The Recharge Initiative

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I. Motivation

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 are a lot of people and programs focusing on reducing water demand; there is less effort being placed on augmenting groundwater supplies. 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. 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 will be 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 will facilitate 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 will empower 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 four primary components:

(1) Delineation of natural groundwater recharge and potential managed recharge areas, through analysis of surface and subsurface data, 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) 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 will be developed from the ground up through collaboration with local stakeholders and resource managers, with participants bringing specific expertise, tools, and resources. Funding will be 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.

(4) 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 a 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 has 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. This project (which ended in 2007) has generated four papers thus far in top-tier, peer-reviewed journals, and additional papers are in preparation.

UCSC researchers and partners are currently collaborating with the PVWMA on a managed aquifer recharge (MAR) project, with a focus on making simultaneous improvements to groundwater supply and quality. Funding for this project has come from the Santa Cruz County Resource Conservation District (through a grant from the State Water Resources Control Board), the National Institutes for Water Resources, the UCSC Committee on Research, and the UC Institute for Geophysics and Planetary Physics. Additional collaborators include California State University (Monterey Bay), University of Alaska Fairbanks, Moss Landing Marine Laboratories, and the USGS. Practical goals of this project include 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 has supported three UCSC graduate students and multiple undergraduate student researchers.

UCSC and CSUMB researchers and students are working on a spatial data analysis of the Pajaro Valley, to assess which areas might be most amenable to managed aquifer recharge using storm water capture. This analysis is based on a compilation and evaluation of several surface and subsurface coverages of soil, land use, aquifer, and groundwater conditions and properties. A preliminary map has been displayed at several public meetings, and we hope to release a final analysis of "MAR suitability" by late 2011, to be used as part of a regional water resource assessment. We are also building a percolation test system to be used for evaluation of MAR potential on a site by site basis. Work will be completed in the Pajaro Valley and in the Carmel Valley, hopefully extending regionally to other parts of the Central Coast hydrologic region.

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 will benefit both groundwater recharge and critical steelhead habitat. The work team including 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.

Recharge Initiative participants worked with the National Park Service in a study of surface water – groundwater interaction during controlled flooding of Poopenaut Valley, Yosemite National park. The emphasis of this project was on restoration and maintenance of riparian wetlands adjacent to the Tuolumne River, particularly an evaluation of the relative roles of inundation versus rising groundwater in developing wetland conditions. We are also involved in a study, in collaboration with students and researchers from Cal Poly and others, of how a recent wildfile north of Santa Cruz may influence the extent of surface water – groundwater exchanges in the Scott Creek Basin.

IV. The Way Forward

Colleagues and I have discussed the priorities of The Recharge Initiative with staff and representatives from numerous agencies and municipalities, including the City of Watsonville, County of Santa Cruz, the Pajaro Valley Water Management Agency, the Soquel Creek Water District, and the Scotts Valley Water District. 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. I have spoken at numerous public events over the last three years, including stakeholder meetings to discuss water supplies, an evening lecture at the UC Berkeley Water Resource Center Archives, a meeting of the Santa Cruz County Board of Supervisors, and an event on water resources and climate change organized by regional municipalities. I regularly participate on technical advisory committees and respond to requests for information and comment from private citizens and print and broadcast media. There is broad public interest in groundwater supply and related topics, and my sense is that many people would like to resolve the imbalance between water demand and supply.

The next step in development of The Recharge Initiative is the mapping and stream seepage component described in Section II. Staff from Santa Cruz County are interested in collaborating on this effort, which will ultimately include creation of digital data products made available to agencies and the public for use in evaluation of land use decisions and water supply and water quality projects. GIS work is underway, but additional mapping and delineation of recharge areas could take 5-6 years, beginning with Santa Cruz County, and eventually expanded to surrounding regions. 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 10+ 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 foundation support for a range of recharge-related activities, and are also 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, and teaching. 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. What we need to do now is secure a modest level of "baseline funding" that can be used to leverage other resources.

I made a personal pledge of $10k to support The Recharge Initiative, working with the UC Physical and Biological Sciences Development Office to establish an account that can be used to support related activities. Colleagues and I are working on proposals to secure more substantial baseline support. This could include funds for a field vehicle, and student and supply support sufficient for 1-2 projects/year. With baseline funding in hand, we can work collaboratively with agencies and municipalities to design and fund projects like those described earlier. We hope to secure baseline support initially for 5-6 years, perhaps contingent on annual or biannual review and demonstration of satisfactory progress. This would allow enough time to develop collaborative projects, recruit excellent students, and generate deliverable results (collaborative grant proposals, data products, theses, papers, teaching materials, public presentations). When soliciting support from foundations, The Recharge Initiative can show a considerable "match" in the form of grants, contracts, and commitments from the Earth and Planetary Sciences Department at UCSC, including allocation of technical support, and graduate student support (teaching assistantships, research fellowships for new students). 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 Water Update shows that conditions are getting worse. 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 year?

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 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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