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Executive Summary: Recommendations on Model Criteria for Groundwater Sampling, Testing, and Monitoring of Oil and Gas Development in California

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Executive Summary
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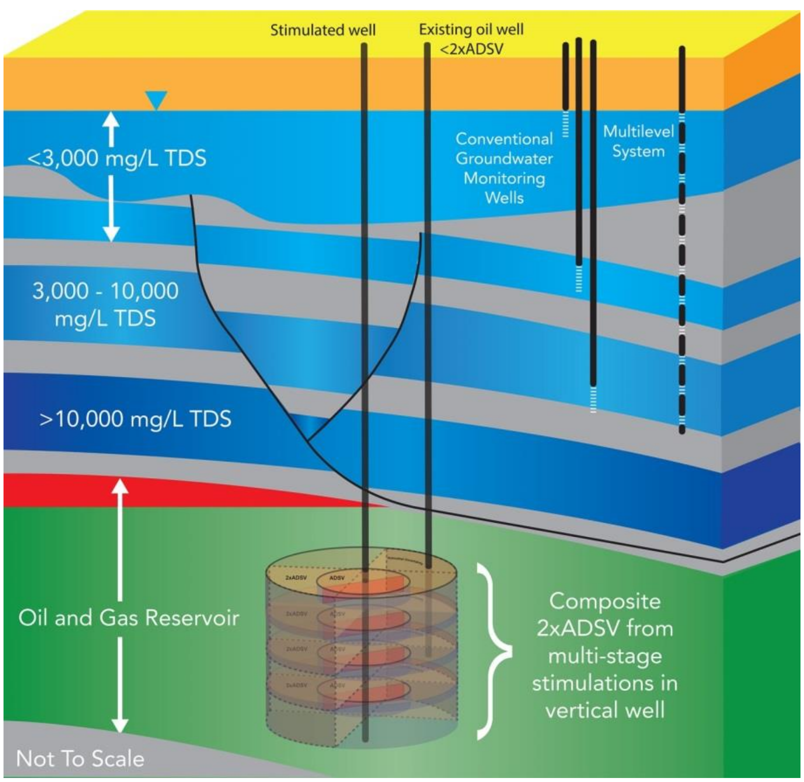

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EXECUTIVE SUMMARY

California Senate Bill 4 (Pavley, 2013; hereafter referred to as "SB4") was passed in response to public concerns about the environmental impacts of oil and gas well stimulation. A focus of these concerns was potential degradation of groundwater used as a supply for drinking water or agricultural irrigation by chemical additives injected into the subsurface during the hydrofracturing process and by chemicals associated with produced water generated by stimulated wells during oil production. SB4 was designed to address these concerns by mandating "strategic, scientifically based groundwater monitoring" of the state's oil and gas fields.

To protect the State's groundwater resources and to allay public concerns, the bill required that the State Water Resources Control Board (State Water Board or SWRCB) develop criteria for groundwater monitoring at scales from single well to regional. SB4 required that the criteria include guidance on the design of groundwater monitoring networks, on which water quality constituents to monitor, and on the frequency and duration of groundwater sampling. The bill also required that, in developing these model criteria, the state seek the advice of experts. This report provides expert recommendations from single wells (area-specific) to regional groundwater monitoring model criteria.

Recommendations for Area-Specific Groundwater Monitoring Model Criteria

In this document, we use "area-specific" monitoring to refer to both "well-by-well" monitoring and to monitoring of a closely spaced set of stimulated wells within a small area. The document recommends requirements for a groundwater monitoring plan for a stimulated well or for a tightly clustered set of stimulated wells. Chapter 6 contains both recommended area-specific groundwater monitoring criteria and a discussion of these criteria.

Groundwater monitoring of well stimulation in California: The challenges in designing a groundwater quality monitoring network for well stimulation in California on either an area-specific or regional scale are enormous. Oil and gas well stimulation occurs at depths that are generally deeper than protected groundwater resources. While the stratigraphy of shallow fresh water zones and deeper oil and gas zones is often known, information relevant to contaminant transport in intervening zones is often unavailable. Oilfields are dynamic with temporally and spatially variable pressure gradients. In fields with long histories of development, legacy impacts from previous drilling, production and other operations on overlying protected groundwater resources may complicate detection of impact from current operations. These fields may also contain active, inactive or abandoned wells in close proximity to the stimulated well being monitored; and the integrity of these nearby wells may or may not be known. And to the extent that wells act as pathways for the migration of liquids and gases, all protected groundwater aquifers overlying hydrocarbon producing zones across depths of up to thousands of feet are potentially at risk. All of these factors and more combine to make designing a site-specific and risk-based groundwater monitoring network extremely difficult.

Adding to the challenge is that very few examples exist where purposeful groundwater monitoring networks have been created to assess impacts by well stimulation on the groundwater resource, and no examples exist where such networks are required by a regulatory program. Several expert panel reports on the environmental impacts of shale gas development in the USA, Canada, Australia, and Europe have all recommended groundwater monitoring, but none of the reports have indicated where and how such monitoring should be accomplished. Whatever information exists about the impacts of petroleum resource development comes from the sampling of household wells, farm wells, municipal wells, and springs.

SB4 requires, however, that well-by-well groundwater monitoring be conducted for all new well stimulation projects. Beginning in July 2015, before a well stimulation can proceed, a groundwater monitoring plan must be submitted to and approved by the State Water Board. The challenge then is to develop a scientifically credible approach to this permit-required monitoring in the absence of experience from similar regulatory programs elsewhere in the nation or world.

Groundwater monitoring network design: The design of a groundwater monitoring network (where and how to place monitoring wells, how often to collect groundwater samples, and what to analyze) is contingent on the purpose of the groundwater monitoring. Several types of groundwater monitoring exist. A common type of groundwater monitoring for a process or source that has the potential to contaminate groundwater, but has not been demonstrated to be leaking, is termed “detection monitoring”. Landfills are often required to have detection monitoring networks in place to provide early detection of leakage. We do not recommend this type of monitoring for well stimulation in California. Such an approach requires knowledge of contaminant pathways and of local hydrology and hydrogeology in order to design a monitoring network and the installation of numerous monitoring locations to be effective. We currently don’t have such knowledge and the cost and expense of installing an early-detection groundwater monitoring network on a well-by-well basis would be prohibitive.

We do recognize a need for groundwater monitoring, however, and recommend monitoring and baseline characterization of protected groundwaters overlying and adjacent to stimulated well operations. The goal of this form of monitoring is not early detection of impact sufficient to identify leakage from an individual stimulation, but rather detection of current or legacy impacts related to well stimulations on a protected groundwater aquifer. Critical to demonstrating impact is having adequate characterization of baseline water quality, including spatial and temporal variability. Establishing baseline and baseline variability is crucial for chemical constituents that occur naturally and for oil and gas related chemical constituents in areas with a long history of oil and gas development. The recent draft EPA Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources states that "*baseline data on local water quality is needed to quantify changes to drinking water resources and to provide insights into whether nearby hydraulic fracturing activities may have caused any detected changes*" and states that a limitation of the assessment is "*insufficient pre- and post-hydraulic fracturing data on the quality of drinking water resources*".

An additional benefit of area-specific monitoring will be in characterizing the spatial distribution of groundwater resources with potential beneficial use. The occurrence, depth distribution, and vertical hydraulic communication of groundwaters with between 3,000 and 10,000 mg/L total dissolved solids (TDS), in particular, is poorly known.

We also recommend sentry monitoring for existing water supply wells within one mile of the well stimulation through the installation of guard well(s) located between the stimulation well and the water supply well, as well as setting up to monitor the aquifers accessed by water supply wells.

Protected groundwater: We recommend monitoring groundwater of less than 10,000 mg/L TDS in an aquifer that produces or could produce water in sufficient quantity for beneficial use and that is not excluded from groundwater monitoring by written concurrence from the State or Regional Water Board. California is in the midst of a historic drought and any water with the potential for beneficial use should be protected. The limit of 10,000 mg/L TDS aligns with federal regulations concerning Underground Injection Control and is technically and economically feasible to desalinate. We also recommend that area-specific groundwater monitoring plans include information on the vertical profile of groundwater salinity in aquifers overlying the stimulated zone.

Risk-based groundwater monitoring: We recommend that monitoring of protected groundwater for impact from well stimulation consider three risk factors: the vertical separation between the base of protected groundwater and the stimulated zone, the presence of potential pathways (wells and transmissive geologic features) in close proximity to the stimulated well, and the density of previously stimulated wells in the immediate vicinity of the stimulated well (Table 6.1). We also recommend that monitoring be tiered on the basis of the quality of the groundwater being protected. We recommend monitoring higher quality water (groundwater with less than 3,000 mg/L TDS that qualifies for a municipal or domestic water supply beneficial use) more intensively than lower-quality water (groundwater with between 3,000 and 10,000 mg/L TDS that qualifies as protected groundwater).

We recommend that, for the purpose of identifying potential contaminant pathways and assessing vertical separation, a conservative estimate of the extent and orientation of fracturing during well stimulation be used, and we propose how to conservatively estimate stimulated volume (which we term the Axial Dimensional Stimulated Volume or ADSV) based on the operator-submitted Axial Dimensional Stimulation Area (ADSA). We recommend using the conservatively defined ADSV to identify potential pathways (i.e., wells and geologic features) in close proximity to the stimulated well and to assess whether these vulnerabilities, including vertical separation, pose an unacceptable risk to protected groundwater resources. We recommend allowing the operator to propose a less conservative estimate of stimulated volume using field data relevant to stress orientation and fracture azimuth for the strata being stimulated, but reserving for the Water Board the final decision on which estimate of stimulated volume will be used.

We believe that one of the more significant potential contaminant pathways is transmission through wells in close proximity to the stimulated well, especially wells that have not been adequately sealed or properly abandoned. We recommend that for wells within close proximity (2 x ADSV) to a stimulated well, the Board require cementing of the outer annular space along the entire length of casing from a regional seal or aquitard below the base of protected groundwater to the ground surface. Wells that do not meet this standard would be considered to be “likely” pathways.

The density of previously stimulated wells in close proximity to the stimulated well being monitored is also a risk factor. Everything else being equal, risk to protected groundwater will scale with the density of stimulations, and the legacy stimulated well densities in California vary by orders of magnitude.

Ground monitoring network configuration: In consideration of the risk factors, we recommend that all new well stimulation projects be required to monitor a low-salinity (0-3,000 mg/L TDS) aquifer with the highest quality water (i.e., lowest salinity), and that all new stimulation projects (with the exception of exploratory wells with no wells or geologic features in close proximity) also be required to monitor an aquifer near the base of the protected groundwater (3,000-10,000 mg/L TDS) zone. For stimulated wells in higher density fields (i.e., wells with >50 previously stimulated wells within ½ mile), we recommend requiring monitoring of an additional third aquifer at the base of the freshwater (0-3,000 mg/L TDS) zone. High-quality freshwater aquifers are the most likely to be used for domestic, municipal, or agricultural water supply and are the most sensitive to degradation. Protected groundwater aquifers closest to the stimulated zone will likely be the first to be impacted by transport of injected fluids through transmissive geologic features or by upwelling or migration of formation fluids out of the hydrocarbon-producing zone into shallower protected groundwater zones through a breach in caprock or confining layers.

For proposed stimulated wells in close proximity to likely pathways, i.e., to geologic features known to be transmissive or to existing wells that cannot be demonstrated to be adequately sealed or abandoned, we recommend additional review of well integrity, site hydrogeology, and potential future use of the aquifers. Based on an assessment of risk, we recommend not allowing well stimulation to proceed unless pre-existing wells are adequately sealed or allowing well stimulation to proceed with monitoring of additional aquifers.

For each aquifer monitored, we recommend requiring one upgradient and two downgradient locations. A single well or location rarely provides information sufficient for groundwater protection. We recommend that the locations be within ½ mile of stimulated wells with existing wells or geologic features in close proximity or within 1 mile of stimulated wells with no potential pathways in close proximity. For stimulated wells in high-density fields (i.e., with more than 50 previously stimulated wells within ½ mile) with existing wells or geologic features in close proximity, we recommend requiring more than three monitor locations at the discretion of the Water Board. Legacy impacts in densely drilled fields may result in spatially variable water quality in protected groundwater aquifers and require more monitoring wells to adequately characterize the spatial variability.

The recommendation to use one upgradient and two downgradient monitoring wells within ½ mile of the stimulated well is a minimum configuration. We recommend allowing operators to submit alternative groundwater monitoring plans when sufficient data are available to develop a credible site conceptual model.

We recommend installation of either traditional monitoring wells with screens up to fifty feet in length or engineered multi-level systems. We do not recommend the use of nested wells (multiple wells in a single borehole) because the integrity of seals between nested wells in such systems is difficult to construct and verify.

Tiered Analysis of Chemical Constituents: We recommend a tiered approach to monitoring of analytes in which all groundwater samples are analyzed for a suite of chemical constituents (Tier 1 constituents) and, if statistically significant changes in water quality consistent with impact by well stimulation are observed, a second set (Tier 2) of chemical constituents are analyzed that are focused on site-specific well stimulation chemical additives but are more analytically challenging than Tier 1 constituents. Tier 1 constituents include total dissolved solids; major and minor anions (e.g., Cl^-, Br^-, I^-, F^-) and cations (e.g., Na^+, Ca^{2+}, K^+, NH_4^+); trace elements (e.g., barium, boron, lithium, strontium); regulated metals and metalloids (e.g., arsenic, copper, chromium, selenium), organic compounds (e.g., benzene, toluene, ethylbenzene, xylenes, naphthalene), and radionuclides (e.g., Ra-226, Ra-228, uranium); methane, ethane, and propane; total petroleum hydrocarbons; the isotopic composition of carbon in methane and of hydrogen and oxygen in water; commonly measured field parameters; and indicator compounds. A key assumption is that impact by injected or produced fluids associated with well stimulations will have a detectable effect on more than one of the chemical constituents on this list. Table 6.2 discusses each class of compound and the rationale for inclusion on the Tier 1 list.

The interim regulation in California required the analysis of a suitable chemical indicator of well stimulation treatment fluid but did not specify such indicators. We recommend analysis of guar gum sugars. Guar gum is commonly used in large quantity in gel-based hydrofracture operations and analysis of guar gum sugars is simple and inexpensive. We also recommend the analysis of two additional compounds to be proposed by the operators with the concurrence of Water Board staff. One compound shall be chosen on the basis of high mass use in the stimulation well being monitored, and a second compound shall be chosen on the basis of high persistence during subsurface transport.

Should chemical additives be detected or should changes in water quality consistent with impact from produced waters be observed, we recommend that samples be collected and analyzed for toxic well stimulation additives, such as biocides, alcohols and glycols, and surfactants. Additional analyses could also include other indicators of impact from well stimulation, such as the isotopic composition of carbon in dissolved inorganic carbon, the isotopic composition of dissolved lithium, boron, sulfur, and strontium; and the concentration and isotopic composition of dissolved noble gases.

We recommend groundwater sampling of each monitoring well before the well stimulation and then semi-annually for at least three years after the well stimulation.

The Need for Database and a Georeferenced Repository: We recommend 1) the submission of groundwater quality data in a timely manner as Electronic Data Deliverables (EDD) and as spreadsheets to a State-maintained database with the goal to provide transparency, and 2) that the data be easily accessible to the public and water resource community and that it support investigations, assessments and research relevant to oil and gas development impacts on groundwater quality. We also recommend the development of a publicly accessible georeferenced repository linked to the water quality data for all hydrogeologic, geologic, and geophysical data or other information gathered or submitted in area-specific groundwater monitoring plans.

The Need for Periodic Review: We recommend that the area-specific groundwater modeling criteria be comprehensively reviewed five years after implementation. The review should consider changes in required monitoring (including the number of aquifers to be monitored; the number of monitoring locations in each aquifer; monitoring well or system construction; sampling protocols, frequency and duration; and chemical constituents to be analyzed) based on area-specific program data and experience over the previous five years, data and results from the regional program, and field-based pilot studies. We also recommend less comprehensive ongoing reviews to address difficulties in program implementation and unexpected results.

The Need for Field-Based Pilot Studies: Field-focused pilot studies are required to advance the state of science sufficiently to allow more robust assessment of the risk that well stimulation poses to protected groundwater resources, to develop better metrics for assessing that risk, and to develop better approaches to monitoring impact. We strongly recommend that pilot studies be an integral component of the monitoring program and be used to inform development of the program over time.

Recommendations for Regional Groundwater Monitoring Model Criteria

Goals of the Regional Groundwater Monitoring Program (RGMP)

We recommend that the regional program not be restricted to monitoring the impact of well stimulation on protected groundwater resources, but should also characterize impacts from all oil and gas activities, including surface and subsurface disposal of produced wastewater.

- The primary goal of the Regional Groundwater Monitoring Program (RGMP) should be to be to establish a current baseline and monitor the impact of all oil and gas activities on protected groundwater resources in the State.
- The RGMP should develop regional-scale conceptual models for protected groundwaters within and adjacent to oil and gas fields.
- The RGMP should establish monitoring networks to detect transport of fluids from hydrocarbon producing zones to protected groundwater aquifers that is related to oil and gas development.
- The RGMP should characterize risks to and impacts on groundwater resources from discharge of oil and gas wastewater to surface ponds
- The RGMP should assess the potential risk of well integrity failures and inadequate seals to protected groundwater quality statewide.

The Protected Groundwater Resource

We recommend that the regional program monitor groundwaters with less than 10,000 mg/L TDS and that the State should implement a program to systematically map this resource.

- The RGMP should monitor groundwater with less than 10,000 mg/L total dissolved solids (TDS) in aquifers that contain a sufficient quantity of water for beneficial use and that are in groundwater basins containing oil and gas fields.
- The State should implement a program to systematically determine the spatial and vertical distribution of all fresh groundwater (< 3,000 mg/L TDS) and protected groundwater (< 10,000 mg/L) in basins containing oil & gas fields throughout the State.

Groundwater Monitoring Systems

We recommend that the regional program install or use dedicated groundwater monitoring systems and investigate the use of deep oil and gas wells for monitoring.

- The RGMP should use or install dedicated wells to monitor protected groundwater, including those in other programs
- The RGMP should consider the use of idle or inactive oil and gas wells as a cost-effective tool for monitoring
- The RGMP should consider using existing water supply wells for monitoring aquifers of beneficial use.

Groundwater Quality Monitoring Constituents

We recommend that the constituents monitored by the regional program be coordinated with other SB4 programs, that water quality data be made available in a publicly accessible *database, and that the regional program have access to produced and injected water. Characterization of the man-made and naturally occurring chemicals in return fluids and produced water from oil and gas wells in different basins in California is essential to identifying impact in protected groundwater.*

- The RGMP should monitor regulated chemical constituents, geochemical and isotopic tracers of source and transport, and anthropogenic constituents indicative of oil and gas development
- Water quality monitoring under the RGMP should be coordinated with other SB4 water quality monitoring efforts.
- The RGMP should have access to injected fluid, produced water, and groundwater samples collected for chemical analysis as a part of SB4 or UIC monitoring programs
- All RGMP water quality data should be submitted to the Water Board in an electronic format that is compatible with the State Board's GeoTracker GAMA database.

Identifying Impact of Oil and Gas Operations on Protected Groundwater Quality

We recommend using multiple lines of evidence for contaminant source attribution, assessing the current distribution of methane in protected groundwater, and assessing aquifer vulnerability through development of regional conceptual models and an improved understanding of well integrity risk factors.

- The RGMP should use multiple lines of evidence to attribute changes in water quality to natural or anthropogenic processes
- The RGMP should actively develop geochemical and isotopic methods to establish signatures that allow attribution of constituent sources and pathways.
- The RGMP should assess the source and distribution of methane in protected groundwater aquifers
- The RGMP should assess the vulnerability of protected groundwater aquifers to potential impact by oil and gas development.

Pilot and Special Studies

We strongly recommend that pilot studies be an integral component of the RGMP. Significant gaps exist in our understanding of the impact of oil and gas development on groundwater resources in California and in how to monitor these impacts. Focused fields studies are absolutely vital to developing better approaches to monitoring; to assessing significant risk factors; and to developing effective mitigation strategies.

- The RGMP should conduct, facilitate and/or participate in focused field or pilot studies in collaboration with industry and with the assistance of a Technical Advisory Committee.
- The RGMP should develop studies to close known data gaps; to improve monitoring of the impact of oil and gas operations on groundwater quality; and to develop better understanding of aquifer vulnerability and contaminant transport. Recommended projects include
    - Investigating the use of inactive oil and gas production wells for groundwater monitoring.

- Investigating the fate and transport of oil and gas development chemical additives and methane in groundwater
- Investigating monitoring methods and defining potential impact pathways for stimulated wells.
- Investigating risk from well integrity failures
- Characterizing the role of aquitards in transport of water and contaminants

Prioritization of oil and gas fields for RGMP

We recommend that the implementation of the RGMP be guided by a coherent and clearly stated set of priorities. California has over 500 active oil and gas fields. The recommendation to monitor the potential impact of all oil and gas operations on protected groundwaters will require substantial effort to design and implement. The criteria below are recommended for consideration in prioritizing initial efforts in the program.

- The RGMP should prioritize monitoring groundwater within and adjacent to fields where well stimulation is currently practiced
- The RGMP should prioritize monitoring based on vulnerability
- The RGMP should prioritize monitoring fresh water aquifers
- The RGMP should consider existing infrastructure and knowledge in its prioritization

Regional Groundwater Monitoring Program Implementation

We recommend that the RGMP use a phased approach to implement the program, compile information from all SB4 monitoring programs into an accessible database, and work closely with a scientific Technical Advisory Committee.

- The RGMP should use a phased approach to the implementation of regional groundwater monitoring with due consideration to characterization and design of pathway-specific monitoring before full implementation of ongoing monitoring.
- The RGMP should compile existing information and develop an information management system for regional monitoring data and models
- The RGMP should periodically review and interpret RGMP data
- The RGMP should establish a Technical Advisory Committee (TAC)