The Recharge Initiative
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The Recharge Initiative is *a focused effort to protect, enhance, and improve the availability and reliability of groundwater resources*. The Recharge Initiative is a partnership between researchers, students, landowners, ranchers, cities and agencies, not-for-profits, and other stakeholders who have interest in the long-term sustainability of water resources. We are raising funds, launching projects, conducting research, educating communities and ourselves, presenting results and discussing ideas for productive groundwater management and use.

The Recharge Initiative was established in 2007, years before the Sustainable Groundwater Management Act (SGMA) was signed into law in California. SGMA makes goals articulated for The Recharge Initiative even more important for the Central Coast and California more broadly.

The United States, and especially California and the rest of the western U.S., is increasingly dependent on groundwater. Although total fresh water withdrawals in the U.S. peaked in the early 1980's, then leveled off for the next two decades, recent data shows that U.S. fresh water use is increasing again. There were enormous improvements in water efficiency in the last part of the 20th century, particularly in agricultural and urban settings, but increasing populations are overwhelming reductions in per-acre and per-capita use, and many regions are unable to meet demand. Surface supplies are the primary source of fresh water in most of the U.S. during "average" years, but for much of the country during dry periods, and for many parts of the western and southern U.S. in general, groundwater is at least as important as surface water.

California leads the nation in both overall fresh water demand and in use of groundwater. California also faces an ongoing water supply crisis, with many parts of the state not having access to high-quality water where and when it is needed. The problem is exacerbated by limitations in the availability of new surface water storage (and the political challenges in developing new surface storage facilities); a massive, complex, expensive, energy-demanding, and over-allocated system for state-wide conveyance of fresh water; rapid population growth and associated demand for housing, infrastructure, and services in some of the driest parts of the state; a changing climate that influences the magnitude, timing, locations, and forms of fresh water available throughout the year; and the need to plan for variability and uncertainty.

II. The Recharge Initiative

The considerations above indicate the need for *a focused effort to protect, enhance, and improve the availability and reliability of groundwater resources*. Of course, a comprehensive and sustainable resolution to the imbalance between California's water demand and supply will require changes to *both* demand and supply sides of the equation. But there have historically been many more people and programs focused on reducing water demand; there has been less effort placed on augmenting groundwater supplies. **NB:** This is now changing, but we have to act quickly to help make SGMA a success, securing and sustaining our freshwater future. Groundwater will play an increasingly important role in California in coming decades, and there is a profound and immediate need to resolve basic scientific and technical questions related to enhancing the availability of groundwater. When the federal government runs a financial deficit, it prints money (literally and by selling bonds to investors). When California runs a water deficit, there is no way to "print" water or remove water from a stream or reservoir when it is empty; instead, we overdraft aquifers. This is evident in the numbers generated by DWR in their periodic water plan updates – the statewide groundwater deficit is many millions of acre-feet. Although this is a pernicious state-wide problem, *the ultimate causes and impacts of groundwater overdraft are local*. Groundwater overdraft contributes to a variety of problems (in addition to the reduction of water in storage), including: ground subsidence and permanent loss of storage, seawater intrusion, upflow of lower-quality water from depth, losses from critical surface systems (streams, lakes, and wetlands), and damage to fragile aquatic ecosystems.

The primary goal of The Recharge Initiative is to contribute to comprehensive, local efforts to bring groundwater basins into hydrologic balance, and to *protect critical fresh water resources* for future generations. This is being accomplished through research, teaching, service, and outreach, *in collaboration with partners* from academia, federal, state, and local agencies, municipalities, and citizen stakeholder groups. The Recharge Initiative facilitates the creation, collection, and communication of knowledge; the development of open source and widely-accessible data sets, data tools, and analytical techniques; and training of the next generation of groundwater professionals to address current and future challenges. The Recharge Initiative is a long-term (multi-decade) effort that empowers local stakeholders, agencies, and municipalities so as to develop the information and technologies they need to understand and manage groundwater resources more effectively. The Recharge Initiative is focused on: finding practical solutions to profound challenges, developing tools and data that will help to resolve basic hydrogeologic questions; and leveraging resources, experience, and local knowledge.

The Recharge Initiative comprises five primary components:

(1) Delineation of natural groundwater recharge and potential managed recharge areas, through analysis of surface and subsurface data, hydrologic simulation, and generation of data products in formats that are most useful to local agencies and individual (e.g., digital well records, georeferenced "shape" files for use with Geographic Information Systems).

(2) Analysis of groundwater recharge areas, both to provide ground truth for predictions based on surface and subsurface map data, and to quantify recharge dynamics and impacts site-by-site and basin-by-basin. In addition to being valuable on its own, providing a snapshot of present day conditions, this information will be important for understanding changes occurring to the hydrologic cycle over time. In decades hence, data sets generated through The Recharge Initiative will provide baseline information that will allow stakeholders, resource managers, and others to quantify the impacts of climate, land use, and other changes to water resources, particularly groundwater. This information will also help to leverage externally funded research projects, and will provide student teaching and research opportunities.

(3) Improving groundwater quality through enhanced recharge. Improvements to quality come from dilution of poor-quality groundwater, especially if we can encourage helpful bio-geochemical reactions when surface water is introduced into the subsurface. Field and laboratory studies that link hydrology, geochemistry, and microbiology help with this goal.

(4) Development of research and implementation projects that straddle the boundary between basic and applied research, with specific application to groundwater recharge and related topics involving both water *quantity* and water *quality*. Projects are developed from the ground up through collaboration with local stakeholders and resource managers, with participants bringing specific expertise, tools, and resources. Funding is leveraged for each project from multiple sources, including in-kind support such as access to facilities and data sets and staff support. Examples of Recharge Initiative projects are described in the next section of this document. Several of these efforts address fundamental hydrogeologic questions – groundwater recharge remains a frontier topic in hydrology, and new methods and tools are needed to assess this important part of the water cycle.

(5) Education and outreach that is integrated with programmatic development. This includes training of undergraduate, graduate, and post-doctoral researchers, development of information and documentation that is accessible to non-technical audiences, service on public panels and technical advisory committees by Recharge Initiative participants, and involvement in public forums and other events that include genuine *conversations* between technical experts and stakeholders, not just lecturing from a podium. Those involved in The Recharge Initiative recognize that, as scientists, *we need to be educated* about the challenging technical aspects of groundwater recharge research, and in terms of local issues, policies, history, economics, and social factors.

III. Example Projects: Past, Present, and Future

UCSC researchers and collaborators completed a project to assess the dynamics and impacts of streambed seepage and groundwater recharge on the *quantity* and *quality* of fresh water resources in southern Santa Cruz County. This project focused on quantifying the flow of water and nutrients in and out of streambeds, in areas of intense groundwater recharge, to understand properties and processes associated with surface water – groundwater exchange. Work included mapping the locations and timing of streambed recharge, evaluating the impacts of sedimentation on groundwater recharge and surface water - groundwater exchange, determining the fate of recharging water, and evaluating influences of streambed seepage on water quality (mainly removal of nutrients). This work was supported over a five-year period by the U.S. Department of Agriculture (USDA), the UCSC Committee on Research, the UCSC Agroecology and Sustainable Food Systems program, the City of Watsonville, and the UC Institute for Geophysics and Planetary Physics. Project collaborators and those who provided in-kind support included the Pajaro Valley Water Management Agency (PVWMA), the City of Watsonville, and the U.S. Geologic Survey (USGS). This project supported four graduate student researchers and 10 undergraduate student researchers, and generated data and other information being used by the PVWMA to assist with resource management, and in classes taught at the lower undergraduate, upper undergraduate, and graduate levels.

UCSC researchers and partners collaborated with the PVWMA on a managed aquifer recharge (MAR) project, with a focus on making simultaneous improvements to groundwater supply and quality. Primary funding for this project came from the Santa Cruz County Resource

Conservation District (through a grant from the State Water Resources Control Board) and the National Institutes for Water Resources. Additional collaborators include California State University (Monterey Bay), University of Alaska Fairbanks, Moss Landing Marine Laboratories, and the USGS. Practical goals of this project included improved functioning of a managed recharge system, which will help to reduce groundwater overdraft, and determining conditions and processes that can help to improve water quality during recharge. MAR systems are sometimes run as part of a regional conjunctive use strategy (cooperative use of surface and groundwater resources), generating benefits to water managers, regulators, stakeholders, and aquatic ecosystems by shifting resource use patterns on the basis of (often unpredictable) availability; this capability will become increasingly important in coming decades as climate changes modify water resource availability and use patterns. Most studies of MAR systems to date have focused on physical aspects of their operation, particularly causes and impacts of clogging. In contrast, our work emphasizes linked quantity/quality issues, including quantitative reduction to nitrate load during MAR operation. This MAR project includes extraordinarily strong control on system mass balance (water, solutes), is applying novel technologies and techniques, and provides unique opportunities to link water supply and water quality objectives, and to quantify relations between processes, properties, and MAR operations. This project supported three UCSC graduate students and multiple undergraduate student researchers.

We conducted GIS/mapping and modeling studies to identify the most suitable locations for future recharge projects. The first study showed that about 7% (15 km^2) of the Pajaro Valley Groundwater Basin appears to be highly suitable for MAR. The second part of the study illustrates trade-offs in the positioning of MAR projects: projects placed adjacent to the ocean help to slow seawater intrusion more rapidly, but quickly become less efficient as a groundwater mound is created and more of the MAR water flows to the ocean. In contrast, placing MAR projects around the basin results in a slower reduction in seawater intrusion, but puts more MAR water in parts of the basin where it can be recovered for regional use. For a larger regional project, we revised analytical methods, released digital datasets and GIS files (http://www.rcdsantacruz.org/managed-aquifer-recharge) that are currently in use by agencies and municipalities around Monterey Bay, and helped to start similar projects elsewhere in California by giving talks, speaking with agency staff, providing guidance on methods, and sharing data and tools.

Recharge Initiative participants helped the City of Watsonville to monitor stream discharge and establish a long-term stream gauge to assist with planning and permitting to move a surface water intake so as to allow greater-in channel flows, which benefits both groundwater recharge and critical steelhead habitat. The work team included City staff and undergraduate UCSC student researchers. We collaborated with the County of Santa Cruz and others in monitoring and assessing regional stream discharge and sediment loads. Sediment load has an indirect (but sometimes powerful) influence on groundwater recharge because increased sedimentation can limit the hydrogeologic connection between the stream and underlying aquifer, limiting surface water - groundwater exchange (which can negatively impact water quality) and reducing the amount of recharge. In fact, if the connection is sufficiently reduced during periods of low streamflow, there can be a subsurface "dry gap" that separates surface and groundwater systems, requiring extra time for reestablishment of a connection when discharges increase again, and representing an additional loss in recharge to the aquifer. This work also involved an undergraduate student researcher.

The Recharge Initiative helped to create a new method for use of natural heat as a tracer to measure infiltration below streams, wetlands, lagoons, and recharge basins, sparking a renaissance of interest in similar methods. We subsequently applied the method to an active recharge system, linking infiltration rates to the cycling of nitrate in native soils. We have extended this work through application of a horizontal permeable reactive barrier to enhance denitrification through shifting of microbial ecology. We have tested additional PRB amendments and configurations in the lab and field, and are preparing for field-scale implementation to assess this approach as a best management practice.

Much of this work has been associated with the UC Water Security and Sustainability Research Initiative (UC Water, ucwater.org), a multi-campus program of research, education, and outreach/engagement. Through UC Water, we have collaborated on a series of policy reports, papers, and issue briefs that are having a positive influence across the state. For example, one of our recent issue briefs urges the State Water Resources Control Board to issue guidance on recharge as beneficial use without requiring specification of end use, recognizing improvements to hydrologic system services. This issue brief is especially timely because of a bill being considered by the California legislature, which would change current law to encourage more recharge projects. Issue Briefs and other documents, and associated talks and meetings with regulatory, management, and stakeholder groups, are helping to change how water is managed in California. It is gratifying to be involved in theoretical and applied research and engagement of this kind, which will have a long-term legacy for the region and state.

IV. The Way Forward

Colleagues and I have discussed the priorities of The Recharge Initiative with staff and representatives from numerous agencies and municipalities. All have expressed interest in seeing this effort expanded, and in developing collaborations to address water supply and water quality challenges with a focus on groundwater recharge. Recharge Initiative participants I have spoken at numerous public events over the last decade, and we regularly participate on technical advisory committees and respond to requests for information and comment from private citizens and print and broadcast media. There is considerable public interest in groundwater supply and related topics, and consensus that we do better to balance water demand and supply.

In 2016, we created with the Resource Conservation District - Santa Cruz County and the Pajaro Valley Water Management Agency, the first Recharge Net Metering (ReNeM0 program in California. ReNeM creates a basis and mechanism to incentivize improvements to water supply and quality in overdrafted basins. This program shares elements with energy net metering and groundwater banking, but differs significantly from both: it recognizes intrinsic hydrologic benefits of groundwater recharge, independent of planned recovery, can be revenue positive for operating agencies, and distributes financial incentives broadly within a basin. We have raised considerable funding in support of these efforts with regional partners, and are helping to operate three recharge systems in southern Santa Cruz County (a fourth is funded, with installation expected in 2019).

Ultimately this kind of information, analysis, and collaboration could be done throughout California, but before this can be proposed or attempted, we need to show that an initiative like this can work on a regional basis, that collaboration and cooperation can be sustained. In addition, it is important that the basis for recharge studies be *local knowledge*, *local experts*, and *local stakeholders* working together to find solutions – I cannot imagine that this approach would be applied to a region on the basis of a cursory review of data or a brief field inspection. It has taken 20+ years of research, teaching, and service in the Central Coast region to establish understanding and trust. *The Research Initiative is a long-term effort*, one that might be expanded regionally and/or serve as an example to be modified for use in other areas, with the identification of suitable partners.

My collaborators are currently seeking support for a range of recharge-related activities, preparing proposals for competitive funding through scientific and technical groups. Supporting the Recharge Initiative on a steady basis over an extended period will be challenging, particularly in working with traditional scientific funding sources, as this work is inherently multidisciplinary and operates at the interface between research, service, teaching, mentoring, and public engagement. My collaborators, students and I have a strong record of securing external funds and completing difficult projects on time and on budget, working collaboratively and with the cooperation of local stakeholders. The Recharge Initiative can show a considerable "match" in the form of grants, contracts, and commitments, including allocation of technical support, and graduate student support (teaching assistantships, research fellowships). The bulk of Recharge Initiative operating funds are generated externally. This is an administratively-lean operation, with no permanent clerical or other staff, operated on a pay-as-we-go basis.

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V. Frequently Asked Questions

What is "groundwater?"

Groundwater is subsurface water that occurs below the water table within geologic formations that are saturated (all pore spaces filled with water rather than air). Most groundwater exists in tiny pore spaces between grains of rock or sediment that comprise aquifers, geologic formations that can store and transmit water in usable quantities. Actual "underground rivers" are rare, although there are some on the UCSC campus within the cave network.

Should I spell it "ground water" or "groundwater?"

It can be spelled either way, but spelling it as two words makes it easier to talk about "surface and ground water," and for many years the U.S. Geological Survey (USGS) used two words for the noun, hyphenating when "ground" was used as a modifier (i.e., "ground-water recharge"). However, USGS personnel recently decided to transition to using one word, so I am doing the same. You will likely find some documents and figures that use the two words, but over time you can expect one-word usage to become more standard.

How much of California's water comes from the ground?

It varies year by year and region by region across the state. Current estimates are that about 40% of annual fresh water demand in California is satisfied by groundwater during an "average" year. During "dry" years, groundwater satisfies more than 60% of California's fresh water needs. Interestingly, the Central Coast hydrologic region, which extends from Santa Cruz south to Santa Barbara, gets a larger percent of its fresh water from the ground than any other hydrologic region in the state (>80%). At the same time, the Central Coast hydrologic region is more "off the grid" with respect to statewide water transfers than any other part of the state. Thus we are both uniquely dependent on groundwater and particularly mindful of needing to live within our means.

What is the "sustainable yield" of a groundwater basin?

This is the amount of water that can be pumped from an aquifer over the long term without causing unacceptable harm. Of course, "unacceptable" is someone's definition (physical, economic, political, legal, sociological); this is not a hydrologic term. Some people use similar terms like "safe yield" or "basin yield;" it is important to define these terms when they are used.

Note that the *sustainable yield is not equal to recharge*. In general the sustainable yield from an aquifer or basin will be less (often a lot less) than recharge.

What is "groundwater overdraft?"

This is a condition within a developed groundwater basin in which the amount of water pumped over the long term exceeds the sustainable yield of the basin. Note that what might be sustainable at one time may not be sustainable at another time, for example if inputs (like recharge) are reduced. Thus overdraft can occur even when there is relatively little pumping. The most accurate way to tell if there is overdraft is by monitoring water levels in aquifers over the long term. If water levels go down year after year, and do not rebound robustly when pumping stops or recharge occurs, there may be a problem with overdraft. In addition, overdraft can occur even if there is no net imbalance between annual inflows and outflows, if pumpage is distributed in such a way as to lead to problems (for example, being concentrated along the coast).

What is the annual groundwater overdraft in California, and how has it changed in recent years?

DWR's California Water Update (Bulletin 160) from 1998 indicated that fresh water demand exceeded supply during "normal" years by 1.6 million acre-feet (Maf, an acre foot is enough water to cover an area of an acre, 200 x 200 feet, with one foot of water). Although they did not call this "overdraft" in Bulletin 160-98, that is what most of it must be. How else can the state produce water in excess of supply year after year (surface reservoirs and rivers can be "overdrafted" for a little while, but not for many years)? DWR's 1998 estimate of the "dry" year water deficit was 5.1 Maf, enough water for 10 million California families. Note that this is *overdraft*, not use; actual water usage was much greater. DWR projected that these water deficits would plummet by 2020, at the same time that California's population went up by 50% (equivalent to the total populations of the nearest eight adjacent states). In the 2005 DWR California Water Update (Bulletin 160-05), the "normal" year deficit was estimated to be 5.8 Maf, an increase from 1998 of 260%. The "dry" year deficit was estimated to be 14.3 Maf (up by 180%). The 2009 and 2013 Water Updates showed that conditions are getting worse, and this was before the recent drought. It does not look like we are going to achieve DWR's 1998 projections for improvements in the state-wide water balance.

How does the DWR think California is going to meet its water needs in coming years?

The 2005 DWR California Water Update shows that the greatest new "supply" will come from improvements to urban water use efficiency, e.g., conservation. Improvements to groundwater management and conjunctive use comprise the next greatest water source. It should be noted that urban water users in the Central Coast hydrologic region *already use less water per capita* than residents in other regions. Obtaining additional large urban conservation benefits in this region will become increasingly difficult as we continue to make improvements. There are other ways to save water, like restricting agricultural use, but we should be very careful about entertaining ideas about taking a "command and control" approach to managing water. Certain water rights are enshrined in the California constitution, including an overlying right to pump groundwater when it is put to constructive use.

Why can't California build more dams to capture winter rains?

Governor Schwarzenegger proposed construction of two new dams in Fall 2007, comprising <1 Maf of additional storage (less than 20% of what is needed during "normal" years to overcome annual shortages), and there was a firestorm of protest. The Governor stopped talking about dams very quickly. The era of big dam projects is probably behind us in California. And even if we did build more dams, we would have to move this stored water around the state where it is needed. Current estimates are that ~8-10% of all the energy expended in California is used to move and treat surface water. That conveyance infrastructure is rickety, and may not survive the next major earthquake or the coming rise in sea level. Also, some hydrologic regions are not strongly connected to the Central Valley Project or the State Water Project, including the Central Coast region, and do not stand to benefit from dam construction unless it occurs on a massive scale. This is unlikely, particularly because people are more aware today of the environmental impact of dams than they were 40-50 years ago. Finally, *conservative* climate projections suggest that 60-90% of the winter snow pack in the Sierra Nevada will be gone by 2100. We will never build enough dams to keep up with this loss of snow pack, never mind the growing state water deficit based on current hydrologic conditions. Although increased surface storage could help to address ongoing and future shortages, it is unlikely that this approach will provide major new sources of fresh water.

Won't climate change result in more rain?

What the models suggest, in addition to massive loss of snow pack, higher mean temperatures, and more extremely warm days, is *greater variability and intensity* of precipitation. Most likely this will result in less opportunity for groundwater recharge. Some studies have suggested that climate change could increase recharge in particular areas, but these studies did not include a full suite of new hydrologic and climatic conditions. Sea level rise will increase seawater intrusion into coastal basins, where much of the population lives. In addition, global and regional climate models are notoriously poor in representing precipitation and related processes, so there is considerable uncertainty as to how precipitation will be distributed following large changes in the atmosphere that are anticipated during the rest of the 21st century. The best approach we can take is to maintain *flexibility* in supply, and to get as much water into the ground as possible when we have the chance. This is not going to get easier or cheaper moving forward.

Can we close the statewide water deficit just by increasing groundwater recharge?

Probably not. Conservation, recycling, artificial recharge, conjunctive use and other approaches are all likely to contribute to solutions. Keep in mind: this problem will need to be solved basin by basin, district by district, on the basis of local conditions and political and economic realities. Given how contentious water projects are, those projects with a strong local component, with the most local control, are most likely to be the most politically feasible. Protecting and enhancing groundwater recharge is about as local as it gets. Certainly, in the Central Coast hydrologic region, enhancing groundwater supplies is going to be profoundly important. We have storage to spare, and we should get busy filling that space with water.

But if groundwater recharge is not "the answer," then why have an initiative dedicated to this topic?

There are many excellent organizations working on reducing urban and agricultural demand, so I don’t think I have much to contribute to that area. Other groups are focusing on desalinization and recycling, both of which are likely to be important in individual basins. But I've not seen any other group working specifically on enhancing recharge. In addition, groundwater recharge is a scientific and technical frontier, one of the most cryptic of the major hydrologic flows. Other flows, like evaportranspiration and runoff, are being evaluated from space by remote sensing, but recharge is not as amenable to spatial approaches in this way. In addition, I think we can get some traction in short order, build momentum, and help to connect people to their groundwater basins. This has a benefit all its own.

Why don't we stop farming so much, won't that solve the problem?

It is clear that some low-value crops (like cotton and rice) probably should not be grown where there is not enough surface water. But it is politically difficult to force farmers to grow or not grow certain crops. Growing strawberries can generate more money than growing apples; who should decide what gets grown? We also need to be careful about fallowing land if that land gets used for construction of housing. It used to be conventional wisdom that changing from farming to housing saved water, but recent studies suggest that there is often little or no water savings associated with this shift. We can be sure that large, rapid shifts in farming practices or farmed acreage would lead to significant economic problems. The best approach may be to shift practices slowly over time, but it can be challenging to sustain these kinds of shifts. Now let me ask you a question: *don't you like having all the wonderful local produce?* Would it really be better if we trucked it all in from elsewhere? One goal of the Recharge Initiative is to facilitate the sustainable transformation of our water supply system, to make it more flexible and increase the capacity to benefit from natural and anthropogenic variability. Some agricultural changes are inevitable, but hopefully they will not be so extreme so as to lose the benefits from living in such a productive region. We include encouragement of sustainable agricultural practices as a fundamental goal of The Recharge Initiative.

For more information, please contact:

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