Groundwater/Aquifer Remediation

A Resource Management Strategy of the California Water Plan

California Department of Water Resources

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Acronyms and Abbreviations

BTEX	benzene, toluene, ethyl benzene, and xylene
CASGEM	California Statewide Groundwater Elevation Monitoring
CC	Central Coast
CDPH	California Department of Public Health
CR	Colorado River
CWS	community water systems
DBCP	1,2-Dibromo-3-chloropropane
DNAPL	dense non-aqueous phase liquids
ex situ	treating contaminated gruondwater outside of the aquifer
GAC	granular activated carbon
GAMA	Groundwater Ambient Monitoring and Assessment Program
GHG	greenhouse gas
in situ	treating contaminated groundwater while it is still in the aquifer
IX	ion exchange
LNAP	light, non-aqueous phase liquid
MCL	maximum contaminant level
MTBE	methyl tertiary butyl ether
NC	North Coast
NL	notification level
NL	North Lahontan
NO_3	nitrate
PCE	perchloroethylene
PCE	tetrachloroethylene

RWQCB	regional water quality control board
SC	South Coast
SFB	San Francisco Bay
SJR	San Joaquin River
SL	South Lahontan
SR	Sacramento River
TCE	trichloroethylene
TL	Tulare Lake
UST	underground storage tank
VOC	volatile organic compound

Groundwater/Aquifer Remediation

Portions of aquifers in many groundwater basins in California have degraded water quality that does not support beneficial use of groundwater. In some areas, groundwater quality is degraded by constituents that occur naturally (e.g., arsenic). In many urban and rural areas, groundwater quality degradation has resulted from a wide range of human (anthropogenic) activities.

Groundwater remediation is necessary to improve the quality of degraded groundwater for beneficial use. Drinking water supply is the beneficial use that typically requires remediation when groundwater quality is degraded.

Contaminants in groundwater can come from a many sources, naturally occurring and anthropogenic. Examples of naturally occurring contaminants include heavy metals and radioactive constituents, as well as high concentrations of various salts from specific geologic formations or conditions. Climate change that results in altered precipitation, snowfall patterns, and rising sea levels may exacerbate salt water intrusion and flooding of low-lying infrastructure and urban facilities. These phenomena will add new challenges to protection of groundwater from contamination. In addition, groundwater can be contaminated by anthropogenic sources with organic, inorganic, and radioactive constituents from point and non-point sources. These anthropogenic sources include industrial sites, mining operations, leaking fuel tanks and pipelines, manufactured gas plants, landfills, impoundments, dairies, septic systems, and urban and agricultural activities. The contaminant having the most widespread and adverse impact on drinking water wells is arsenic, followed by nitrates, naturally occurring radioactivity, industrial/commercial solvents, and pesticides (see Table 1).

Groundwater remediation removes constituents, hereafter called contaminants, which affect beneficial use of groundwater. Groundwater remediation systems can employ passive or active methods to remove contaminants. Passive groundwater remediation allows contaminants to degrade biologically or chemically or disperse in situ over time. Active groundwater remediation involves either treating contaminated groundwater while it is still in the aquifer (in situ) or extracting contaminated groundwater from the aquifer and treating it outside of the aquifer (ex situ). Active in situ methods generally involve injecting chemicals into the contaminant plume to obtain a chemical or biological removal of the contaminant. Ex situ methods for treating contaminated groundwater can involve physical, chemical, and/or biological processes.

Active groundwater remediation systems that extract, treat, and discharge the treated groundwater to a water body or inject it back into the aquifer are commonly termed “pump and treat” systems. Remediation systems that extract and treat contaminated groundwater for direct potable, irrigation, or industrial use are commonly termed “wellhead treatment” systems. Any wellhead treatment prior to direct potable use must receive a permit from the California Department of Public Health (CDPH).

In the process of extracting groundwater for remediation, the groundwater flows through the aquifer toward the extraction wells where it is removed for treatment. A number of ex situ treatment methods are

Table 1 **Ten Most Commonly Detected Contaminants at Active Community Drinking Water Wells**

Anthropogenic Contaminants	Naturally Occurring Contaminants
Nitrate (as NO_3)	Arsenic
Perchlorate	Gross alpha particle activity
Tetrachloroethylene (PCE)	Uranium
Trichloroethylene (TCE)	Fluoride
1,2-Dibromo-3-chloropropane (DBCP)	
Carbon tetrachloride	

Source: State Water Resources Control Board 2012.

available to remove contaminants from groundwater and the cost effectiveness of each treatment method should be evaluated prior to selection of a specific treatment method. Ex situ treatment methods can either transfer the contaminant to the atmosphere (directly or after combustion), to an adsorptive media, or to a concentrated liquid waste stream. If a volatile contaminant is transferred from the groundwater to the atmosphere, permits must be obtained from the local air district. If an adsorption media is used, such as granular activated carbon or ion exchange resin, the media may have to be disposed of as hazardous waste and this significantly increases the disposal cost. If the media is regenerated, then the waste residuals which are produced have to be disposed of as hazardous waste. If the contaminant is radioactive or the adsorption media removes radioactive compounds as a co- contaminant, such as uranium, then waste residuals may need to be disposed of as radioactive waste.

Whatever the treatment method listed below (see Table 2), it must be suited to the constituent that has contaminated the groundwater. Light, non-aqueous phase liquids (LNAPLs), such as hydrocarbons, float on the surface of the groundwater. Dense non-aqueous phase liquids (DNAPLs), such as perchloroethylene (PCE), have a specific gravity greater than water and sink to the bottom of the aquifer. Other contaminants, such as methyl tertiary butyl ether (MTBE), may be miscible in water and are in solution in the groundwater. Both LNAPLs and DNAPLs may partially dissolve in the groundwater or be adsorbed on soil particles within the aquifer.

Groundwater Remediation in California

Groundwater remediation in California involves ex situ groundwater extraction and treatment and passive (in situ) remediation, such as biodegradation and natural attenuation. There are approximately 16,000 sites in the state where investigation or remediation of contaminants is ongoing. Regional water quality control boards (RWQCBs), the California Department of Toxic Substances Control, or local agencies have regulatory oversight of these cleanups. The Superfund remediation sites are under control of the U.S. Environmental Protection Agency. About 7,500 of these sites have had a petroleum release from a leaking underground storage tank (UST) system. A petroleum release is usually detected by analyzing for total petroleum hydrocarbons and the more soluble constituents in fuel (benzene, toluene, ethyl benzene, and xylene, commonly called BTEX). In addition to these contaminants, polyaromatic hydrocarbons, naphthalene, and MTBE can be found at former leaking UST sites. Groundwater cleanup at petroleum sites primarily focuses on reduction of BTEX and MTBE because most other components of petroleum are only very slightly soluble in water and do not migrate far from the original source of the leak.

Table 2 **Treatment Methods**

Pump and Treat — Groundwater Remediation
Activated alumina
Biological
Blending
Coagulation/filtration
Granular activated carbon, GAC
Ion exchange, IX
Lime softening
Packed tower aeration (air stripping)
Reverse osmosis, RO
Ultra-violet photo ionization
In situ — Aquifer Remediation
Air sparging
Bio-sparging
Bio-venting
Cosolvents
Electrokinetics
Electron acceptors (nitrate, sulfate, ferric ions)
Electron donors (to degrade chlorinated hydrocarbons)
Fluid cycling
Hydrofracturing/Pneumatic fracturing
Soil vapor extraction
Surfactant enhancements
Thermal enhancements
Treatment walls
Vitrification

Remediation at petroleum UST sites may involve contaminant source removal (soil excavation and free-product removal if applicable). Further remediation can include soil vapor extraction, pump and treat, in situ remediation, or a combination of these methods. Pump and treat methodology tends to be expensive and is not employed if other effective remediation options are available. The discharge from a pump and treat system may also require a discharge permit issued by a regional water quality control board.

Approximately 800 sites in California use pump and treat systems. About one-third of these are at UST sites where shallow groundwater is typically affected. The treated-flow volumes are typically 10 to 20 gallons per minute.

Most groundwater extraction and treatment remediation systems are located at sites where volatile organic compound (VOC) solvents, such as trichloroethylene (TCE) and PCE, have contaminated groundwater. TCE has been used as an industrial cleaning and degreasing agent and PCE is a degreasing agent and has been the primary chemical used by dry cleaners for decades. Because TCE and PCE are DNAPLs in free phase, they tend to sink to the bottom of aquifers or pool on top of low permeability units, they rarely can be excavated and removed from greater depths. Both compounds have low solubilities in water but are considered carcinogenic at low concentrations. Remediation systems to extract and treat groundwater contaminated with such solvents may be required. These systems are expensive to operate and may be required to run for decades. The total volume of impacted groundwater remains unknown.

TCE and PCE are both being removed from groundwater in the San Gabriel Valley of Los Angeles. More than 30 square miles of the valley has been designated as a federal Superfund site due to commercial and industrial discharges contaminating groundwater. Since the San Gabriel basin aquifer supplies more than 90 percent of the water for the valley, the treated groundwater is pumped directly into the public water supply distribution system, provided it meets drinking water quality standards. Table 3 lists other projects for removal of VOCs.

Dry cleaning business operations present a significant threat to groundwater quality. Past practices commonly employed by dry cleaners resulted in PCE being discharged onto the ground at the business site or to the sewer. As many as 15,000 dry cleaning facilities have operated in California. Most of these sites, past and present, are small businesses in urban areas. The owners of these facilities typically do not have the resources necessary to fund an investigation and, if necessary, the remediation to remove PCE. Therefore, relatively few of the current and former dry cleaning sites have been investigated. Remediation at dry cleaning facilities typically involves soil vapor extraction. Where groundwater has been affected, pump and treat systems are employed.

Recent studies indicate that operating, non-operating, or poorly designed water wells and possibly oil and gas wells provide conduits whereby chlorinated solvents spread from shallow to deeper aquifers. The burden of dealing with PCE contamination of drinking water often falls on the water purveyor who pumps the groundwater and who may have to discontinue use of the well or install costly treatment equipment. The cost of dealing with the legacy of dry cleaning operations and other sources of chlorinated solvents is estimated to be in the billions of dollars. Treatment systems to remove PCE and other chlorinated solvents from groundwater may need to be operated for decades.

Perchlorate is used to manufacture solid propellant for rockets, fireworks, and other uses (e.g., production of matches, flares, pyrotechnics, ordnance, and explosives). Aerospace, military, and flare manufacturing facilities have been primary sources of perchlorate. Perchlorate also occurs naturally and has been found in fertilizer imported from Chile. Perchlorate is highly soluble in water and has adverse health effects at very low concentrations in drinking water. Perchlorate is being removed by either ion exchange or biological treatment from the Bunker Hill, Gilroy- Hollister Valley, Rialto-Colton, Sacramento, and San Gabriel groundwater basins. In the Gilroy- Hollister Valley, the groundwater is being treated to reduce/remove perchlorate prior to injection into the shallow aquifer.

Pesticides, especially the agricultural soil fumigants 1,2-dibromo-3-chloropropane (DBCP) and ethylene dibromide, have been found in groundwater in the San Joaquin Valley, Tulare Lake region and in Riverside and San Bernardino counties. Wellhead treatment systems have been installed by water purveyors in several communities.

Arsenic is the most widespread contaminant affecting an estimated 587 community drinking water wells (State Water Resources Control Board 2012). All 10 hydrologic regions in the state have community

Table 3 Community Drinking Water Systems that Rely on One or More Contaminated Groundwater Wells by Hydrologic Region

Regulated Contaminants												
Hydrologic Region[a]		**NC**	**SFB**	**CC**	**SC**	**SR**	**SJR**	**TL**	**NL**	**SL**	**CR**	
Inorganic Chemicals												**Total**
Arsenic	No. of Systems / Wells Affected[b]	12 / 16	9 / 10	21/ 36	26 / 44	41 / 73	58 / 120	62 / 131	8 / 19	41 / 119	9 / 19	287 / 587
Nitrate	No. of Systems / Wells Affected[b]	1 / 3	4 / 10	33 / 51	81 / 270	9 / 9	17 / 26	54 / 75	0 / 0	6 / 6	1 / 2	206 / 452
Perchlorate	No. of Systems / Wells Affected[b]	0 / 0	0 / 0	3 / 3	47 / 166	1 / 1	0 / 0	4 / 4	0 / 0	1 / 2	1 / 1	57 / 177
Hydrologic Region		**NC**	**SF**	**CC**	**SC**	**SR**	**SJR**	**TL**	**NL**	**SL**	**CR**	
Radioactivity												**Total**
Gross Alpha Particle Activity	No. of Systems / Wells Affected[b]	0 / 0	0 / 0	5 / 6	47 / 89	3 / 4	38 / 76	46 / 78	3 / 7	28 / 50	13 / 23	183 / 333
Hydrologic Region		**NC**	**SF**	**CC**	**SC**	**SR**	**SJR**	**TL**	**NL**	**SL**	**CR**	
Volatile Organic Chemicals												**Total**
Tetrachloroethylene (PCE)	No. of Systems / Wells Affected[b]	0 / 0	1 / 2	0 / 0	40 / 141	7 / 10	4 / 4	7 / 10	1 / 1	0 / 0	0 / 0	60 / 168
Trichloroethylene (TCE)	No. of Systems / Wells Affected[b]	2 / 2	1 / 2	0 / 0	38 / 146	0 / 0	1 / 2	2 / 7	0 / 0	0 / 0	0 / 0	44 / 159
Hydrologic Region		**NC**	**SF**	**CC**	**SC**	**SR**	**SJR**	**TL**	**NL**	**SL**	**CR**	
Pesticides												**Total**
1,2-Dibromo-3-chloropropane (DBCP)	No. of Systems / Wells Affected[b]	0 / 0	0 / 0	0 / 0	7 / 29	0 / 0	12 / 28	17 / 61	0 / 0	0 / 0	0 / 0	36 / 118

Source: State Water Resources Control Board 2013

Notes:

[a] Hydrologic regions: NC - North Coast, SFB - San Francisco Bay, CC - Central Coast, SC - South Coast, SR - Sacramento River, SJR - San Joaquin River, TL - Tulare Lake, NL - North Lahontan, SL - South Lahontan, CR - Colorado River.

[b] Wells Affected exceeded a Primary Maximum Contaminant Level prior to treatment at least twice from 2002 to 2010. Gross alpha levels were used as a screening assessment only and did not consider uranium correction.

water systems that are affected by arsenic and must treat their water from affected wells to reduce the arsenic level below 10 micrograms per liter, the current maximum contaminant level (MCL).

Nitrate is considered the second most widespread groundwater contamination problem in California affecting community drinking water wells, primarily due to decades of agricultural application of -nitrogen-based fertilizers. Other contributors of nitrate to groundwater are septic systems, concentrated animal waste facilities (e.g., dairies), and percolation of wastewater treatment plant and food processing wastes. Nitrate-contaminated groundwater can be either treated with reverse osmosis, resin-based processes, or blended with higher quality water before being placed in a water supply distribution system. Several small communities throughout the state have not been able to afford nitrate treatment systems and they must inform residents that sensitive populations, including small infants and pregnant and nursing women, should not consume this untreated drinking water. Accordingly, these small communities should explore other options such as developing a new water source or interconnecting/consolidating with a neighboring community water system.

One area that is effectively dealing with salt management is the Chino basin in the Santa Ana River watershed. The Chino Basin Optimum Basin Management Program is operating a desalter to remove nitrate that has accumulated in the groundwater from long-term agricultural operations. The treated water is used for potable supply once the nitrate drinking water standard is met. The brine from the desalters is discharged to a “brine line” that feeds into the Orange County Sanitation District’s wastewater treatment plant. Effluent from the treatment plant is discharged to the Pacific Ocean through an outfall.

Septic tank systems can be a localized source of high nitrate contamination in groundwater as well as dairies and other agricultural activities. An estimated 250,000 to 600,000 private domestic wells in California are commonly located near septic systems because building codes allow a minimum of 100 feet of separation between the two. Contaminant plumes from septic tank leach fields have been shown to travel hundreds of feet horizontally in groundwater with little dispersion or dilution of the plume. Domestic wells that are shallow and are not properly sealed are vulnerable to surface contaminants including leachate plumes from nearby septic tank systems.

Potential Benefits

The potential benefits of remediating contaminated groundwater to use the water as a part of the available water supply are:

- There is an additional available water supply that would not be available without remediation.
- Avoiding the cost of buying an alternate water supply.
- Treated groundwater that meets water quality standards may be blended with other water supplies to increase the total available water supply.
- Groundwater from remediation projects and blended supplies that do not meet drinking water or other high water quality requirements may still be available to meet water needs that do not require such high quality water, thus increasing the overall water supply.
- There is a supply that is maintained and used throughout the state to meet up to 40 percent of the state’s water demand.
- Less future wellhead treatment costs by preventing contaminant plumes from spreading.
- Use of the remediated aquifer for storage of excess surface water supplies.

Potential Costs

The cost of remediating groundwater includes:

- Cost of characterizing the groundwater or aquifer in terms of the contaminants present and the hydrogeology underlying the contaminant site.
- Capital cost of the remediation system.
- Operation and maintenance costs during the life of the project; remediation may be required for a long time.

Except for petroleum USTs, it is difficult to estimate the cost of cleaning contaminated sites. In 1989, the Legislature established the Underground Storage Tank Cleanup Fund to reimburse petroleum UST owners for the costs associated with the cleanup of leaking petroleum USTs. The fund disburses about $200 million annually to eligible claimants. In the 1990s, the cost to clean up an individual UST site typically ranged from $100,000 to $200,000. The cleanup of UST sites contaminated with MTBE costs significantly more, with reimbursements as high as the fund's limit of $1.5 million per site. As of June 2011, the Fund disbursed more than $3.1 billion to eligible claimants since its establishment.

A site where solvent contamination has reached groundwater may require continuous pump and treat operation for decades and cost millions of dollars. As previously discussed, most sites with solvent discharges (e.g., dry cleaning facilities) have yet to be investigated and remediated.

Based on cost data from the State Water Resources Control Board and the California Department of Public Health, Division of Drinking Water and Environmental Management, total groundwater remediation costs in California, excluding costs of salt management, could approach $20 billion during the next 25 years. The estimate is based on current costs for remediation, estimated future costs for similar remediation, newly discovered contamination, and emerging contaminants. Almost all of these costs are associated with contaminants from previous human activities (legacy contaminants). Current pollution prevention strategies are expected to result in significantly less discharge of contaminants such as petroleum fuel, solvents, and perchlorate.

Major Implementation Issues

Water Quality

Several groundwater quality issues complicate remediation efforts. The type and the concentration of the constituents vary from aquifer to aquifer. Contaminated water associated with historic commercial, agricultural, and industrial chemical discharges may contain a variety of regulated and unregulated contaminants. Non-point-source contamination, such as nitrates or elevated concentrations of boron or salts in agricultural areas, can be widespread in the subsurface and can leach into the groundwater from surface infiltration or rising groundwater levels. Rising sea levels may also increase resource needs to combat seawater intrusion. Contaminated water may be poorly characterized in terms of the contaminants that are present and defining the dimension of the plume is costly. California has a number of Superfund sites where treatment system costs may transfer to the State, which will require additional funding. Emerging contaminants may not be known at current detection levels. The impact of emerging contaminants is also not known. The ability to remediate emerging contaminants is not fully known because they usually occur at very low concentrations, although research is being conducted. Reverse osmosis and advanced oxidation processes may prove to be viable water treatment technologies for emerging contaminants that occur at low concentrations. To improve knowledge of groundwater quality, using analytical methods with very low detection levels, the State Water Resources Control Board's Groundwater Ambient Monitoring and Assessment Program (GAMA) was created in 2000. The program's main goals are 1) to improve statewide groundwater monitoring, and 2) to increase the amount of groundwater quality information available to the public. While this program has made significant progress, much more data is needed to overcome the current lack of knowledge of groundwater hydrogeology and geometry.

Aquifer Characteristics

California's groundwater basins usually include a series of alluvial aquifers intermingled with aquitards (California Department of Water Resources 2003). Lack of specific knowledge about the geometry and characteristics of an aquifer complicates groundwater remediation. Without this information, it is not possible to develop a cost-effective remediation strategy. How much groundwater is being pumped is unknown. The storage volume of each aquifer and how much of it is contaminated are likewise unknown. While such programs as GAMA, GeoTracker- GAMA (groundwater information system), and California Statewide Groundwater Elevation Monitoring (CASGEM) have significantly improved understanding of groundwater conditions in the state, much more data is needed to overcome the current lack of knowledge of groundwater hydrogeology, geometry, and characteristics.

Costs of Investigation and Treatment

Costs can impede groundwater remediation. Who will pay, who are the responsible parties, and what is the appropriate share for each responsible party? Site investigation is expensive, particularly when solvents are the contaminant. Groundwater treatment is expensive, and it can take years, decades, or longer to remediate contaminated groundwater sites. Delays in implementing groundwater remediation while the contaminants spread can significantly increase the cost and time required for remediation. This is especially true if long-term litigation is involved to determine responsible parties.

Aside from the UST Cleanup Fund, funding for remediation is provided by responsible parties or parties willing to do the remediation (e.g., city and county agencies). In urban areas, it is often difficult to assign responsibility for the legacy of many decades of discharges of contaminants from disparate sources. Where responsibility can be assigned, responsible parties may not be able to fund investigation and remediation (e.g., dry cleaning business owners). Therefore, wellhead treatment costs are often borne by water purveyors and their customers.

Climate Change

Climate change is likely to create increased groundwater pumping due to reduced surface water flows during summer months. Surface water flows will be reduced because more winter precipitation will fall as rain instead of snow which provides surface water flows when it melts in the summer. As extraction pressures on groundwater basins increase, there may be increased attempts to remediate contaminated aquifers. Climate change will also cause further degradation of groundwater quality in coastal areas due to seawater intrusion from sea level rise.

Adaptation

Developing additional groundwater supplies through remediation will increase California’s ability to provide water supplies during drought periods. Making more groundwater basins available for water storage also allows for augmentation of groundwater supplies with recycled or desalinated water. Desalination of coastal groundwater affected by seawater intrusion due to sea level rise may also serve as an adaptation strategy to protect groundwater supplies.

Mitigation

Some of the treatment technologies used for groundwater remediation are energy-intensive. Therefore, groundwater remediation may result in increased greenhouse gas (GHG) emissions. However, if groundwater basins can be restored and replenished, their reliable yield may facilitate less energy-intensive water imports, leading to reduced GHG emissions.

Better Public Education

Better public education and outreach is needed to inform people why source water protection and pollution prevention measures are important and necessary to protect groundwater resources. A better understanding of these measures would enable people to make educated choices and select appropriate actions when their activities may degrade water quality. When groundwater resources are not protected and become impacted by pollution, a community’s drinking water supply could require treatment that was previously not needed, significantly increasing the cost to rate payers. Additional information is available in resource management strategy reports, *Pollution Prevention*,”and *Outreach and Education*.

Small Communities

Larger community water systems (CWS) are generally in a better position to deal with contaminated groundwater supplies, because these systems are better able to absorb costs associated with treatment or engineering solutions that address the contamination. These costs are passed onto the rate payers. Small CWS typically lack the infrastructure and economies of scale of larger systems and in some cases cannot afford to treat or find alternative supplies for a contaminated drinking water source. As a result, a small CWS can be more vulnerable to delivering contaminated groundwater to their customers. Some of these communities are small, rural, and disadvantaged and are the focus of environmental justice concerns (State Water Resources Control Board 2012).

Operation and Maintenance Costs for Removing Inorganic Chemicals

When evaluating alternatives to provide safe water to a community, water systems managers should evaluate the operation and maintenance costs associated with any treatment system being considered. For small water systems, a financial analysis should also be completed to assess if the community can afford to operate and maintain a new treatment facility. Annual operation and maintenance costs are typically high for removing inorganic chemicals such as arsenic, nitrate, and perchlorate. In the past the operation and maintenance costs for these treatment facilities has been underestimated, resulting in cost overruns and causing insolvency in some communities. State and federal funding is available to water systems, however most funding programs only cover the capital costs of installing the treatment system, and do not cover the ongoing operation and maintenance costs. There have been instances in which a community installed a treatment plant to remove a groundwater contaminant only to shut down the treatment facility later when it could not afford to operate and maintain the treatment facility.

Use of Extremely Impaired Water Sources for Domestic Water Supply

CDPH considers sources that exceed 10 times a chronic MCL or notification level (NL), or exceed three times an acute MCL or NL, or have several different types of contaminants, to be extremely impaired water sources and require more investigation and reliable treatment. The investigation involves identifying all known and possible contaminants that could be in the source, a risk assessment in the event of a treatment failure, and the resultant quality of the treated water. The treated water quality objective must take into account the allowable levels of the contaminants and the synergistic effect of similar compounds in the source water. This requires a public hearing to assess public acceptance.

Recommendations

The following recommendations can help prevent pollution, protect groundwater quality, and remediate groundwater where necessary to maintain California's water resources:

1. The Legislature should fund State regulatory agencies to identify historic commercial and industrial sites with contaminant discharges and identify viable responsible parties to investigate and remediate those sites.
2. State agencies, in coordination with local groundwater management agencies, should assist local governments and local agencies to implement source water protection measures based on the source water assessments that were completed as of 2003 to protect recharge areas from contamination and prevent future contamination.
3. State agencies, in coordination with local groundwater management agencies, should assist local agencies with authority over land use to prevent contamination of recharge areas.
4. Local government and local agencies with responsibility over land use should, in coordination with local groundwater management agencies, limit potentially contaminating activities in areas where recharge takes place and work together with entities that propose potentially contaminating activities to develop a sustainable good quality, long-term water supply for beneficial uses.
5. Work with the U.S. Environmental Protection Agency, the Bureau of Indian Affairs, and tribes to accomplish the objectives of recommendations 2, 3, and 4.
6. The State should establish and support research funding at California universities for wellhead treatment systems.
7. The State should establish and support research for detecting emerging contaminants by commercial laboratories and research how these contaminants affect human health and the environment.
8. Agencies involved in groundwater cleanup and oversight projects should collaborate and leverage resources and authorities to minimize overlap and improve outcomes.
9. Agencies involved in groundwater cleanup and groundwater purveyors should improve outreach and coordination for regional issues to develop new approaches to aquifer preservation and cleanup.
10. The State should re-evaluate the Water Well Standards and any related oil and gas well standards to ensure the standards spell out how to protect groundwater and drinking water from cross contamination via existing, abandoned, and destroyed wells.

References

References Cited

California Department of Water Resources. 2003. *California's Groundwater Bulletin 118 Update 2003*. Sacramento (CA). Viewed online at: http://www.water.ca.gov/groundwater/bulletin118/bulletin118update2003.cfm. Accessed: October, 2003.

State Water Resources Control Board. 2012. *Communities that Rely on Contaminated Groundwater. Draft Report to Legislature*. Sacramento (CA). Viewed online at: http://www.waterboards.ca.gov/water_issues/programs/gama/ ab2222/index.shtml.

———. 2013. Communities that Rely on a Contaminated Groundwater Source for Drinking Water. Sacramento (CA). Viewed online at: http://www.waterboards.ca.gov/water_issues/programs/gama/ab2222/docs/ab2222.pdf.

Additional References

Belitz K, Dubrovsky MN, Burow K, Jurgers B, Johnson T. 2003. *Framework for a Ground-water Quality Monitoring and Assessment Program for California*. Sacramento (CA): U.S. Geological Survey and California Water Resources Control Board. Water Resources Investigations Report 03-4166. 78 pp.

California Department of Public Health. 2009. "Chemicals and Contaminants in Drinking Water." California Department of Public Health. Sacramento (CA): [Web site.] Viewed online at: http://www.cdph.ca.gov/certlic/drinkingwater/ Pages/Chemicalcontaminants.aspx. Accessed: Nov. 16, 2009.

California State Water Resources Control Board. 2009. "GAMA — Groundwater Ambient Monitoring & Assessment Program." California State Water Resources Control Board. Sacramento (CA): [Web site.] Viewed online at: http://www.waterboards.ca.gov/gama/. Accessed: Nov. 16, 2009.

Centers for Disease Control and Prevention. 2007. "NIOSH Pocket Guide to Chemical Hazards." Atlanta (GA): [Web site]. Viewed online at: http://www.cdc.gov/niosh/npg. Accessed: Oct. 26, 2012.

Focazio MJ, Reilly TE, Rupert MG, Helsel DR. 2002. *Assessing Ground-water Vulnerability to Contamination: Providing Scientifically Defensible Information for Decision Makers*. Circular 1224. Washington (DC): U.S. Department of the Interior and U.S. Geological Survey. 33 pp.

Freeze RA, Cherry JA. 1979. *Groundwater*. Englewood Cliffs (NJ): Prentice-Hall. 604 pp.

Harter T, Lund JR, Darby J, Fogg GE, Howitt R, Jessoe KK, Pettygrove GS, Quinn JF, Viers JH, Boyle DB, et al. 2012. "Addressing Nitrate in California's Drinking Water: With a Focus on Tulare Lake Basin and Salinas Valley Groundwater." [Report for the State Water Resources Control Board Report to the Legislature.] [California Nitrate Project, Implementation of Senate Bill X2

1.] Davis (CA): University of California, Davis, Center for Watershed Sciences. 78 pp. Viewed online at: http://groundwaternitrate.ucdavis.edu. Accessed: Nov. 27, 2012.