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Well Decommission, Policy, Processes, and the Urban Environment

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Abstract: An afterthought in many well construction and design plans is the regulatory compliant destruction or decommission of the well at some point in the future. Agricultural lands that evolved into urban areas in southern California are likely to have thousands of lost or unmanaged wells. For the general public, landowners, and others these wells pose safety, environmental, logistical, and monetary issues. This discussion will cover regulatory guidelines, procedures, and case examples of well decommissioning. In California, regulations for well destruction are rooted in Department of Water Resources bulletins, state water code, legislation, local ordinance, and drilling contractor licensing compliance. In most cases the county departments of public health take the lead role for permitting and enforcing well destruction requirements. Well terminology used can be misleading; for example, by state law, an abandoned well is a noncompliant hazard- not a safely destroyed or decommissioned well adhering to standards. Permitted well decommission typically involves cement-bentonite sealing and casing perforation. With the goal of effective prevention of surface liquid intrusion or aquifer cross contamination, sometimes explosives, over-drilling, and other practices are applied. Challenges are frequent in locating and decommissioning abandoned wells. Lost records lead to reconnaissance, geophysical investigations, and excavation of unintended anomalies. Urban development may surround an abandoned well within a structure, foundation, or utilities. Environmentally sensitive areas will affect standard techniques. With increasing water demand and urbanization, effective well decommission is important for analysis and regulatory emphasis.

Keywords: *destruction, abandoned, shot perforation, California Water Code, permits*

This discussion considers the problem of abandoned or unmanaged wells, reviews common terminology, regulations, well decommission practices, and provides program case examples of well decommission. Emphasis is mainly on water well decommission, as these are the types of wells directly associated with water resources and often have larger casing diameters and open internal designs that can increase potential environmental and/or safety hazards. However, in practice, many other well types in addition to water wells are encountered in an unmanaged condition.

Applicable experiences of the author are mostly within the state of California regulatory environment, thus some definitions, accepted procedures, and compliance matter examples given will not apply directly in other states. However, the practices, issues, and technical aspects of well decommission are universal. Regulatory programs administered in all U.S. states and counties are logically similar or identical in technical implementation. Abandoned well safety, environmental, and water resources issues affect almost all urban areas internationally.

Overall, the importance of well management programs for large land owners, property managers, utilities, municipalities, and water supply operations is encouraged, and awareness is advocated for all those who work with wells. University students and faculty usually do not cover well decommissioning in detail, but it is an extremely important technical topic to consider in limiting contamination between stacked aquifers, in addition to addressing public safety hazards in our growing urban environment. Although well destruction in an ideal case gives the appearance of a simple procedure, most professionals realize that the practical complexities of effective and compliant well destruction in multi-aquifer systems, environmentally sensitive locations, urbanized areas, and other situations are challenging and surprisingly complex.

Unknown wells are commonly discovered during field reconnaissance by trained personnel or from a government records review of large land areas in urban or agricultural areas. These will often be water wells, but also might include oil wells, monitoring wells, grounding wells, cathodic wells, injection wells, and dry wells for water drainage, among others. Regulations for compliant destruction or decommission of wells are in-place, but often are unknown, not enforced, or were not correctly applied by former well owners when property was vacated. When a well ends its useful service life, active regulations require that it be destroyed. The cost of compliant well destruction is another factor that may cause some well owners to forget the unmanaged wells. Aside from the cost of material and drilling contractor expertise, well decommission agency permit fees typically exceed $1,000 per individual well.

With over 800,000 documented well completion records in California Department of Water Resources files, it is likely that thousands of unmanaged deep holes/wells without any discrete known location exist throughout the environment. The lost or unmanaged well problem is present in all states and internationally. As rural areas continue to urbanize, these unmanaged or abandoned wells present safety, environmental, financial, and water resource management challenges.

The urban environment increases the possibility that unmanaged wells will act as conduits for organic and inorganic contaminants into potable groundwater supply. Spills and industrial chemical or domestic waste storage can find rapid transport through damaged abandoned wells and vertical groundwater gradients are increased as deeper wells are installed to avoid surface contaminated waters. The issue has been recognized by the groundwater scientific community for some time and the political structure has been established to mitigate groundwater contamination through programs including well decommission and permitting. Some of these statutes are discussed in the following section.

Environmental Policy and Regulatory Framework

A basis for well management in California is Department of Water Resources Bulletin 74-81 and the updated Bulletin 74-90 (California Department of Water Resources 1981, 1990, 2013). These well standards documents cover well design, construction, renovation, and destruction of wells including water wells, monitoring wells, and cathodic protection wells. The standards given in Bulletins 74-81 and 74-90 have been adopted by the State Water Resources Control Board pursuant to California Water Code Section 13801. For state wide implementation, under the Water Code, a Model Well Ordinance was established in 1989. The judgment defines required minimum standards for wells in California, and it includes permitting and enforcement authorities for state and local agencies. If a local government does not adopt an ordinance that meets or exceeds the standards, the state Model Well Ordinance 13801 will apply and take effect within the local jurisdiction. In the majority of California, the county government has established local ordinance that meets or exceeds the minimum well standards to regulate compliance. In other states, and internationally different but similar codes and practices have been established to protect the public and environment from unmanaged wells (American Water Works Association 1984; Gordon and Koch 1988; Kraemer et al. 1991)

Well permits are required by the regulatory agency for initial well construction, renovation, and final destruction. When planning the construction, renovation, or destruction of a well, the county in which the well is located should be contacted to begin the permitting process. County staff will advise if a separate local agency has adopted an ordinance for jurisdiction. If a local city agency has taken well permit authority by court ordinance, no additional county permit should be necessary. In some less common cases, a city or local governmental authority holds an aspect of well permitting authority via ordinance and may require a well permit in addition to the county. The legal basis for this is unclear, but in some cases it might reflect the addition of more stringent local standards related to business use or zoning that is not captured in the county permit.

In adjudicated groundwater basins in California, the Watermaster may also have a stake in water well decommission permitting in accordance with administrative orders, local

court, or administrative board judgements. For example, the Main San Gabriel Groundwater Basin Watermaster of Los Angeles County follows this process (Main San Gabriel Basin Watermaster 1992). The Watermaster may also require additional approval, installation permits, renovation permits, and field inspection in advance of well destruction activity. With statewide adjudication of every California groundwater basin coming into effect under the Sustainable Groundwater Management Act, by the 2017 implementation date, additional Watermaster regulation of wells and well destruction-decommission is expected.

An important part of the well legislation regulatory framework, especially for those who are trying to locate or determine prior existence of wells on a property, is the drillers license requirement to submit a Well Completion Report to the State Department of Water Resources whenever a well is installed. California Water Code section 13752 was amended in 2015 by SB 83 to allow public access to these Well Completion Reports. Most of the older Well Completion Reports seldom give accurate well locations, but at least give an indication of an address or cross streets. Other agency file well permits are available; however for older well construction information, the Well Completion Report record is the more comprehensive resource.

Oil, natural gas, and geothermal resources wells that may exist on a property are regulated separately from water wells. These fall under jurisdiction of the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources, "DOGGR" (California Department of Conservation, Division of Oil, Gas, and Geothermal Resources 2015). DOGGR maintains a database of these wells and separate permitting, terminology, and reporting requirements apply. Though not the emphasis of this paper, it should be noted that somewhat similar procedures apply to destruction of DOGGR wells, but the complexity of much greater depth, safety, formation pressures, and environmental issues should not be underestimated. A property manager should explore past ownership and other options to avoid destruction expense if such a well is located on the property.

Well Decommission Terminology, Definitions, and Well Classes

Various types of wells/subsurface excavations may be encountered on a property. The surface appearance, subsurface design, and management requirements are not the same for different wells, but are important factors when considering potential safety or environmental risks associated with well management and destruction. For example, properly installed electrical ground wells, cathodic wells, and geotechnical borings are relatively small in diameter. These wells are cement grouted/closed as part of the installation design or are shallow and grouted immediately following soil sampling. If compliantly installed, when left unattended these permitted well types seldom create eminent environmental or safety issues. For definition, the common well types are given in Table 1.

A source of confusion for a well manager is the use of the term well abandonment or abandoned well. In California an abandoned well has the legal definition of, "any well whose original purpose and use has been permanently discontinued or which is in such a state of disrepair that it cannot be used for its original purpose" (California Department of Water Resources 1981, 1990). An abandoned well is in a non-compliant condition and subject to compliance actions and/or fines from the responsible regulatory authority. Regulations require that an abandoned well must be destroyed/decommissioned. Confusion results when individuals and regulatory agencies use the term abandoned well or well abandonment to describe wells that were destroyed or decommissioned in accordance with the appropriate regulatory procedures, or to describe the actual compliant well destruction procedure. However, the terminology is ingrained and will not be corrected easily, and some states differ in legal definition of the term (Nye 1987; Sara 1987). For clarity, the correct terminology and regulatory difference is good to recognize, and that many entities incorrectly use abandoned well synonymously with compliant well destruction or decommission. If a well owner or manager receives a notice of violation for abandoned wells on their property, with fines and action required,

Table 1. Well Types/Classes.

Well Class	Description
Cathodic protection wells	Wells installed to protect equipment or subsurface piping from corrosion.
Grounding wells/electrodes	Wells installed with in-place conductive copper wire or solid electrode to establish electrical ground for high voltage.
Monitoring wells	Water level, water quality, and environmental sampling.
Oil and natural gas wells	Wells installed for extraction of petroleum or petroleum related products.
Open borings that encounter primary groundwater	Historical wells from poorly managed construction, mining, or exploratory operations.
Soil gas monitoring probes or vapor extraction wells	Typically wells mandated for remediation projects or landfill methane recovery.
Water recharge wells/ injection wells/UIC wells	Water resource replenishment, water drainage, or water disposal.
Water wells	Includes: Production/irrigation/agricultural/industrial/non-potable use water wells/ potable water wells/domestic water wells/fire suppression water supply wells.
Remediation/environmental pumping wells	Generally similar to water wells but have additional considerations and regulatory agency involvement for destruction.

the regulatory distinction of terms is understood. Other definitions or terminology applicable to well destruction practices and this discussion are listed and pictured in Table 2 and Figure 1.

Well Decommission-Destruction Compliant Procedures

Well destruction procedures have the goal of effectively sealing the well casing and borehole to prevent water mixing between discrete aquifer zones and to prevent intrusion of surface waters, liquids, or other contaminants. In a simple explanation, steps include removing equipment, pumps, pipe, and obstructions; evaluating, removing, or perforating well casing; and sealing the well or borehole with cement-bentonite grout. Procedures, grout seals, and techniques for evaluating effectiveness have been noted in other studies (Lamb and Kinney 1989; Edil et al. 1992; Christman et al. 2002).

Securing permits, removing surface infrastructure, clearing downhole water pumps, pipe, and other equipment come first. Unfortunately, in older abandoned wells this equipment is sometimes seized in place and can only be partially removed and cut to a certain depth. In these cases, a mitigated solution is reached in collaboration with the permit agency and the later procedure steps are modified in a way that adequately protects the environment.

Before destruction, perforation, or sealing procedures, a cleared well is investigated to determine its condition, details of construction (if unknown), and whether there are obstructions that will cause bridging and interfere with the process of filling and sealing. This may include bailing the well of turbid fluids and video inspection of the well. If no construction records are available for a well, the permit agency will typically require a videolog to locate screen or perforation zones. The videolog assists in determining casing condition and zones that will be targeted for mechanical perforation or penetration with explosives.

The acceptable sealing procedure will depend on well design, depth, casing diameter, and site

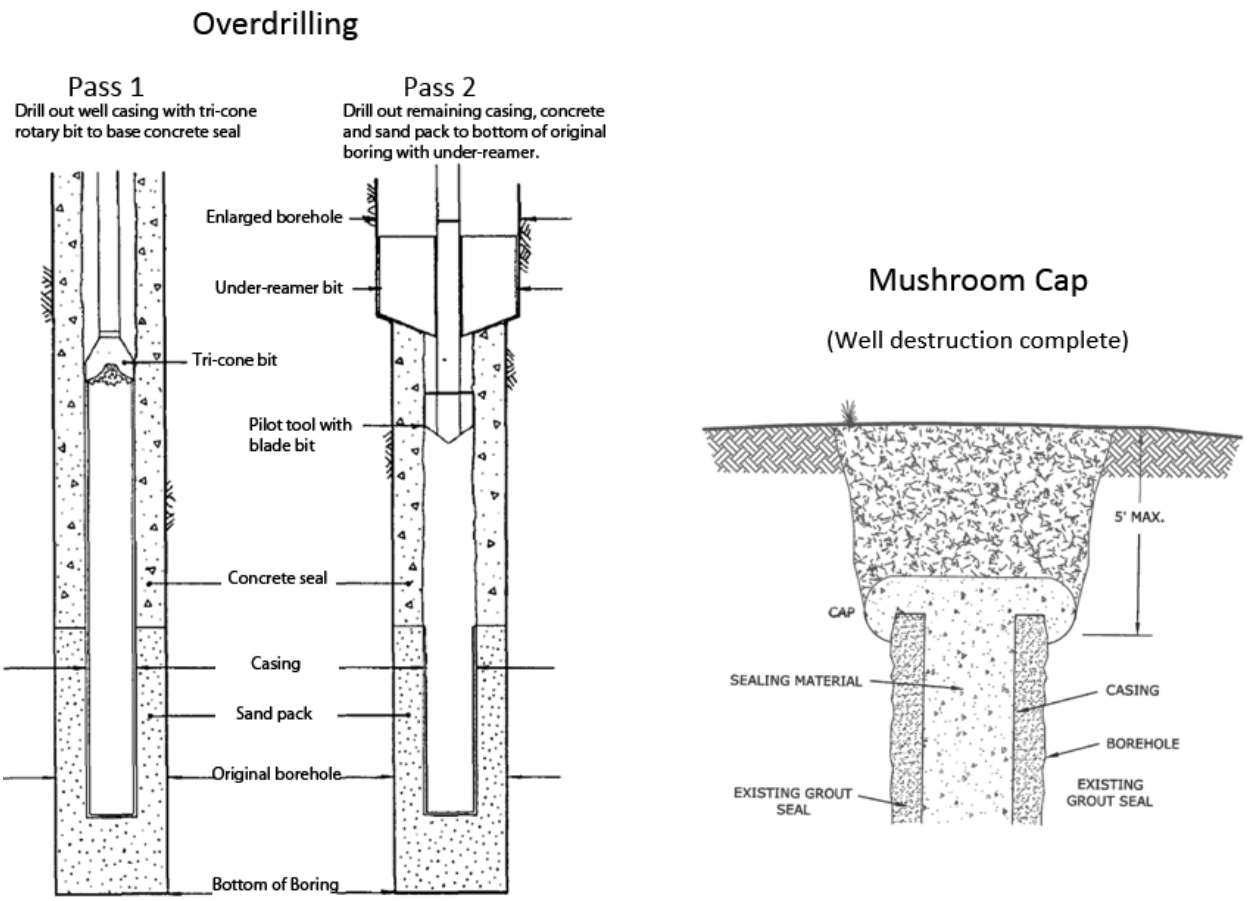


Figure 1. Overdrilling and Mushroom Cap, well destruction step examples. Redrawn from Lamb and Kinney 1989 and California Department of Water Resources 2013.

specific conditions. In advance, the volume of grout needed to fill the well bore and gravel pack zone is calculated. Shallow wells or dry wells are generally acceptable for simple pressure grout techniques or casing pull and pressure grouting of the remaining borehole. In all cases the grout is emplaced from the bottom of the well upward using tremie pipe methods (in other terms, the grout is not allowed to free-fall into the well). The delivery method is appropriate for quality grout seals that need emplacement underwater. Small diameter wells of relatively shallow construction are good candidates for overdrilling techniques in which larger diameter hollow stem augers are advanced. After target depth is reached, the casing is pulled and the remaining borehole is pressure grouted. Overdrilling steel casings with rock bit tools for decommission can be difficult, costly work, but in some situations necessary.

In the current technical, regulatory, and business environment, the preferred sealing procedure for deeper, large diameter water wells involves filling the well bore with grout and applying explosive perforation charges via wireline at set intervals. Use of explosives in well work and decommission is not new but the advantages have been noted (California Department of Water Resources 1990; Cawley 2005). Additional grout is added immediately after the charges are detonated. The grout volume delivered using this technique is usually considerably more than what is calculated to fill void space, so an effective seal is assured. Some agencies require the explosive perforation method in California if no records of well construction details are available. Mechanical casing perforation followed by pressure grouting is applied when required to assure sealing or when other considerations do not allow use of explosives.

Table 2: Well Decommission Procedures and Terminology Definitions.

Procedure or Terminology	Definition
Cement-bentonite grout	Well sealing material composed of standard C150 Portland cement and approximately 5% bentonite. It is commonly applied in subsurface well sealing and destruction.
Tremie pipe	The tremie concrete placement method uses a tremie pipe, through which concrete is placed below the water level in a well. The tremie pipe extends to the bottom of the well and is raised as the grout fills the well. The lower end of the pipe is kept immersed in fresh concrete so that the rising concrete from the bottom displaces the water without washing out the cement content, and standing liquid in the well is displaced. The method allows void free sealing of a well.
Pressure grouting	The simplest compliant well destruction method that involves pressure emplacement of wet cement-bentonite grout by tremie pipe.
Shot perforation	Perforation of well casing to allow thorough penetration and grout sealing of well and borehole void spaces. The procedure involves shell shots within a well to be destroyed or synchronized explosive charges.
Mechanical perforation	Mechanical perforation of well casing involving “mills knife” steel cutting tools or similar metal cutting or perforating devices of mechanical means.
Mushroom cap	The inverted conical or mushroom shaped cement grout cap emplaced at the top of a grout sealed well casing. The cap is emplaced after well casing is cut at least three feet or more below existing surface grade. In the subsurface, the shape helps deflect potential polluting liquid accumulation in the area above the former well with an impermeable cap.
Overdrilling	Involves complete removal of a well casing by drilling on top with oversized hollow stem augers or by combinations of hard rock bit pulverization of existing well casing. The overdrilled borehole is pressure grout sealed when casing is removed to the target depth.

In some cases, a well found abandoned may have future value to be reactivated for beneficial water use or monitoring purposes. In this situation, an intent for future use may be filed with the agency and, thus, it is assured that the well is appropriately secured for safety and environmental protection. Exercising this option is usually only feasible when the subsurface construction design is known. California agencies do not allow wells with questionable annular seals to be reactivated or remain in place without action. Reactivation may require relatively expensive neutron logging in addition to video and other geophysical logs to evaluate whether the annular seal emplaced during original construction is adequate.

Case Examples: Well Management

The example case of well management for this study is one adopted by a California electric utility. The author is employed as a project manager with the utility, with responsibilities including managing well standards and well decommissioning. The utility is a large land owner in California and the land is generally associated with electric power transmission corridors and electrical supply operations locations. The utility has an operational history of over 100 years, and urban development in the region has grown significantly. In 2012, the inventory of known wells owned by the utility mostly fell under the categories of electrical grounding wells, cathodic wells, and in some cases water wells where limited infrastructure existed to supply industrial water, irrigation, or drinking water. Environmental monitoring wells installed for due diligence or managed under specific regulatory directives made up another large portion of the utility well inventory. The known wells were managed relatively independently and effectively within the utility operating units.

However, in 2012, fifteen unmanaged water wells were discovered abandoned on utility property by the regulatory agency in active urban locations. The wells were found beneath power lines within transmission line corridors or within adjacent utility-owned land leased to others. Farms, plant nurseries, and similar businesses were often present, or had been operating. The wells were in varying states of condition and their exact origin was unknown. Some of the wells were apparently on the land when the utility purchased it, others may have been installed possibly illegally by others and left behind when the property was vacated. In any case, the finding revealed that the utility owned, by default, far more wells than was previously realized and that along with this ownership came regulatory, environmental, and safety responsibilities. Examples of unmanaged wells are shown in Figure 2.

The finding of previously unknown and unmanaged wells triggered immediate action to secure those that posed potential environmental or safety hazards. Following the temporary securement, assessment, permitting, and qualified contractor assignment, the abandoned wells identified by the agency were destroyed under approved permits in 2013. Concurrently a well management program was established by the utility to centralize the well inventory, evaluate government records, and field check utility lands to locate unmanaged wells. Under the program many additional unmanaged wells of unknown origin were identified to exist or formerly exist on the utility property. Steps were taken to field locate the additional wells, leading to many being found and destroyed/decommissioned. The well management and decommissioning program has continued and wells have been field identified, secured, and decommissioned annually since the initial program work was established in 2013.

Establishing well management and installation policies to prevent occurrence or reoccurrence of future well issues is advisable to land managers. Not granting license to third party lessees to install wells is a mitigating recommendation to land managers. There are offsetting exceptions that might allow a well installation, but they should be considered carefully and with knowledge of the encumbrance to the property and potential environmental dangers associated with insolvent or irresponsible lessees. As is clear from the proceeding and following examples, wells installed on a property come with significant long-term management obligations.

Finding the location of unmanaged wells based on available references can be problematic. Agency records will exist that reference locations that cannot be found in the field or give the same well identification at different locations. Older records seldom give discrete locations and even relatively recent records may be flawed. The well may have been backfilled or grouted without permit record, may have already been destroyed under a different well name, or was buried, or otherwise obscured. In some cases, the well is lost or has dubious existence and all that can be done is to save the reference information in case construction or development encounters it in the future.

In the case study, some of the abandoned buried wells have been successfully located with the aid of geophysical surveys. The surveys considered practical for locating well-type structures include electromagnetic (EM), magnetic, and ground penetrating radar (GPR). Steel casings can be detected using an EM instrument (buried metal detector) or a magnetometer (which measures the strength of the earth's naturally occurring magnetic field). The magnetic anomalies can be investigated by shallow digging. Magnetic techniques are especially effective in unpaved, unimproved areas with good egress. Other buried metal items like light bases or pipes can result in excavation of false anomalies. However, impressive results have been yielded when interference is minor and the well actually exists within the survey area. In other cases, a GPR survey may be used when the well can be of non-metal construction. Due to cost considerations, a GPR survey is most effective when focused on a few key areas of a possible well site (Shortt 2010).

Destruction or decommission of unmanaged wells in urban areas presents other procedural and logistic challenges. Buildings, roads, freeways, and rail lines may be installed near or on top of wells; abandoned wells are commonly looted of metal, vandalized, and other equipment is left in a potentially hazardous state. Homeless camps develop around or near many abandoned wells, increasing public danger and making access difficult

or dangerous for well workers. Increased chances for pollution or waste disposal issues in the area of the well can be expected in these urban situations.

Additionally challenging are abandoned wells found in land that has become a designated critical area for biological habitat, archaeological significance, or those that require special federal waterway permitting before field work may begin. Two 2014 abandoned case well locations for the utility-adjacent urban areas also had this environmental permitting factor to consider. Frequent access to the wells by teens and the transient community aroused public complaints and triggered agency calls for action. The wells, however, were also in a flood zone biologically sensitive area, and required archeological work to meet regulatory requirements before destruction-decommission could proceed. The options were evaluated, reviewed with the applicable agencies, and helicopter equipment and material unloading/loading was selected as the most cost-effective method to accomplish the work. Creation of temporary roads and permits would have resulted in long-term studies, a prolonged schedule, and may have required significant mitigation of separate land areas. Other variations of options proved to have similar issues and were cost-prohibitive or unacceptable from a regulatory perspective. In addition to the equipment drops, the helicopter was applied to directly lifting pump and pipe from the wells (Figure 3).

Conclusions

In summary, well management and regulatory compliant destruction or decommission of wells is worthy of additional attention from the environmental, industrial, technical, and regulatory communities. While in the simplest sense well decommission may be dismissed as filling an open hole in the ground with concrete, in reality it is much more complicated. Deep wells penetrating many aquifer zones and other wells with unknown designs, as well as environmental, archeological, safety, permitting, and surface issues, add to the procedural complexity. New laws and technical procedures have developed in well decommissioning since the 1980's; newer unique procedures including explosives, casing perforation, and applications of helicopters are discussed in the case study of this manuscript.

Larger commercial organizations, landowners, and government land managers could benefit by establishing internal well management programs to alleviate potential issues as the utility in the case study presented has done. Those who install wells or knowingly or unknowingly come to own wells, hold the long-term responsibility to safely and compliantly destroy the wells at a future time. Major oil and gas companies may already have well management programs, but reconsideration is needed based on notable poorly managed wells that have failed recently resulting in catastrophic gas and oil releases with environmental, safety, and financial consequences.

Existing regulations in California and elsewhere provide a good framework and guidance for safe and effective decommission of wells. The California State Water Resources Control Board has established a model ordinance that includes well decommission and management practices. However, in some instances, jurisdiction is not clear and permits overlap between municipalities or are duplicated. Regulatory staff experience with wells and availability to review and consider permit approval may be limited. County governments and environmental or public health departments are the agencies primarily responsible for regulation and enforcement of well standards in California and may be contacted for advice if matters of jurisdiction are in question. The well regulations are not unique; generally they are similar throughout the U.S. and in most cases the compliant procedures can be determined and implemented in collaboration with the agencies.

With increasing urbanization and dwindling surface water resources, groundwater will continue to grow in importance, and with thousands of lost or unmanaged wells in California alone, water quality is at risk. Well decommission is an important component of water resource management and the volume, variety, and surface appearance of well types already present in the environment often is unrecognized. It is the author's desire to raise awareness of the issue, help educate those who may not recognize a well in the field, and advocate well decommission practices and programs that are protective of safety and the environment.



Figure 2. Case study abandoned well examples, 2012.



Figure 3. Well decommission heavy lift helicopter assisted well pump and pipe removal, 2014. On left: Rigging to lift well turbine pump and pipe. On right: Lifting to remove from well.

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