Recharge Area Protection

A Resource Management Strategy of the California Water Plan

California Department of Water Resources

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Acronyms and Abbreviations

BMP	best management practice
CDPH	California Department of Public Health
CO_2	carbon dioxide
CWC	California Water Code
DWSAP	Drinking Water Source Assessment and Protection Program
LID	low-impact development
SWRCB	State Water Resources Control Board

Recharge Area Protection

Recharge areas are those areas that provide the primary means of replenishing groundwater. Good natural recharge areas are those where good quality surface water is able to percolate through the sediments and rocks to the saturated zone which contains groundwater. If recharge areas cease to function properly, it will limit groundwater replenishment and/or groundwater quality for storage or use. Protection of recharge areas requires a number of actions based on two primary goals: (1) ensuring that areas suitable for recharge continue to be capable of adequate recharge rather than being covered by urban infrastructure, such as buildings and roads, and (2) preventing pollutants from entering groundwater to avoid expensive treatment that may be necessary prior to beneficial use.

Protection of recharge areas is necessary to maintain the quantity and quality of groundwater in the aquifer. However, protecting recharge areas by itself does not provide a supply of water. Recharge areas are functioning properly when aquifer storage capacity is available, sufficient permeable surface is present, and the adequate supply of good quality water to recharge the aquifer is available. Protecting existing and potential recharge areas allows them to serve as valuable components of a conjunctive management and groundwater strategy. Additional information on this strategy is available in the resource management strategy report, *Conjunctive Management and Groundwater*.

There are three resource management strategy reports related to recharge areas protection:

1. *Conjunctive Management and Groundwater Storage*
2. *Groundwater/Aquifer Remediation.*
3. *Urban Stormwater Runoff Management*.

Management of a natural resource, especially water, requires integration of various management efforts.

In simple terms, a groundwater system consists of three components: (1) recharge areas where surface water moves to groundwater, (2) storage media consisting of aquifers that store groundwater, and (3) discharge areas consisting of wells, springs, and rivers. As with many natural systems, there is an almost infinite variety in the way these components relate to each other in the real world. Some terms that are used in discussing recharge are defined in Box 1.

Managed Recharge Areas in California

The first documented artificial recharge program in California began in Los Angeles basin in 1889. In the early 1900s, water agencies operated recharge areas in the San Joaquin Valley. Additional areas for artificial recharge were established later in Southern California and in the San Francisco Bay area. While a certain amount of recharge takes place in many areas, the areas chosen by water management agencies were those that met three conditions. First, the sediment is coarse enough to allow surface water to infiltrate at a higher rate than through finer sediments. Second, there is hydraulic continuity between the recharge area, the aquifer in which the groundwater is stored and transported, and the discharge area where wells are built to extract the groundwater. Third, a local agency had access to the land on which these first two conditions existed.

Box 1 Terminology

The definitions are taken primarily from California Department of Water Resources Bulletin 118, *California's Groundwater 2003*.

Abandoned well. Wells that are abandoned but that have not been properly destroyed and provide a vertical conduit for contamination of the aquifer. While there is no accurate count of the number of such abandoned wells in California, one estimate is that there are more than 1 million such wells that are potential vertical conduits for contamination of the aquifer because they have not be properly destroyed. State law requires destroying such wells. Some local jurisdictions require an old well on the property to be destroyed before a permit is issued for construction of a new well (Health & Safety Code Section 115700).

Aquifer. A body of rock or sediment that is sufficiently porous and permeable to store, transmit, and yield significant or economic quantities of good quality groundwater to wells and springs.

- Unconfined aquifer. An aquifer that is not bounded on top by an aquitard. The upper surface of an unconfined aquifer is the water table.
- Confined aquifer. A body of rock or sediment bounded on top by an aquitard and containing groundwater that is under greater than hydrostatic pressure i.e., an artesian aquifer. When a confined aquifer is penetrated by a well, the water level will rise above the top of the aquifer.

Aquitard. A confining bed composed of rock or sediment that retards but does not prevent the flow of water to or from an adjacent aquifer. The movement of groundwater in an aquitard is exceedingly slow (very low permeability) and it does not yield water readily to wells or springs, even though it stores groundwater.

Artificial recharge. The addition of water to a groundwater reservoir or aquifer by human activity, such as putting surface water into constructed spreading basins, allowing surface water to flow in strategically located unlined watercourses and ditches, or injecting water through wells. This may also be referred to as managed or intentional recharge.

Deep percolation. Percolation of water through the ground and beyond the lower limit of the root zone of plants into groundwater. Efficient agricultural and urban irrigation practices limit or eliminate deep percolation.

Discharge area. An area where the recharged groundwater flows out of the aquifer under natural conditions or is removed from the aquifer by wells. In general terms, the Earth consists of recharge areas and discharge areas which may be either very close together (within meters) or are very far apart (many kilometers).

Natural recharge. Recharge of an aquifer that occurs without human interference. This may also be referred to as unintentional recharge.

Recharge area. An area where surface water infiltrates into the ground and reaches a saturated zone in either an unconfined aquifer or a confined aquifer.

The recharge area for an unconfined aquifer is the ground surface above the aquifer. The recharge area for a confined aquifer is always some distance away from the area where wells have been built that extract groundwater from the confined aquifer. In at least one instance in California, a water district overlies a confined aquifer but the recharge area for that confined aquifer lies many miles outside the district's boundaries. In some older publications, the recharge area for a confined aquifer has been called the forebay to the confined aquifer. In other instances, recharge of the confined aquifer may occur only where a stream has eroded through the aquitard into the confined aquifer, allowing recharge to occur through the stream bottom which is below the aquitard.

Restored recharge area. Describes some small basins, usually in the mountains, that have been reclaimed from activities that caused severe erosion and vegetation loss and that are now viable storage sites for groundwater that is released throughout most of the year into the watercourse.

Recharge occurs instream, offstream, and through injection wells. Instream recharge allows water to percolate through the stream bed itself. Offstream recharge uses suitable sites outside the streambed. In some operations, the water must be pumped from its distant source to the offstream recharge area. Injection wells are used at locations where the cost to purchase large tracts of land for offstream spreading basins would be prohibitive, due to their small footprint, or when the soil/ surface permeability does not allow for surface recharge.

Each method has its pros and cons. Instream and offstream spreading basins eventually become clogged by suspended fine-grained material carried in the surface water. As a result, the rate of recharge declines considerably making the basin much less effective. The fine-grained material must be removed to increase rate of recharge. In urban areas, the cost of land necessary for spreading basins is often prohibitive. Injection wells are expensive to build, but their small footprint make them more affordable than spreading basins in urban areas where land is very expensive. However, they could also clog unless the water is treated, turbidity is minimal, and air is not entrained.

Potential recharge areas are hydrogeologically suited for use if they meet the three conditions cited above — coarser sediments, hydraulic continuity between the recharge area and the discharge area, and local agency ownership. Table 1 shows current sites in California that are managed for artificial recharge.

The State Water Resources Control Board (SWRCB) has compiled a hydrogeologically vulnerable areas map shown in Figure 1. The map shows areas where published reports and well logs indicate that there is potential hydrogeologic connection between the ground surface and groundwater. An area was defined as vulnerable, if a low permeability soil layer (e.g., clayey layer) of at least a 5-foot thickness did not exist between the groundwater table and land surface.

Contamination of these areas would lead to contamination of the groundwater in the aquifer (State Water Resources Control Board 2011 updated). These areas do not include zones of fractured bedrock that recharge groundwater and can also serve as a conduit for groundwater contamination.

The size of existing recharge areas and the amount of groundwater that is artificially recharged annually is substantial, but there is no procedure in place that quantifies that amount on a statewide basis. The total amount of land devoted to spreading basins and offstream and instream recharge most likely exceeds 50 square miles. The actual area is difficult to determine, partially because many diversion ditches and creeks are active artificial recharge sites during some periods of the year. These active recharge areas and other areas should be protected for recharge purposes.

For purposes of analysis and planning, actual and potential recharge areas can be assigned to one of three categories.

- Category 1. Active recharge areas at the present time under the control of water management agencies. These areas are listed in Table 1. The infiltration rate at these areas is high and they are carefully managed to maintain that high infiltration rate and to protect the quality of the water undergoing recharge. Most of these sites monitoring activities track groundwater levels, rate of movement of the recharged water into the aquifer, and chemical changes.
- Category 2. Areas that are known to have a fairly high infiltration rate, but are not under the control of a water management agency. There may be little or no monitoring of these areas. Programs should be considered that monitor recharge, prevent potential contaminating activities, and educate the public about the importance of protecting the quantity and quality of their water supply to enable people to select appropriate actions to protect water quality.
- Category 3. Areas with a lower infiltration rate making the area much less suitable for an artificial recharge program managed by a local water agency. These areas may have a lower degree of monitoring and management of potential contaminating activities.

Figure 1 Hydrogeologically Vulnerable Areas Map

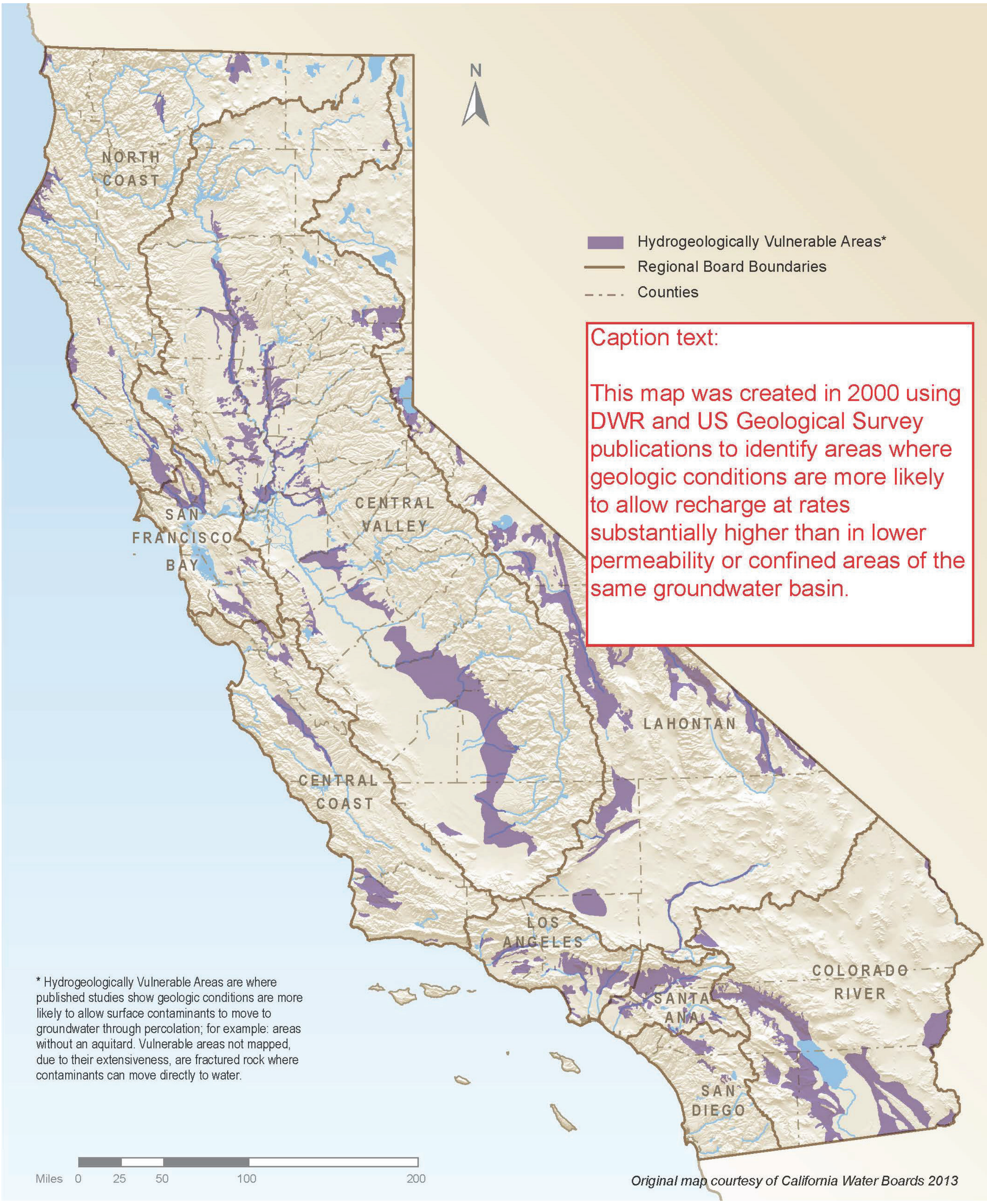

Table 1 Recharge Sites in California

Agency	Type of Recharge Site
Arvin-Edison Water Storage District	Offstream
Berrenda Mesa Water District	Offstream
Calleguas Municipal Water District	Injection wells
City of Bakersfield	Instream, offstream
Coachella Valley Water District	Instream, offstream
Flintridge-Cañada	Injection well
Fresno Metropolitan Flood Control District	Offstream
Friant-Kern Water Users Authority	Instream
Kern Water Bank	Offstream
Los Angeles County Department of Public Works	Instream, offstream, injection wells
North Kern Water Storage District	Offstream
Orange County Water District	Instream, offstream, injection wells
Pioneer (Kern County Water Agency)	Instream, offstream
San Bernardino Valley Water Conservation District	Offstream
Santa Ana Watershed Project Authority	Offstream, injection wells
Santa Clara Valley Water District	Instream, Offstream
Semitropic Water Storage District	Offstream
United Water Conservation District	Instream, offstream

The Drinking Water Source Assessment and Protection Program (DWSAP) administered by the California Department of Public Health (CDPH) defines areas of protection for individual wells. The program could easily be expanded to include larger areas within the watershed to assess and protect groundwater recharge areas.

Other Methods of Enhancing Recharge

Four other methods of enhancing recharge and reducing runoff are flood water detention basins, reduced hardscape, increased softscape, and utilizing low-impact development practices.

In the first half of the 20th century, the U.S. Army Corps of Engineers, in conjunction with local flood control agencies, built detention dams in the canyons at the foot of Southern California mountain ranges. These detention dams had a three-fold purpose. First, when storms dropped large amounts of water high in the mountains, the dams stopped the uncontrolled rush of water into downstream residential areas. Second, some of the water stored behind the detention dams infiltrated into the coarse sediment in the bottom of the detention area and recharged the local aquifer. Third, the dams were designed to release a smaller controlled amount of water into the flood control channels and streams so that the water would not cause damage downstream. Some of these dams are also used to store excess water for release and use during the dry season. Many of these facilities are still functioning and some provide significant recreational opportunities during the dry season.

In the last half of the 20th century, a different type of detention basin was built in a number of urban areas. These detention basins, excavated so that they are lower than the surrounding land surface, serve as grass-covered parks during most of the year. During the winter, they can fill with runoff from storms. Again, their purpose is three-fold. First, they are used as recreational facilities during the non-storm season. Second, they fill with storm runoff during the wet season, thereby reducing flood risk. Third, some of the water stored in these basins during the wet season recharges the local unconfined aquifer, while some of these basins may be located in the recharge area for a confined aquifer. In any such operation using urban runoff, adequate control must be exercised to prevent contamination of the aquifer by petroleum products and other urban contaminants.

A third method to increase recharge and reduce runoff is being implemented by TreePeople, a non-governmental organization. TreePeople has been working with local government to retrofit playgrounds, school grounds, parking lots, and other parcels of land to collect, treat, and funnel stormwater to dry wells or other small scale infiltration facilities. Such wells are called Class V injection wells. While the goal of TreePeople is to reduce hardscapes and reduce runoff, the use of dry wells for disposal of the urban runoff can affect groundwater quality. To avoid contaminating the aquifer, certain best management practices (BMPs) are recommended, which include:

- Construction of low-flow basins for runoff from industrial and other areas that could be a source of chemical contamination.
- Pre-treatment of stormwater runoff.
- Water quality monitoring.
- Periodic evaluation of project data.
- Implementation of corrective action(s) as necessary (Ben-Horin 2007; TreePeople 2009).

California's 58 counties are required by the California Water Code (CWC) to regulate any type of water-related well, including injection wells, but the effectiveness of that program varies considerably depending upon the county. Class V injection wells are further regulated for groundwater quality purposes by the U.S. Environmental Protection Agency in accordance with the Underground Injection Control program authorized by the federal Safe Drinking Water Act.

A fourth method to increase groundwater recharge is to utilize low-impact development (LID) or BMP features for stormwater capture and reuse. This is to be consistent with both the State Water Resources Control Board Strategic Plan Goal 1, which is to implement strategies to fully support the beneficial uses for all 2006 Clean Water Act Section 303(d) listed water bodies by 2030 and the CWC, Section 10561(e), "stormwater, properly managed, can contribute significantly to local water supplies through onsite storage and reuse, or letting it percolate into ground to recharge groundwater, therefore increasing available supplies of drinking water."

Potential Benefits

The primary benefit of protecting recharge areas is water managers using those recharge areas to store water in aquifers as part of a program to provide a sustainable, reliable, and high quality water supply. In some cases, diverting flood water to recharge facilities may benefit both flood control efforts and maintenance of a local water supply. The availability of a sustainable and reliable water supply may lessen the need to purchase alternative water supplies at greater expense. Efforts to protect groundwater quality by preventing the release of contaminants may reduce the need for expensive groundwater treatment[2], thereby eliminating or lowering carbon dioxide (CO_2) emissions related to groundwater treatment. Protection of recharge areas does not make a water supply available. A water supply to recharge the aquifer depends on coordination of regional and local governments and water management agencies.

Additional benefits of recharging groundwater include: 1) partial removal of microbes and chemicals while the water moves through the unsaturated zone to the saturated zone, 2) an increase in the amount of groundwater in storage that can later be extracted for local use or export, and 3) in some cases, use of the aquifer itself as the conveyance system from the recharge area to the point of extraction and use. In some cities, recharge basins are combined with flood control basins to reduce the amount of urban runoff. However, this practice may introduce contaminants, especially hydrocarbons, nitrates, and solvents into the aquifer unless there is pre- treatment to remove the contaminants.

Potential Costs

Some of the costs that may be associated with protecting recharge areas are:

- Purchase or lease price of the land that may be used for a recharge area.
- Design and construction of facilities.
- Land reserved for recharge areas cannot be used for other purposes that might provide a significant income for the landowner and tax revenues for the government.
- No tax revenue for the county if a local government agency owns the land.
- Periodic well field monitoring that warns about contamination.
- Groundwater remediation used to control contaminant releases near recharge areas.

Water supply can be lost by not protecting recharge areas. The growth of urban areas with large impervious roads, freeways, parking lots, and large warehouse-type buildings means that these areas no longer allow runoff to infiltrate into the ground. Instead, the runoff flows rapidly into streams which peak more quickly and at higher flow rates than before these urban structures were built. This runoff may create more frequent flood flows, losing the opportunity and effectiveness for natural groundwater recharge. Facilities are then needed to artificially recharge the groundwater at a cost to ratepayers. In a few urban areas, injection wells have been built to take the place of recharge areas that were lost to urban development. Injection wells are expensive, require careful technical control, and are not always successful. However, they may be cost- effective compared to the high cost of urban land in many cities.

Many potentially contaminating activities occurring on areas such as farms, dairies, and industrial complexes routinely have been allowed in recharge areas and contaminants have been carried into the aquifers. Because groundwater processes and the potential for contamination are not well understood by the public, many of these practices continue today. Remediation of contaminated aquifers can take decades or longer, cost millions or billions of dollars, and increase the rate of global climate change due to CO_2 emissions from remediation systems. Groundwater remediation may never remove the contaminant completely from the aquifer. In such cases, the extracted groundwater must be treated at the wellhead at a significant expense before it is suitable for potable and other uses.

A lack of protection of recharge areas could decrease the availability of usable groundwater. Studies by the U.S. Geological Survey show contaminants present in recharge areas for aquifers in the Los Angeles area. Because of the low velocity of groundwater movement through the aquifer, contamination that occurs today may not arrive at down-gradient wells for 10 years or longer. When the contamination does arrive at the down-gradient wells in 10 or more years, treatment may be needed before the groundwater can be used thereby increasing the cost of water to future users. Protecting recharge areas now may help to prevent costs from escalating excessively in the future by reducing the need for expensive groundwater treatment. Protecting recharge areas by retaining those areas for recharge and preventing contamination today will reduce future costs of drinking water. Restoration of recharge areas may also help to keep future costs lower.

Major Implementation Issues

Climate Change

Changing precipitation patterns may affect the availability of surface water supplies capable of recharging groundwater basins. In the past decades, there has been a gradual shift in snowpack and runoff timing in California where runoff is occurring earlier in the year. This shift may also reduce groundwater recharge during the summer months. In addition, sea level rise may impact coastal aquifers by decreasing their capacity for recharge and storage of groundwater.

Adaptation

Monitoring, maintaining, and enhancing the health of recharge areas and groundwater basins are important adaptive strategies. Groundwater use may be a central response to droughts. During drought periods, cities and regions that have adequate groundwater supplies may be less likely to rely upon distant water supply sources. Protecting recharge areas allows for additional recharge during wet winters, which can provide a better reserve for drought periods. Coastal regions that recharge and maintain groundwater aquifers may be less likely to lose aquifer capacity due to sea level rise. Maintaining recharge areas may also enhance flood management by reducing the volume of flood flows to populated areas.

Mitigation

Recycled water of adequate quality can supplement other sources of recharge water and provide additional water to groundwater basins. More recharge areas may be needed to fully utilize the state’s available recycled water supply used for groundwater recharge. Greater reliance upon local groundwater in many areas of the state is less energy intensive than relying upon imported or desalinated water. Reduced energy use for water supply results in lower greenhouse gas emissions.

Zoning

Zoning can play a major role in protecting recharge areas by amending local codes to establish minimum softscape requirements for parcels so these sites are retained as recharge areas. Some areas that would provide good rates of recharge have been paved over or built upon and are no longer available to recharge the aquifer. Local governments often lack a clear understanding of recharge areas and the need to protect those areas from development or contamination. Land use zoning staff should consider the need for recharge area protection for water quantity and water quality.

Vector and Odor Issues

Standing water in recharge ponds or spreading basins attracts mosquitoes, dragonflies, and other insects whose egg, larval, and pupal stages mature underwater. Dragonflies eat insects they catch on-the-fly, including mosquitoes, which can be vectors for a number of serious or deadly diseases. Existing recharge programs use large numbers of mosquitofish which feed on the mosquito larvae in the water. Odors can be generated by growth and decay of algae and other water-borne vegetation. Both vectors and odors must be addressed in any recharge program that involves standing water.

Recommendations

The State can help promote additional protection of recharge areas implementing the following recommendations:

1. Increase State funding for programs to identify and protect recharge areas including incentives for locating and for the proper destruction of abandoned water wells, monitoring wells, cathodic protection wells, and other wells that could become vertical conduits for contaminating the aquifer.
2. Provide funding and staff for the CDPH to initiate a program that would provide guidance and funding for tribes, local governments, and agencies to implement source water protection measures that are logical outgrowths of the Drinking Water Source Assessment and Protection Program.
3. Continue and expand research into surface spreading as a means of groundwater recharge and the fate and transport of chemicals and microbes contained in the recharge water.
4. Develop a statewide program to identify and inventory actual and potential recharge areas throughout the state and provide that information to tribal, city, and county governments.
5. Engage the public in an active dialogue using a value-based decision-making model in planning land use decisions that involve recharge areas.
6. Adopt a State-sponsored media campaign to increase public awareness and knowledge of groundwater and the importance of recharge areas.
7. Local governments should coordinate with groundwater management agencies to identify recharge areas and appropriate groundwater protection actions to include in the groundwater protection section of each local government’s general plan.

8. Ensure that federal and State programs regulating subsurface disposal in accordance with the federal Safe Drinking Water Act's Underground Injection Control program and the California Clean Water Act's waste discharge requirements are fully funded and staffed.
9. Require local governments to coordinate with groundwater management agencies to provide protection of recharge areas for aquifers that have been identified as "sole source aquifers" pursuant to the Safe Drinking Water Act of 1974 and Amendments.
10. Develop educational programs, that are coordinated through local groundwater management agencies, for public works officials and other officials of local agencies and governments that help them to develop programs that realistically deal with the interaction of groundwater, surface water, stormwater, recycled water, other surface flows, and the effect of contaminants in surface flows on contaminant levels in the aquifers.
11. Require that source water protection plans include an element that addresses recharge areas if groundwater is a part of the supply.
12. Convene a statewide panel to recommend changes to public schools and higher education curricula relating to groundwater. Encourage an integrated academic program on one or more campuses to promote groundwater (quantity and quality) protection strategies and why recharge areas are critical components.
13. Develop a uniform method for analyzing the economic benefits and cost of recharge areas. Provide guidance and assistance for economic feasibility analyses that could be used by project planners and funding agencies to assess different recharge options as compared with long-term reduction of water supplies, wellhead treatment, recharge (injection) wells, surface spreading areas, or conversion to other land uses.
14. Develop a signage program, modeled on similar programs in other states, to notify people that they are entering an area of critical recharge for the groundwater they use daily, and that improper disposal of wastes can contaminate their drinking water.
15. Support implementation and research for stormwater LID and BMP techniques for groundwater recharge under the provisions of the Stormwater Resource Planning Act (CWC Section 10560 et seq.).
16. Support leak prevention protocols for stored contaminants to minimize the potential of surface and groundwater contamination, thus mitigating carbon dioxide (CO_2) emissions related to groundwater remediation.

References

References Cited

Ben-Horin E. 2007. *Rainwater as a Resource: A Report on Three Sites Demonstrating Sustainable Stormwater Management.* Beverly Hills (CA): TreePeople. 56 pp. Viewed online at: http://www.treepeople.org/sites/default/ files/images/about/Rainwater_as_a_Resource.pdf.

State Water Resources Control Board. 2011 (updated). Hydrogeologically Vulnerable Areas Map. Sacramento (CA): Viewed online at: http://www.waterboards.ca.gov/water_issues/programs/gama/docs/hva_map_table.pdf.

TreePeople. 2009. "TreePeople." Beverly Hills (CA): [Web site.] Viewed online at: http://www.treepeople.org/. Accessed: Nov. 16, 2009.

Additional References

Aiken GR, Kuniansky EL, editors. 2002. *U.S. Geological Survey Artificial Recharge Workshop Proceedings*. April 2-4. Sacramento (CA): U.S. Geological Survey. 92 pp. Viewed online at: http://water.usgs.gov/ogw/pubs/ofr0289/.

Bachman SB. 1997. *California Groundwater Management*. Sacramento (CA): Groundwater Resources Association of California. 145 pp.

Blomquist WA, Schlager E, Heikkila T. 2004. *Common Waters, Diverging Streams; Linking Institutions and Water Management in Arizona, California, and Colorado*. Washington (DC): Resources for the Future. [Book.] 205 pp.

California Department of Public Health. 1999. *Drinking Water Source Assessment and Protection (DWSAP) Program*. Sacramento (CA): California Department of Health Services. Division of Drinking Water and Environmental Management. 209 pp. Viewed online at: http://www.cdph.ca.gov/certlic/drinkingwater/Documents/DWSAPGuidance/DWSAP_document.pdf.

———.2007. Drinking water source assessment and protection (DWSAP) program. Sacramento (CA): California Department of Public Health. [Web site.] Viewed online at: http://www.cdph.ca.gov/certlic/drinkingwater/pages/ dwsap.aspx. Accessed: Nov.16, 2009.

California Department of Water Resources. 2003. *California's Groundwater Update 2003*. Bulletin 118. Sacramento (CA): California Department of Water Resources. 246 pp. Viewed online at: http://www.water.ca.gov/ groundwater/bulletin118/bulletin118update2003.cfm.

Driscoll FG. 1986. *Groundwater and Wells*. 2nd edition. St. Paul (MN): Johnson Division. [Book.] 1089 pp.

Dunne T, Luna LB. 1978. *Water in Environmental Planning*. San Francisco (CA): W.H. Freeman and Co. [Book.] 818 pp.

Fetter CW. 1994. *Applied Hydrogeology*. 3rd edition. Englewood Cliffs (NJ): Prentice-Hall Inc. [Book.] 691 pp.

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). 33 pp. Prepared for the U.S. Geological Survey. Viewed online at: http://pubs.usgs.gov/circ/2002/circ1224/.

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

Heath R. 1983. *Basic Ground-water Hydrology*. Water-Supply Paper 2220. Washington (DC): U.S. Geological Survey. 84 pp.

Madrid C. 1989. "Artificial ground water recharge in Northern California." In: Johnson AI, Finlayson D, editors. *Artificial Recharge of Ground Water: Proceedings of the International Symposium*. August 23-27, 1988. Anaheim (CA): American Society of Civil Engineers.

Sherman LK, Musgrave GW. 1942. "Infiltration." In: Meinzer, OE, Baver, LD, editors. *Hydrology*. Volume IX. Physics of the earth. 1st edition. New York (NY): McGraw-Hill. [Book.]

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

University of California Center for Water Resources. 2001. *Managing California's Groundwater: the Challenges of Quality and Quantity; Abstracts from the 23d Biennial Groundwater Conference*. Biennial groundwater conference and annual meeting of the Groundwater Resources Association of California. October 30-31. Sacramento (CA). 83 pp.

Winter TC, Harvey JW, Franke OL, Alley WM. 1998. *Ground Water and Surface Water, A Single Resource*. Circular 1139. Washington (DC). Prepared for U.S Geological Survey. 79 pp. Viewed online at: http://pubs.usgs.gov/circ/ circ1139/.