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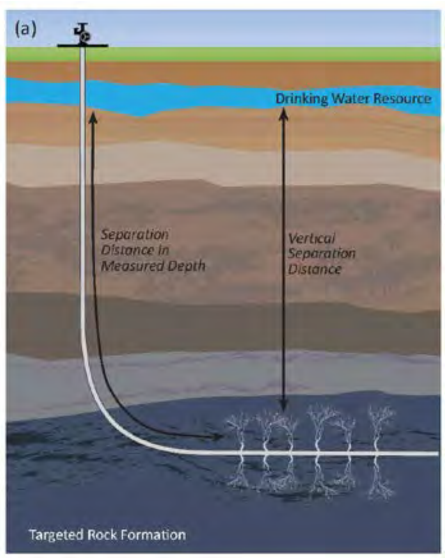
HYDRAULIC FRACTURING FOR OIL AND GAS- IMPACTS ON WATER SUPPLY



Richard Corneille

Assembly Room, A. K. Smiley Public Library

HYDRAULIC FRACTURING FOR OIL AND GAS- IMPACTS ON WATER SUPPLY

BY

Richard Corneille

SUMMARY

The use of the oil and gas drilling and recovery technique of hydraulic fracturing and commonly known as “fracking” has increased significantly since 2000. Hydraulic fracturing has transformed the U.S. into an international leader in oil and gas production (not just the leader in energy consumption!). This technology has allowed the U.S. to tap into vast amounts of shale oil and gas reserves. It has created somewhat of a glut of oil and natural gas bringing down prices substantially, and increasing U.S. energy independence, but also dependence. The technique in 2015 accounted for more than 50% of oil production and 70% of the natural gas production in the U.S. However, some argue this is a short-term economic benefit with significant longer-term costs to the environment. Also some fear the lower costs for fossil fuels might derail California’s commitment to wind, solar, and alternative energy sources.

This paper presents the author’s research into the impacts of oil and gas fracturing on surface and groundwater supplies. Other potential impacts of hydraulic fracturing such as air pollution, greenhouse gases, earthquakes, and community impacts are not discussed in this paper.

A primary reference for this paper was the EPA’s December 2016 report on” Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States”. The hydraulic fracturing water cycle includes: water acquisition, chemical mixing, well injection, produced water handling, and wastewater disposal and reuse.

Since the passing of SB4 by the California Legislature in 2013, which specifically requires new fracking regulations and studies, DOGGR and the SWRCB and RWQCBs have responded with comprehensive requirements and increased oversight.

The hydraulic fracturing water cycle studied by EPA and expanded in this paper to include more California information shows that there are risks, but the water resources impacts are manageable. If implemented and enforces strictly, the new California regulations for oil and gas wells should protect our freshwater aquifers. Legacy oil and gas drilling and production operations are more of a concern, than the development of new wells using the hydraulic fracturing technology.

In the author’s opinion the ongoing management of produced water is the most risky aspect of the hydraulic fracturing water cycle, but no more risky than conventional oil and gas drilling activities. Produced water should only be discharged in Class II injections well or unlined ponds in exempted aquifers. Finally, the reuse of treated produced water for agricultural uses, if proved safe, should be expanded.

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INTRODUCTION

The use of the oil and gas drilling and recovery technique of hydraulic fracturing (sometimes called well stimulation) and commonly known as "fracking" has increased significantly since the year 2000. Fracking has contributed significantly to the surge in oil and gas production in the United States. The technique in 2015 accounted for more than 50% of oil production and 70% of the natural gas production in the U.S. This significant increase in the use of hydraulic fracturing has raised concerns about potential impacts to both surface and groundwater drinking water resources from nearby oil and gas production wells.

Figure 1 shows the hydraulically fractured well locations across the US from 2000 through 2013 (<u>note Figures appear in Appendix A)</u>. As can be seen from the map most of the wells are located in western Pennsylvania and eastern Ohio, Texas and Oklahoma, and western North Dakota and Wyoming. In California 95% of the fracturing operations occurs in the southern San Joaquin Valley in four oil fields in Kern County. Wells treated with fracturing produces 20% of the oil and gas in California. According to the Western States Petroleum Association, California is the 4th largest oil producing state at 585,000 barrels per day, which is 10% of U.S. oil production. In addition in California alone there are almost 333,000 jobs directly or indirectly associated with the petroleum industry (over 21,000 jobs in oil extraction) and the oil industry generates $8.7 billion in total tax revenues in the state.

While the current amount of oil and gas fracturing in California is relatively small and concentrated in one area in comparison to other areas of the US, the California potential is estimated to be huge. It has been estimated by various agencies, including the United States Geologic Survey (USGS) and U.S. Energy Information Administration, that California Monterey shale could potentially yield 14-15 billion barrels of oil and 18 billion cubic feet of natural gas (see **Figure 2** for map of this area). Therefore, a significant increase in oil and gas fracking in California is possible. One short-term negative that is limiting this potential is the fact that the break-even point for the development of oil by fracturing is about $75 to $80 per barrel and the current price of oil is only $50-$55 per barrel. Also, the results of fracturing in Monterey shale to date has not been as promising as expected, reducing somewhat the estimates for the extraction of oil and gas from this source.

This paper presents the author's research into the impacts of oil and gas fracturing on surface and groundwater supplies. The U.S. Environmental Protection Agency (EPA) was requested by Congress to study hydraulic fracturing and produced a final report in December 2016 titled "Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States" (Reference 1- <u>see list of references in Appendix B</u>).

According to this report, the potentially more frequent and severe impacts of fracking related to water resources include:

- The amount of water use in the process, particularly in water short areas
- Spills of fracking fluids and chemicals into surface water and groundwaters
- Leakage of fracturing fluids into groundwater through well casings
- Injection of fracturing liquids directly into groundwater resources
- Discharge of inadequately treated fracking wastewater into surface water resources
- Disposal and storage of fracturing wastewater in pits and disposal wells

The EPA report is a primary reference for this paper. However, the EPA report containes only limited information on California fracking practices, which I have researched and included in this paper. The primary California references used in preparing this paper are: "An Independent Scientific Assessment of Well Stimulation in California" by the California Council on Science and Technology July 2015 (Reference 4); the Groundwater Resources Association of California "Summary of GRA's California Oil, Gas, and Groundwater Symposium Spring 2015 (Reference 3); and information from the Western States Petroleum Association (WSPA) website (Reference 5). Regulations and agencies involved in California governing hydraulic fracturing are presented.

This paper focuses on the impacts of fracking on surface and groundwater water resources only. Other potential impacts of hydraulic fracturing such as air pollution, greenhouse gases, stimulating earthquakes, and community land-use impacts are not discussed in this paper.

WHAT IS HYDRAULIC FRACTURING FOR OIL AND GAS?

Hydraulic fracturing to enhance oil and gas recovery is not new. The process has been used since the late 1940s. Historically fracking was used only in oil and gas wells by fracturing the shale rock relatively close to the vertical well casing. However, since 2000 the process has been significantly enhanced by the development of horizontal directional drilling methods, which allows drilling along the targeted rock formations, exposing more oil or gas bearing formations to the well. This has greatly expanded oil and gas production in new formations that were previously considered not feasible and uneconomical.

A typical hydraulically fractured well section is show on **Figure 3**. A vertical well is drilled into an oil shale rock formation and then extended horizontally into the formation. During fracturing, a fluid of mainly water with chemicals and a "proppant" (usually sand) is injected under great pressure into the rock formation to fracture the rock. The sand fills the fractures to keep them open while remaining porous. The fluids (oil, formation water, and residual fracturing fluids) and methane gas flow through the fractures into the perforated horizontal well casing and up the vertical well to the surface. The oil, gas and fluids are collected at the surface and stored, treated and discharged, or recycled. The definitions of liquids in hydraulic fracturing (Reference 3) are as follows:

- <u>Hydraulic fracturing water</u>- water used to make-up the majority of the fracturing liquid.

- Hydraulic fracturing fluid- liquid injected into the subsurface through the well to increase fracture permeability, typically a mixture of surface water or groundwater, proppants, and proprietary chemical additives.
- Formation water- water naturally present in the rock formation
- Flowback (recovered) water- the hydraulic fracturing fluid that returns to the surface through the well after completion of hydraulic fracturing.
- Produced Water- the combination of flowback water and the formation water that returns to the surface through the well with the produced oil and gas during ongoing operations.

The impacts of handling and disposing or reusing each of these fluids will be discussed in subsequent sections of this paper.

The timeline for construction of a fractured well is from 12 to 20 weeks, while the operation of the well is generally several years or even decades, while the oil and gas is being extracted. Therefore, there are short- term construction impacts that need to be mitigated and much longer term operational impacts with the handling of produced water and wastewater treatment, disposal, and or reuse.

The EPA report (Reference 1) discusses the hydraulic fracturing water cycle and potential impacts to water resources. This cycle is show on Figure 4 and includes the following stages and activities:

- Water Acquisition: the withdrawal of groundwater or use of surface water to make fracturing fluids.
- Chemical Mixing: the preparation of the fracturing fluid consisting mainly of water, proppant (sand) and chemicals.
- Well Injection: the movement of the fracturing fluid under high pressure in the oil and gas production well and into the targeted shale rock formation.
- Produced Water Handling: on-site collection and handling, including storage and transport, of produced water that returns to the surface.
- Wastewater Disposal and Reuse: disposing, treating, and/or reusing produced water not returned to the well.

This paper discusses these activities and their impact in the following sections.

REGULATION OF HYDRAULIC FRACTURING FOR OIL AND GAS IN CALIFORNIA

Under California's Department of Conservation, the Division of Oil, Gas, and Geothermal Resources (DOGGR) has regulated oil and gas activities since 1915. According to their website "the Division supervises the drilling, operation, maintenance, and plugging and abandonment of onshore and offshore oil, gas, and geothermal wells, preventing damage to: (1) life, health, property, and natural resources; (2) underground and surface waters suitable for irrigation or domestic use; and (3) oil, gas, and geothermal resources while protecting the environment". DOGGR is the repository for oil, gas, and geothermal well information and publishes statistics on drilling, production and injection. They report that about 210,000 oil, gas, and geothermal wells have been drilled in California with around 88,500 still in use. In 2012 4,680 new wells were drilled.

Due to the increase in the use of hydraulic fracturing in California and the concern about the potential impacts and unknowns associated with fracking, the California Legislature passed Senate Bill 4 (Pavley) in 2013. SB 4 outlined the contents and engaged the State Water Resources Control Board (SWRCB) in assisting DOGGR in the development of the regulations for the protection of surface and groundwaters. DOGGR produced final well stimulation regulations for permitting new wells at the end of 2014. The law established a deadline for the regulation development, a risk analysis, and environmental review in 2015. The new DOGGR regulations implement the following legislative requirements in SB 4:

- Permitting from DOGGR must contain plans for water management, spill contingency, and waste disposal.
- Requiring 30 days advance notice to all property owners in the vicinity of planned hydraulic fracturing sites.
- Conducting groundwater testing and monitoring before and after every fracking event.
- Mandatory reporting on the volume of water used and disposition of fracturing wastewater.
- Requiring full disclosure of all chemicals used in fracking.
- Requiring seismic testing and mapping for all fault zones prior to the fracturing event.
- Greater coordination among agencies to ensure information sharing and accountability.
- Performing a State-wide EIR and independent peer review study on the risks of fracking by July 1, 2015.

In addition to partnering with DOGGR on the new regulations, the SWRCB is the primary agency for the recommendations to EPA for aquifer exemptions. As discussed in detail in the Wastewater Disposal and Reuse section of this paper, the injection in Class II injection wells of produced fracturing wastewater into the groundwater aquifer is a prime method of disposal. The aquifer exemptions program is designed to protect aquifers that are "existing, or future drinking water sources" in accordance with the EPA administered Safe Drinking Water Act (SDWA).

The SWRCB and the local Regional Water Quality Control Boards (RWQCB) are responsible for the regulation of all waste discharges and inspection of oil spill incidents. They also review and comment on all new fracturing well applications. Some of the chemicals used in fracking liquids and the residual chemicals in the produced water are largely unreported or unknown due to the lack of hard data, but the chemical analysis data required by the SB4 regulations will start to in fill these gaps.

Detailed groundwater monitoring requirements are being developed by the SWRCB in consultation with DOGGR and should be published early next year. The oil well operators will be required to monitor groundwater near wells subject to fracking and the SWRCB will be monitoring on a regional scale. Monitoring criteria will include: monitoring methods, chemical analyses, frequency and duration of monitoring, and areas to monitor.

HYDRAULIC FRACTURING WATER ACQUISITION AND USE

Water acquisition and use is the first stage in the water cycle that supports hydraulic fracturing. Groundwater and surface water provide the water source for the hydraulic fracturing fluids. In some cases produced water is also used. Water is the major component of all hydraulic fracturing fluids (except acid fracturing which is used for only a very small number wells). In California the use of groundwater is generally the main source of the fracturing water. The amount of groundwater to be acquired for use in hydraulic fracturing fluids varies widely, but has been reported as follows:

- U.S. overall median volume per well 1.5 million gallons (MG)
- U.S. typical range of water use 74,000 gallon to 6 MG per well
- California water median use as reported by EPA 76,800 gallons per well
- California water use range as reported by EPA 21,500 to 285,000 gallons per well
- WSPA reported average water use in 2013 127,000 gallons per well.

The amount of fracturing water is relatively small compared to other uses of water. The total yearly amount of acquired fracking water in California is about 800 Acre Feet (AF-one AF is 325,800 gallons). The total yearly amount of municipal water demand in Kern County is 400,000 AF and the amount used by agriculture is 2.7 million AF. However, 95% of California's hydraulic fracturing takes play in Kern County, which is an arid area. Kern County has already depleted groundwater resources and significant land subsidence, due to unsustainable groundwater extractions. The County relies mainly on imported surface water to supply agricultural water demands, but during drought conditions this surface supply is greatly reduced, as it has been in the last 5 years, and more groundwater is extracted. Therefore, the additional demand on water supplies for acquired water for fracking is more significant for arid areas. The potential impact of fracking on water quality that can also reduce local potable water supplies is discussed in a subsequent section of this paper.

EPA notes in their 2016 report that fracturing water withdrawals can affect the quantity and quality of drinking water sources. Water management strategies, including finding alternative water sources, water withdrawal restrictions, and reuse of produced water can reduce the frequency or severity of impacts on fresh water resources.

HYDRAULIC FRACTURING FLUIDS AND CHEMICAL MIXING

The mixing of water, proppant (sand), and chemical additives create the hydraulic fracturing fluids. The fluids are engineered to create and grow fractures and carry the sand into the fractures. The largest component of the fluids is water and the second largest component is the sand. The mixing takes place on the well drilling site just prior to well injection at very high pressures. The sand and chemicals are stored in tanks and bins. The mixing equipment consists of flexible and rigid pipes, pumps, mechanical mixers, and tanks. A schematic of the chemical mixing equipment and a photograph of a well pad during hydraulic fracturing are shown on **Figure 5**.

The chemical additives are the smallest portion of the composition of the fracking fluid, but have the greatest potential to impact surface or groundwater quality from spills. Over 1,000 chemicals used in the fracturing fluids were reported to EPA. The chemicals are used in proprietary mixes and can include 4 to 28 different chemicals. These chemicals are stored in large quantities onsite. The more common chemicals are methanol, hydrotreated light petroleum distillates, hydrochloric and other acids, and biocides. Some of the chemicals have unknown environmental hazard profiles. Many of these chemicals are highly toxic and hazardous. A declaration of the chemicals used is now required in the DOGGR regulations permitting process for new wells, but was not required in the past, and is not required for existing wells.

There have been spills of hydraulic fracturing fluids or their additive chemicals. The causes of the spills are primarily due to equipment failure or human error. Spills have been documented from chemical storage unit leaks. In 151 spills from January 2006 to April 2012 EPA reports the median volume of spills has been 420 gallons, while the maximum has been 19,320 gallons. The chemical composition of these spills has generally not been reported.

The generalized potential pathways for a spill entering the ground or surface waters are shown on **Figure 6**. The impact of a spill on surface or groundwater depends on a number of factors, including the volume of the spill, the chemical(s) spilled, location and pathway to the water resource, and the emergency response activities. In highly permeable soils or fractured rock a liquid spill can move more quickly into the groundwater, while in low permeable soils the liquid can flow longer distances overland to surface water resources. Larger volume spills of course are more likely to reach either water resource. These larger spills increase the likelihood of more severe and long-term impacts to drinking water sources, unless immediately remediated. In Southern California due to the lack of surface water resources (flowing rivers, etc.), groundwater contamination from spills is more likely and is much more difficult to remediate.

Spill prevention and containment practices are required in the in the new California DOGGR regulations. The primary spill containment methods are liners and berms surrounding the chemical storage and mixing equipment designed to capture spilled fluids and prevent them from percolating or flowing offsite.

WELL INJECTION AND MOVEMENT OF FRACTURING FLUIDS

The movement of fracturing fluids through an oil and gas production well, or into the fractured shale formation, can reach the groundwater. The pathways for the potential movement of fluids are from the well casing and through the fractures in the rock formation. Preventing unintentional fluid movement from the inside of the well casing to the outside groundwater and from the fractures into the shallower groundwater is required.

Well casings for oil and gas wells are welded steel pipes and casings. The vertical well section of a properly design well has two or more well casings and cement seals as show on **Figure 7**. During fracking the well casing is subjected to extreme pressures needed to fracture the shale and results in large temperature changes. The range of pressures applied to wells can range from 2,000 to 12,000 pounds per square inch (psi). This compares to atmospheric pressure of 15 psi or a car tire pressure of 35 psi. Temperatures can range from 64 to 212 degrees Farenheit. The structural integrity of the well casing must be designed, manufactured, and installed to prevent leaks due to bursting or longer term corrosion. An oil production well constructed with insufficient mechanical integrity may allow fractured fluid movement from the inside or outside of the well casing. Concrete seals are used to further prevent leaks into the aquifer. Fracturing in an existing well with unknown mechanical integrity and seals is particularly risky for casing failures.

More difficult to control or detect is fracking fluid leakage from the created fracture network into a groundwater aquifer. Normally the targeted rock formation is well below (sometimes thousands of feet) the groundwater source. This separation allows for a safety factor for the fractures not extending vertically into the bottom of the fresh water aquifer. However, in California it has been reported that currently about three-quarters of the fracturing occurs in wells less than 2,000 feet deep. In some places potable groundwater exists close to where the fracturing occurs (See **Figure 8**). Also**,** in infrequent cases the oil and gas well and drinking water source may be co-located with no vertical separation between the bottom of the fresh water sources and the fractured rock formation, so the fracking fluid can directly flow into the groundwater. This can result from an uncertainty of the bottom of fresh water aquifer depth (this is unknown by some water supply agencies), and the unknown extent of the fractures. Data requirements under the new DOGGR permitting regulations, including coordination between drinking water agencies and oil and gas drillers, should minimize this situation from happening.

The location of both abandoned oil and gas wells in the vicinity of the fracturing operation can also provide pathways for chemicals to enter fresh water aquifers. There have been cases where fracturing near an existing well has increased an existing well pressure, either blowing-out the well underground or spilling fracking fluid on the surface at the well. Locating abandoned wells can be a challenge, due to the lack information in data bases, and the unknown status of how a well was abandoned (with no plugs, proper plugs or if the plugs have not degraded).

PRODUCED WATER HANDLING

As mentioned previously, produced water consists of fracking fluids, flowback water, and formation water. On-site collection and storage of this water is required during and after the fracking process. The initial produced water is mainly fracking fluids and is generally the largest volume to be handled during the life of the oil or gas well. As the well is operated, oil and gas flows into the well and to the surface mixed with flowback and formation groundwater. The oil and gas are separated from the water. The water remaining must be handled prior to disposing or reuse. The quantity of the produced water during ongoing well production is generally much less than water produced during active fracking. WSPA estimates that on the average in California about 15 barrels (630 gallons) of water is produced for each barrel (42 gallons) of oil. The produced water must be collected, stored and disposed of throughout the life of the well.

Produced water contains the following:

- High TDS (total dissolved solids) greater than 1,000 ppm up to 43,000 ppm.
- Salts including chloride, bromide, sulfate, sodium, magnesium, and calcium.
- Metals including barium, manganese, iron, and strontium.

- Organic compounds including benzene, toluene, ethylbenzene, xylenes (BTEC), and oil and grease.
- Naturedly occurring radioactive materials, including radium.
- Hydraulic fracturing chemicals and their chemical transition products.

The quantity and quality of produced water to be handled varies greatly based on the total amount of fracturing fluids used and the groundwater aquifer characteristics. For example the amount of fracturing fluids used on the average is about 77,000 gallons. A lined storage pond and storage tanks (see **Figure 9**) would need to be available onsite just to handle this amount of water prior to disposal without consideration of other produced water. Some of this produced water may be recycled to make-up additional fracturing fluids or reused for irrigation (discussed in the next section).

With these large quantities of water to be handled, produced water spills have occurred across the U.S. Common causes of water spills include inadequate volume of storage facilities, human error, and equipment leaks and failures. The mechanical equipment (pipes, pumps, tanks) is similar to those used in chemical mixing, but stays on the well site during long-term well operation, until the well is abandoned. Also, produced water spills can reach surface and groundwater through the same pathways described in the Hydraulic Fracturing Fluids and Chemical Mixing section above. The difference with spills in chemical mixing versus produced water, is the volume of the spills is likely to be much larger for produced water handling, but with lower concentrations of potential contaminants.

An assessment of produced water spills in California reported to the California Office of Emergency Services between January 2009 and December 2014 showed that 18% of the produced water spills impacted waterways. Documented impacts have included elevated levels of salinity in groundwater. The largest spill reported to date in the U.S. has been 2.9 million gallons in North Dakota, which flowed into a creek and increased the salinity in the creek.

WASTEWATER DISPOSAL AND REUSE

Produced water disposal is probably the most controversial topic and has the largest potential impact on water resources. Disposal and reuse practices of inadequately treated or untreated hydraulic fracturing wastewater can pollute surface and groundwater resources. The procuded water discussed in the last section must be disposed of throughout the life of the fractured well. DOGGR has determined that there is no substantial difference between the volume of the produced wastewater generated from fractured wells versus non-fractured wells. So disposal of oil and gas wastewater applies to all oil and gas well drilling and ongoing operations.

Across the U.S. the most common method of disposal is through what are called Class II injection wells. How water is pumped up with oil and injected back into the ground is shown on **Figure 10**. Oil and gas wastewater is simply pumped into the injection well and the wastewater is dispersed into the ground at the bottom of the well. Evaporation and percolation ponds have also been used extensively in California for disposal. Large ponds used for several oil wells in Kern County are show on **Figure 11**. In these ponds wastewater that is not evaporated percolates into the groundwater. As noted in the last section, the produced wastewater has a high salt content and contains other chemicals.

As mentioned previously, the EPA has a program to categorize aquifers that qualify as underground sources of drinking water (USDW) under the Safe Drinking Water Act. A "protected aquifer" is one that is an existing or potential USDW. An "exempt aquifer" is one which has been approved by EPA where Class II injection wells can be permitted to inject fracturing fluids and produced water into the aquifer. Unlined percolation ponds can also be located over an exempt aquifer. The determination to exempt an aquifer includes evaluation of the following criteria:

- Aquifer does not currently serve as a source of drinking water
- The aquifer cannot now or in the future serve as a source of drinking water because:
  - -It is in a hydrocarbon bearing zone
  - -Its depth or location makes drinking water recovery uneconomical or impractical
  - -It is contaminated and uneconomical and technically impractical to treat to standards.
  - -The TDS is more than 3,000 ppm, but less than 10,000 ppm (for comparison drinking water normally has a maximum TDS of 500).

DOGGR oversees the preparation of aquifer exemption applications with the RWQCB and the SWRCB reviewing, commenting and, if acceptable, submitting to EPA for approval. The SWRCB has determined that aquifers in California that contain more than 10,000 ppm of TDS are categorically exempt. This is a much higher standard than in other states.

WSPA reports that injection wells are the "crucial backbone of oil production in California". They state that injection wells are used by the oil and gas industry in California for 80 to 85% of the oil well drilling and ongoing operations. They also state the average depth of an injection well is 2,000 ft. in California (elsewhere in their website information they say 5,000 ft.). In terms of the water disposed DOGGR says that 60% of the water produced is disposed in 25,000 injection wells. DOGGR states the remaining produced water is either recycled for enhanced oil recovery or treated and sold to agriculture.

Information from the California Council on Science and Technology (Reference 4) conflicts with the some of the DOGGR and WSPA disposal information. The Council states that only 25% of the water produced is injected in Class II wells, while 60% is disposed of by infiltration and evaporation using unlined pits, and 17% of the disposal practices is either unknown or not reported. This is an example of a data gap that needs to be reconciled.

Both the use of injection wells and unlined pits in protected aquifers has been reported in the last few years in Kern County. According the LA Times (3/11/15) DOGGR admitted that it inadvertently allowed oil companies to inject wastewater from hydraulic fracturing and other oil production operations into hundreds of disposal wells into protected aquifers, which is a violation of Federal Law. There were over 2500 wells that were suspected of injecting into protected aquifers. After further investigation the number of non-compliant wells was reduced to about 460 active wells and the agency shut down 23 wells in 2015.

In addition, DOGGR has been accused of lackluster regulation of unlined ponds used for evaporation and percolation. According to the LA Times (2/27/15) in Kern County hundreds of unlined ponds are operating without proper permits. The Central Valley RWQCB has inspected a number of sites and determined more than 300 unidentified waste sites and one-third of the ponds are operating without permits. WSPA disputes the inventory because it says the RWQCB mistakenly included stormwater management basins, secondary containment basins, and lined temporary storage sumps and pits.

Reuse of the produced water is another method of disposal. WSPA reports that reuse of a large amount of the produced wastewater is mostly to enhanced oil recovery in existing wells. In Kern County treated wastewater has been used for agricultural irrigation. Some blending of the produced wastewater is done with traditional irrigation supplies to reduce the higher TDS.

Chevron's oil field wastewater in Kern County is recycled and sold to farmers after a treatment process which includes skimming and filtration through walnut shells to absorb oils. In 2015 (LA Times 5/2/15) Chevron recycled 21 million gallons (64.5 acre-feet) of produced wastewater each day. The water is used by about 90 farmers on 45,000 acres of crops or about 10% of Kern County's farmland. The program is a good deal for both the oil companies and the farmers, who paid only $30/ acre-ft., which is about half the open market rate for irrigation water. However, environmental activist groups and SWRCB are concerned about the crop uptake of oil produced wastewater chemicals if used for irrigation water. A study is now being performed by a Food Safety Panel sponsored by Central Valley RWQCB to determine the impact.

SUMMARY AND CONCLUSIONS

Hydraulic fracturing has transformed the U.S. into an international leader in oil and gas production (not just the leader in energy consumption!), which has upended the global energy market place. This technology has allowed the U.S. to tap into vast amounts of shale oil and gas reserves. It has created somewhat of a glut of oil and natural gas bringing down prices for consumers substantially, while increasing U.S. energy independence, but also dependence on oil. However, some argue this is a short-term economic benefit with significant longer-term costs to the environment. Also, some fear the lower costs for fossil fuels might derail California's commitment to wind, solar, and alternative energy sources.

Since the passing of SB4 by the Legislature in 2013, which specifically required new fracking regulations and studies, DOGGR and the SWRCB and RWQCB have responded with comprehensive requirements and increased oversight. New well permitting is now a multi-agency process, including drinking water agency reviews. In addition, a statewide independent risk analysis and an EIR has been prepared that shows the impacts of fracking can be mitigated. Results of these studies, recommend tighter control of all aspects of hydraulic fracturing and filling in data gaps, but not implementing a moratorium on fracking. Even our environmental Governor Jerry Brown after extensive study supports the technology.

The hydraulic fracturing water cycle studied by EPA and expanded in this paper to include more California information shows that there are risks, but the water resources impacts are manageable. If implemented and enforced strictly, the California regulations for new wells should protect our freshwater aquifers. Legacy oil drilling and production operations are more of a concern, than the development of new wells using the hydraulic fracturing technology.

In the author's opinion the ongoing management of produced water is the most risky aspect of the hydraulic fracturing water cycle, but no more risky than conventional oil and gas drilling activities. Produced water should only be discharged in Class II injection wells or unlined ponds in exempted aquifers. Finally, the reuse of produced water for agricultural uses, if confirmed safe, should be expanded.

APPENDIX A

FIGURE 1

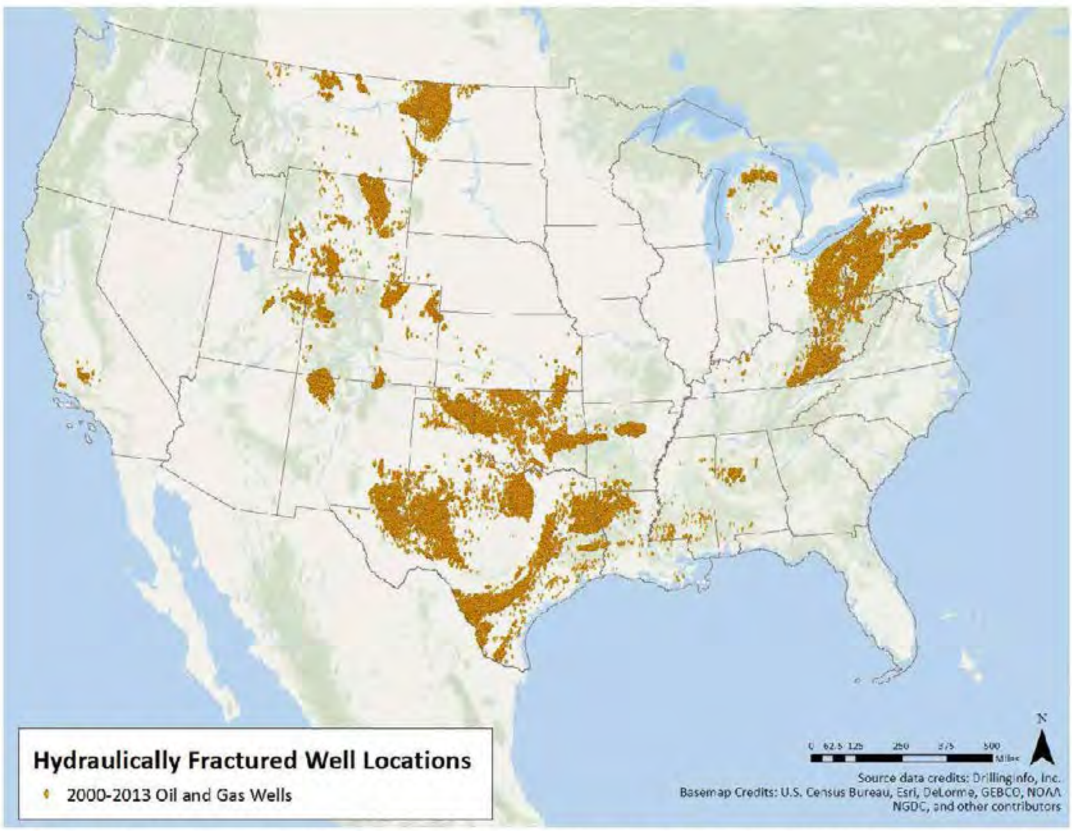


Figure ES-2. Locations of approximately 275,000 wells that were drilled and likely hydraulically fractured between 2000 and 2013. Data from DrillingInfo (2014).

SOURCE- EPA- REFERENCE 1

FIGURE 2

CALIFORNIA MONTEREY SHALE FORMATION MAP

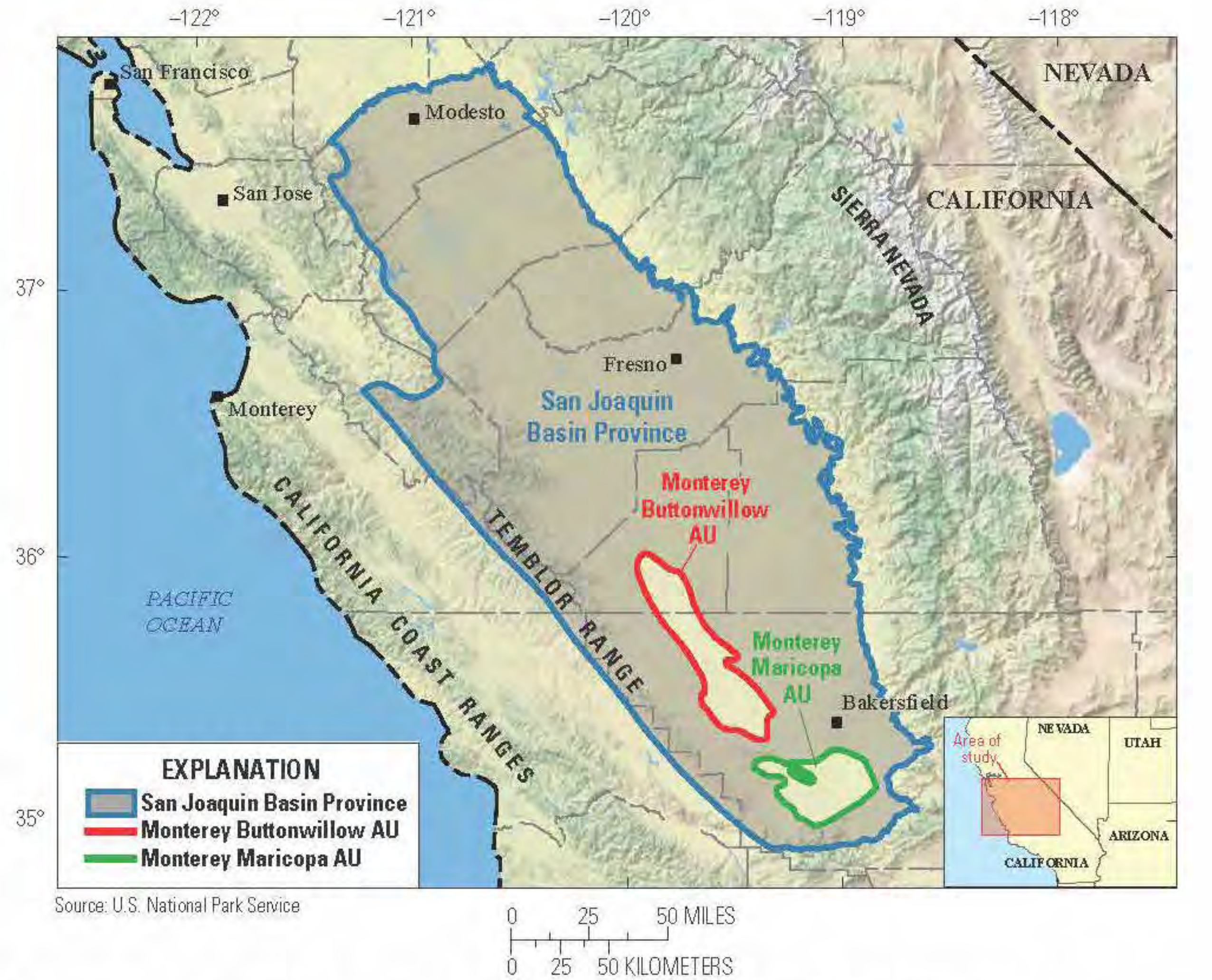
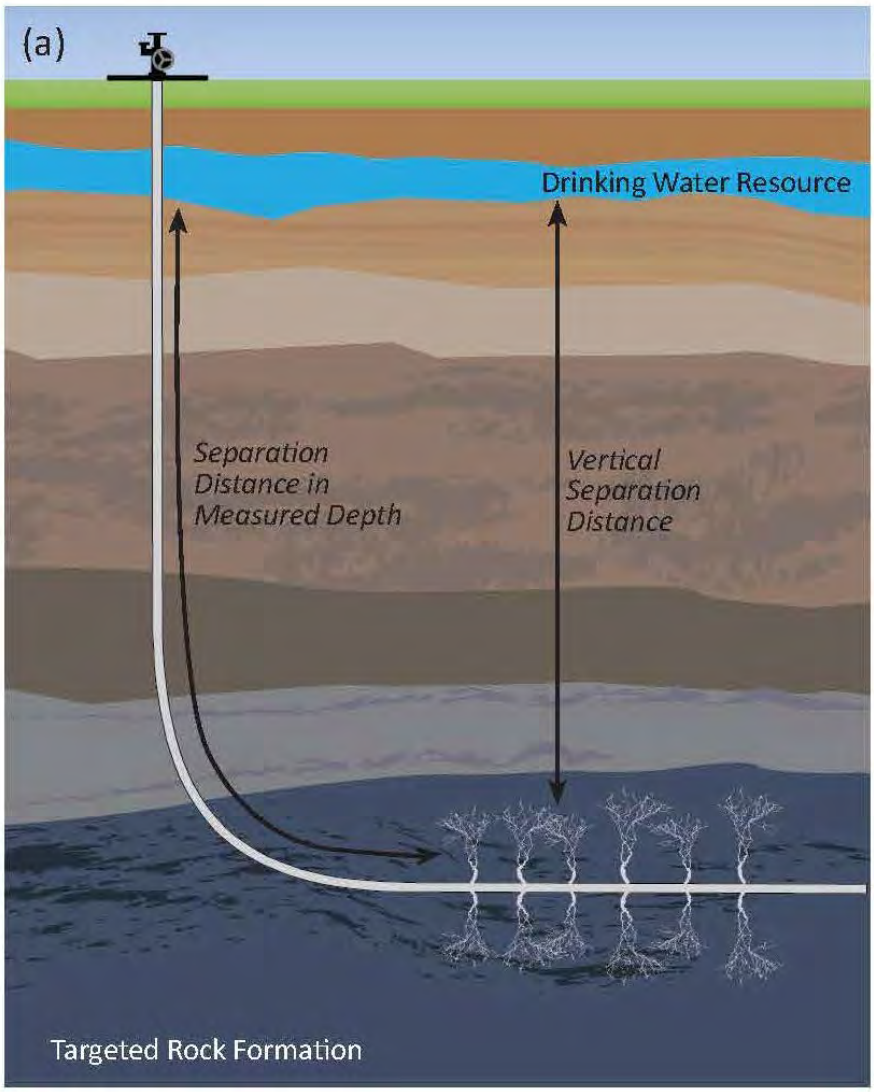


Figure 1. Map of the San Joaquin Basin Province. Assessment unit (AU) boundaries approximate the 10,000-foot structure contour on the top of the Monterey Formation, as revised from maps of Webb (1981) and Graham and Williams (1985) using well penetrations from data available online from the California Division of Oil, Gas, and Geothermal Resources.

SOURCE- USGS REFERENCE 2

FIGURE 3

TYPICAL FRACTURED WELL SECTION



SOURCE- EPA REFERENCE 1

FIGURE 4

HYDRAULC FRACTURING WATER CYCLE

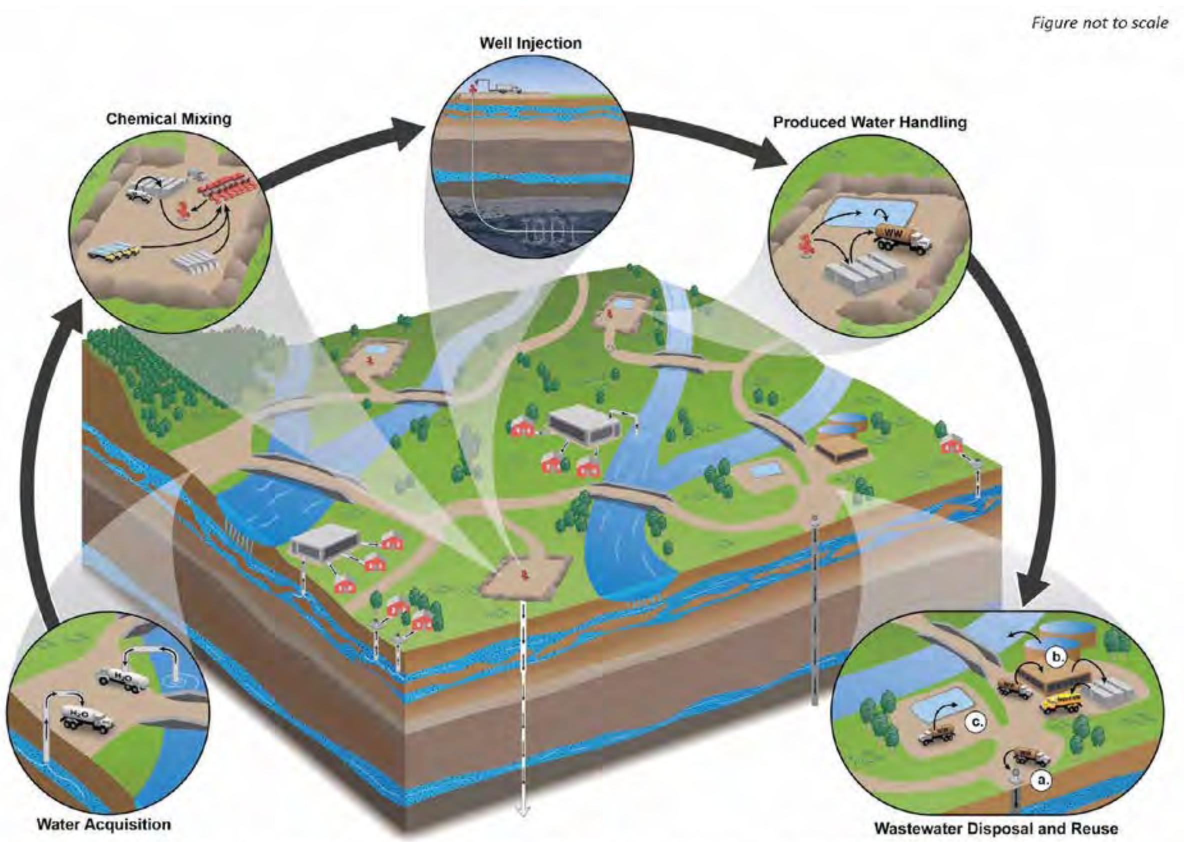


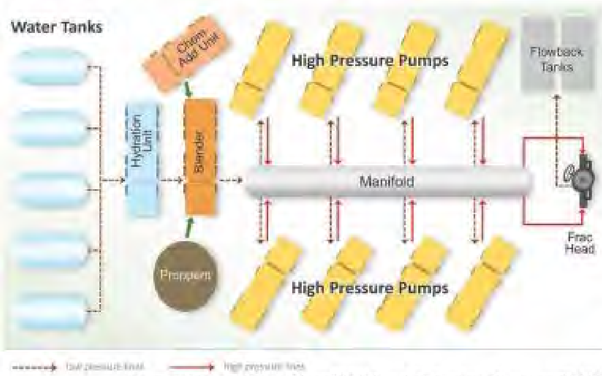
Figure ES-3. The five stages of the hydraulic fracturing water cycle. The stages (shown in the insets) identify activities involving water that support hydraulic fracturing for oil and gas. Activities may take place in the same watershed or different watersheds and close to or far from drinking water resources. Thin arrows in the insets depict the movement of water and chemicals. Specific activities in the "Wastewater Disposal and Reuse" inset include (a) disposal of wastewater through underground injection, (b) wastewater treatment followed by reuse in other hydraulic fracturing operations or discharge to surface waters, and (c) disposal through evaporation or percolation pits.

SOURCE EPA- REFERENCE 1

FIGURE 5

CHEMICAL MIXING & WELL PAD

Text Box ES-7: Chemical Mixing Equipment



Source: *Adapted from Olson (2011) and BJ Services Company (2009)*

Typical Layout of Chemical Mixing Equipment

This illustration shows how the different pieces of equipment fit together to contain, mix, and inject hydraulic fracturing fluid into a production well.

Water, proppant, and additives are blended together and pumped to the manifold, where high pressure pumps transfer the fluid to the frac head.

Additives and proppant can be blended with water at different times and in different amounts during hydraulic fracturing. Thus, the composition of hydraulic fracturing fluids can vary during the hydraulic fracturing job.

Well Pad During Hydraulic Fracturing

Equipment set up for hydraulic fracturing.

Source: Schlumberger

SOURCE- EPA REFERENCE 1

FIGURE 6

FLOW PATHS INTO SURFACE & GROUNDWATERS FROM SPILLS

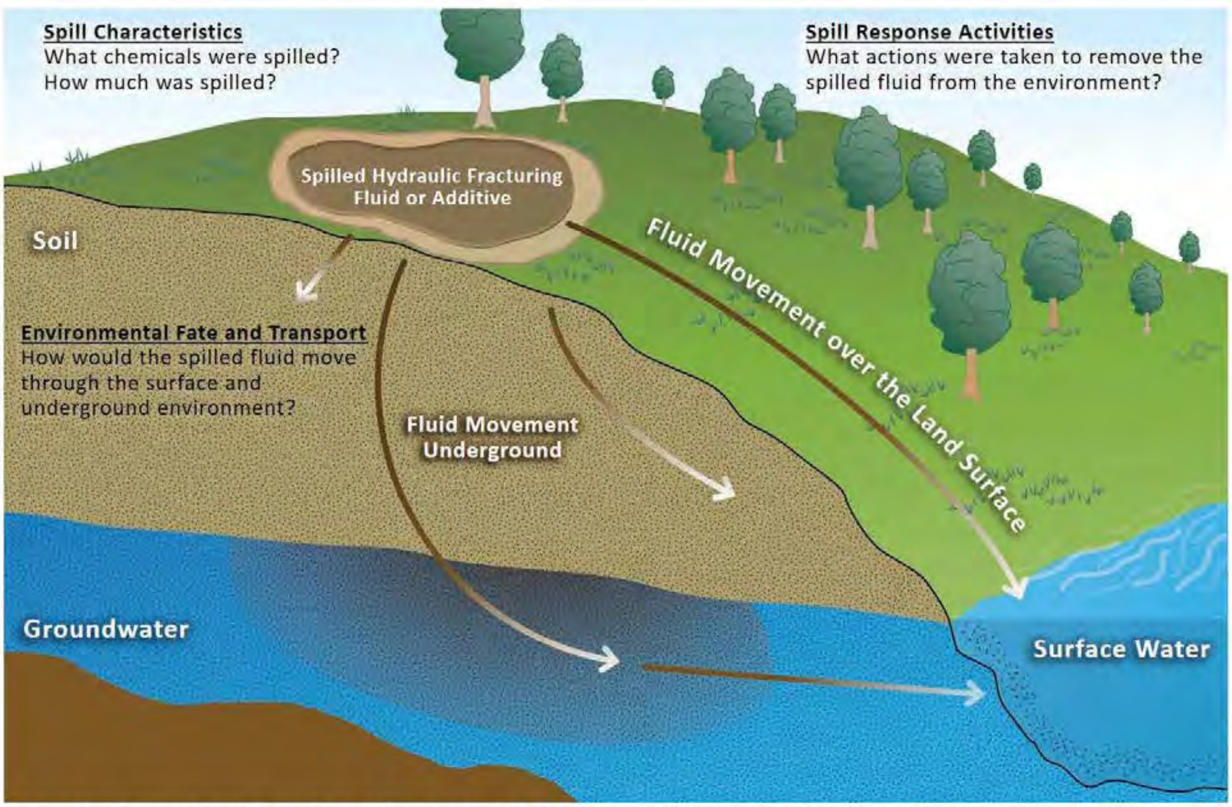


Figure ES-5. Generalized depiction of factors that influence whether spilled hydraulic fracturing fluids or additives reach drinking water resources, including spill characteristics, environmental fate and transport, and spill response activities.

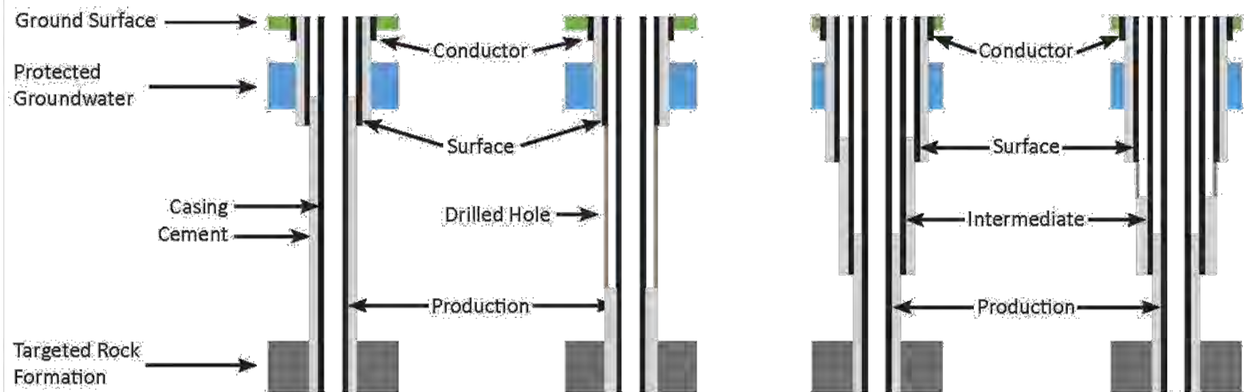
SOURCE- EPA REFERENCE 1

FIGURE 7

WELL CASINGS AND CEMENT SEALS

Well Construction Characteristics

Wells are typically constructed using multiple layers of casing and cement. The subsurface environment, state and federal regulations, and industry experience and practices influence the number and placement of casing and cement.



Conductor, surface, and production casings

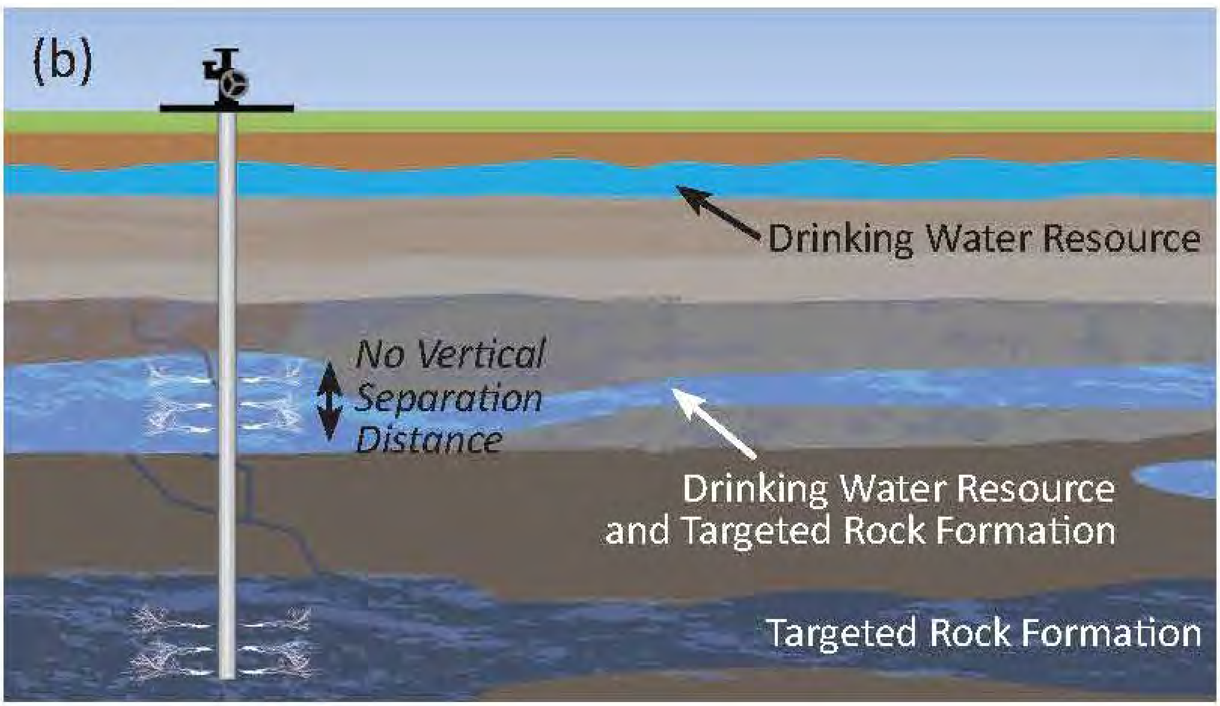
Conductor, surface, intermediate, and production casings

Well diagrams are not to scale.

SOURCE- EPA REFERENCE 1

FIGURE 8

FRACTURING SEPARATION FROM GROUNDWATER RESOURCES



SOURCE- EPA REFERNCE 1

FIGURE 9

PRODUCED WATER HANDLING

Text Box ES-10: On-Site Storage of Produced Water

Water that returns to the surface after hydraulic fracturing is collected and stored on site in pits or tanks.

Above: Flowback pit. (Source: U.S. DOE/NETL)
Right: Flowback tanks. (Source: U.S. EPA)

Produced Water Storage During Oil or Gas Production

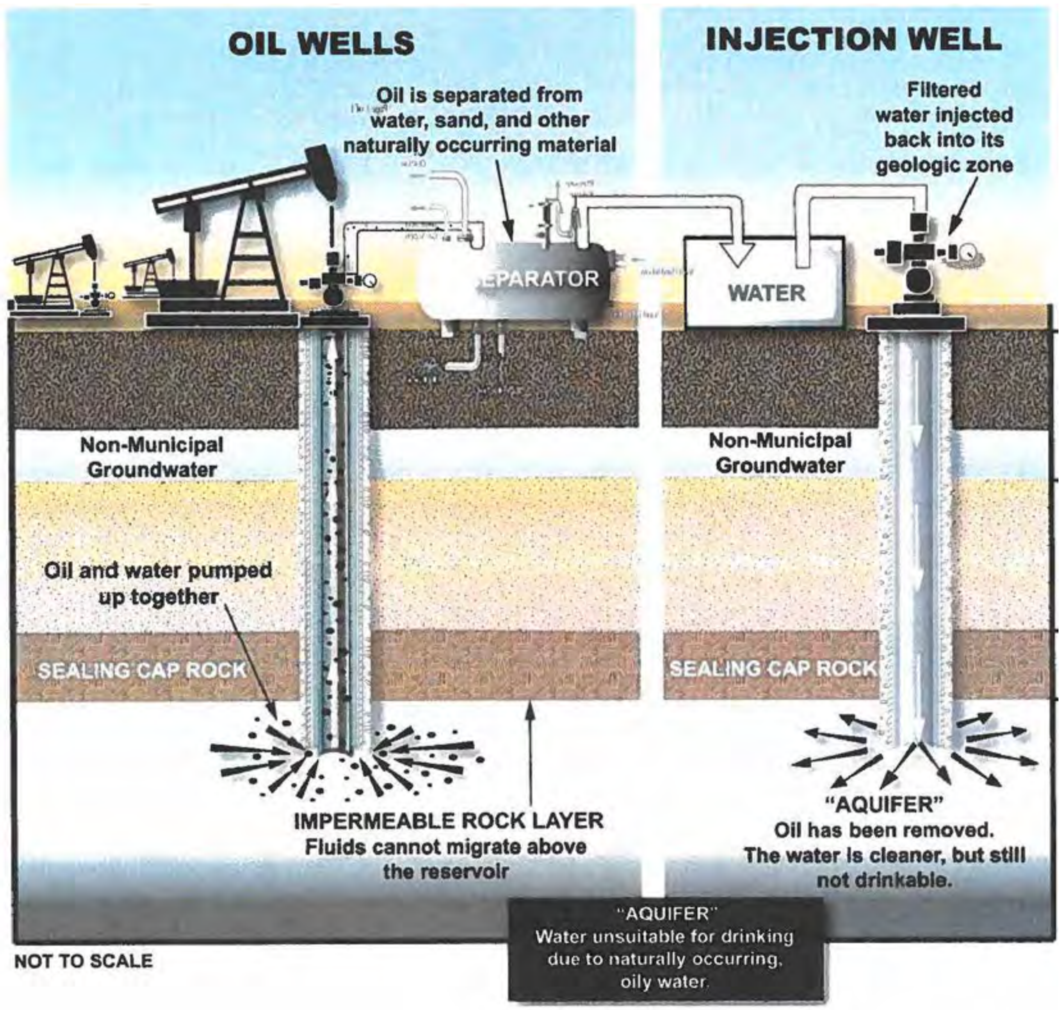
Water is generally produced throughout the life of an oil and gas production well. During oil and gas production, the equipment on the well pad often includes the wellhead and storage tanks or pits for gas, oil, and produced water.

Above: Produced water storage pit. (Source: U.S. EPA)
Left: Produced water storage tanks. (Source: U.S. EPA)

SOURCE- EPA REFERENCE 1

FIGURE 10

How Water is Pumped Up with Oil and Injected Back into the Ground



SOURCE- WSPA REFERENCE 5

FIGURE 11

LARGE PRODUCED WATER PONDS IN KERN COUNTY

SOURCE- LA TIMES MARCH 11, 2016

APPENDIX B

HYDRAULIC FRACTURING FOR OIL AND GAS- IMPACTS ON WATER SUPPLY

By

Richard Corneille

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7. California Legislative Information- Senate Bill No. 4 oil and gas well simulation permitting approve by the Governor on 9/20/13
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9. Various sources identified by Jim Hendon

APPENDIX C

Richard Corneille, PE

Summary Resume

Richard (Dick) Corneille grew up in Crown Point, New York on Lake Champlain. He attended the University of Vermont and graduated with a bachelor's degree in civil engineering in 1970. His first job was for the environmental consulting engineering firm of Metcalf & Eddy in Boston. While working, he attended Northeastern University at night and received a master's degree in sanitary engineering in 1975. He obtained his first professional engineering registrations in Maine and Massachusetts in 1974. He accepted an overseas assignment with Metcalf & Eddy in 1975 and worked in Saudi Arabia on a variety of water supply and wastewater treatment projects from 1975 to 1978. When returning to the States in 1978, he moved to Redlands and accepted a position with Metcalf & Eddy in their newly opened San Bernardino office. He obtained his professional engineering registration in California and later in Arizona and Nevada.

In 1986 he accepted a job with the City of Redlands and served as the Director of the Municipal Utilities Department, responsible for the City's water and wastewater facilities from 1986 to 1989. He rejoined the consulting engineering world in 1989 with the international environmental consulting engineering firm of Camp Dresser & McKee (CDM) in their Ontario office. He retired from CDM in January of 2012.

While at CDM he managed the design of several major projects for public agencies including the Groundwater Replenishment System for Orange County Water District, which is the largest indirect potable recycling treatment system in the world. He also managed the design of other projects including: a major wastewater treatment project for the Orange County Sanitation District, the Owens Valley Dust Mitigation Project for the Los Angeles Department of Water and Power, and the Machado Lake Ecosystem Rehabilitation project for the Los Angeles Bureau of Engineering.

He is active professionally. He served as President of the San Bernardino-Riverside Branch of the American Society of Civil Engineers and on the Board of Directors of the California-Nevada Section of the American Water Works Association. He has also served for over 20 years as the Southern California representative for the American Academy of Environmental Engineers.

Locally he has served on the Board of Directors of the San Bernardino Valley Water Conservation District since 2005, and has been the President of the Board since January 2012. He is also a Board Member of the YMCA of the East Valley and currently chair of their Asset Committee.

He and his wife Colleen raised three children in Redlands – all of them RHS graduates.