casing string cemented in place to isolate protected sources of groundwater and to serve as a base for the blowout preventer.

Surface facility: The surface infrastructure at a Class II injection well to receive, segregate, treat, store, filter, and pump fluids into the well.

Surfactants: The compounds that lower the surface tension of water include detergents, wetting agents, emulsifiers, and dispersants.

T

Tank bottoms: The produced sand, formation solids, and/or emulsions that settle-out in production operation process vessels.

Thermogenic gas: A natural gas that is formed deep in the earth by the combined forces of high pressure and temperature.

Tight formation: A low-permeability formation that may contain significant volumes of hydrocarbons.

Total Dissolved Solids (TDS): The dry weight of dissolved material in water usually expressed in milligrams per liter or parts per million.

Transporter: A person engaged in the offsite transportation of waste.

U

Unconfined aquifer: An aquifer that is partially saturated, and the water level responds to changes in atmospheric pressure.

Underground Source of Drinking Water (USDW): An aquifer or portion of an aquifer that supplies any public water system, or that contains a sufficient quantity of groundwater to supply a public water system, and currently supplies drinking water for human consumption, or that contains fewer than 10,000 mg/L total dissolved solids and is not an exempted aquifer.

Useable-quality water: Groundwater of sufficient quality that can be used for public, domestic, agricultural, industrial, or any other legitimate purpose. Typically groundwater that is deemed useable has less than 3,000 mg/L total dissolved solids.

W

Waste minimization: The reduction, to the extent feasible, in the amount of waste generated prior to any treatment, storage, or disposal of the waste. Because waste minimization efforts eliminate waste before it is generated, disposal costs may be reduced, and the impact on the environment may be lessened.

Waterflood: A method used to enhance oil recovery in which water is injected into a reservoir to remove additional quantities of oil that have been left behind after the primary recovery. Usually, a waterflood involves the injection of water into strategically placed wells so that it sweeps through the reservoir and moves remaining oil to the producing wells.

Workover: A remedial operation performed on a producing well to increase production including deepening, plugging back, or resetting a liner.

Workover fluid: A special fluid used to keep a well under control when it is being worked over.

Workover pit: A temporary pit used to store fluids generated during a workover operation.

References

Bair, E. Scott, R.K. Digel, and M. Springfield, 1989. Ground-Water Quality Changes Resulting from Surface Application of Oilfield Brine: Brine Management Research Report, prepared for the Ohio Department of Natural Resources, Division of Oil and Gas, by the Ohio State University Department of Earth Science.

Beach, F. and M. E. Webber, 2011. How Oil and Water Helped the United Sates Win World War II, Earth Magazine, March 2011, vol. 56, no. 3, p. 34.

Belieu, S., S.R. Kell, D. Lowther, and D. Gillespie, 2007. Using Risk-Based Analysis to Identify Inspection Priorities: SPE-106753-PP, prepared for 2007 SPE E&P Environmental and Safety Conference, Galveston, Texas, March 2007.

Boster, R.J., 1967. A Study of Ground-Water Contamination due to Oil-field Brines in Morrow and Delaware Counties, Ohio: unpublished. M. S. thesis, the Oho State University, p. 191.

Breen, K., K. Revesz, F.J. Baldassare, and S.D. McAuley, 2007. Natural Gases in Ground Water near Tioga Junction, Tioga County, north-central Pennsylvania-occurrence and use of Isotopes to Determine Origins, 2005: U.S. Geological Survey in cooperation with the Pennsylvania Department of Environmental Protection, Scientific Investigations Report Series 2007-5085.

Corbett, R.G, 1990. Dissolved Organics in Oilfield brine: Concentrations Reaching the Surface Environment through Surface Application: Brine Management Research Report prepared for the Ohio Department of Natural Resources, Division of Oil and Gas, by the University of Akron, Department of Geology.

Digel, R.K., 1988. Evaluation of Groundwater Quality Changes caused by Brine Spreading for Dust and Ice Control. M.S thesis, The Ohio State University. 141 p.

Division of Mineral Resources, 2011, Ohio Oil and Gas Law.Web.1 March, 2011. www.ohiodnr.com/mineral/law/tabid/10375/Default.aspx

Division of Mineral Resources Management, 2000-2007, Annual Report. Web. 1 March, 2011. www.ohiodnr.com/publications/tabid/10310/Default.aspx

Eltshlager, K.K., J.W. Hawkins, W.C. Ehler, and F. Baldassare, 2001, Technical Measures for the Investigation and Mitigation of Fugitive Methane Hazards in Areas of Coal Mining, U.S. Department of Interior, Office of Surface Mining Reclamation and Enforcement, Appalachian Regional Coordinating Center, 123 p.

Foster, K.R., D.E. Berstein, and P.W. Huber, 1993. Science and the Toxic Tort: Science, vol. 261, no. 1509, p.1614.

Future Gen Texas, 2010. Enhanced Oil Recovery. Web 1 March, 2011. www.beg.utexas,edu/futuregentexas

Glosser, A.L. 1965. Oil and Gas Law in Ohio, prepared by the Ohio Legislative Service Commission, Staff Research Report No. 63.

Ground Water Protection Council, 2002. Assessment of Oil Field Activities, Non-point Source Pollution and Water Quality in the Spring Creek Water Shed & the City of Edmond Municipal Well Field: prepared for the Oklahoma Conservation Commission.

Ground Water Protection Council and ALL Consulting, 2009. Modern Shale Gas Development in the United States: a Primer, prepared for the United States Department of Energy, 98 p. Web. 1 March, 2011. http://www.gwpc:org/e-library/documents/general/Shale%20Gas%20Primer%202009.pdf

ICF Resources Incorporated, 1993. Oil and Gas Exploration Production Waste Management: a 17-State Study: prepared for the U.S. Department of Energy and the Interstate Oil and Gas Compact Commission.

IPAA, 2009. The Oil and Gas Producing Industry in your State, Web. 1 March, 2011. http://www.ipaa.org/reports/docs/2008-2009 IPAAOPI.pdf

Knapp, N.F. and D.A. Stith, 1989. Characterization of Trace Metals in Ohio Brines: Open-File Report 89-1, Brine Management Research Report prepared for the Ohio Department of Natural Resources, Division of Oil and Gas.

Knuth, M., J.L. Jackson, and D.O. Whittemore, 1990. An Integrated Approach to Identifying the Salinity Source Contaminating a Ground Water Supply: Ground Water, vol. 28, no. 3, p.202-214.

Lehr, J.H., 1968. A Study of Ground-Water Contamination due to Saline Water Disposal in the Morrow County oil fields: submitted to: Office of Water Resources Research, The United States Department of Interior.

McCormac, M.P., 1983-2007. Summary of Ohio Oil and Gas Developments: Ohio Department of Natural Resources, Division of Mineral Resources Management. Web.1 March, 2011. http://www.Ohiodnr.com/publications/tabid/10370/Default.aspx

McKain, D.L. and B.L. Allen, 1994. Where it All Began, published by D.L. McKain in cooperation with the Oil and Gas Museum, Parkersburg, West Virginia.

Norling, D.L., 1970. Ohio-110 Years of Oil & Gas: Ohio Department of Natural Resources, presented to the Research Committee of the Interstate Oil Compact Commission.

Ohio Division of Water, 2011-a. Precipitation in Ohio, Fact Sheet 92-11.Web. 1 March, 2011. http:/www.dnr.state.oh.us/Portals/7/pubs/pdfs/fetsht11.pdf

Ohio Division of Water, 2011-b. What's Ground Water, Fact sheet 93-24.Web. 1 March, 2011. http://www.dnr.state.oh.us/Portal/7/pubs/pdfs/fctsht24.pdf

Pettijohn, W.A., 1971. Water Pollution by Oil-Field Brines and Related Industrial Wastes in Ohio: The Ohio Journal of Science, vol. 71, no. 5, pp. 257-269.

Railroad Commission of Texas, 1991. "An Informal History compiled for its Centennial (April 1991)-Oil &Gas History" Web. 1 March, 2011. http://www.rrc/state.tx.us/about/history/centennial/centennial05.php

Railroad Commission of Texas, 2011-a. Oil Field Cleanup Program Annual Report-Fiscal Year 2009. Web.1 March, 2011.
http://www.rrc.state.tx.us/environmental/ofcfund/expenditures/ofcannualreports.php

Railroad Commission of Texas, 2011-b. Railroad Commission Milestones. Web. 1 March, 2011. http://www.rrc.state.tx.us/about/history/milestones/milestones.php

Railroad Commission of Texas, 2011-c. Drilling Statistics. Web. 1 March, 2011. http://www.rrc.state.tx.us/data/drilling/txdrillingstat.pdf

Railroad Commission of Texas, 2011-d. RRC Self Evaluation. Web. 1 March, 2011. http://www.rrc.state.tx.us/about/divisions/RRCSelfEvaluationReport2009.pdf

Railroad Commission of Texas, 2011-e. Oil and Gas Rules. Web. 1 March, 2011. http://www.rrc.state.tx.us/rules/index/php

Railroad Commission of Texas, 2011-f. *Waste Minimization in the Oilfield*, 2001. Web. 1 March, 2011. http://www.rrc.state.tx.us/forms/publications/wasteminmanual/wastemin.pdf

Railroad Commission of Texas, 2011-g. *Surface Waste Management Manual*. Web.1 March, 2011. http://www.rrcstate.tx.us/forms/publications/Surface Waste Management Manual

Railroad Commission of Texas, 2011-h. Monthly Drilling, Completion, and Plugging Summaries, 2011. Web. 1 March, 2011. http://www.rrc.state.tx.us/data/drilling/drillingsummary/index.php

Railroad Commission of Texas, 2011-i. Cleanup of Condensate Contaminated Groundwater. Web. 1 March, 2011. http://www.rrc.state.tx.us/environmental/spills/spillcleanup.php

Ramos, M.G., 2010. "Texas: a Cultural History": Texas-Almanac. Web. 1 March 2011. http://www.texasalmanac.com/topics/business/oil-and-texas-cultural-history

Riley, R., 2001. Mapping the Deepest Underground Source of Drinking Water in Ohio, Ohio Department of Natural Resources, Division of Geological Survey.

Schmidt, J.J., 1978. Ground-Water Resources of Medina County: Ohio Department of Natural Resources, Division of Water.

Shaw, J.E., 1966. An Investigation of Ground-Water Contamination by Oil-field Brine Disposal in Morrow and Delaware Counties, Ohio: Unpub. M.S. thesis, The Ohio State University, 127 p.

Springfield, M.J., 1988. The Detection and Delineation of a Known Brine Contamination Plume and Groundwater Flow Boundary Conditions using Surface Geophysical Methods. M.S. thesis, The Ohio State University, 354 p.

STRONGER, 1993. Texas state review: I0GCC/EPA State Review of Oil and Gas Exploration & Production Waste Management Regulatory Programs. Web. 1 March, 2011. http://strongerinc.org/reviews/reviews.asp

STRONGER, 1995. Ohio state review. IOGCC/EPA State Review of Oil and Gas Exploration & Production Waste Management Regulatory Programs. Web. 1 March, 2011. http://strongerinc.org/reviews/reviews.asp

STRONGER, 2003. Texas Follow-up and Supplemental Review: State Review of Oil and Natural Gas Environmental Regulations. Web. 1 March, 2011. http://strongerinc.org/reviews/reviews.asp

STRONGER, 2005. Ohio Follow-up and Supplemental Review: State Review of Oil and Natural Gas Environmental Regulations. Web. 1 March, 2011. http://strongerinc.org/reviews/reviews.asp

Templeton, E.E., 1980. Environmentally Acceptable Disposal of Salt Brines Produced with Oil and Gas: a report prepared by Elmer E. Templeton and Associates, Inc. for the Ohio Water Development Authority, 85 p.

Texas Bureau of Economic Geology, 2005. Oil and Gas fields Map of Texas: Web.1 March, 2011. http://www.beg.utexas.edu/Utopia/images/pagesizemaps/oilgas.pdf

Texas Groundwater Protection Committee, 1993-2008. Joint Groundwater Monitoring and Contamination Report: Web.1 March, 2011. http://www.tceq.state.tx.us/publications/sfr/056_09_index.html

Texas Water Development Board, 2006-a. Major Aquifers of Texas. Web. 1 March, 2011. http://www.twdb.state.tx.us/mapping/maps/pdf/aqu_maj_8x11.pdf

Texas Water Development Board, 2006-b. Minor Aquifers of Texas. Web. 1 March, 2011. http://www.twdb.state.tx.us/mapping/maps/pdf/aqu_min_8x11.pdf

Texas Water Development Board. *State Water Plan*, 2007. Web. 1 March, 2011. http://www.twdb.state.tx.us/publications/reports/state_water_plan/2007/2007statewaterplan/chapter%207%20FINAL_112906.pdf

Tomastik, T.E., 1999. Large Potential Reserves remain for Secondary Recovery in Ohio: Oil & Gas Journal (January 18, 1999) p.70-73.

Tomastik, T.E., and S.R. Kell, 1987. An Evaluation of Annular Disposal Wells in Ohio: Ohio Department of Natural Resources, Division of Oil and Gas, prepared for The United States Environmental Protection Agency, Project Grant No. G005938-01.

Underground Injection Practices Council, 1989. A Peer Review: The Ohio Department of Natural Resources, Division of Oil and Gas Underground Injection Control Program.

United States Census Bureau, 2000. Web. 1 March, 2011. www.census,gov/main/www/cen2000.html

U.S. Environmental Protection Agency, 2002-a. Primary Maximum Contaminant Levels (Sections 141.11-16 of part 141, National Primary Drinking-Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 2002.

U.S. Environmental Protection Agency, 2002-b. Secondary Maximum Contaminant Levels (Section 143.3 of part 143, National Secondary Drinking-Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 2002.

U.S. Environmental Protection Agency, 2002-c. definition: Underground Source of Drinking Water (Section 146.3 of part 146): U.S. Code of Federal Regulations, Title 40, Part 146, revised as of July 1, 2002.

U.S. Geological Survey, 2005. Estimated use of Water in the United States (2005): Circular 1344 U.S. Department of Interior, U.S. Geological Survey. Web.1 March, 2011. http://pubs.usgs.gov/circ/1344/

Van Doren, L., 2004. Ohio's Oil and Gas Industry through Time: Ohio Department of Natural Resources, Division of Geological Survey, presented at Eastern Section AAPG Annual Meeting, Columbus, Ohio, 2004.

Veil, J.A., M.G. Puder, D. Elcock, R.J. Redweik, 2004, A White Paper describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane, prepared by Argonne National Laboratory, prepared for the U.S. Department of Energy, 79 p.

Voqt, K.L. and J.G. Wells, 2007. Historic Oil and Gas Wells in and Adjacent to Grand Lake St. Marys: Ohio Department of Natural Resources, Division of Geological Survey. Web.1 March 2011. http://www.dnr.state.oh.us/Portals/10/gandlakestmarytn.pdf

Whittemore, D.O., 1988. Bromide as a Tracer in Ground water Studies-Geochemistry and Analytical Determination: in National Water Well Association, Ground Water Geochemistry Conference, Denver, Colo., February 16-18, 1988, Proceedings: p. 339-359.

Wickstrom, L.H.,J.D. Gray, and R.D. Stieglitz, 1992. Stratigraphy, Structure, and Production History of the Trenton Limestone (Ordovician) and Adjacent Strata in Northwestern Ohio: Ohio Department of Natural Resources, Division of Geological Survey, Report of Investigations No. 143.

Wickstrom, L., 2004. Oil and Gas Fields Map of Ohio: Ohio Department of Natural Resources, Division of Geological Survey. Web. 1 March, 2011. http://www.dnr.state,oh.us/Portal/10/pdf/pg01/pdf

Wolfe, M.E., 2008. Report on Ohio Mineral Industries :an Annual Summary of the State's Economic Geology: Ohio Department of Natural Resources, Division of Geological Survey. Web. 1 March, 2011. http://www.dnr.state.oh/us/Portals/10/pdf/min_ind_report/MinInd08.pdf

Appendix A - Incident Classification Scheme

Activity/ Phase	Potential Sources	Potential Contaminants	Possible Contaminant Release Mechanisms
1.) Site Preparation (well pad and access road construction and reserve pit/ impoundment excavation)	a.) Fuel storage tanks or mobile powered equipment	Diesel fuel, antifreeze, transmission fluids, etc.	Failure of tanks, valves, or distribution lines that store or deliver fuel, lubricants, coolants, or transmission fluids for mobile powered equipment
2.) Drilling and Completion	a.) Reserve pit	Brackish water, brine, circulated drilling fluids	Slump or tear of the synthetic liner, overtopping or breach of the berm, or infiltration into subsurface in unlined pits
	b.) Steel tanks used in lieu of reserve pits	Brackish water, brine, circulated drilling fluids	Valve or line leak, or integrity failure of the containment system, or overtopping
	c.) Surface hole drilling	Drilling mud, surfactants (if drilling on compressed air), brine (if drilling through saline or brackish aquifers)	Lost circulation of drilling fluids into USDW while drilling the surface hole, prior to isolation behind cemented conductor and/or surface casing
	d.) Blowout	Natural gas, brine, crude oil, and/or drilling fluids	Improper control/confinement of reservoir fluids within the production borehole, at pressures sufficient to overpressurize the surface casing shoe, prior to installation and cementing of production casing, or failure of the surface casing primary cement job due to inadequate or improper placement of cement leading to insufficient cement bond
	e.) Emergency pit	Brine, drilling fluids, and/or crude oil	Overflow or failure to properly construct or maintain pits to contain unanticipated volume of fluids circulating to surface

Activity/ Phase	Potential Sources	Potential Contaminants	Possible Contaminant Release Mechanisms
2.) Drilling and Completion	f.) Fuel and other product storage tanks or conveyance lines for fixed-location compressors and engines associated with drilling and circulation of fluids and cuttings	Diesel fuel, antifreeze, transmission fluids, etc.	Failure of tanks, valves, or distribution lines that store or deliver fuel, lubricants, coolants, or transmission fluids for powered equipment and inadequate secondary containment and/or remedial action
3.) Well Stimulation (including hydraulic fracturing)	a.) Storage tanks for stimulation fluids and additives prior to stimulation	Stimulation fluids and additives	Storage vessel or pressurized line leaks followed by inadequate secondary containment and/or corrective action
	b.) Pumping directly into an aquifer (typically for stimulation of shallow coal bed methane bearing zones)	Stimulation fluids and additives	Direct pumping of stimulation fluids containing additives in sufficient volume and concentration to degrade groundwater quality

Activity/ Phase	Potential Sources	Potential Contaminants	Possible Contaminant Release Mechanisms
3.) Well Stimulation (including hydraulic fracturing)	c.) Migration of pumped fluids from a stimulated oil and gas reservoir hydraulically connected to an adjacent aquifer	Produced water consisting of stimulation fluids, commingled with brine and petroleum hydrocarbons	Vertical migration of stimulation fluids into an aquifer via: 1.) Proximal, unplugged, or improperly plugged boreholes that penetrate the stimulated zone or overlying confining strata with extended vertical fractures; or 2.) Offset, improperly constructed oil and gas wells developed in the stimulated reservoir within the fracture network created by the stimulation; or 3.) Inadequate confining strata (vertically limited confining strata, or confining strata transected by transmissive fault(s) or joints connecting the reservoir to the overlying aquifer); and 4.) Failure to terminate the operation based on real-time monitoring observations
	d.) Out-of-zone stimulation	Produced water consisting of stimulation fluids, commingled with brine and petroleum hydrocarbons	Failure of the production casing primary cement job, or failure of the production casing to confine pumped fluids within the stimulated oil and gas reservoir, and failure to monitor and terminate the job as a result of abnormal annular pressure readings, vertical migration in the uncemented surface-production casing annulus, and failure of the surface casing cement job and/or defective surface
	e.) Storage tanks for containment of flowback fluids following	Produced water consisting of stimulation fluids, commingled with brine and petroleum hydrocarbons	Tank failure or flow line leaks followed by inadequate secondary containment and/or corrective action, or impoundment failure
	f.) Impoundments for temporary storage of flowback fluids	Produced water consisting of stimulation fluids, commingled with brine and petroleum hydrocarbons	Synthetic liner failure, overtopping, or flow line leaks

Activity/ Phase	Potential Sources	Potential Contaminants	Possible Contaminant Release Mechanisms
4.) Production, On-lease Transport, and Storage	a.) Storage tanks/ separators	Produced water and/or crude oil	Defective materials, corrosion, weather events, or vandalism of storage vessels
	b.) On-lease flow/ gathering lines	Produced water and/or crude oil	Defective materials, corrosion, or accidental damage to distribution lines
	c.) Skimming/ settling pit	Produced water and/or crude oil	Synthetic liner failure, failure to install liner, overtopping, or breach
	d.) Produced water storage pit	Produced water	Synthetic liner failure, failure to install liner, overtopping, or breach
	e.) Emergency pit	Produced water	Volume and/or salinity of discharged wastes exceeds the attenuation capacity of the aquifer
	f.) Evaporation pit	Produced water	Synthetic liner failure, failure to install liner, or breach
	g.) Blowdown pit	Produced water and/or crude oil	Synthetic liner failure, failure to install liner, overtopping, or breach
	h.) Basic sediment pit	Crude oil	Synthetic liner failure, failure to install liner, overtopping, or breach
	i.) Earthen crude oil storage pit	Crude oil	Synthetic liner failure, failure to install liner, overtopping, or breach
	j.) Workover pit	Crude oil	Synthetic liner failure, or failure to install liner
	k.) Well construction (subsurface)	Natural gas, brine, or other annular fluids	Annular overpressurization resulting from primary well construction failure(s), or deterioration of casing and/or casing cement during the productive life of the oil and gas well

Activity/ Phase	Potential Sources	Potential Contaminants	Possible Contaminant Release Mechanisms
4.) Production, On-lease Transport, and Storage	l.) Wellhead leaks	Crude oil and produced water	Equipment failures, corrosion, or valve or stuffing box leaks
5.) Waste Management and Disposal	a.) Landspreading of saline soils or solids	Salts	Spreading at rates or frequencies exceeding regulatory limits or poor site selection
	b.) Landfarming of oily solids for bioremediation	Crude oil	Spreading at rates exceeding regulatory limits, poor site selection, or improper management of bioremediation process needs (e.g. nutrition, hydration, salt remediation prior to bioremediation in salt affected soil)
	c.) Roadspreading of produced water for dust or ice control	Produced water	Spreading at rates exceeding regulatory limits or poor site selection
	d.) Roadspreading of heavy hydrocarbons for dust control	Crude oil	Improper spreading pattern, over-application, or poor road selection (impervious surfaces, highly crowned roads, application too close to road edge)
	e.) Annular disposal of drilling solids	Drill cuttings and muds	Unauthorized direct injection into USDWs, or injection at pressures exceeding regulatory limits

Activity/ Phase	Potential Sources	Potential Contaminants	Possible Contaminant Release Mechanisms
5.) Waste Management and Disposal	f.) Annular disposal of produced water	Produced water	Mechanical failure (corrosion) of surface casing and failure of casing sealant, and hydrostatic head of annular fluids exceeding hydrostatic head of inadequately protected USDWs
	g.) Class II D injection for disposal	Produced water	Mechanical integrity failure of tubing or packer with simultaneous failure of cemented injection, intermediate and surface casing strings, and/or associated casing sealants
	h.) Class II D surface facilities	Produced water	Improper design, material type, or corrosion-related failure of distribution lines, storage vessels, impoundments, and/or vaults
	i.) Class II EOR injection	Produced water and/or crude oil	Mechanical integrity failure of tubing or packer with simultaneous failure of cemented injection, intermediate and surface casing strings, and/or associated casing sealants
	j.) Class II EOR surface facilities	Produced water	Improper design, material type, or corrosion-related failure of distribution lines, storage vessels, impoundments, and/or vaults
	k.) Improperly plugged wells in a repressurized reservoir	Produced water and/or crude oil	Pressurized fluids migrating vertically through an unsealed borehole, usually without surface casing
	l.) Percolation pit	Produced water	Improper siting. Volume and/or salinity of discharged waste exceeds the attenuation capacity of the aquifer
	m.) Dumping	Produced water	Illegal disposal of produced water by discharge from produced water hauling trucks

Activity/ Phase	Potential Sources	Potential Contaminants	Possible Contaminant Release Mechanisms
6.) Plugging and Site Reclamation	a.) Pit reclamation	Produced water and/or crude oil	Failure to properly remove produced water and/or oily wastes from production-related pits prior to reclamation, or failure of the synthetic liner of temporary pit used to contain fluids circulated from the borehole during plugging operations, overtopping, or breach
	b.) Tank/ Pipeline removal or closure	Produced water and/or crude oil	Failure to recover mobile fluids or oily bottom sediments for storage equipment prior to removal
	c.) Well plugging	Produced water and/or crude oil	Circulation of brine and/or oily fluids from the borehole after withdrawal of uncemented surface casing
7.) Orphaned Wells and Sites	a.) Pits/ Tanks/ Pipelines	Produced water and/or crude oil	Unreclaimed pits and/or storage vessels (typically pre-bonding or pre-regulation). Failure to remove or reclaim oil or brine contaminated soils inside the tank battery or containment dike by former insolvent owners
	b.) Abandoned/ Orphaned wells	Produced water and/or crude oil or natural gas	Inter-zonal migration of borehole fluids allowed by corrosion or withdrawal of the surface casing string and failure to isolate deeper pressurized zones with effective plugging material by former insolvent owners

Appendix B – Chronology of Ohio Regulatory Enhancements for Protection of Groundwater (1976-2010)

Year	Enhancement	Description
1976	Statute (HB 28)	**Orphan Well Program:** Ohio was one of the first states in the Appalachian Basin to establish an Idle and Orphan Well Program (abandoned wells for which no legally responsible party can be found to assume the costs). This program responds to public complaints, researches well ownership records to determine eligibility, contracts well plugging services, and monitors well plugging and restoration work to ensure contract compliance.
1980	Research: Produced Water	**Templeton Report:** The Ohio Water Development Authority commissioned Templeton and Associates to characterize and quantify produced water production volumes in Ohio, and to make recommendations regarding environmentally-responsible disposal methods. The report provided the foundation for Ohio's Class II injection primacy application.
1982	Statute (HB 743)	**Underground Injection Control Primacy:** In response to agency recognition and public dissatisfaction with contamination problems associated with improper storage and disposal of brine in earthen pits, this bill enabled Ohio to assume primacy of the Underground Injection Control (UIC) Program pursuant to the Safe Drinking Water Act of 1974.
1982	Rule (OAC 1501:9-11)	**Plugging Standards:** Replacing antiquated plugging methods defined in the 1965 statute, the new rules established standards for materials and methods used to plug wells in non-coal-bearing townships. The Division of Mines within the Ohio Industrial Commission retained authority to plug all wells (approximately 60 percent) within coal-bearing townships.
1983	Rule (OAC 1501:9-3-5&7)	**Class II Injection Well Rules:** The U.S. EPA approved Ohio's regulations for Class II wells establishing requirements for permit issuance, well construction, monitoring and reporting for conventional brine injection wells, enhanced recovery projects, and annular disposal wells.

Year	Enhancement	Description
1984	**Permit Conditions**	**Terms and Conditions for Contamination Sensitive Aquifers: While lacking clear statutory authority, the DMRM designed and implemented special permit conditions to protect shallow, unconfined sand and gravel aquifers adjacent to the Lake Erie Shoreline and improved construction and remediation of drilling pits. The conditions were implemented with full industry participation and consent in response to a series of private water supply contamination incidents documented in 1983. This marked the first time that DMRM geologists mapped a regional aquifer based upon contamination vulnerability and successfully implemented protective conditions for drilling operations.**
	Rule (OAC 1501:9-103)	**Surety Bonds:** Required filing of a surety bond to ensure compliance with well plugging and final restoration requirements, and established rates for single, multiple, and blanket bonds. In part, bonding requirements are conditioned on plugging of inactive wells and help prevent improper abandonment that can lead to groundwater contamination.
1985	**Statute (Am Sub HB 501)**	**Produced Water (Brine) Management:** Reacting to a rising number of documented surface and groundwater contamination incidents, HB 501 greatly expanded the Division responsibilities in protection of groundwater resources through the following: • Eliminated thousands of "brine storage pits"; • Established injection at permitted Class II injection wells as the preferred produced water disposal method; • Required brine hauler registration, review of hauler disposal plans and all subsequent modifications; • Established annual reporting requirements (brine haulers and local jurisdictions that authorize brine spreading); • Established state minimum standards for surface application of produced water for dust or ice control, and required local approval of surface spreading via resolution by the local jurisdictional authority; • Established specific standards to define contamination of water supplies by brine, and authorized the Chief to order replacement of contaminated water supplies;

Year	Enhancement	Description
1985	**Statute (Am Sub HB 501)**	**• Authorized the Chief to design and implement special permit conditions for protection of sensitive groundwater areas as well as public health and safety; and • Created the Brine Management Research Special Account to fund research to assess environmental and public health risks associated with low-cost brine disposal practices (including surface spreading for dust or ice control and annular disposal).**
1986	**Permit Conditions: Reserve Pits**	**Reserve Pit Construction Standards: The DMRM completed mapping of areas in northeastern and north-central Ohio where fractured sandstone aquifers are exposed at surface or are overlain by thin glacial till deposits. This mapping project was initiated in response to a pattern of incidents caused by inadequate reserve pit construction and maintenance problems. Since 1986, the DMRM has applied special permit conditions pertaining to pit construction grading, subliner practices, and synthetic liner standards to all areas where vulnerable aquifers were mapped.**
1987	**Research: Annular Disposal**	**Annular Disposal: In 1987, with funding support from U.S. EPA, the DMRM initiated a two year study of the practice of produced water disposal by annular disposal. DMRM applied for the grant application as a result of groundwater contamination incidents. The results, published in 1990, found significant deficiencies in the practice resulting in rule amendments that strengthened construction and mechanical integrity testing standards.**
1988	**Test Standard**	**Annular Disposal Well Mechanical Integrity Test: The DMRM worked with the Ohio Oil and Gas Association to develop a Mechanical Integrity Test for annular disposal wells. U.S. EPA's National Technical Workgroup reviewed and approved Ohio's proposal for the Positive Differential Test in April of 1988.**
1988	**Permit Conditions: H2S**	**H2S Permit Conditions: DMRM implemented permit conditions in parts of a three-county area where surface casing corrosion problems developed as a result of unsealed, H2S-bearing zones in the surface-production casing annulus. The conditions require isolation of all zones in the Onandaga Limestone that emit H2S.**

Year	Enhancement	Description
1989	**Best Management Practices**	**Temporary Storage of Brine: Chartered in 1987, the DMRM created two task force teams, consisting of agency, public, and industry representatives to define Best Management Practices (BMP) for:** **1.) Construction of surface facilities at Class II injection wells; and** **2.) Minimum standards for drilling pit liners** **BMPs developed by both workgroups were implemented as permit conditions.**
1989	**Research: Surface Application**	**Produced Water Disposal Research: Using BMRSA monies, the DMRM funded research through the Ohio Geological Survey to characterize the inorganic composition of produced water including characterization of trace metal concentrations. The results were published in OGS Open File Report 89-1.**
1989	**Research: Surface Application**	**Produced Water Disposal Research: Using BMRSA monies, the DMRM funded research through The Ohio State University Geology Department to characterize groundwater quality changes resulting from surface application of produced water for dust or ice control. Findings were presented in a published report (November, 1989) and two unpublished masters theses (Springfield, 1988 and Digel, 1989).**
1990	**Rule (OAC 1501:9-3-11)**	**Annular Disposal Rules: In response to U.S. EPA and citizen concerns about the environmental risks associated with annular disposal of brine, new rules required:** **• Improved construction practices;** **• Initial mechanical integrity demonstration prior to disposal authorization; and** **• Ongoing mechanical integrity verification using new tests approved by U.S. EPA's National Technical Workgroup.**
1991	**Research: Surface Application**	**Research: Using BMRSA funds, the DMRM funded research through the University of Akron Geology Department to characterize concentrations of dissolved organics in produced water that reach the environment during surface spreading for dust or ice control. From wellhead to road surface, measured removal efficiencies averaged 87.2 percent.**

Year	Enhancement	Description
1992	Data Management	**Risk-Based Data Management System (RBDMS):** The ODNR worked with the Ground Water Protection Council, with funding support of the U.S. Department of Energy to expand the functionality of RBDMS to store and retrieve data for oil and gas wells in addition to Class II injection wells. RBDMS is currently used in 22 of 29 oil and gas producing states.
1992	Program Certification	**U.S. EPA Certification:** DMRM submitted a program certification to U.S. EPA required by the 1996 Safe Drinking Water Act Amendments of 1986 demonstrating that Ohio's regulatory program is protective of groundwater resources and is protective of human health. U.S. EPA certified Ohio's program.
1993	Rule: Plugging Material Standards	**Cement Quality Standards:** The DMRM amended plugging rules to include cement quality standards.
1994	Statute (SB 182)	**Orphan Well Emergency Expenditures:** Authorized the Chief to spend oil and gas well fund monies to address imminent public health and safety risks not subject to competitive bidding requirements, or controlling board authorization. As a result, DMRM can respond expeditiously to fund corrective action at orphaned wells that are threatening or contaminating water supplies without delays formerly caused by bid advertisement and contract processes. **Spill Control**: Provided DMRM authority to enact and administer Spill Prevention Control and Countermeasure (SPCC) regulations. The DMRM assumed enforcement authority for tens-of-thousands of spill control dikes at crude oil storage tanks statewide.
1996	Permit Conditions: WHPA	**Wellhead Protection Area Permit Conditions:** The DMRM implemented special permit conditions for any oil and gas well drilled within the five year Time-of-Travel zone of a municipal water wellhead protection area. Extensive conditions include: standards for well construction, BOP testing, reserve pit construction and management, steel tanks, pit closure, and documentation of all fluids and additives used on location during drilling, well construction, and stimulation.

Year	Enhancement	Description
2000	Data Management: EMW	**Emergency Management Website:** DMRM worked with Argonne National Laboratory to develop the Emergency Management Website (EMW), with U.S. DOE funding support. This system provides oil and gas well information to local officials, emergency responders, and the public in the event of an oil spill, chemical release, fire, or other emergency in order to expedite response and remedial action.
2002	UIC SOPs	**UIC Standard Operating Procedures (SOPs):** DMRM secured U.S. EPA approval of the UIC Program Quality Management Plan including Standard Operating Procedures for a variety of permitting, inspection, and enforcement functions.
2004	Rule: Plugging Practices	**Harmonized Plugging Rules:** DMRM implemented harmonized well plugging standards (coal vs. non-coal-bearing townships) including requirements for meeting MSHA standards for plugging wells that penetrate economically mineable coal seams identified by coal owners. Oil and Gas Program inspectors began to oversee all plugging operations statewide, including plug jobs in coal-bearing townships.
2004	Statute (HB 278)	**Urban Drilling Law:** While primarily a resource access Bill, HB 278 required DMRM to create a multi-stakeholder workgroup to develop rule standards for urban drilling operations relative to a variety of performance objectives including protection of fresh groundwater resources.
2005	Rules for Urban Area Drilling	**Urban Drilling Rules:** Rules required collection of groundwater samples from all water wells within 300 feet of the proposed drilling operation, witnessed BOP tests, closure of reserve pits within 30 days, and standards for storage tank and separator security.
2006	Data Management: RBDMS-Water	**RBDMS-Water:** With funding assistance from the U.S. Department of Energy and the Office of Surface Mining, the DMRM worked with GWPC to develop a GIS-based system to store, retrieve, and statistically evaluate water data associated with mining and oil and gas exploration activities.
2008	Permit Conditions	**Well Construction Standards:** In response to a stray natural gas incident, the DMRM implemented enhanced well construction, electric line logging, and monitoring requirements for the surface-production casing annulus to prevent annular overpressurization.

Year	Enhancement	Description
2010	**SB 165**	**Comprehensive Reforms: This comprehensive update of Chapter 1509 ORC included the following provisions that enhance protection of groundwater resources:** **• Establishes performance objectives for all well construction processes;** **• Requires agency notification prior to all casing cement jobs, hydraulic fracturing operations, and immediate notification upon detection of defective pipe, cement or other well construction components;** **• Prohibits annular overpressurization and requires immediate corrective action, or plugging if construction deficiencies cannot be corrected;** **• Requires operators to submit additional records regarding well stimulation operations including job logs, invoices listing additives by volumes, and pumping and pressure charts;** **• Mandates disposal of flowback produced water at Class II injection wells;** **• Reduces timeframes for closure of lined reserve pits to 14 days in urban areas and 60 days in non-urban areas;** **• Establishes reporting and escalating bonding requirements for temporarily inactive wells;** **• Increases orphan well funding by directing 14 percent of annual revenues to plug orphan wells and reclaim legacy sites; and** **• Increases enforcement authority by defining material and substantial violations and authorizing the chief to suspend producing operations.**

Appendix C - Ohio Incident Data by Phase and Activity (1983-2007)

Phase	Site Preparation			Drilling and Completion							
Activity	Excavation	Other	Total	Reserve Pit	Steel Tanks	Surface Hole Drilling	Blowout	Emergency Pit	Fuel/ Fluids	Other	Total
Year											
1983	0	0	0	4	0	0	0	0	0	0	4
1984	0	0	0	8	0	0	0	0	0	0	8
1985	0	0	0	6	0	0	0	0	0	0	6
1986	0	0	0	15	0	0	0	0	0	0	15
1987	0	0	0	3	0	0	0	0	0	0	3
1988	0	0	0	6	0	0	0	0	0	0	6
1989	0	0	0	2	0	0	0	0	0	0	2
1990	0	0	0	2	0	0	0	0	0	0	2
1991	0	0	0	1	0	0	0	0	0	0	1
1992	0	0	0	2	0	0	0	0	0	0	2
1993	0	0	0	2	0	0	0	0	0	0	2
1994	0	0	0	1	0	3	0	0	0	0	4
1995	0	0	0	3	0	0	0	0	0	0	3
1996	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	2	0	2	0	0	0	0	4
1998	0	0	0	1	0	1	0	0	0	0	2
1999	0	0	0	1	0	0	0	0	0	0	1
2000	0	0	0	1	0	0	0	0	0	0	1
2001	0	0	0	2	0	1	0	0	0	0	3
2002	0	0	0	1	0	1	0	0	0	0	2
2003	0	0	0	0	0	1	0	0	0	0	1
2004	0	0	0	0	0	1	0	0	0	0	1
2005	0	0	0	0	0	1	0	0	0	0	1
2006	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	63	0	11	0	0	0	0	74

Appendix C - Ohio Incident Data by Phase and Activity (1983-2007)

Phase	Well Stimulation							
Activity	Storage Tanks	Pumping Directly Into Aquifer	Migration due to Inadequate Confinement or Improperly Plugged or Constructed	Out-of-zone Stimulation	Flowback Fluid Storage Tanks	Impoundment Failure	Other	Total
Year								
1983	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0

Appendix C - Ohio Incident Data by Phase and Activity (1983-2007)

Phase	Production, On-lease Transport, and Storage													
Activity	Storage Tanks/ Separators	On-lease Flow/ Gathering Lines	Skimming/ Settling Pit	Produced Water Storage Pit	Emergency Pit	Evaporation Pit	Blowdown Pit	Basic Sediment Pit	Earthen Crude Oil Storage Pit	Workover Pit	Well Construction (subsurface)	Wellhead Leaks	Other	Total
Year														
1983	0	0	0	1	0	0	0	0	0	0	0	0	0	1
1984	0	0	0	1	0	0	0	0	0	0	1	0	0	2
1985	1	0	0	6	0	0	0	0	0	0	0	0	0	7
1986	2	0	0	2	0	0	0	0	0	0	0	0	0	4
1987	0	3	0	0	0	0	0	0	0	0	1	0	0	4
1988	1	0	0	0	0	0	0	0	0	0	0	0	0	1
1989	0	0	0	0	0	0	0	0	0	0	1	0	0	1
1990	1	0	0	0	0	0	0	0	0	0	0	0	0	1
1991	1	0	0	0	0	0	0	0	0	0	1	0	0	2
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	3	0	0	3
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	1	0	0	0	0	0	0	0	0	0	0	0	0	1
1996	0	0	0	0	0	0	0	0	0	0	2	0	0	2
1997	1	0	0	0	0	0	0	0	0	0	0	0	0	1
1998	1	1	0	0	0	0	0	0	0	0	0	0	0	2
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	1	0	0	0	0	0	0	0	0	0	1	0	0	2
2001	1	0	0	0	0	0	0	0	0	0	0	0	0	1
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	1	0	0	0	0	0	0	0	0	1	0	0	2
2006	1	0	0	0	0	0	0	0	0	0	0	0	0	1
2007	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Total	12	5	0	10	0	0	0	0	0	0	12	0	0	39

Appendix C - Ohio Incident Data by Phase and Activity (1983-2007)

Phase	Waste Management and Disposal														
Activity	Landspreading of Saline Soils or Solids	Landfarming/ Bioremediation Oily-Solids	Roadspreading Produced Water	Roadspreading Heavy Hydrocarbons	Annular Disposal of Drilling Solids	Annular Disposal of Produced Water	Class II D Injection for Disposal	Class II D Surface Facilities	Class II EOR Injection	Class II EOR Surface Facilities	Improperly Plugged Wells in AOR	Percolation Pit	Illegal Dumping	Other	Total
Year															
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	4	0	0	0	0	0	0	0	0	4
1985	0	0	0	0	0	4	0	3	0	0	0	0	2	0	9
1986	0	0	0	0	0	1	0	1	0	0	0	0	0	0	2
1987	0	0	0	0	0	3	0	0	0	0	0	0	2	0	5
1988	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2
1989	0	0	0	0	0	0	0	1	1	0	0	0	0	0	2
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix C - Ohio Incident Data by Phase and Activity (1983-2007)

Phase	Plugging and Site Reclamation					Orphaned Wells and Sites			
Activity	Pit Reclamation	Tank/ Pipe Removal or Closure	Well Plugging	Other	Total	Pits/ Tanks/ Pipelines	Abandoned/ Orphaned Wells	Other	Total
Year									
1983	0	0	0	0	0	0	0	0	0
1984	0	0	1	0	1	0	0	0	0
1985	0	0	0	0	0	0	1	0	1
1986	0	0	1	0	1	0	1	0	1
1987	0	0	0	0	0	0	2	0	2
1988	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	3	0	3
1991	0	0	1	0	1	0	2	0	2
1992	0	0	0	0	0	0	3	0	3
1993	0	0	0	0	0	0	3	0	3
1994	0	0	1	0	1	0	3	0	3
1995	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	3	0	3
1997	0	0	0	0	0	0	5	0	5
1998	0	0	1	0	1	0	5	0	5
1999	0	0	0	0	0	0	3	0	3
2000	0	0	0	0	0	0	1	0	1
2001	0	0	0	0	0	0	1	0	1
2002	0	0	0	0	0	0	3	0	3
2003	0	0	0	0	0	0	1	0	1
2004	0	0	0	0	0	0	1	0	1
2005	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0
Total	0	0	5	0	5	0	41	0	41

Appendix C - Ohio Incident Data by Phase and Activity (1983-2007)

TOTAL BY PHASE

Activity	Site Preparation	Drilling & Completion	Well Stimulation	Production, On-lease Transport, & Storage	Waste Management & Disposal	Plugging & Site Reclamation	Orphaned Wells & Sites	Total	Total Regulated Activity
Year									
1983	0	4	0	1	0	0	0	5	5
1984	0	8	0	2	4	1	0	15	15
1985	0	6	0	7	9	0	1	23	22
1986	0	15	0	4	2	1	1	23	22
1987	0	3	0	4	5	0	2	14	12
1988	0	6	0	1	2	0	0	9	9
1989	0	2	0	1	2	0	0	5	5
1990	0	2	0	1	0	0	3	6	3
1991	0	1	0	2	0	1	2	6	4
1992	0	2	0	0	1	0	3	6	3
1993	0	2	0	3	0	0	3	8	5
1994	0	4	0	0	0	1	3	8	5
1995	0	3	0	1	0	0	0	4	4
1996	0	0	0	2	0	0	3	5	2
1997	0	4	0	1	0	0	5	10	5
1998	0	2	0	2	0	1	5	10	5
1999	0	1	0	0	0	0	3	4	1
2000	0	1	0	2	1	0	1	5	4
2001	0	3	0	1	0	0	1	5	4
2002	0	2	0	0	0	0	3	5	2
2003	0	1	0	0	0	0	1	2	1
2004	0	1	0	0	0	0	1	2	1
2005	0	1	0	2	0	0	0	3	3
2006	0	0	0	1	0	0	0	1	1
2007	0	0	0	1	0	0	0	1	1
Total	0	74	0	39	26	5	41	185	144

Appendix D - Ohio Oil and Gas Industry Activity Data (1983-2007)

Year	Wells Drilled	Wells Stimulated	Wells Producing	Wells Plugged	Crude Oil Produced (bbls)	Natural Gas Produced	Produced Water (bbls)	Class II Injection Wells		
								Disposal	EOR	Ann. Disposal
1983	4,299	3,948	50,342	691	14,971,072	151,300,431	2,987,966	79	142	NRA
1984	4,963	4,528	55,681	795	15,271,100	186,480,420	6,559,306	110	167	NRA
1985	3,760	3,452	60,553	1,050	14,987,592	182,244,648	15,667,380	154	156	NRA
1986	1,850	1,663	62,380	939	13,442,162	182,072,348	13,310,929	166	170	NRA
1987	1,882	1,666	63,618	1,052	12,152,567	166,633,260	11,468,044	173	178	NRA
1988	1,423	1,265	63,741	1,255	11,710,728	166,690,130	9,777,730	182	178	7,039
1989	1,312	1,076	64,590	1,100	10,218,674	159,729,510	9,366,161	176	171	1,560
1990	1,327	1,045	64,695	1,093	10,008,263	154,618,630	9,255,917	184	176	NRA
1991	1,169	892	64,830	917	9,158,332	147,651,188	9,145,672	180	184	NRA
1992	875	623	64,729	906	9,196,711	144,815,438	8,797,089	177	184	NRA
1993	823	552	64,622	793	8,282,023	135,938,848	8,448,506	175	194	NRA
1994	783	517	64,473	846	8,757,872	130,855,248	8,099,923	167	185	328
1995	670	411	64,035	994	8,257,621	126,335,936	7,751,340	161	193	294
1996	725	468	63,870	792	8,305,366	120,443,871	6,848,362	164	171	292
1997	797	509	63,538	934	8,593,359	117,408,373	7,361,015	166	152	239
1998	518	322	63,267	746	6,541,307	108,542,132	7,751,337	158	139	218
1999	502	347	63,122	603	5,968,342	103,540,658	6,338,996	159	140	181
2000	567	375	62,977	598	6,573,881	98,550,667	6,444,774	160	140	172
2001	699	540	62,999	624	6,049,524	98,255,015	6,414,326	154	138	158
2002	502	383	62,902	581	6,004,345	97,153,501	6,444,721	159	138	142
2003	519	412	62,867	500	5,647,275	93,640,733	6,740,146	157	129	132
2004	589	509	62,852	572	5,785,338	90,301,118	6,688,227	154	125	120
2005	727	601	62,675	818	5,651,705	84,135,020	6,751,588	152	124	108
2006	958	884	62,966	577	5,422,194	86,315,100	6,939,771	155	126	107
2007	1,065	981	63,654	598	5,454,629	88,094,732	6,842,115	154	121	94
Total	33,304	27,969	N/A	20,374	222,411,982	3,221,746,955	202,201,341	N/A	N/A	N/A

NRA: data not readily available
N/A: not applicable

Appendix E - Chronology of Texas Regulatory Enhancements for Protection of Groundwater (1982-2010)

Year	Enhancement	Description
1982	Rules 9 and 46 (16 TAC 3.9 and 16 TAC 3.46)	**Class II UIC Primacy**: U.S. Environmental Protection Agency granted the RRC with enforcement primacy for the Class II UIC program.
1983	Texas General Laws, Ch. 996	**Water Injection**: Legislature amended the Water Code (see 1971 Texas General Laws, supra) to require the RRC to determine the feasibility of injecting substances other than fresh water when injection well permits are sought for secondary recovery projects.
	Texas General Laws, Ch. 967	**Well Plugging Fund**: Legislature established a fund solely dedicated to plugging orphaned wells, with an annual cap of $3 million. Funding from RRC assessment of a $100 drilling permit application fee for each new or materially amended application to drill.
	Texas General Laws, Ch. 967	**Civil Penalties**: Various sections of the Natural Resources Code and the Water Code were amended to provide a maximum civil penalty of $10,000 per day for pollution or safety violations of rules or orders.
1984	SWR 8 Amendments (16 TAC 3.8)	**Pit Permits**: Almost all previously permitted pits had to be repermitted and other pits had to be permitted for the first time under new, more stringent standards. The amendments also increased record keeping requirements and penalties. The amendments authorized by rule common waste management methods, such as reserve pits and workover/completion pits, as long as the pits are constructed and operated consistent with conditions specified in the rule.
1985	HB 1867	**Jurisdictional Clarification**: Clarified that the RRC has the sole responsibility for the control and disposition of waste and the abatement and prevention of pollution of surface and subsurface water resulting from activities associated with the exploration, development, and production of oil or gas or geothermal resources.
	HB 1942	**Organization Reports**: Required anyone performing any operation under the RRC's jurisdiction to file an Organization Report.

Year	Enhancement	Description
1987	Rule 8 Amendment (16 TAC 3.8)	**MOU**: Adopted by reference the MOU between the RRC, the Texas Water Commission (now the Texas Commission on Environmental Quality), the Texas Department of Health (TDH), and the Texas Air Control Board (TACB) (Duties of the TDH and TACB were later adsorbed by the TCEQ). The MOU clarified the division of jurisdiction among the agencies.
1988	RRC Order	**Cathodic Protection Holes**: RRC issued guidelines requiring drilling permit applications for cathodic protection holes which penetrate the base of useable water.
1990	SB 830	**Waste Reduction Legislation**: Legislature amended Chapter 91 of the Texas Natural Resources Code (TNRC) to require the RRC to implement a program to provide operators with training, technical assistance, and incentives to reduce the volume and toxicity of E&P wastes.
	SWR 57 Amendment (16 TAC 3.57)	**Reclamation Plant Bonding**: Required operators of tank bottom reclamation plants to file bonds to ensure that plants are operated and closed in accordance with RRC rules.
1991	SB 1103	**Oil Field Cleanup Fund**: Replaced previous Well Plugging Fund with an expanded Oil Field Cleanup Fund, increased industry fees, expanded the scope of the program to include investigation and clean up of contaminated surface sites, and established a $10 million annual cap. The legislation also created a hazardous oil and gas waste regulatory program to be funded by fees levied on generators of such waste with the fee determined by the type and quantity of waste generated.
	SWR 14 and 78 Amendments (16 TAC 3.14 and 16 TAC 3.78)	**Bonding Amendments**: Established alternative financial assurance mechanisms that are paid into the Oil Field Cleanup Fund.
1992	SWR 8 Amendment (16 TAC 3.8)	**Expanded Waste Hauler Requirements**: Required permitted oil and gas waste haulers to track and document all types of transported E&P wastes.

Year	Enhancement	Description
1992	SWR 14 Amendments (16 TAC 3.14)	**Well Plugging Extensions**: Limited the number of time extensions an operator can receive before plugging an inactive well without filing a bond. Shut-in wells, those with shut-in-wellhead pressure, become subject to the plugging provisions of Statewide Rule 14(b)(2). Once such a well has been inactive for a year, it must either be plugged, put back into production, or have a 14(b)(2) extension based on a financial assurance.
	SWR 5 Amendment (16 TAC 3.5)	**Drilling Permit Denial**: Authorized the RRC to deny a drilling permit submitted by an operator with an outstanding final order for a safety or pollution violation.
	SWR 99	**Cathodic Protection Wells**: RRC adopted SWR 99 relating to Cathodic Protection wells to place in rule the guidance issued in 1989 to require the protection of useable-quality groundwater during installation of cathodic protection wells.
	Guidelines	**Source Reduction and Recycling Program**: Established the Oil and Gas Waste Reduction and Minimization Program to provide training and technical assistance to operators and incentives for operators to reduce and minimize waste. The goal of this voluntary program is to reduce the potential for pollution of water, soil, and air resources by reducing the volume and toxicity of E&P wastes, and to encourage recycling. www.rrc.state.tx.us/forms/publications/wasteminmanual/index.php
1993	Guidelines	**Orphan Well Plugging Priorities**: The RRC established a formal prioritization scheme for plugging orphaned wells that includes weighting factors for protecting groundwater.
	Rule 83 Amendment	**Incentives to Restore Inactive Wells**: Provided a severance tax exemption for wells that had been inactive for at least three years and were returned to production– reducing bond forfeiture risk and potential liability to the Oil Field Cleanup Fund.
	Rule 91	**Oil Spill Cleanup**: Established regulatory standards and procedures for clean up of crude oil spills into non-sensitive areas.
1995	HB 1407	**Permit Denial/Revocation**: Expanded the RRC’s authority to deny and revoke permits held by operators that have unresolved violations under an order.

Year	Enhancement	Description
1996	SWR 98	**Standards for Management of Hazardous Oil and Gas Waste**: Adopted new rules for management of hazardous oil and gas wastes. Required identification of hazardous E&P wastes, compliance with federal transportation requirements for hazardous oil and gas waste, as well as other federal requirements for generation, storage, and disposal of hazardous waste.
1997	SB 639	**Outstanding Violation Disqualification**: Provided the RRC with authority to disqualify an operator from obtaining an Organization Report (which is required to perform any E&P activity in Texas) because of outstanding violations.
	SWR 93	**Water Quality Certification**: §401 of the federal Clean Water Act provided that states must certify that certain federal licenses and permits comply with applicable state water quality requirements. Rule 93 governs issuance of §401 certifications by the RRC.
	Other	**State Fund Pluggings**: The RRC streamlined the approval process for plugging non-leaking wells with state funds by eliminating the requirement of issuing a final order directing the operator to plug a well prior to approving it for plugging with state funds. The result was the approval of 2,155 wells for plugging with state funds in fiscal year 1997, the second highest number of approvals since the inception of the Well Plugging Program in September 1983.
	SWR 83	**Inactive Wells**: Provided tax exemption for two-year inactive wells and three-year inactive wells to encourage production, and ultimate plugging of inactive wells.

Year	Enhancement	Description
1998	SWR 78 Amendment (Fees, Performance Bonds, and Alternate Forms of Financial Assurance Required to be Filed)	**Commercial Facility Financial Security**: Established financial assurance requirements for facilities that reclaim tank bottoms and other hydrocarbon wastes and commercial disposal facilities. Operators of such facilities are required to file financial security in an amount sufficient to ensure proper closure after operations cease.
	State Funded Well Plugging Program	**Orphan Well Priorities**: The RRC approved the use of a revised extended service, multiple well plugging contract designed to increase efficiencies in the bidding process and to achieve some economies of scale by bidding multiple leases with multiple wells under one contract. The revised contract allowed the RRC to reduce the number of invitations to bid and attain overall lower plugging costs. In addition, the RRC approved use of a revised well plugging priority system, which improved on the previous system by placing additional emphasis on risk factors addressing environmental and safety concerns and allowed the RRC to focus its well plugging efforts on wells posing a greater threat to the environment.
	SWR 9 and 46 Amendments	**Disposal/Injection Wells**: Expanded public notice requirements for commercial Class II injection well permit applications. Codified standards for conducting mechanical integrity tests.
	SWR 14 Amendments	**Plugging**: The RRC clarified standards regarding plugging responsibility for inactive wells, established an approved plugging contractors list, and amended procedures and plugging material standards. New standards hold both operator and the plugging contractor responsible for compliance with well plugging standards. Provided RRC with authority to suspend an approved plugging contractors' status for violations of RRC rules. Provided RRC authority to require tagging, pressure testing, and/or respotting of plugs if necessary to ensure that a well does not pose a potential threat or harm to natural resources, including groundwater. Required emptying and removal of tanks, vessels, surface and subsurface flow lines after plugging last well on the lease.

Year	Enhancement	Description
1999	SWR 91	**Commercial Surface Disposal Facilities**: Amended notification requirements for commercial surface disposal facilities allowing public hearing if in the public interest.
	SWR 14 and 78	**Temporary Inactive Wells**: Required unbonded operator to obtain a well plugging bond for any well that had been inactive for over 36 months, and prohibited transfer of any inactive well without a bond.
2000	SWR 1	**Organization Report Disqualification**: Rules implement SB 639, which authorized the RRC to disqualify an operator from obtaining an organization report because of outstanding violations. Without an organization report, the operator cannot obtain permits or conduct E&P activities in Texas.
	SWR 14	**Plugging Extensions**: Amended requirements for obtaining plugging extension. Required fluid level test or mechanical integrity test before granting of plugging extension.
2001	SB 310	**Oil Field Cleanup Fund Expansion**: Increased several fees and increased the cap from $10 million to $20 million. Authorized the RRC to require bonds for all facilities and inactive wells effective September 1, 2004. Required that financial assurance be in place upon transfer of wells from one operator to another. Established the Oil Field Cleanup Advisory Committee. Created the Voluntary Cleanup Program.
	Chapter 8	**Pipeline Integrity Management**: Required natural gas and petroleum pipeline operators to verify the integrity of their pipelines.
2002	SWR 14 and 78	**Universal Bonding**: Amended financial assurance provisions to be consistent with new standards established under SB 310.
	VCP	**Voluntary Cleanup Program (VCP)**: Adopted regulations to implement the VCP program, which provides an incentive to remediate oil and gas related pollution by participants as long as they did not cause or contribute to the contamination. Applicants to the program receive a release of liability to the state in exchange for a successful cleanup.
2003	SWR 14	**Plugging Standards**: Required verification of the plug at the Base of Useable-Quality Water (BUQW) and established an approval process for alternative materials for plugging, removal of casing during plugging operations, and amended standards for plug placement at UQW zones.

Year	Enhancement	Description
2003	HB 3442	**Oil Field Cleanup Fund**: Required the collection of the Oil Field Cleanup Regulatory Fee on Crude Oil (5/8th of 1 cent/bbl) and the Oil Field Cleanup Regulatory Fee on Natural Gas (1/30 of 1 cent/Mcf) on production regardless of whether that production is exempt from severance tax or has been granted a severance tax reduction. Previously, the regulatory fee for gas was not collected on high-cost gas production that was exempt from severance tax under the provisions of §201.057 of the Tax Code.
	SWR 1 (HB 2021)	**Bankruptcy Notice**: Amended §91.142, Natural Resources Code, to require that an entity, required to file a Organization Report or an affiliate of such an entity performing operations within the jurisdiction of the RRC that files for federal bankruptcy protection, must give written notice to the RRC's Office of General Counsel no later than the 30th day after the date of filing.
	SB 1484	**Organization Reports**: Increased the number of years of records the RRC reviews in determining whether or not an officer in an organization has violated a statute, rule, order, license, permit, or certificate that relates to safety or the prevention or control of pollution. The RRC now reviews an organization's seven year compliance history when determining whether to accept an organization report or permit application from an organization, or to issue a certificate of compliance for that organization.
	SWR 78	**Reconnect Fees**: Increased the reconnect fee for any oil lease or gas well that had a Certificate of Compliance canceled by severance or seal order. Currently, the fee to reconnect a lease or well and reissue a Certificate of Compliance is $100 per lease. The new legislatively mandated fee will be $300 per severance/seal order violation. The effective date of this fee increase was September 1, 2003.
	SWR 20	**Release Reporting**: Clarified circumstances that require an operator to report gas releases or petroleum spills.
	Guidance	**Condensate Cleanup**: Published a field guide for the assessment and cleanup of soil and groundwater contaminated with condensate from a spill incident.

Year	Enhancement	Description
2004	SWR 78	**Universal Bonding**: Consistent with amendments adopted in 2001, operators must provide a bond, letter of credit or cash deposit as financial security with the filing of the annual organization report renewal application.
	SWR 14 and 78	**Universal Bonding:** Amendments to 16 TAC §3.14 (Plugging) and 16 TAC §3.78 (Financial Security Requirements) to implement universal bonding and adoption of conforming amendments to §§3.5, 3.8, 3.32, 3.37, 3.38, 3.57, 3.73, 3.86, and 3.96, relating to Application To Drill, Deepen, Reenter, or Plug Back; Water Protection; Gas Well Gas and Casinghead Gas Shall Be Utilized for Legal Purposes; Statewide Spacing Rule; Well Densities; Reclaiming Tank Bottoms, Other Hydrocarbon Wastes, and Other Waste Materials; Pipeline Connection; Cancellation of Certificate of Compliance; Severance; Horizontal Drainhole Wells; and Underground Storage of Gas in Productive or Depleted Reservoirs, respectively.
2005	SWR 78 and HB 380	**Financial Assurance**: Amendment of 16 TAC §3.78 (Fees and Financial Security Requirements) to implement HB 380, 79th Legislature, RS (2005). An operator who files an application for a drilling permit (Form W-1) who does not currently have financial assurance on file with their Organization Report (Form P-5) filing will be required to post financial assurance prior to the issuance of the requested permit. After issuance of the drilling permit, and for so long as the permit remains valid, the operator will be required to maintain financial assurance on file. It also provides for single well insurance policies.
	HB 2161	**Orphan Well Reduction Program**: Established tax incentives and credits to encourage production from marginal wells and reduce the number of orphaned wells.
	HB 380	**Alternative Financial Security**: Authorized RRC to accept well-specific insurance policies as an alternative form of financial assurance for plugging wells.
2006	16 TAC 4.2	**Commercial Recycling of Flowback Fluids**: Established standards for commercial recycling of hydraulic fracture flowback fluids.

Year	Enhancement	Description
2007	SB 1670	**Compliance Certificates**: Clarified that any well under the RRC's jurisdiction, including an injection or disposal well, for which RRC has cancelled the certificate of compliance cannot be used until RRC has reissued the certificate of compliance. Provided that where an operator uses a well, or reports such use, after the certificate of compliance for the well has been canceled, RRC may refuse to renew the operator's organization report until the operator has paid the reconnect fee(s) and the certificate of compliance has been reissued.
	HB 4	**Tax Incentive for Reuse/Recycling of Fracturing Water**: Amended §151.355, Tax Code, relating to Water-Related Exemptions, to include in the list of items that are exempt from sales, excise, and use taxes, tangible personal property specifically used to process, reuse, or recycle wastewater that will be used in fracturing work performed at an oil or gas well.
	HB 630	**Operator Notice to Surface Owner of Certain Permits**: Required operators with permits issued on or after October 1, 2007, to notify the surface owner within 15 days after the RRC issues a permit to drill a new well, or re-enter a plugged well. "Surface owner" is defined as the first person (and address) shown on the tax appraisal roles. Notice is not required to plugback, rework, sidetrack or deepen an unplugged well, for use of a surface location of an existing well to drill a horizontal well, or if there is a written agreement regarding such notice between the operator and the surface owner or a waiver of such notice by the surface owner.
	SB 714	**Groundwater Withdrawals**: Authorized a groundwater conservation district to adopt rules to require an owner or operator of a water well that is not an exempt low-capacity domestic or livestock water well and that is required to be registered with or permitted by the groundwater conservation district to report groundwater withdrawals using reasonable and appropriate reporting methods and frequency. Could require reporting of withdrawals from certain registered rig supply wells and/or a permitted injection water source wells.

Year	Enhancement	Description
2007	SWR 1, 58, 73, and 78	**Organization Reports**: Adopted amendments to implement SB 1670 regarding Seals and Severances Amendment of: §3.1 (Organization Report; Retention of Records; Notice Requirements) §3.58 (Oil, Gas, or Geothermal Resource Operator's Reports) §3.73 (Pipeline Connection; Cancellation of Certificate of Compliance; Severance) §3.78 (Fees and Financial Security Requirements) Adoption of amendments to implement the provisions of SB 1670, 80th Leg (2007), regarding circumstances under which RRC may refuse to renew an operator's organization report, and to make conforming amendments; O&G 20-0252949.
2010	SWR 30	**MOU**: MOU between RRC and TCEQ amended to update and clarify new issues.
	SWR 1, 14, 15, 21, 78	**Various Amendments**: Repeal of current 16 TAC §3.15 (Surface Casing To Be Left in Place); amendment of 16 TAC §3.1, relating to Organization Report; Retention of Records; Notice Requirements; amendment of 16 Tex. Admin. Code§3.14, relating to Plugging; new 16 Tex. Admin. Code §3.15, relating to Surface Equipment Removal Requirements and Inactive Wells; amendment of 16 Tex. Admin. Code §3.21, relating to Fire Prevention and Swabbing; and amendment of 16 Tex. Admin. Code §3.78, relating to Fees and Financial Security Requirements, to implement HB 2259, 81st Legislature (Regular Session, 2009).
	Chapter 5	**CO2 Injection**: Implemented provisions in the Texas Water Code and the TNRC, as enacted by SB 1387, 81st Legislature (RS 2009), relating to geologic sequestration of CO2 incidental to the production of oil, gas, or geothermal resources (O&G Docket No. 20-0268565).
	SWR 8	**Drilling Mud and Waste Transport**: In response to reports of incidents in which drilling mud and other oil and gas waste had escaped from open vehicles that were being used for transportation for disposal, the RRC issued a notice to waste haulers and other operators that under RRC jurisdiction to remind them of their duty to use the appropriate vehicles for such transport and to operate and maintain their vehicles in such a manner as to prevent spillage, leakage, or other escape of oil and gas waste during transportation so as not to cause or allow pollution.

Year	Enhancement	Description
2010	SWR 9 and 46	**Injection Well Monitoring**: Notice of requirement for a RRC inspection to validate wellhead monitoring for injection wells for which the RRC has approved an alternative to five-year pressure testing requirement.

Appendix F - Texas Incident Data by Phase and Activity (1993-2008)

Phase	Site Preparation			Drilling and Completion							
Activity	Excavation	Other	Total	Reserve Pit	Steel Tanks	Surface Hole Drilling	Blowout	Emergency Pit	Fuel/ Fluids	Other	Total
Year											
1993	0	0	0	0	0	0	1	0	0	0	1
1994	0	0	0	0	0	0	1	0	0	0	1
1995	0	0	0	2	0	0	0	0	0	0	2
1996	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	1	0	0	0	1
2000	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	1	0	0	0	1
2002	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	1	0	0	0	1
2006	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	1	0	0	0	0	0	0	1
2008	0	0	0	0	0	0	2	0	0	0	2
Total	0	0	0	3	0	0	7	0	0	0	10

Appendix F - Texas Incident Data by Phase and Activity (1993-2008)

Phase	Well Stimulation							
Activity	Storage Tanks	Pumping Directly Into Aquifer	Migration due to Inadequate Confinement or Improperly Plugged or Constructed Borehole	Out-of-zone Stimulation	Flowback Fluid Storage Tanks	Impoundment Failure	Other	Total
Year								
1993	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0
2008	0	0	0		0	0	0	0
Total	0	0	0	0	0	0	0	0

Appendix F - Texas Incident Data by Phase and Activity (1993-2008)

Phase	Production, On-lease Transport, and Storage													
Activity	Storage Tanks/ Separators	On-lease Flow/ Gathering Lines	Skimming/ Settling Pit	Produced Water Storage Pit	Emergency Pit	Evaporation Pit	Blowdown Pit	Basic Sediment Pit	Earthen Crude Oil Storage Pit	Workover Pit	Well Construction (subsurface)	Wellhead Leaks	Other	Total
Year														
1993	0	1	0	0	0	0	0	0	0	0	0	0	0	1
1994	0	0	0	0	0	0	0	0	0	0	1	0	0	1
1995	0	1	0	0	0	0	0	0	0	0	0	0	0	1
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	1	0	0	0	0	0	0	0	0	0	0	0	1
1999	0	0	0	0	0	0	0	0	0	0	0	1	0	1
2000	3	3	0	0	0	0	0	0	0	0	1	1	0	8
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	1	1	0	0	0	0	0	0	0	0	0	0	0	2
2003	2	0	0	0	0	0	0	0	0	0	0	0	0	2
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	13	0	0	0	0	0	0	0	3	0	0	2	0	18
2006	4	1	0	0	0	0	0	0	1	0	0	0	0	6
2007	8	0	0	0	0	0	0	0	0	0	0	0	0	8
2008	4	0	0	0	0	0	0	0	3	0	0	0	0	7
Total	35	8	0	0	0	0	0	0	7	0	2	4	0	56

Appendix F - Texas Incident Data by Phase and Activity (1993-2008)

Phase	Waste Management and Disposal													
Activity	Landspreading of Saline Soils or Solids	Landfarming/ Bioremediation Oily-Solids	Roadspreading Produced Water	Roadspreading Heavy Hydrocarbons	Annular Disposal of Drilling Solids	Annular Disposal of Produced Water	Class II D Injection for Disposal	Class II D Surface Facilities	Class II EOR Injection	Class II EOR Surface Facilities	Improperly Plugged Wells in AOR	Percolation Pit	Illegal Dumping	Other	Total
Year															
1993	0	0	0	0	0	0	1	0	0	1	0	4	0	0	6
1994	0	0	0	0	0	0	0	0	0	0	0	4	0	0	4
1995	0	0	0	0	0	0	0	0	0	0	0	6	0	0	6
1996	0	0	0	0	0	0	1	0	0	0	0	3	0	0	4
1997	0	0	0	0	0	0	0	0	0	0	0	5	0	0	5
1998	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
1999	0	0	0	0	0	0	0	0	0	0	0	4	0	0	4
2000	0	0	0	0	0	0	1	3	0	0	0	2	0	1	7
2001	0	0	0	0	0	0	0	0	0	0	0	3	0	1	4
2002	0	0	0	0	0	0	0	0	0	3	0	3	0	0	6
2003	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3
2004	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
2005	0	0	0	0	0	0	0	1	0	0	0	8	0	0	9
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	1	0	0	0	0	7	0	0	8
2008	0	2	0	0	0	0	1	0	0	0	0	2	0	0	5
Total	0	2	0	0	0	0	5	4	0	4	1	57	0	2	75

Appendix F - Texas Incident Data by Phase and Activity (1993-2008)

Phase	Plugging and Site Reclamation					Orphaned Wells and Sites			
Activity	Pit Reclamation	Tank/ Pipe Removal or Closure	Well Plugging	Other	Total	Pits/ Tanks/ Pipelines	Abandoned/ Orphaned Wells	Other	Total
Year									
1993	0	0	0	0	0	0	2	0	2
1994	0	0	0	0	0	0	1	0	1
1995	0	0	0	0	0	0	1	0	1
1996	0	0	0	0	0	0	1	0	1
1997	0	0	0	0	0	0	3	0	3
1998	0	0	0	0	1	0	4	0	4
1999	0	0	0	0	0	0	4	0	4
2000	0	0	0	0	0	0	4	0	4
2001	0	0	0	0	0	0	1	0	1
2002	0	0	0	0	0	0	3	0	3
2003	0	0	0	0	0	1	1	0	2
2004	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	1	0	1
2006	0	0	1	0	0	1	0	0	1
2007	0	0	0	0	0	0	2	0	2
2008	0	0	0	0	0	0	0	0	0
Total	0	0	1	0	1	2	28	0	30

Appendix F - Texas Incident Data by Phase and Activity (1993-2008)

TOTAL BY PHASE

Activity	Site Preparation	Drilling & Completion	Well Stimulation	Production, On-lease Transport, & Storage	Waste Management & Disposal	Plugging & Site Reclamation	Orphaned Wells & Sites	Unknown	Total
Year									
1993	0	1	0	1	6	0	2	3	13
1994	0	1	0	1	4	0	1	1	8
1995	0	2	0	1	6	0	1	2	12
1996	0	0	0	0	4	0	1	1	6
1997	0	0	0	0	5	0	3	1	9
1998	0	0	0	1	2	0	4	2	9
1999	0	1	0	1	4	0	4	4	14
2000	0	0	0	8	7	0	4	4	23
2001	0	1	0	0	4	0	1	5	11
2002	0	0	0	2	6	0	3	3	14
2003	0	0	0	2	3	0	2	0	7
2004	0	0	0	0	2	0	0	2	4
2005	0	1	0	18	9	0	1	3	32
2006	0	0	0	6	0	1	0	1	8
2007	0	1	0	8	8	0	3	5	25
2008	0	2	0	7	5	0	0	2	16
Total	0	10	0	56	75	1	30	39	211

Appendix G - Texas Oil and Gas Industry Activity Data (1993-2008)

Year	Wells Drilled	Completions				Wells Plugged	Crude Oil Produced (bbls)	Oil Wells	Natural Gas Produced (Mcf)	Gas Wells	Totals Producing Wells	Produced Water: Injected (bbls)	Active Injection Wells	
		Total	Oil Wells	Gas Wells	Injection Wells								Class II D	Class II EOR
1993	9,969	8,319	4,646	3,295	378	11,552	574,568,000	186,342	5,606,497,721	50,794	237,136	NRA	NRA	NRA
1994	9,299	7,837	3,962	3,553	322	13,657	541,482,000	179,955	5,675,748,270	52,614	232,569	NRA	NRA	NRA
1995	9,785	8,464	4,334	3,778	352	11,081	511,962,000	177,397	5,672,105,129	53,612	231,009	NRA	NRA	NRA
1996	9,747	8,451	4,061	4,060	330	10,901	495,378,000	175,277	5,770,254,648	55,052	230,329	NRA	12,567	39,511
1997	10,778	9,417	4,482	4,594	307	9,336	488,860,000	175,475	5,814,744,733	56,736	232,211	NRA	12,586	39,466
1998	11,057	9,811	4,509	4,907	366	8,951	457,499,000	170,288	5,772,079,829	58,436	228,724	5,665,228,545	12,394	39,427
1999	6,658	5,804	2,049	3,566	165	7,011	406,815,000	162,620	5,538,929,430	59,088	221,708	5,077,990,191	12,311	39,281
2000	8,854	7,974	3,111	4,580	256	7,219	398,678,000	161,097	5,645,792,009	60,486	221,583	6,176,588,652	12,191	39,466
2001	10,005	9,151	3,082	5,787	258	8,023	378,849,000	159,357	5,668,602,291	63,598	222,955	6,170,238,500	12,001	38,880
2002	9,877	9,192	3,268	5,474	418	8,343	364,314,000	155,865	5,611,957,703	65,686	221,551	6,301,478,966	11,991	38,577
2003	10,420	9,741	3,111	6,336	294	8,720	357,240,000	153,461	5,671,689,242	68,488	221,949	6,375,599,659	11,788	38,178
2004	11,587	10,966	3,446	7,118	402	8,391	349,233,000	151,205	5,817,226,749	72,237	223,442	6,616,941,718	11,736	38,164
2005	12,664	11,007	3,454	7,197	356	7,191	344,226,000	151,286	5,700,612,714	76,510	227,796	6,995,824,761	11,720	38,094
2006	13,854	13,665	4,761	8,534	349	7,504	340,885,000	151,832	6,077,785,935	83,218	235,050	6,969,177,049	11,734	38,050
2007	20,619	14,247	5,084	8,643	471	6,892	336,222,000	153,223	6,421,374,997	88,311	241,534	7,208,901,474	11,250	38,253
2008	22,615	17,337	6,208	10,361	719	6,046	346,632,000	156,588	7,271,814,561	96,502	253,090	7,452,248,595	11,880	38,624
Total	187,788	161,383	63,568	91,783	5,743	140,818	6,692,843,000	N/A	93,737,215,961	N/A	N/A	71,010,218,110	N/A	N/A

NRA: data not readily available
N/A: not applicable