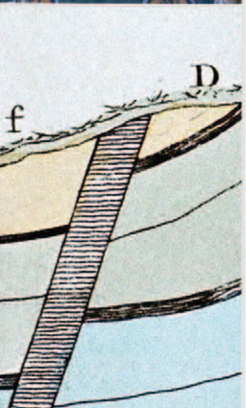
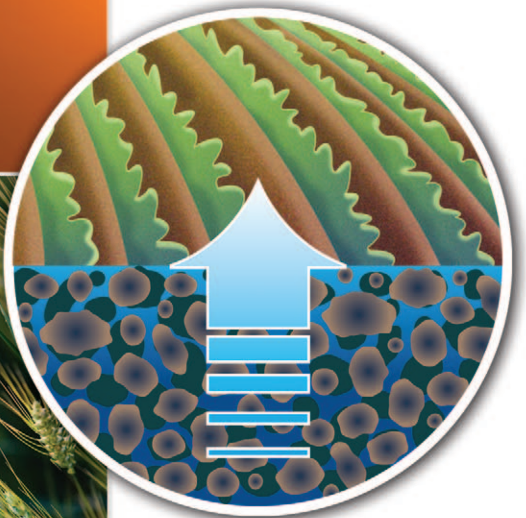


Abstracts



Toward Sustainable Groundwater in Agriculture

An International Conference Linking Science and Policy

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Hyatt Regency San Francisco Airport
Burlingame, California

Organized by:

Water Education Foundation

UC Davis
University of California

Conference Framework

Groundwater is the lifeline for many rural and agricultural regions and their associated cultures and populations around the globe and a cornerstone of global food production. Groundwater constitutes nearly half the world's drinking water and much of the world's irrigation water supply. Population growth, overexploitation, salinization, nonpoint source pollution from agricultural activities (including animal farming, ranching, and forestry activities), impacts of groundwater use and degradation to surface water, and groundwater quality and quantity conflicts at the urban-rural interface have reached global dimensions and threaten the health and livelihood of this planet.

Groundwater is inherently a local and regional resource. Access is mostly through individual landowners and also through local and regional water purveyors. Groundwater overdraft and/or groundwater degradation from agricultural activities have broadly affected regions, states, and nations. Agricultural practices and management, groundwater management, groundwater use and degradation policies, regulations, and groundwater resource assessment and forecasting occurs at the farm, community, region, or state level, delineated by groundwater basin and jurisdictional boundaries. Yet, around the globe, many groundwater users and benefactors share similar experiences in their struggle to control or curtail overdraft and groundwater quality degradation.

Information sharing, management, policy and legal control of groundwater in agricultural regions, and assessment of agricultural practices and associated effects on groundwater quantity and quality occur across a highly disparate community. At local to global scales, we are faced with the dilemmas posed by water quantity versus water quality, science versus policy and management, local versus state versus national and international issues, groundwater versus surface water, and agricultural versus environmental resources. Much can be gained by dialogue among stakeholders, including scientists, policy and decision makers, groundwater managers and agronomists, who can offer their worldwide perspectives about these issues. Through coordinated efforts, stakeholders have the opportunity to learn from others' experiences and solve common resource management conflicts.

This three-day international conference brings together leading scientists, policy analysts, policy and decision makers, and agricultural and environmental stakeholder groups to define and highlight the science, challenges, and potential policy solutions in agricultural groundwater resources management and groundwater quality protection that will provide a sustainable future at regional, national, and global scales.

This conference provides participants with a unique opportunity for outreach, sharing, learning, and networking with key players and stakeholders from around the world to synergize ideas and formulate the steps needed to address common challenges.

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Challenges of Water Sector: Groundwater and Agriculture in Egypt

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Water issues are the most important challenges in the middle of this century. In 2050, the entire earth would be threatened thirsty, due to a number of reasons, perhaps most important the rising world population, inefficient water use; especially in irrigation systems and pollution. Because of the Earth's temperature rising, this is called the phenomenon of global warming, which increases the drought areas and densification. Egypt is about 1080 km. The Egyptian terrain consists of a vast desert plateau interrupted by the Nile Valley and delta, which occupies about four percent of the total country area. The total cultivated area (arable land plus permanent crops) is 3.8 million hectares (ha) (2005), or about three percent of the total area of the country. There is no forest land. Total water withdrawal in 2000 was estimated at 68.3 cubic kilometers (km3). This included 59 km^3 for agriculture (86 percent); 5.3 km3 for domestic use (8 percent); and 4.0 km^3 for industry (6 percent). Apart from that, 4.0 km^3 were used for navigation and hydropower. Agriculture in Egypt represents a milestone in the national economy as it has its special historical background. Irrigation projects that lead to a better use of the available fresh water are very important for the sustainable agricultural development. However, changes introduced in any national equilibrium may result in a number of other changes and precautions which ought to be considered to prevent land deterioration. Egypt is a water rich country but the growth in population since 2005 makes it a water scarce country. Furthermore, it is forecasted that in 2025 the population will reach 95 million. The decreasing amount of water thus represents the most important challenge for the future. The River Nile is the main source of water for Egypt. Owing to the rapid growth of the population and the increasing consumption of water, it is expected that Egypt will rely to some extent on groundwater in order to achieve agricultural expansion in the vast desert areas. Issues related to groundwater in Egypt are identified with the common geological features associated with formation of the aquifers and demonstrating the location of the main resources of groundwater, followed by the main objective of this paper, which is addressing the environmental issues related to groundwater in Egypt. Several studies have been reviewed and provide an overview of the groundwater quality problems in Egypt which are available for agricultural irrigation systems, with examples from different parts of the country.

The Impact of Climate Change on Groundwater Recharge in Karkheh River Basin (Iran)

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In Iran, most research on the potential impacts of climate change on the hydrologic cycle has been directed at assessing the potential impacts on temperature, precipitation, and streamflow, while no significant research studies have reported on the impacts of climate change on groundwater resources, despite the fact that groundwater constitutes a significant proportion of freshwater supply in Iran. This paper represents the results of a study on the impact of climate change on groundwater recharge in the Karkheh River Basin in Khuzestan, Iran, using a physically-based methodology that can be used for predicting both temporal and spatial varying groundwater recharge. Recharge was estimated by using the Hydrological Evaluation of Landfill Performance (HELP3) water budget model. As the Karkheh River Basin is a semiarid region and all sectors of water demands, including domestic, rural, and irrigation, rely significantly on groundwater resources, it is essential that the potential impacts of climate change on the aquifers be identified for long-term sustainable integrated water resources management in the region. The Karkheh River Basin, with an area of 50,764 km^2, has a population of around 4 million, of which 67 percent are living in rural areas. The mean annual precipitation varies from 150 mm in the south to 750 mm in the north and the climate is mainly semiarid. The future of the Karkheh River Basin and its people's livelihoods clearly depends on natural resources like water. As water is the most limited natural resource in this basin, any increase in water productivity due to better water management will certainly benefit rural livelihoods. To ensure the sustainability of the improvements in water productivity, assessment of the possible impacts of climate change on hydrology and water resources in the basin is necessary. In this study, the potential impacts of climate change on groundwater recharge was modeled using two downscaled precipitation and temperature scenarios A2 and B2 due to CGCM2 and two large scale precipitation and temperature scenarios A1B and B1 due to CGCM3 model results for three periods: 2010-2039, 2040-2069, and 2070-2099. Results indicated that prediction of future recharge is very uncertain and highly depends on the scenario selected. While groundwater recharge is predicted to increase under B2 scenario, it will change slightly under other scenarios. The results also showed how groundwater recharge varies spatially, due to variations in land use and underlying soil characteristics.

Cropping System Model for Integrated Evaluation of Agricultural Activities

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Agriculture plays an important role in environmental pollution, mainly related to leaching of nitrate, sediment, nitrogen and phosphorus in surface water and greenhouse gas emissions. Cropping systems at field, farm and land scale are driven by different driving forces, such as market, policies, climate, and soil characteristics. Policy-makers and farmers have to develop, respectively, a set of regulations and management strategies to obtain simultaneous environmental and economic sustainability. The use of the cropping system model, describing all relevant processes involved with water and nitrogen in plant-soil system and adequately supported by networks of field experiments, allows for a priori evaluation of current cropping systems under alternate management scenarios. Since Po Valley (Northern Italy) is characterized by intensive agriculture, then an adequate analysis of cropping systems is required. This area accounts for 68 percent of dairy cattle, 61 percent of other cattle, 85 percent of pigs and 80 percent of poultry of the total livestock reared in Italy, with about 7 ml of livestock units, and a density of about 1.7 LSU ha-1 of utilized agricultural area (UAA), and has the largest aquifer in Europe. In Po Valley, 67 percent of the UAA is considered a Nitrate Vulnerable Zone (NVZ) and arable cropping systems including maize, winter or summer herbage and grassland represent the 64 percent of UAA. An analysis to support policy-makers and farmers based on ARMOSA model was carried out on different cropping systems scenarios in the Lombardy region (44 percent of LSU and 24percent of UAA of the Po Valley) in order to estimate N losses and in particular nitrate leaching. Lombardy UUA for extensive crops was divided using the 2-step cluster analysis into 35 homogenous districts with similar pedo-climatic characteristics and agricultural management practices. According to the regional agricultural database and regional soil map i) representative crop rotations, ii) N load calculated from livestock density, iii) two representative soil types were identified for each district. N leaching was estimated over 20 years. Then a weighted mean of leaching was obtained for the whole district (Fig 1). ARMOSA model was subsequently used to simulate different cropping systems scenarios (A and B), characterized by the same total N input (about 350 kg ha-1 y-1) but a different amount of N from livestock manure (170 and 280 kg ha-1 y-1, respectively for A and B). B scenario is based on the use of long growing seasons and high nitrogen uptake crops, introduction of catch crops. B scenario shows yields similar to the A scenario and a clear decrease in N losses. A scenario is not compliant with the EU threshold for water drinkability of 50 mg NO3- l-1.Since the European Nitrates Directive 91/676/EEC allows for the possibility for a derogation in respect to the maximum amount of 170 kg N ha-1 y-1for livestock manure in NVZ, the simulation results are a scientific base for the derogation asked by Italian Government, currently under revision by the EU Nitrate Committee. A detailed analysis of current condition and cropping case meeting derogation guidelines is provided, showing that the Directive's objectives are still achieved.

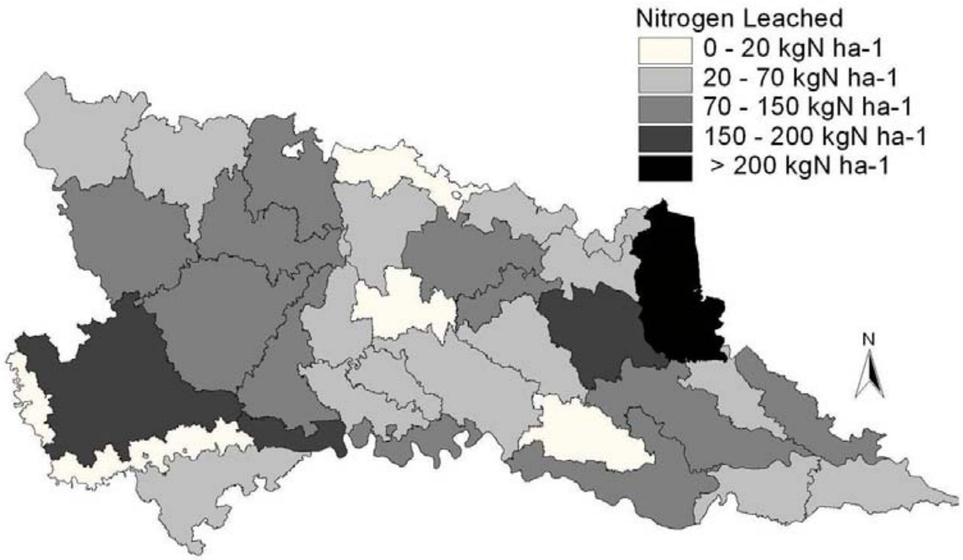

Fig. 1. Simulated N leached (kg N ha^{-1}) in Lombardy UAA divided in 35 homogenous districts.

Nitrate Leaching in Various Irrigation Methods and Simulating Nitrate Movement and Transport with LEACHN Model

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On-farm activities such as pesticide and fertilizer application are considered as important non-point sources pollutions for surface and ground waters. Over-application of the chemical inputs compounded by lack of the farmers' knowledge of the use on one, and water resource limitation on the other, increases the environmental challenges. Fast development of the irrigation and drainage networks has also increased the transport of these materials. Nitrate, phosphorous and potassium fertilizers are used with the considerable amounts in Ghazvin Plain, Iran. This research was carried out to investigate the impact of irrigation and drainage systems on surface and groundwater pollution caused by nitrate. Results showed higher rate of nitrate transportation in surface run-off via border irrigation compared with furrow irrigation method. However there was no significant statistical difference. Results further indicated higher nitrate transportation in drain water via border irrigation method compared with furrow and linear sprinkler irrigation methods. The results of this showed significant statistical differences between surface and linear sprinkler irrigation methods. Further results indicated that in three irrigation methods, there was no significant difference in concentration of nitrate in drain water, but this was higher in border irrigation than other methods. The measured rate of nitrate transport into the groundwater was compared with the simulation estimates by LEACHN model which showed a close value. This is interpreted to mean that the model can be used as a powerful analytical tool which simulates nitrogen reactions in soil. Final error, CV and effectiveness of the model were 0.922 percent, 6.21 percent and 0.63 respectively. Given these results, scenarios were offered to reduce nitrate losing to ground waters by LEACHN model.

Environmental and Socio-Economic Implications of Overexploitation of Groundwater Resources in Hassa Oasis in Eastern Saudi Arabia

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Hassa Oasis is the largest and most populated oasis in the hyper-arid Arabian Peninsula. Throughout history, the oasis maintained artesian flow of fossil groundwater from the confined Neogene aquifer in the form of natural springs via scores of fractures and sinkholes. By definition, development of fossil groundwater resources is non-sustainable and can induce serious undesirable consequences. This paper investigates the present and potential environmental and socio-economic implications of overexploitation of groundwater resources in the oasis. Development of fossil groundwater from the confined Neogene aquifer in the oasis began in the late 1950s and resulted in the complete cessation of natural springs flow in the mid 1960s. Despite unequivocal recommendations of consulting firms to limit groundwater development to safe levels and the establishment of an authority for the management of irrigation and drainage, overexploitation of groundwater resources in the oasis increased since then and is still practiced to date. Presently, the impacts of groundwater overexploitation are manifested in a sharp decline of groundwater level, deterioration of groundwater quality (total salinity and ionic composition), increased costs of well drilling and groundwater abstraction, soil salinization and sodification and reduction of crops relative yield. Unless progressive corrective measures are adopted swiftly, the negative impacts are expected to widen and intensify with time to reach unbearable environmental and socio-economic consequences.

Just Water? Environmental Justice and Drinking Water Quality in California's Central Valley

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Preliminary policy reports have found that California counties with higher rates of poverty and greater percentages of people of color have a disproportionate rate (i.e. almost twenty-fold higher) of violations of the Safe Drinking Water Act. Such reports suggest a case of environmental injustice in these communities. However, there is little rigorous research on the intersection of drinking water quality, environmental justice (EJ) and environmental health at the community scale in California. We examine the relationship between race, class (i.e. poverty level and home ownership), and exposure to nitrate in community water systems (CWS) in the entire San Joaquin Valley. Combining datasets on water quality monitoring results, CWS characteristics and customer demographics, we hypothesize that: 1) CWS that serve a higher proportion of people of color, higher poverty residents, and/or greater fractions of renters (vs. those that serve higher proportions of whites, residents above the poverty line, and/or residents with higher rates of home ownership) have higher concentrations of nitrates. We use a hierarchical, longitudinal statistical model to analyze these relationships for data from 1999 to 2001. Our hierarchical model indicates that race and home ownership are more significant ($p<.05$) than poverty level in predicting concentration levels. These disproportionate impacts create an economic burden: customers and systems with the worst water quality have the least economic means by which to fix the problems. Two key health risks emerge; one of exposure to high levels of nitrates, and a second of a lack of informing customers of risks of consuming high nitrate levels. These findings suggest that California's drinking water laws are not equally protective, and that water policy reforms should focus on this issue.

The Impact of Dairy Farms on the Groundwater Quality of Israel's Coastal Aquifer

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Concentrated animal feeding operations (CAFOs), such as dairy farming, have been repeatedly found to impair underlying groundwater quality. Little is known about the impact of dairy farms on Israel's groundwater quality, even though the overall pollutants mass generated by the dairies equals that of the entire population. Nevertheless, the dairy farming industry was recently reformed in order to minimize liquid waste (including manure, feces, water from washing shades and cooling water) and contaminated runoff from reaching the environment. The objective of this work is to assess the direct impact of dairy farms on the quality of groundwater recharge in Israel's phreatic Coastal Aquifer at its most intensive dairy farming area. Groundwater observation wells and unique vadose-zone monitoring systems (VMSs) that enable monitoring of the temporal variation in the sediment's water content along with continuous sampling of the sediment's pore water in deep sections of the vadose zone were installed in a representative dairy farm. Results from 3 years of continuous monitoring showed that unlined dairy farm waste lagoons are point sources for highly concentrated solutions recharging the aquifer (~4000 mg L-1 chloride and ~700 mg L-1 nitrate). Overflows from the waste lagoon as well as local runoff during high intensity rain events, preferentially infiltrate into desiccation cracks around the dairy farms. This process accelerates groundwater contamination since it rapidly transports contaminants and salts (such as nitrate, testosterone and estrogen) into the deep sections of the vadose zone (>10m) bypassing the sediment's most bio-geo-active parts. The VMS is shown to be an effective tool for continuous long-term monitoring of contaminant transport along the vadose zone as well as for assessments of natural attenuation and early detection of pollutants in the vadose zone.

Using a Multi-Actor Framework for Simulating the Interaction between Various Actors, Water Supply and Groundwater in Response to Global Change

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The aim of GLOWA-Danube (www.glowa-danube.de; financed by the German Ministry of Research and Education) is to provide an integrated approach to predicting changes to the hydrological cycle due to Global Change in the Upper Danube Catchment (UDC), an area with an extent of 77,000 km^2 situated in Germany and Austria. GLOWA-Danube considers both the influence of natural changes in the ecosystem, such as climate changes, as well as social changes, e.g. changes in land use as a consequence of farmers' decisions. For that purpose, GLOWA-Danube has developed the coupled simulation system DANUBIA, which is comprised of a total of 17 disciplinary simulation models coupled to each other dynamically during runtime. The UDC is a mountainous, heterogeneous catchment with altitudes between 287 and 4049 m a.s.l., precipitation levels (P) between 650 and >2,000 mm/a, average annual temperature values (T) between -4.8 and +9 °C, and evaporation levels (E) between 0 and 550 mm/a. Taking socio-economic processes into account within such an integrated hydrological simulation system is challenging. Systems that aim at evaluating the impact of climatic change on large spatial and long temporal scales cannot be based on the assumption that infrastructure, economy, demography, agricultural practices and political frameworks remain constant while physical boundary conditions change. Therefore, any meaningful simulation of possible future scenarios needs to allow socio-economic systems to react and adapt to climatic changes. To achieve this, it is necessary to simulate the decision-making processes of the relevant actors in a way which is adequate for the scale under consideration, the catchment-specific management problems under investigation and finally, the availability of data. Here we present a multi-actor approach for representing such human decision processes, the so-called DeepActor framework, which has similarities to agent-based approaches. In the present contribution, we focus on the simulation of decisions made by farming actors (agents) and their consequences on land use, plant ecology and the nitrogen cycle, groundwater quality, groundwater quantity, and finally, water supply. Potential interactions and conflicts with other actors are explained. The DANUBIA and the DeepActor framework will be presented together with the main sub-models they involve. Results are shown for various scenario simulations based on climate scenarios combined with socio-economic scenarios. The scenario definition approach is shown briefly. A stakeholder process initiated by the GLOWA-Project will also be covered.

Municipal / Agricultural Conservation Tools Applied in Central Texas, U.S.

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The majority of water providers in the West and Southwest U.S., including Texas, have not achieved significant water conservation savings, nor have they optimized the efficiency of existing facilities and delivery systems despite reduced water supplies and persistent drought. Adopting cost-efficient conservation measures and best management practices, however, could reduce water supply stresses and alleviate future water deficits. Central Texas provides a unique setting of water sources for municipal and agricultural water providers, based on the mixing of surface and groundwater sources for either use category. Accordingly, this study discusses the development and application of municipal and agricultural water conservation tools, both with significant potential for water savings, based not only on water provider category, but also from optimizing surface and groundwater use. The Municipal Water Conservation Tool was developed to assist municipal water providers in estimating the current and potential future volumes of water saved by utilizing recommended conservation best management practices and determining the potential savings derived from such practices. Among the results from utilizing the Municipal Tool are that water providers characterized as predominantly rural, with some suburban coverage, exhibited the lowest average customer water consumption value (92 gallons per person per day) in Central Texas, while suburban, urban and strictly-rural water providers trended towards higher individual water consumption values. Further, urban and primarily urban water providers tend to have higher per capita use rates for several reasons (and often despite aggressive conservation programs), including a larger percentage of affluent, high water use customers, and higher water leakage rates because of larger water volumes and longer distances supplied. The Agricultural Conservation Tool was developed to assist agricultural producers and water planners in managing available water supplies and financial resources to achieve maximum irrigation results for the least cost suite of on-farm and irrigation best management practices. Groundwater is the predominant source for agricultural use in Central Texas, although not necessarily the only source. The Agricultural Tool first estimates, in situations of little or no meter data, the percentage of groundwater vs. surface water volumes for agricultural applications. Based on crop types, irrigation practices, and other data, the Tool estimates current water conservation savings, or water saved by employing water conservation practices. The conservation savings of incorporating additional best management practices or water saving measures, as well as the potential costs and monetary savings also are determined. Identifying measures for conserving agricultural water without significantly reducing crop yields, coupled with increasing municipal conservation savings, and being able to estimate the associated costs of each, will allow producers and water managers to effectively plan for future water needs in the face of impending water shortages from recurrent droughts, increased municipal demands and increasing water prices.

			Current costs/savings of one shower head per household			Current costs/savings of two faucets per household		
Provider	**# & type of customers METERS**	**Conservation Measure SHOWER/FAUCET RETROFIT**	cost (ave cost $13.63) at 50% adoption rate	Annual savings million gal, AF	Cost per gal saved Cost per AF saved	cost (ave cost $1.75) at 50% adoption rate	Annual savings million gal, AF	Cost per gal saved Cost per AF saved
1	184,823	Free showerheads for residents	$ 1,259,569	44.5 mill gal 1,366 af	$0.003 $922	$ -	0	$ -
2	4,861	LF faucet aerators and shower heads at a **discounted** price (50%)	$ 16,564	13.5 mill gal 428 af	$0.0012 $401	$ 4,253	26.9 mill gal 82.655 af	$0.0002 $51
3	3,889	voluntary ordinance for LF shower head and faucets	$ -	16.4 mill gal 50 af	$ -	$ -	32.8 mill gal 101 af	$ -
4	1,252	require LF shower head,faucets in new construction and in replacement of plumbing in existing structures	$ -	4.0 mill gal 12 af	$ -	$ -	8.0 mill gal 25 af	$ -
5	28,935	Free low-flow faucet aerators and showerheads to replace existing high-volume fixtures	$ 197,192	91.55 mill gal 281 af	$0.0022 $702	$ 50,636	18.3 mill gal 562 af	$0.0003 $90

Table 2. Results of Municipal Conservation Tool for Showerhead, Faucet Rebate Programs in Central Texas

Development of the Focus Groundwater Scenarios for the Assessment of the Leaching of Plant Protection Products in EU Registration

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In 1993, the European Commission initiated the Forum for the Co-ordination of pesticide fate models and their use (FOCUS). The aim was to harmonize the calculation of predicted environmental concentrations of active substances of plant protection products in the framework of the EU registration procedure. FOCUS is based on co-operation between scientists of regulatory agencies, academia and industry. Since then three FOCUS workgroups have been developing guidance for leaching to groundwater (1993-1995, 1997-2000 and 2004-2009). Also for other environmental compartments, FOCUS workgroups were established. Around 2007, the European Commission transferred the responsibility for developing guidance for environmental risk assessment to the European Food Safety Agency (EFSA), so FOCUS is now finalizing its activities. The first groundwater workgroup agreed on a terminology for crucial terms such as validation status of a model and made an inventory of existing leaching models. The second groundwater workgroup aimed at developing a limited number of scenarios. This workgroup divided the EU into a number of climatic zones and developed a scenario for each of these zones. This procedure was adopted because the EU registration procedure is based on the principle of a safe use of a sufficient size. So the consequence is that the use does have to be safe only in part of the climatic zones for a positive decision at EU level. Within each zone, the aim was to select a realistic worst case scenario which was specified as a 90th percentile case (considering both soil and weather as drivers for the vulnerability). The selection of the soil profiles had to be based on local experts and expert judgment because a pan-European soil database was not available. This led to the release of nine FOCUS groundwater scenarios at the end of 2000 (Figure 1). These scenarios are software packages that each contain a numerical model (PRZM, PELMO or PEARL), a database and a user interface, enabling leaching calculations for these nine scenarios (additionally there is also a software package for the MACRO model for one of these nine scenarios). Since their release these software packages have been under strict version control and all released packages are still available for downloading (http://focus.jrc.ec.europa.eu). Among EU regulators the FOCUS groundwater scenarios are considered to be a successful example of harmonization within the EU registration procedure. The third FOCUS groundwater workgroup was put into life (i) to develop tiered leaching assessment schemes for EU and national levels (see Figure 2), (ii) to improve the parameterization of the existing nine Tier-1 scenarios in view of experiences gained in R&D projects and in the EU registration procedure, (iii) to develop the role of higher-tier modeling and higher-tier experiments (such as lysimeter studies, the use of spatial data in assessments, and incorporation of non-equilibrium sorption) in the leaching assessment, (iv) to assess whether these nine scenarios were still sufficient after the EU was enlarged from 15 to 25 Member States. The report of the third workgroup has been submitted for review to EFSA in summer 2009.

Figure 1. Locations of the nine FOCUS groundwater scenarios.

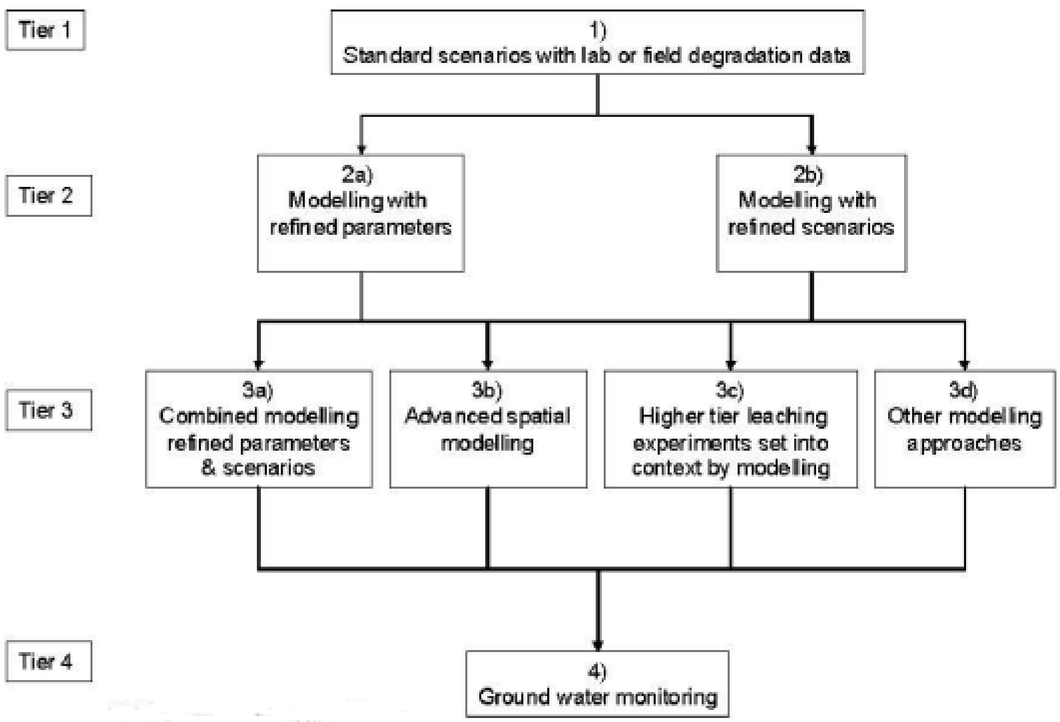

Figure 2. Proposed generic tiered assessment scheme for leaching of plant protection products to groundwater.

Saving Water and Energy Using Spatially Distributed Real Time Water Potential Sensors in Cranberry

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There are increasing pressures to improve irrigation management in cranberry to optimize crop yield and to reduce water and energy use in Canada, as this crop requires a large amount of water for harvest but also for summer and fall irrigation. Irrigation guidelines are lacking in this crop, with the few available references (3 references over 70 years) indicating high soil water potential values (-2 to -4 kPa). For this crop, because of the specific design of the sub-irrigation systems and of the crop bed configuration, important spatial patterns in irrigation requirements are likely to exist. New wireless real time water potential sensors now exist to identify these irrigation needs and open the route for important water and energy savings by managing local irrigation needs. The objectives of this study were therefore to identify appropriate irrigation set points for cranberry production in Quebec and then, knowing these set points, to identify spatial irrigation patterns on a commercial production site. Those set points were first evaluated using soil physical properties, a hydrological model, field experiments and photosynthesis measurements carried out in a growth chamber. Using unsaturated hydraulic conductivity and water desorption data, an ideal -3.5 to -7.5 kPa range was identified while a minimum value of -8 kPa was determined from a hydrological model combined with field estimation of evapotranspiration. Growth chamber experiments confirmed that the ideal range was in the -3.5 to -8 kPa range, limited at its upper boundary by aeration constraints and at the lower boundary by a low unsaturated hydraulic conductivity. Quebec and Wisconsin's data for the relationship between yield and soil water potential showed the same trend as that between photosynthesis and water potential. Then, it becomes possible to conclude so far that adequate irrigation setpoints should range between -3.5 to -7 kPa for cranberry production. With respect to the second objective, different real time irrigation sensors were installed and monitored and the data generated were mapped to identify spatial irrigation requirements. The data lead to the conclusion that 1/3 of the production site had sufficient recharge to compensate for irrigation requirement leading to 33 percent saving in water and energy. The identification of appropriate irrigation set points reduce water requirement by 2 to 6 times with respects to evapotranspiration estimate, and to common irrigation practice at the commercial scale.

Case Study of Groundwater Remediation of Non-Point Source Nitrate

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Groundwater quality in agricultural settings is of great concern because worldwide it serves as an important source of drinking water. The most common groundwater pollutant, nitrate, is closely associated with rural, agricultural regions, and like other chemicals associated with agricultural activity, it is commonly found in groundwater as a non-point source pollutant. Lessons learned from groundwater remediation research over the past two decades can be helpful in solving the nitrate problem. However, the non-point source nature of nitrate contamination poses challenges that go beyond our experiences with industrial pollutants, which usually emanate from point sources. One approach that has proven effective for in situ groundwater remediation is bioremediation. A methodology for dealing with non-point source nitrate is currently under development near the town of Woodstock, Ontario, Canada, and consists of two essential parts: first, best management practices (BMPs) are instituted to abate the continued influx of nitrate to the regional aquifer; second, bioremediation is conducted upstream of the municipal water supply wells to maintain nitrate levels below the drinking water limits until the BMPs are effective at establishing low background nitrate levels. In implementing a pilot test of the bioremediation scheme, based on the cross-injection method, the aquifer near Woodstock was found to contain a very highly conductive stratum in which groundwater was moving in excess of 20 m/day. The stratum was first discovered using point velocity probes for direct groundwater velocity measurement, and then confirmed with tracer tests. Initial attempts to promote bioremediation in the form of in situ denitrification were partially successful, but additional work is needed to determine the conditions required to completely denitrify the highly permeable stratum.

Reuse of CAFO Wastewater on Agricultural Lands: Potential Environmental Contaminants, Transport Pathways and Treatments

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Concentrated animal feeding operations (CAFOs) generate large volumes of manure and manure-contaminated wash and runoff water. When applied to land at agronomic rates, CAFO wastewater has the potential to be a valuable fertilizer and soil amendment that can improve the physical condition of the soil for plant growth and reduce the demand for high quality water resources. However, excess amounts of nutrients, heavy metals, salts, pathogenic microorganisms, and pharmaceutically active compounds (antibiotics and hormones) in CAFO wastewater can adversely impact soil and water quality. The Environmental Protection Agency currently requires that application of CAFO wastes to agricultural lands follow an approved Nutrient Management Plan (NMP). A NMP is a design document that sets rates for waste application to meet the water and nutrient requirements of the selected crops and soil types, and is typically written so as to be protective of surface water resources. The tacit assumption is that a well-designed and executed NMP ensures that all lagoon water contaminants are taken up or degraded in the root zone so that groundwater is inherently protected. The validity of this assumption for all lagoon water contaminants has not yet been thoroughly studied. This presentation reviews our current level of understanding on the sustainability of CAFO wastewater reuse on agricultural lands and the environmental impact of this practice on groundwater resources. Specifically, we address the source, composition, application practices, environmental issues, transport pathways, and potential treatments that are associated with the reuse of CAFO wastewater on agricultural lands.

Conjunctive Use: Streamflow Depletion Caused by Pumping Wells on a Nearby Stream

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A well pumping seasonally for irrigation that is within one quarter mile of a stream creates a cyclical streamflow rate of depletion that is in phase with the pumping and the same each year. However, as the well is further removed from the stream the aquifer tends to dampen the seasonal fluctuations. At a distance of approximately two miles from the stream, the streamflow depletion created by the well is approximately equal to pumping at a constant rate, equal to the total withdrawal averaged over the year. There is very little seasonal fluctuation. For example, if one were to pump the well two miles from the stream at 4 cfs for three months; the effect on the stream would be approximately the same as if the well were pumped continually at 1 cfs. The effect of distance is dependent upon the aquifer properties: transmissivity and storativity. In the case of the well two miles or further away from the stream, the full impact of the pumping on the stream takes a decade or more to fully develop. In the situation where wells are uniformly distributed across an aquifer, associated with a stream, the impact of the ensemble of wells on the streamflow is similar to the single well two miles or more away the stream. Again, it takes at least a decade of pumping for the full impact on the stream to occur. Were one to stop pumping an ensemble of wells, it would take at least a decade for the streamflow to return to a state where it is not impacted by the prior pumping. In other words, if one wanted to eliminate the full impact of pumping an ensemble of wells on the stream today, one would have had to stop the pumping at least a decade ago. Managing a conjunctive stream and associated aquifer system requires long-range planning because of the lag time in response created by the aquifer; it cannot be managed effectively on a short-term basis.

Detection of Trends in Groundwater Quality: An Overview of Methods Developed in Europe

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Recent EU legislation, especially the Nitrates Directive (1991) and the Groundwater Directive (GWD, 2006), demand for the analysis of trends in groundwater quality. In fact, the detection of trends and the demonstration of trend reversal is one of the pillars of the new GWD. Therefore, trend approaches have been developed which enable us to observe changes in groundwater quality with time and to evaluate the effects of action programs which aim to reduce pollutant inputs into groundwater. The trend reversal obligation of the GWD requires that any significant and sustained upward trend will need to be reversed when reaching 75 percent of the values of EU-wide groundwater quality standards and/or threshold values, and such trend reversal has to be achieved through establishing programs of measures. We will present an overview of trend approaches being developed in some EU countries and discuss the monitoring objectives, the technical procedures that were applied and the effectiveness of the approaches. The overview is partly based on the European research project Aquaterra-Trend2 which tested trend analysis techniques at a wide range of hydrogeological conditions, including unconsolidated lowland deposits, chalk aquifers and fractured aquifers with a thick unsaturated zone (a). The presentation compares approaches of different monitoring and trend analyses techniques, focusing on 1. trends in upper groundwater under agricultural lands; 2. trends in national scale monitoring networks with observation screens at specific depths; 3. trends in spring waters and at abstraction sites and 4. the interaction between trends in groundwater and trends in receiving surface waters. A trend was defined as a change in groundwater quality over a specific period in time, over a given region, which is related to land use or water quality management. Trend analysis techniques aim to reduce the variability which is not related to the anthropogenic changes. Therefore, trend detection becomes more efficient when spatial and temporal variability are reduced by taking into account the physical and chemical temporal characteristics of the body of groundwater, including flow conditions, recharge rates and percolation times. The travel time to a monitoring screen and the travel time distribution of pumped wells or springs appeared to be a key factor in effectively demonstrating trends and trend reversal, which is why age dating appeared to be an effective tool for trend detection. Travel time distributions also appeared to be a key factor in relating trends in groundwater with corresponding temporal changes in surface water quality. The presentation will address modeling and monitoring approaches to unravel the dynamics of groundwater-surface water interaction and show how the slow movement of pollution fronts in the subsurface affected trends in surface water quality in the past and may continue to do so in the coming decades.

(a) Visser, A. et al. (2009) Comparison of methods for the detection and extrapolation of trends in groundwater quality. Journal of Environmental Monitoring 11:2030-2043.

Implementing the EU Water Framework and Groundwater Directives in the Netherlands: Monitoring and Compliance Regime for Groundwater

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New EU legislation, which includes the Water Framework Directive [WFD, EU 2000] and the Groundwater Directive [GWD, EU 2006] aims for integrated management of surface water and groundwater. In relation to groundwater quality, the WFD requires Member States to delineate groundwater bodies and characterize them and to establish a groundwater monitoring network to provide a comprehensive overview of the chemical and quantitative status of the groundwater body. The GWD additionally specifies criteria for "good chemical status" and criteria for the detection of significant and sustained long-term anthropogenic induced upward trends in the concentrations of pollutants. EU member states reported that the main reasons for not coping with the "good chemical status" are related to agriculture derived contaminants, mainly nitrate and pesticides. Within the EU, the Netherlands is notorious for large inputs of nutrients to groundwater and high concentrations of nitrate in shallow groundwater because of the intensive livestock farming practices. In implementing the requirements of the WFD and GWD, the Netherlands uses the national and regional scale monitoring networks that were established between 1980 and 1995. These networks have time series of groundwater quality available with annual measurements between 1984 and present at about 10 and 25 m depth below surface level. These networks were originally established to evaluate groundwater protection strategies, with the main aim to protect groundwater as a resource for drinking water. However, the new WFD and GWD involve a new paradigm in groundwater protection with much stronger emphasis on the ecological status of surface water bodies and terrestrial and aquatic ecosystems. Therefore, criteria for good chemical status of groundwater now also involve the influence of groundwater on these receptors, which implicates adaptations to monitoring locations, frequencies and data-analysis approaches. The presentation summarizes the adapted design of the monitoring networks, the objectives and the compliance regime based on the monitoring objectives. The data which were present from the existing monitoring networks were used to define threshold values for chemical parameters to distinguish between groundwater bodies at poor and good status. These threshold values were based on natural background concentrations and on environmental quality standards for the main receptors of groundwater, which are drinking water abstractions and surface waters. A procedure was developed for the aggregation of groundwater quality data at the groundwater body scale, which includes tests to quantify how large a proportion of groundwater is above the threshold value and tests to determine whether surface water bodies are influenced by poor quality of groundwater. Examples of the use of these criteria will be presented for selected cases such as the artificial infiltration of brine effluent and the shallow transport of nutrients and metals towards the connected surface waters. It was recognized that the highest concentrations of agricultural derived pollutants are within the first 10 m of the subsurface, and large loads of these pollutants end up in the surface water through an intensive network of artificial ditches, tile drains and small watercourses. Trend analysis is another aspect of the compliance regime for the WFD and GWD. The amount of time series available enabled us to quantify trends at multiple depths in the subsurface, which are related to the downward movement of agricultural pollution fronts. A major improvement, however, was obtained by tritium-helium age dating of groundwater, which allowed for the significant demonstration of trend reversal following the 1985 and 1991 action programs which aimed at reducing the input of nutrients and other solutes into groundwater.

Innovative Nitrogen Management Strategies to Reduce Groundwater Impacts in Drinking Water Source Protection Areas

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A two-year field experiment comparing different nitrogen management practices was established for a corn crop in Ontario, Canada, starting in 2009. This work is part of an ongoing effort to reduce the amount of nitrates leaching from agricultural fields located within the well head protection area of a municipal well field currently impaired by elevated levels of nitrate. The municipality has purchased the surrounding land and maintains agricultural productivity under a farmer lease agreement. Results from the first year of the study will be presented. The random-block experiment encompassed 2 blocks each comprised of 5 fertilizer applications with 3 trials. One block was planted on wheat stubble residue and the other on wheat stubble with red clover (legume) residue. The 5 nitrogen fertilizer application treatments included a polymer coated nitrogen fertilizer and a conventional urea fertilizer applied in the spring, a conventional rate and calculator rate side dress application and a control. Fertilizer rates were determined using a soil nitrate test and a corn nitrogen calculator developed by the Ontario Ministry of Agriculture, Food and Rural Affairs. Plots with the legume cover crop were given a nitrogen credit to account for the additional residual soil nitrogen fixed by the plants. Environmental monitoring included a chemical tracer applied to the soil surface, soil solution samplers installed below the root zone, a neutron moisture meter, and an on-site meteorological station. The top 0.3m of soil were also routinely sampled for nitrate nitrogen, and 4.5m soil cores were taken at the beginning and the end of the growing season in order to establish the extent of vertical nitrate migration of each fertilizer application. Crop yield results for the spring applied polymer coated and urea fertilizers were similar, while soil nitrate samples show that there was a delay in release of nitrogen for the polymer coated product. This has the environmental benefit of releasing nitrogen closer to when plants can take it up, reducing the risk of leaching losses in the wetter period of the spring. The delayed application of nitrogen at side dress time using a lower rate from the nitrogen calculator had comparable yields to spring nitrogen applications (polymer coated nitrogen and urea). Plots with a red clover cover crop that received reduced nitrogen application rates using the nitrogen calculator had similar yields to plots without a cover crop. Overall, the initial results suggest that the polymer coated fertilizer product may provide significant environmental benefits related to reduced nitrogen leaching, yet still achieve acceptable crop yields. In addition, the use of a legume cover crop permits reductions in total nitrogen application, subsequently reducing associated environmental risk.

Groundwater or Livelihood? The Case of Al-Ajaz Community in Northern Syria

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The small community of Al-Ajaz in northern Syria has benefited greatly from the access to groundwater. Farmers use the water for supplemental irrigation of wheat and legumes during the highly variable rain fed winter season, while sugar beet, potatoes and summer vegetables are also irrigated. But groundwater levels have dropped substantially since the start of groundwater-based irrigation in the 1980s, with current water levels more than 150 m below the surface. The main aim of our cooperation with the community was to combine research and farmers' knowledge in irrigation and agricultural management to improve the sustainable and productive use of groundwater in rural Mediterranean environments. Upon request of the farmers, ICARDA provided 20 different bread wheat varieties for irrigated and rain fed conditions. A total of 14 farmers participated in these wheat trials during the 2006/07-2008/09 seasons, with seven or eight farmers each season. A much larger number of farmers also joined our discussion meetings and the scoring of varieties. Provision of irrigation scheduling advice proved more complex than expected. The main difficulties are the widely varying initial soil moisture conditions, as a result of the previous crop and management, and the farmers' irrigation management practices. Basically, three groups of farmers could be distinguished. The first group is the less well-off farmers, who have neither a functioning irrigation well nor ready cash to purchase fuel. They grow rain-fed crops, but they may ask a neighboring farmer to irrigate their field during exceptionally dry periods. The second group is the farmers who try to economize their irrigation and who are generally most interested in soil and water measurements and advice. The third group is the farmers who are a little better off; these farmers simply try to maximize their yield and would rather irrigate too much than too little. Rainfall was below the long-term average of 340 mm for all three seasons, but was fairly well distributed during the 2008/09 season. Average yields for the three groups of farmers during this last season were 1.9, 5.1, and 8.2 ton/ha, respectively, which is clearly indicative of the important effect of irrigation. Even though the price of fuel for the irrigation pump nearly tripled during the research period, the farmers' irrigation behavior did not markedly change. Considering the hydrogeologic, climatic and socioeconomic conditions of these rural Mediterranean environments, the sustainable use of groundwater resources may only be achieved through official, community-based control of groundwater. Although groundwater control may be relatively easy to establish on a community basis, it will require a dedicated campaign to educate the farmer union and government officials, supported by studies that provide clear information on groundwater resources. At the same time, field research to improve our understanding of the response of different crops and varieties to water availability and stress throughout the season are needed. Increasing the cost of fuel does not seem to be an effective strategy for reducing groundwater use, because it could run the poorer farmers, who actually irrigate less, out of business.

Improved Production Efficiency in High Value Irrigated Row Crops: Moving Past a Grower's Negative Perceptions of BMPs

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The Monterey Bay area in the Central Coast region of California is a key center of production for a large number of high value vegetable and fruit crops. Climatic, soil, and water resources, as well as a highly developed infrastructure and labor supply are the key components that continue to make high input farming economically attractive and viable. With more than 80 percent of demand met by groundwater, the Central Coast is heavily reliant on groundwater to meet local needs. However, the degradation of groundwater quality (and quantity) in many watersheds, historically due to less than optimal fertilization and irrigation practices in prior years has been well documented. In the past 20 years, numerous federal, state, and locally funded educational outreach, technical and cost-share assistance initiatives for BMP adoption have come and gone, while most groundwater water quality indicators (e.g. nitrate) remain largely unchanged (Figure 1). Agencies have been largely unable to concentrate technical and training resources for adequate time periods on a few key farms and are more likely to have a wide criteria to maximum the number of grower participants. This diffusion of effort results in lower impact and makes it difficult to monitor effects. Growers generally have not adopted BMPs except in special projects or where high levels of cost-sharing and technical assistance were available. Grower perceptions about of the economic risks of adopting BMPs for irrigation and fertilization often outweigh the less tangible objectives of water quality protection. Between 2000 and 2007, the author was a contractor on a series of different short-term, state-and locally-funded projects and programs, all with the goals of increasing irrigation efficiency and reducing nitrate leaching. This case study describes the scope and progress resulting from an unusually time intensive effort working with one farming company that was not initially receptive to BMP recommendations. Celery is an irrigation and nitrogen fertilizer-intensive crop. In the region it is not uncommon for the crop to receive up to 2 acre-feet of irrigation and over 400 lbs of fertilizer N. In this case example a series of irrigation system and soil nitrate monitoring evaluations were initially required. This was followed by a season of small plot yield demonstrations where N fertilizer was reduced. Finally a field scale trial where the grower's standard practice was compared to an irrigation scheduling and N fertilization BMP program where yields and irrigation efficiency were determined and simulation modeling was used to estimate nitrate leaching potential. This work required 3 full growing seasons and significant effort before the company adopted these practices for all of their production acreage (over 160 acres). Improvements in drip irrigation uniformity, irrigation scheduling and efficiency reduced N fertilization and leaching potential with stable yields and improved crop quality are presented. The author concludes that directing BMP funding for intensive technical assistance and education to key grower stakeholders is critical to maximum impact in most agricultural BMP programs.

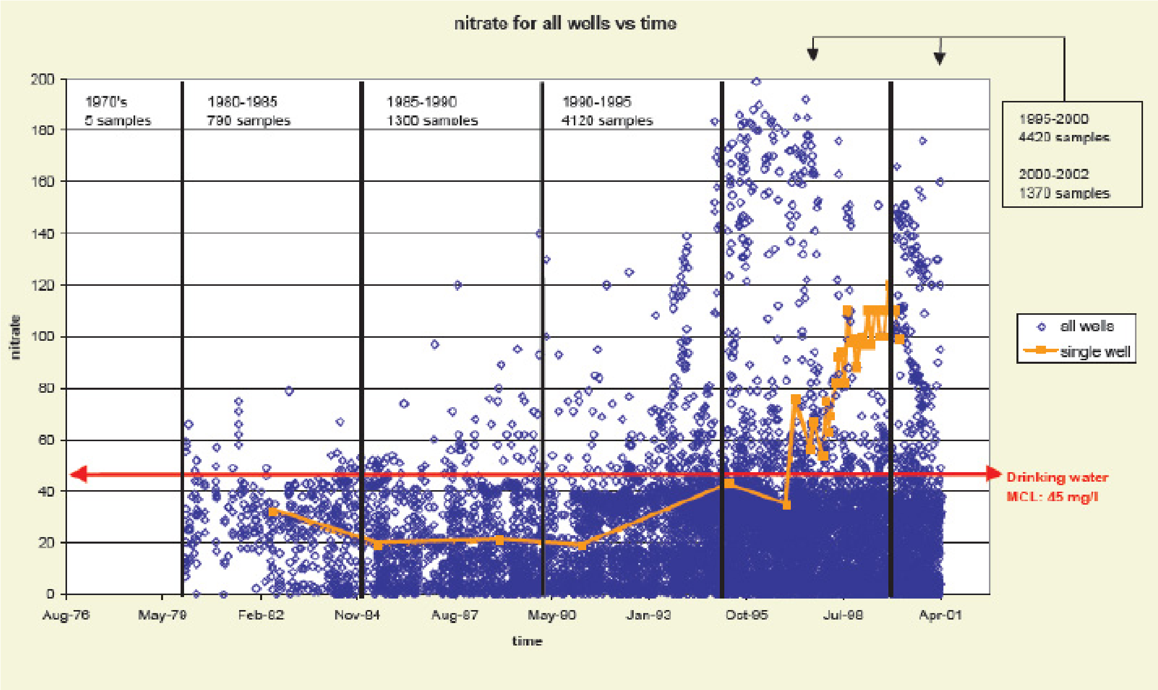

Figure 1. Groundwater nitrate trends in the Salinas Basin of Central Coast California between 1976 and 2001.

Year	N applied (lbs/acre)	Market yield (lbs/acre)	Irrigation Efficiency
2002	405	74,732[1]	~35%
	345	75,437	
2003	445	89,130[2]	NC
	368	84,540	
	362	83,775	
	302	89,350	
2005	368	116,400[3] (63,600)	46
	303	96,800 (75,400)	58
2006	285 - 345	82,400 – 110,650	55 - 74
2007	285 - 345	85,600 – 105,700	60 - 75
2009	285 - 345	92,700	84

Table 1. Trends in N fertilizer reductions, celery yields, and irrigation efficiency prior to and following grower adoption of nutrent and irrigation BMPs.

Legal Tools for Managing Groundwater Resources: Options, Best Practices and Issues

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The sustainable management and use of groundwater resources for irrigation, as a source of drinking water supplies and as a supplementary source of surface river flows and wetlands and wildlife habitats call for increasing attention to two major and interdependent sources of concern – namely, depletion and pollution. The former is linked to the unsustainable extraction and use of groundwater, the latter to the contamination of available groundwater supplies from point and non-point (or diffuse) sources. Both phenomena stand to be exacerbated by growing climate variability conditions. To the extent that either or both phenomena threaten the long-term viability of available supplies and the sustainability of their development and use, the legal systems have been prompted to respond with a view to defusing the social tension and the potential for conflict generated by such threats. National regulation of groundwater extraction and use and of polluting activities has largely - but not entirely - supplanted private legal remedies available to injured plaintiffs across the groundwater-agriculture nexus, in particular, where perceptions of groundwater as an intensely private resource have been and continue to be strong. Other non-regulatory approaches have also been framed in contemporary water resources legislation, reverberating on that same nexus in particular. Through a comparative review and analysis of the contemporary water legislation of selected countries the choice of mechanisms and options - regulatory and otherwise - available to the lawmakers will be illustrated. Emerging trends and best practice approaches will also be teased out, and relevant issues discussed. Pointers for the possible future direction of water legislation, particularly as it impacts on the groundwater-agriculture nexus, will be finally volunteered.

Groundwater Use for Irrigation: A Global Inventory

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Irrigation is the most important water use sector accounting for about 70 percent of the global freshwater withdrawals and 90percent of consumptive water uses. While the extent of irrigation and related water uses are reported in statistical databases or estimated by model simulations, information on the source of irrigation water are still very rare. Here we present a new global inventory on the extent of areas irrigated with groundwater based on available sub-national data.

Solar-Powered Drip Irrigation Systems in the Sudano-Sahel

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Most of the world's poor populations live in rural areas, depend on agriculture for their livelihoods, and spend the majority of their incomes on food. Improved agricultural productivity in the developing world is thus critical for food security and poverty alleviation. At the same time, agriculture is currently responsible for 10-12 percent of global greenhouse gas emissions (not including land-use change, which adds an additional 10-12 percent) and approximately two thirds of the world's annual water withdrawals, along with a host of environmental ills, including eutrophication, biodiversity loss, and soil degradation. Meeting the food needs of a growing population under tightening climate and resource constraints (or meeting mitigation targets while eliminating global poverty) will therefore require new technologies and strategies that significantly improve rural livelihoods at minimal environmental cost. This project quantifies the impact of emissions-free distributed water delivery and irrigation technologies in the dry tropics. Most rural, poor farmers depend on rain-fed production of staple crops for their livelihoods. These smallholder production systems are typically limited to a 3-6 month rainy season, and are often high-risk and relatively low-return; in addition, despite producing grain crops, these farmers are nevertheless net consumers of food across food groups, particularly in non-staples. Promotion of irrigation is frequently cited as a strategy for both poverty reduction and improved food and nutrition security in developing countries, as it can enable year-round cultivation, promote increased yields, and facilitate the introduction of new crops in regions where they could not be sustained by rainfall alone. In remote locations far from the grid, the most reliable and cost-effective energy option for irrigation is solar power. A recent evaluation of the pilot phase of a novel solar-powered drip irrigation project in northern Benin, West Africa, demonstrated strong and significant poverty-reduction and food security impacts for farmers using this technology, and showed that solar pumps are cost-effective, especially in rural areas where fuel access for liquid fuel pumps may be sporadic at best. Building on this work, I optimize the solar-powered water pumping system in future installation villages to minimize cost and maximize system efficiency and lifetime for both surface and groundwater sources. Solar-powered pumps and drip irrigation are well-matched technologies, as both pump speed and crop evapotranspiration scale with incident solar radiation. A properly designed system thus passively self-regulates and can be implemented in a direct-coupled configuration, eliminating the need for batteries, which reduce system lifetime, cost-effectiveness, and performance in the developing world. The optimization of solar-powered drip irrigation systems has potential global application as an efficient water use technology.

Investigation of Groundwater Flow Paths During Leaching of Salt-Affected Soils

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Petroleum reservoirs typically produce a mixture of hydrocarbons and saline water (brine). Due to past operational practices, accidental spills, or pipeline breaks, salt-affected soils are a significant environmental problem. A three year study to optimize the remediation of salt-affected soils is being conducted for an existing tile drain salt-leachate collection system installed on agricultural land in central Alberta, Canada. The tile drains are installed at a depth of 2 m below ground near the base of fine-grained glaciolacustrine material, immediately above a dense glacial till layer. The objective of the remediation system is to lower salt concentrations in the rooting zone to meet local regulatory remediation guidelines for agricultural land use. Due to the semiarid climate, water drainage into the leachate collection system has been intermittent and limited. Irrigation water was applied to a test plot during the summer of 2009 in order to conduct a salt-flushing experiment. Time-lapse soil salinity profiles are used to investigate the rate of salt leaching. The initial conceptual model for flow to the tile drains was one of vertical infiltration to the water table and lateral flow to the tile drains, with negligible vertical flow penetrating the dense basal till below. However, relatively low leachate recovery in the tile drain system compared to the amount of irrigation water applied has demonstrated that the initial conceptual model requires revision. Root casts have been observed in the shallow glaciolacustrine material above the tile drains, and oxidized fractures have been observed in glacial till below the tile drains. The effect of macropores and fractures on the flow system and the potential for leaching of salts to sand layers at depth is a primary component of this study. A chemical tracer experiment using 2.6-difluorobenzoic acid [2.6-DFBA] was conducted to investigate the groundwater flow paths in detail. Understanding the flow paths is necessary for the optimal design of the tile drain system and optimal irrigation scheduling. The flow paths also control the volume and concentrations of leachate water recovered for potential water recycling, and are a primary control on the risk to ecological receptors.

Groundwater and Integrated Water Resources Management: And Never the Twain Shall Meet?

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Integrated Water Resources Management (IWRM), espoused by the Global Water Partnership (www.gwpforum.org), USAID, and other organizations, is a process to manage water resources holistically, or a process that promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. The GWP lists five principles, based on the Dublin Principles, of IWRM: 1.) freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment; 2.) water development and management should be based on a participatory approach involving users, planners and policy makers at all levels; 3.) women play a central part in the provision, management and safeguarding of water; 4.) water is a public good and has a social and economic value in all its competing uses; and 5.) IWRM is based on the equitable and efficient management and sustainable use of water and recognizes that water is an integral part of the ecosystem, a natural resource, and a social and economic good, whose quantity and quality determine the nature of its utilization. IWRM is not an end in itself but a means of achieving three key strategic objectives: 1.) efficiency to make water resources go as far as possible; 2.) equity in the allocation of water across different social and economic groups; and 3.) environmental sustainability, to protect the water resources base and associated ecosystems. Although IWRM has been adopted by many organizations it has not yet found wide acceptance among the groundwater community. The river basin is the fundamental spatial unit for IWRM and this can preclude the incorporation of aquifer systems, particularly deep systems that are not well-connected to surface water or underlie several river basins. Nonrenewable groundwater resources may prove to be particularly difficult to address with the IWRM approach. Thus, in the case of groundwater, IWRM is essentially a two-dimensional approach to a three-dimensional system. This presentation will discuss the apparent groundwater-IWRM conundrum with suggestions for a path forward.

Denitrification at a Dairy Site Supported by Gas-Liquid Phase Modeling of Tritium/Helium-3 Groundwater Age

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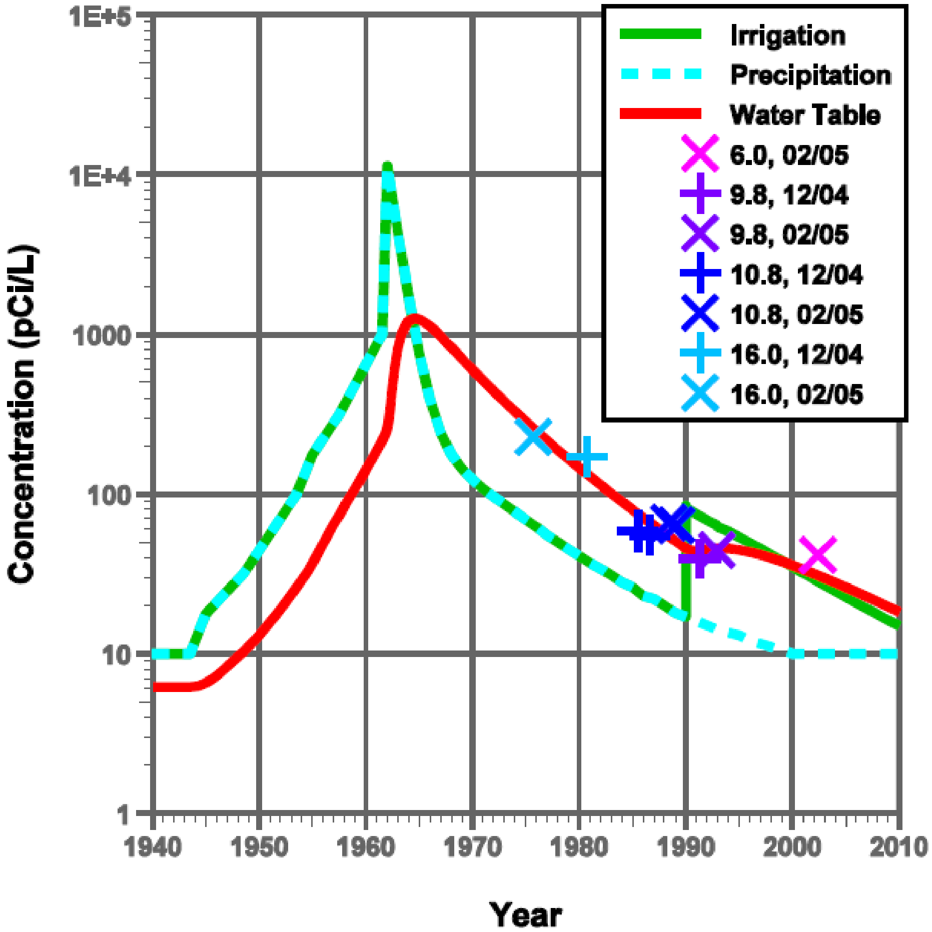
Surface irrigation incorporating effluent from dairy operations can be a non-point source of nitrate in groundwater. To investigate the source and fate of nitrate at a dairy site in the San Joaquin Valley, California, we determined tritium/helium-3 (3H/3He) groundwater age, nitrate concentration and isotopic composition, and excess nitrogen gas concentration in vertical profiles at several locations in a shallow groundwater system beneath fields irrigated by groundwater mixed with dairy effluent. The nitrogen data provided direct evidence for saturated-zone denitrification in groundwater underlying the site. In this study, we model the transport of 3H and 3He continuously through the unsaturated and saturated zones to determine the source and flux of groundwater in which the denitrification is occurring. Our finding is that the groundwater originates directly from irrigation water applied on the site, which demonstrates that nitrate loading from the dairy operation is being actively mitigated in the local subsurface. Other lines of evidence in conjunction with the nitrogen and groundwater tracer data suggest that the dairy's nutrient and farm management practices promote subsurface denitrification resulting in remediation of dairy nitrate contamination of underlying groundwater. A novel aspect of this study is that we account for transport of 3H and 3He in the unsaturated zone, where 3He preferentially partitions into the gas phase. By doing so we address a recurring problem in 3H/3He age interpretation - the tritium activity in surface water (generally inferred from IAEA precipitation records) is often assumed for both the source activity for groundwater recharge and the initial activity for the 3H/3He groundwater age dating chronometer. The problem occurs because the 3H concentration history reaching the water table, the location of recharge, can be significantly different than the 3H concentration history in surface water, the location of 3H source measurements. For the dairy site, a conventional 3H/3He age interpretation would suggest tritium activities in recharging groundwater at the water table are higher than seen in precipitation for the calculated recharge year (see figure). Our gas-liquid phase 3H and 3He modeling results show that accounting for travel time and dispersion from transport through the 5-meter thick unsaturated zone to the water table completely resolves this unrealistic discrepancy and confirms the recharge source is irrigation return. In the larger realm of 3H/3He age interpretation, our data and modeling approach show the importance of unsaturated zone transport in reconciling recent controversy sparked by discrepancy between inferred and measured 3H source activity.



Modeled tritium concentrations in irrigation source (green line), precipitation (light blue dashed line), and water table (red line) compared to calculated tritium source concentration and year of recharge for data from different depths (m) beneath a field irrigated by shallow groundwater mixed with dairy effluent.

Colloid Transport Behavior in Agricultural Soils: Microbes and Microspheres

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Pathogens originating from agricultural fields have the potential to adversely impact groundwater quality. In Canada, this was clearly brought to light by the Walkerton groundwater tragedy where E. coli contamination of shallow groundwater resulted in the deaths of seven residents. Yet increasing field evidence suggests that pathogen detections occur infrequently in both time and space even in vulnerable aquifers. There is clearly a need for field based studies to better understand the processes controlling biocolloid transport in the subsurface. Here we present a series of field studies that were conducted to achieve the following: (1) determine the suitability of using microspheres as surrogates for E. coli; (2) evaluate colloid transport and attenuation during infiltration through undisturbed agricultural field soils; and (3) investigate the importance of macropores on preferential transport of colloids. Small-scale infiltration experiments were conducted at three separate field sites in southern Ontario. A tension infiltrometer was used to infiltrate a solution of Brilliant Blue dye and surface applied colloids (different sized microspheres and E. coli RS2g) under partially saturated conditions. Upon completion of infiltration, excavations were completed to examine the dye-stained flow patterns, map soil and macropore features, and collect soil samples for enumeration of microspheres and E. coli. All soils contained significant macroporosity, predominantly in the form of vertical worm burrows. Colloid properties had a significant influence on transport, but results showed that microspheres with similar size and surface properties to E. coli RS2g exhibited similar transport behavior. Despite differences in soil type, infiltration rates and flow patterns, colloid transport behavior was similar across all sites. Colloids were readily attenuated near surface with >2 log reduction in the top 5 to 10 cm of the soil profile. At greater depths colloid concentrations remained relatively consistent and were closely related to the intensity of dye staining. Flow along macropores was the most important factor controlling deep vertical migration of both dye and colloids. These field tests highlight the need for suitable methods to monitor and describe field-scale pathogen migration in order to better assess the vulnerability of shallow groundwater resources.

Bioavailability of Dissolved Organic Carbon and Ambient Redox Processes in Groundwater Associated With Agricultural Land Use

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Agricultural practices have the potential to mobilize dissolved organic carbon (DOC) from soil zones and transport it to underlying aquifers. The bioavailability of this potential DOC source, and thus its ability to affect ambient redox processes in aquifers affected by agricultural practices, is uncertain. One potential metric of DOC bioavailability is its observed reactivity with dissolved oxygen. If DOC is highly bioavailable, it would be expected that DOC and dissolved oxygen would be inversely related according to a hyperbolic function. That is, high concentrations of DOC would be expected to correlate with low concentrations of dissolved oxygen and vice versa. Conversely, if DOC is relatively nonreactive, little correlation between the two parameters would be expected. Thus, the statistical correlation of DOC-dissolved oxygen plots to a hyperbolic function may allow comparison of the relative bioavailability of DOC characteristic of different agricultural settings. This approach was applied to a variety of agricultural settings in the United States including the San Joaquin Valley of California, the Great Salt Lake Valley, the High Plains of Nebraska, the White River Valley of Indiana, the western Lake Michigan drainage, the Delmarva Peninsula of Maryland, and the Santee River Basin of South Carolina using a large data base compiled by the National Water-Quality Assessment (NAWQA) program of the U.S. Geological Survey. The results suggest that (1) DOC associated with western agricultural areas is generally less bioavailable than DOC associated with eastern agricultural areas; (2) the bioavailability of DOC decreases as the thickness of the unsaturated zone increases, and (3) relatively bioavailable DOC identified with the dissolved oxygen metric also correlates hyperbolically with nitrate concentrations.

Measuring and Monitoring HydroBiogeochemical Flux in a Forested Riparian Floodplain/Wetland

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Advances in management of riparian wetlands require innovative reach-scale experimental studies and improvements in riparian modeling. Riparian recommended best management practices (BMPs) in Missouri have not been validated. Studies are therefore warranted to describe subsurface interactions between the stream, hyporheic zone and adjoining riparian wetland/floodplain. The following research is ongoing in the Baskett Research and Education Area (BREA), located 8 km east of Ashland in the Ozark border region of South Central Missouri. To quantify hydrobiogeochemical flux, spatial and temporal (3 water years) variability in key nutrients (NO3, P, K, NH3) and hyporheic exchange are being monitored. Key hydrologic variables approaching a mass balance, plus groundwater monitoring are being studied. In Iowa, study results showed that NO3concentrations in surface water ranged from 0.4-10.8 mg/L in larger watersheds while in smaller watersheds it ranged from 3.1-10 mg/L. Nitrate was shown to travel 5-10 times farther than other constituents of concern including ammonia. It is expected that headwater streams of the BREA will supply nutrients at higher concentrations. Riparian floodplains of the BREA will be characterized with respect to the fluxes of water and nutrients, from which BMP efficacy can be assessed. Results will quantify the relationships between riparian buffer density and floodplain efficacy in ameliorating hydrologic and biogeochemical processes. This work will provide regionally specific and scientifically validated information that will justify the use of current or modified BMPs.

CV-SALTS Initiative Central Valley Regional Water Quality Control Board Efforts to Tackle Salinity and Nitrate Throughout the Central Valley and Who Needs to be Involved

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Accumulation of salts in soil and surface and groundwater supplies continues to negatively impact water quality and quantity throughout the state, and is of particular concern throughout the Central Valley. Researchers have found if salinity increases at the current rate until 2030, the production of goods and services in California could be reduced from $5 billion to $8.7 billion a year. In terms of job losses the increase in salinity by 2030 could cost California 34,000 to 64,000 jobs. To address these concerns, the Central Valley Regional Water Quality Control Board (Regional Water Board) is moving forward with a stakeholder-driven effort to develop a comprehensive salinity and nitrate management program for the entire Central Valley region. The Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) initiative was launched in January 2006 after the Central Valley Regional Water Board and the State Water Board held a joint workshop to receive information on salinity and nitrate in the Central Valley. The goal of CV-SALTS is to develop a comprehensive region-wide Salt and Nitrate Management Plan (Plan). The Plan will be developed and implemented through amendments to the three water quality control plans that cover the Regional Water Board's jurisdictional area, which include the Sacramento and San Joaquin Rivers Basin Plan, the Tulare Lake Basin Plan and the Sacramento/San Joaquin Rivers Delta Plan. This comprehensive basin plan amendment will involve 1) the review of all surface and groundwater basins through the region to expand the listed water bodies and to confirm, revise or add designated beneficial uses of water bodies currently listed or added; 2) the review and establishment of applicable water quality objectives to meet the beneficial uses, and 3) to establish a comprehensive implementation plan to achieve the water quality objectives. The stakeholder CV-SALTS Initiative is the Central Valley Regional Water Board's primary mechanism to conduct the necessary studies, research and develop technical and science reports to develop all components of the basin plan amendment and to implement the Plan once it's adopted by the Board. Due to the complexity and far-reaching impacts of the Plan, the Regional Water Board has determined that any and all users of Central Valley waters, within and outside of the Regional Water Board's jurisdictional area are considered stakeholders for this Plan. The Regional Water Board believes all stakeholders should be very involved in the development of basin plan amendments that could affect the use designation and quality of Central Valley waters they use. In July 2008, the non-profit Central Valley Salinity Coalition (CVSC) was formed to work in partnership with CV-SALTS. A key role of CVSC is to organize, facilitate and collect funding for the efforts needed to develop and implement a salinity and nitrate Plan in the most efficient and effective manner throughout the Central Valley. CVSC was formed in a similar format to the Southern and Northern California Salinity Coalitions. The Regional Water Board supports CVSC's efforts and continues to strongly encourage more active participation in CV-SALTS.

Nitrates Directive Compliance Checking for Nitrate in Groundwater in the Netherlands

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The EU Nitrates Directive states a threshold level of 50 mg/l nitrate in groundwater. In the Netherlands, compliance is currently checked in the upper one meter of groundwater. A draft EU monitoring guideline leaves open the possibility to check compliance in the upper five meters of groundwater. The nitrate concentration in groundwater in the Netherlands has significantly decreased between 1996 and 2004 due to policy measures. Nitrate concentrations are below the EU threshold level in large parts of the Netherlands. In sandy soils, however, the average nitrate concentration still exceeds the 50 mg/l value in the upper one meter of the groundwater. Additional measures are required to meet EU threshold values. Changing the checking level from the upper one meter to the upper five meters of groundwater could provide the Netherlands with the possibility to meet the EU threshold level for groundwater, without having to implement major additional measures by farmers. Nitrate concentrations are likely to decrease with depth because of denitrification. Any adjustment in the compliance checking level requires well-founded data on whether nitrate concentrations actually decrease with depth in the upper five meters of the groundwater. It must also be clear which processes cause the decrease, and in particular whether such an adjustment would result in a shifting of the problems to the surface water. The Nitrates Directive also has targets for surface water quality. A study showed that in sandy soils with relatively deep groundwater tables (i.e. > 1 meter) nitrate concentrations did not decrease with depth in the upper five meters of groundwater. Here, the act of denitrification may be blurred by temporal changes in nitrate leaching from the soil. In sandy soils with high and intermediate groundwater tables (within 1 meter) a decrease in nitrate concentrations with depth was shown. Results indicated that in these soils significant loads of agricultural nitrate are transported into surface waters. Thus, allowing higher nitrate concentrations in the upper groundwater may cause eutrophication of surface waters. The Dutch Parliament introduced a motion in 2009 stating that maintaining the current compliance checking level in the upper one meter of groundwater would result in unfair competition for Dutch farmers. The Dutch Parliament requested the Government to calculate the decrease in nitrate with depth using models and to measure the nitrate concentrations not only in the upper one meter of groundwater, but in the upper second and upper fifth meter of groundwater as well. A new monitoring network to meet the Parliaments request is currently drafted.

Characterization of Land Cover for Estimating Nitrogen and Salt Losses to Groundwater

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Water quality parameters influence the usability of water supplies, with uses generally becoming more restricted as concentrations increase. Concentrations are determined by watershed characteristics such as land and water uses, hydrography, hydrology, and water treatment and discharge. Leaching of constituents like salt and nitrate through surface soil, and the influence of these losses on groundwater quality, is a focus of interest for producers and regulators in California's Central Valley. Various models can be used to predict groundwater quality and to assess risk of salt and nitrate pollution. Fate and transport of constituents emanating from widely distributed sources are extremely sensitive to the character of these sources and their location in the landscape. The more detailed models therefore depend to some extent on accurate characterization and mapping of land cover, land management, and soils to estimate load and concentration of salt and nitrate moving through the soil. Land cover units were developed such that diverse uses generally similar in their influence on salt and nitrate budgets were grouped together, resulting in 32 distinct land cover classes to characterize the Central Valley landscape. Natural and managed parameters, such as percent impervious surfaces, plant communities, as well as fertilization, amendment, irrigation, and nitrogen removal rates were characterized for each land cover class. These classes were intended to capture source and sink characteristics of urban, industrial, commercial, agricultural, and undeveloped land. Existing land cover mapping by the California Department of Water Resources and the U.S. Geological Survey were employed and re-coded into the 32 classes. Supplementary information collected under the auspices of a developing dairy waste management regulatory program (dairy locations, herd sizes, waste loads, and land application practices), by the California Department of Food and Agriculture (fertilizer and amendment use), and by county agricultural commissioners (annual production reports) were used to refine the land cover mapping and to refine management parameters for each class. The resulting data set greatly enhances the level of detail relative to land cover mapping previously employed in similar modeling efforts. Further refinements will be prioritized based on results of sensitivity analysis. These include validation of surface parameters for land cover classes, and characterization of other livestock land cover classes at a level of detail similar to current dairy classes. Incorporating more detailed soils data based on SSURGO (NRCS) mapping data is also being evaluated.

Modeling Crop Water Demand and Root Zone Flow Processes at Regional Scales in the Context of Integrated Hydrology

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In developed watersheds, the stresses on surface and subsurface water resources are generally created by groundwater pumping and stream flow diversions to satisfy agricultural and urban water requirements. The application of pumping and diversion to meet these requirements also affects the surface and subsurface water system through recharge of the aquifer and surface runoff back into the streams. The agricultural crop water requirement is a function of climate, soil and land surface physical properties as well as land use management practices which are spatially distributed and evolve in time. In almost all modeling studies pumping and diversions are specified as predefined stresses and are not included in the simulation as an integral and dynamic component of the hydrologic cycle that depends on other hydrologic components as well as anthropogenic influences. To address this issue, California Department of Water Resources has developed a new root zone module that can either be used as a stand-alone modeling tool or can be linked to integrated hydrologic models. The tool, named Integrated Water Flow Model Demand Calculator (IDC), computes crop and urban water requirements under user-specified climatic, land-use and irrigation management settings at regional scales, and routes the precipitation and irrigation water through the root zone using physically-based methods. In calculating the crop water requirement, IDC uses an irrigation-scheduling type approach where irrigation is triggered when the soil moisture falls below a user-specified level. Water demands for managed wetlands, urban areas, and agricultural crops including rice, can either be computed by IDC or specified by the user. For areas covered with native vegetation water demand is not computed, irrigation is set to zero and only precipitation is routed through the root zone. Many water management practices such as deficit irrigation, re-use of irrigation return flow, flooding and draining of rice fields and seasonal wetlands are addressed. IDC operates on a finite-difference or finite-element computational grid even though it does not use finite-element or finite-difference simulation techniques. The utilization of a computational grid facilitates accurate representation of spatially distributed input data as well as easy linking to integrated hydrologic models that use such grids. When used as a stand-alone tool, IDC assumes that the irrigation amount equals the computed or specified water demand. When linked to integrated hydrologic models, the irrigation amount equals the sum of simulated pumping and diversions which may be less than the IDC-computed water demand based on available aquifer storage and stream flows. In such cases IDC effectively computes increased water demands for the next time step as well as decreased groundwater recharge and surface runoff. IDC has been tested by applying it to three counties in California; the results in terms of applied water demand, evapotranspiration of applied water (ETAW) and effective precipitation compared well to data that are available through 1998 to 2001.

Groundwater Sustainability: Merely an Illusion?

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This paper discusses the challenge of seeking groundwater sustainability in a real regulatory setting involving irrigated agriculture and competing water uses. The state of Texas has for the past five years been asking regional groundwater management areas (GMAs) that each include multiple groundwater conservation districts (GCDs) to use groundwater models and public participation to set the "desired future conditions" for their regional aquifer use. The experience of using public processes to weigh current use, future growth, vs. sustainability raises questions whether "sustainability" is a feasible goal for science and policy. This paper presents the experience of the authors in working with nine GCDs within a GMA (the so-called GMA #9 of the Texas Hill Country) to establish "desired" future aquifer conditions. This experience is set in the context of the other 15 efforts within Texas towards regional aquifer management rules, using both science and public participation. The paper closes with some speculation on the challenges that any regional groundwater authority may face in seeking sustainable groundwater use.

Denitrification and Nitrate Transport in Groundwater Underlying Large Dairy Operations in California's Central Valley

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California has the largest dairy industry in the nation. California also relies on groundwater for more than half of its drinking water supply, and nitrate contamination is a demonstrated impact of dairy operations. Denitrification, the microbially-mediated conversion of nitrate to molecular nitrogen, is the largest sink for nitrate in the subsurface. Quantifying denitrification is important to validating groundwater and farm models, to predicting the arrival of dairy nitrate at drinking water wells, and to developing and assessing best management practices. Denitrification also affects the use of new contaminant and water tracers, including nitrate dual isotopic composition for source attribution, and dissolved noble gases for tritium/helium-3 age dating and identification of lagoon seepage. In this presentation, we will discuss evidence for denitrication at dairy sites in both the vadose and saturated zone; the impact of denitrification on the use of dissolved gas tracers; and how best to use new non-traditional tracers for dairy groundwater monitoring. Over the past six years, Lawrence Livermore National Laboratory has conducted research on nitrate transport and denitrification at five dairies in the San Joaquin-Tulare basins of California. These studies have sampled water collected from production wells, monitor wells and manure lagoons; and core sediment and water samples from the installation of monitor wells. They have integrated the use of field and laboratory measurements of dissolved gas to identify excess nitrogen from saturated zone denitrification and to identify manure lagoon seepage; isotopic characterization of nitrate-N and O across a large dynamic range in nitrate concentration for both source attribution and identification of denitrification; quantitative real-time PCR to identify sites of active denitrification; direct push cone penetrometer surveys and geostatistics to characterize heterogeneity in subsurface hydraulic properties; and tritium/helium-3 age dating with multi-phase modeling of both tritium and helium in the saturated and vadose zones. On the most intensively studied dairy in Kings County, this approach has identified saturated-zone denitrification that is actively mitigating nitrate loading from the dairy operation, and may be enhanced by the operation's water management practices. Denitrification has also been identified in shallow groundwaters underlying the northern dairies. The production of nitrogen through denitrification can drive gas stripping, and affect the interpretation of both nitrogen data used to determine the degree of denitrification, noble gas signatures used to estimate recharge temperature and identify manure lagoon seepage, and helium content used in the calculation of tritium/helium-3 groundwater age. The routine use of measurements of excess nitrogen, nitrate isotopic composition and groundwater age in dairy groundwater monitoring provides a powerful approach to source attribution and to assessment of the effectiveness of best management practices. This work was carried out with funding from Lawrence Livermore National Laboratory, the California State Water Board, and Sustainable Conservation in collaboration with the University of California, Davis and the USGS. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Land Clearing, Rain-fed Cropping and Increased Groundwater Resources in Semiarid SW Niger, Africa

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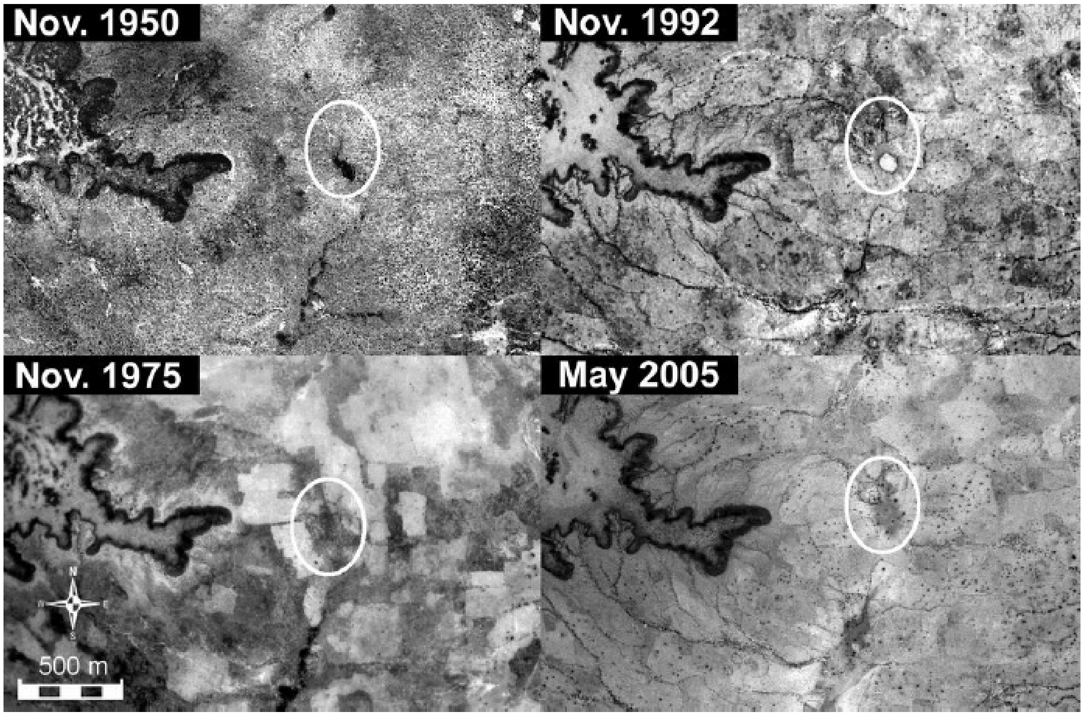
During the last five decades, land clearing for increasing the surface area cultivated for growing rain-fed millet in southwestern Niger has resulted in gullying and increased runoff on crusted slopes. In this semiarid, endoreic landscape, runoff concentrates in seasonal ponds and then recharges the aquifer (focused recharge): therefore, higher runoff increased aquifer recharge. Because groundwater pumping remained low (< 1 mm/yr), this has resulted in a long-term rise in the water table (4 m rise from 1963 to 2007). Combined use of various methods (subsurface geophysics, isotope geochemistry, neutron probe soundings, remote sensing, hydrological modeling, piezometric surveys, unsaturated zone sampling) consistently pointed out a threefold increase in surface runoff and a tenfold increase in groundwater recharge through ponds, from ~2 mm/yr in the 1950s (pre-clearing conditions) to ~25 mm/yr in the 1990s-2000s (i.e. ~5 percent of rainfall). This increase in focused recharge also had an influence on groundwater salinity near ponds, as shown by a rising trend in groundwater nitrate concentrations of non-human origin (75 percent of d.15N values range between +4 to and +80). Recently observed increases in irrigation by using fresh pond water would, however, increase return flow to the aquifer and may trigger soil salinization. In this well-documented region of the Sahel, impacts of land use change on water quantity and quality are therefore much greater than the direct impact of climate variability.



Change in land cover (plateaux, left) ad land use (valleys) as a result of land clearing. Note the increase in millet fields (polygonal shapes). The white ellipse shows where the lower part of the lanscape changed from a small dense forested area (1950) to a seasonal pond as a result of increased runoff to the valley bottom (1992 and 2005). May 2005 is a satellite high resolution Spot Image, whereas others are aerial photos (modified, after Leblanc et al., 2008)

Impact of Irrigation on Soil and Groundwater Salinity in the Komadugu Yobe Valley, Lake Chad Basin

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During the past four decades (1970s-2000s), land irrigation using river water has expanded in the semiarid Lake Chad Basin, Africa. Irrigation was shown to have an impact on groundwater resources in the Komadugu Yobe valley, a river shared by Niger and Nigeria: Piezometric surveys showed a pluridecennial (1993-2008) rise in the water table and this was interpreted as the result of irrigation return flow to the shallow (< 10 m) aquifer. In this region, agricultural land dedicated to irrigated cash crops (sweet pepper) increased dramatically at the expense of natural savannah; conversely, surface areas dedicated to rain-fed subsistence crops (millet and sorghum), economically less profitable, have decreased. Impacts of land clearing and irrigation on drainage and recharge were estimated in 2009 by drilling 4 bores down to 6 to 10 m deep through the unsaturated zone (2 irrigated croplands, 2 in natural savannah). Soil samples were analyzed for water content, matric potential (MP) and solute chemistry (major and trace elements, including Cl, NO3, PO4, K, F) to determine direction of water movement, recharge rates and predict changes in groundwater quality. Seven bores drilled in 2007 and 2008 (Favreau et al., 2008) supplemented the data set. Natural profiles have low MP (-200 to -5000 m) but high solute inventories (e.g., Cl: 40 to 60 kg/ha/m), indicating no water movement below the ~1 m herbaceous root zone. Profiles below rain-fed crops have low inventories (Cl: 12 kg/ha/m) and variable MP, depending on the land use history (high MP when cultivated, low MP when abandoned). Irrigated profiles have intermediate solute inventories (Cl: 24 - 77 kg/ha/m), locally enriched in anions concentrated in fertilizers (NO3, PO4, F) where clayey layers occur. Where sandy layers dominate, inventories are lower (Cl: ~20 kg/ha/m) and MP are high, showing drainage and recharge to the unconfined aquifer. Change from natural savannah to rain-fed cropping has a limited impact on groundwater quality (groundwater Cl content would increase by <10 mg/L). Conversion from rain-fed cropping to irrigation increases solute flux to the aquifer (sandy soils) may result in salt accumulation in clayey soil profiles. Both changes in land use result in increasing drainage and recharge rates.

Reference: Favreau G., Scanlon B., Reedy R.C, (2008) Impact of land clearing and irrigation on groundwater recharge in the Lake Chad basin, Africa. In: Geological Society of America Abstracts with programs, 40, 6, 470.

Impacts of Groundwater Pumping and Irrigation on Regional Hydrology and Climate

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The land surface water and energy balance is an important component of hydrologic and climate variability. Recent studies have shown that interactions between groundwater, surface water, and land surface processes significantly influence surface water and energy budgets and hydrologic response under changing climate conditions. These studies suggest that water management practices which alter the distribution of water between the subsurface and near-surface; e.g., groundwater pumping and irrigation, will impact both surface-subsurface interactions and the surface water and energy balance, with potentially significant feedbacks across the hydrologic cycle. Here we examine the impacts of groundwater pumping and irrigation on surface-subsurface interactions, hydrologic response, and terrestrial water and energy budgets using ParFlow, a three-dimensional, variably-saturated groundwater model with integrated overland flow and land surface processes. Four water management scenarios are evaluated for the Little Washita River watershed in Central Oklahoma: (1) no pumping, no irrigation; (2) pumping, no irrigation (pumping for out-of-basin use); (3) pumping, with irrigation (pumping for in-basin use); (4) no pumping with irrigation (irrigation with imported water). Pumping and irrigation are shown to significantly alter the quantity and distribution of groundwater. Over regions of intermediate water table depth (~1m to ~10m), changes in groundwater levels due to pumping significantly impact the land surface water and energy balance. By contrast, irrigation is shown to decrease the magnitude of groundwater land surface coupling. Results demonstrate that water management practices such as groundwater pumping and irrigation can significantly impact land-atmosphere moisture and energy fluxes, with potentially significant impacts on local and regional climate.

Developing Ground-Up Solutions to Non-Point Source Pollution of Groundwater - An Environmental Justice Perspective

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Throughout the world, communities rely on groundwater for drinking water sources, yet very few regulatory systems protect groundwater from non-point sources. Increasingly, this is the primary cause of unsafe drinking water. In agricultural areas of the United States, nitrate is the most common drinking water contaminant, often far exceeding legal and safe limits. In California's San Joaquin Valley, approximately 90 percent of communities rely on groundwater for their drinking water sources, although those sources are becoming increasingly contaminated primarily from non-point sources. It is often farm workers and the poorest agricultural communities whose wells are contaminated with nitrate and pesticides and other non-point source contaminants. While these communities rely on agriculture for jobs and their economy, they are impacted on a daily basis by the externalities of contamination allowed to occur due to inadequate regulation or control. Community members in many of these small farm worker communities are beginning to demand that regulatory bodies address the impacts of regulatory inaction on community drinking water supplies. Already, due to stakeholder involvement of impacted communities, regulatory agencies have begun to institute programs to control groundwater contamination of dairy operations and even irrigated agriculture. Current regulatory approaches ignore the issue of source protection and often regulatory regimes leave out the major economic industries all together, meaning the poorest and most disenfranchised communities often remain without safe water to drink. This is true even in California. Today over 20 percent of small public water systems in Tulare County have nitrate over legal drinking water standards, and many have pesticide contamination as well. Yet there are no requirements on irrigated agriculture's fertilizer application. Without regulatory regimes to protect groundwater from non-point sources, we will never solve our drinking water crisis. But that challenge will take the involvement of impacted communities to ensure that those needs are being addressed. The Community Water Center works with low income and communities of color in California's rural San Joaquin Valley. Our mission is to create community-driven water solutions through organizing, education and advocacy in California's San Joaquin Valley. Much of our work focuses on improving groundwater used as a source of drinking water in the southern San Joaquin Valley, the agricultural heart of and poorest county in the state. Our work focuses on the coordination and development of the AGUA coalition and its campaign for groundwater protection, particularly from sources of nitrate.

Climate Change and Subsurface Storage

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Adaptation to climate change, groundwater quantity, and groundwater quality sustainability are interlinked in the Central Valley of California. The adaptation can be partly accomplished with strategically located subsurface storage and recovery operations designed to capitalize on the complex but heretofore largely uncharacterized subsurface geologic architecture, wherein only 20 to 50 percent of system volume can be considered aquifer yet the available volume for water storage easily exceeds the combined capacity of California's four largest reservoirs. The source of water for this recharge could come from excess winter flows as the runoff timing continues to shift toward winter months and away from the spring and summer months. The mechanisms for recharging this water sufficiently and rapidly need to be part of a growing area of research that includes new methods of managing both the floodplains and the vadose zone. The recharge could strongly affect sustainability of both groundwater quantity and quality. Currently groundwater quantity suffers from overdraft in many areas of the Valley and the recharge would obviously help. Further, groundwater quality is likely nonsustainable as long as the dominant source of recharge remains irrigation water, which includes salinity and other contaminants. Groundwater quality could benefit or not, depending on whether the enhanced winter recharge water is less contaminated than the current irrigation sources. Determination of the subsurface geologic architecture, methods for strategic recharge and its role in solving California's water storage problem as well as groundwater sustainability should be part of a priority research agenda for the future. Integrated hydrologic modeling of groundwater recharge and recovery schemes in the Cosumnes River watershed beneath the Central Valley floor provides insight into how subsurface storage can mitigate loss of snow storage in the Sierra Nevada Mountains.

The Global Boom in Groundwater Irrigation: Experience of Reconciling Resource Use and Sustainability

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In the developing world, the last 20-25 years has witnessed a massive increase in groundwater resource exploitation for irrigated agriculture, producing enormous benefits in terms of food production security, farmer incomes and rural livelihoods, but raising serious questions of resource sustainability and even irreversible degradation. This paper is based on the experience of World Bank-funded projects, supported by GW-MATE, on the North China Plain, the Gangetic Plain and Hard-Rock Peninsula of India, the Sousse Basin of Morocco, the Sana'a Basin of Yemen, Mendoza-Argentina, Ica-Peru, Guanajuato State-Mexico and the Apodi Region of North-East Brasil and represents a review and synthesis of approaches (both successful and unsuccessful) to the problem of reconciling agricultural demand with long-term groundwater resource availability. The approaches considered are a balance between: community awareness-raising, participation and self-regulation, macro-policy agricultural interventions to constrain demand, groundwater resource administration and use regulation. Successful examples of each will be presented. The appropriate balance between such measures will depend greatly on the local hydrogeological setting of groundwater resources and socioeconomic status of groundwater users (Figure 1 illustrates the sort of pragmatic framework advocated) with a standardized blueprint for groundwater resource management or one-size-fits-all approach being simply inadequate. Amongst the more common challenges and misconceptions that have regularly to be confronted that will be illustrated: 1.) Community participation. Whilst groundwater management without user participation is impossible; resource administration by users alone is always questionable. 2.) Irrigation technology improvements in irrigation efficiency do not equate to real groundwater resource savings and without other parallel interventions the reverse is quite often found to be the case. 3.) Rural energy subsidies, although often argued to be the key factor in excessive groundwater exploitation, on detailed consideration their influence may prove less significant and not as perverse as they might at first appear, 4.) Non-renewable groundwater resources. There is a widespread reluctance of public administrations to live with the reality of such resource exploitation and thus to make corresponding realistic policy decisions. 5.) Conjunctive use of groundwater and surface water. A great opportunity for improving irrigation water security and expanding agricultural production sustainability, but major socioeconomic and institutional impediments often have to be overcome.

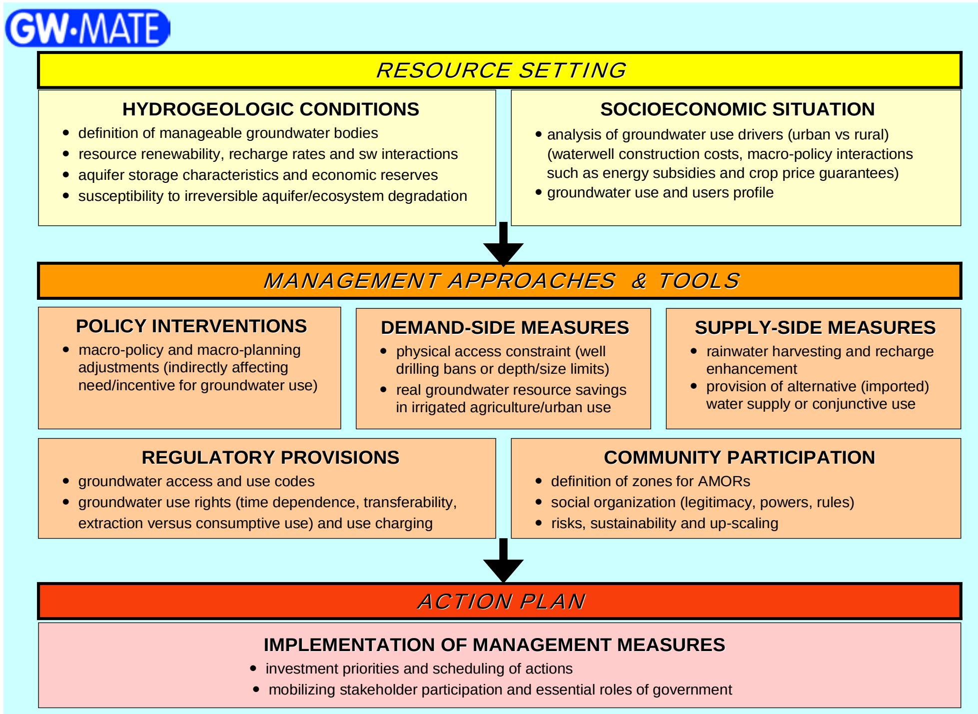

Figure 1: The GW-MATE pragmatic framework for confronting excessive groundwater resource exploitation

Relationship between Nitrogen Surpluses and Nitrate Leaching on Sandy Soils

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Nitrogen is one of the most important nutrients for crop production. Excessive use of nitrogen in agriculture in the previous century has led to widespread pollution of groundwater with nitrate. Agricultural use of nitrogen decreased since the mid-80s in the Netherlands, as it did in many other countries of the European Union. In the Netherlands, nitrogen use and nitrogen surplus in agriculture decreased in the last decades, resulting in a decrease in nitrate concentrations in the upper groundwater of farms in the sandy regions from an average of about 140 mg/l in 1992 to about 75 mg/l in 2006. Nevertheless, the EU nitrate standard for groundwater of 50 mg/l is exceeded on about 60 percent of the farms in the sandy region. To calculate environmentally safe nitrogen use standards for Dutch agriculture, two empirically derived relationships are used. First, a relationship between nitrogen use and nitrogen surplus on the soil surface balance, derived from data from field experiments. And, secondly, a relationship between nitrogen surplus and nitrogen leaching, derived from data from farms in the LMM. This study focused on deriving a relationship between nitrogen surplus and nitrogen leaching. We calculated nitrate leaching from the root zone of agricultural land as a fraction of the nitrogen surplus on the soil surface balance. Nitrate nitrogen leaching fractions were calculated for grassland and arable land in the sand region of the Netherlands, which is the most vulnerable to nitrate leaching. Farm practice data and water quality data from dairy farms and arable farms, participating in the Minerals Policy Monitoring Program (LMM) in the period 1991-2005 were used in these calculations. LMM farms in the sand region have other soil types than vulnerable sandy soils. Dairy farms have grassland as well as arable land (mainly silage maize). We developed a procedure to account for the presence of other soil types and different land use on LMM farms in nitrate leaching calculations. The results show that nitrate leaching decreases as nitrogen surpluses decrease. The decrease in nitrate leaching is smaller for dairy farms with mainly grassland (0.67 kg per kg surplus) than for arable farms (1.01 kg per kg surplus). The nitrate nitrogen leaching fraction is almost twice as high for arable land (0.89, standard deviation 0.15) than for grassland (0.46, standard deviation 0.09). No clear relationship is found between the leaching fraction and the nitrogen surplus or between the leaching fraction and the precipitation surplus. Therefore, the nitrate nitrogen leaching fractions used to calculate nitrogen use standards were not differentiated for these factors

Nationwide, Ambient Groundwater Monitoring Approaches in Europe for Monitoring the Effectiveness of the Nitrate Directive Action Program

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Introduction: Use of nitrogen and phosphorus in agriculture increased rapidly after the Second World War in Europe, increasing agricultural production but also pollution of waters. This was recognized by policy makers in the European Union and led to the adoption of a directive to abate the nitrate pollution of waters by agriculture in 1991 - the Nitrates Directive. This directive obliges Member States amongst others to designate Nitrate Vulnerable Zones; make Action Programs that regulate nitrogen use in agriculture; to monitor the effects of these Action Programs and to report every four years to the European Commission. There are large differences between countries with respect to use of surface water and groundwater, and with respect to the intensity and structure of the agriculture. There seems, however, no relationship between intensity of agriculture and whether Member States have designated Nitrate Vulnerable Zones, or whether they apply their Nitrates Directive Action Programs to the entire territory. Member States regulate nitrogen use by use standards for artificial fertilizer and animal manure. Derogation with respect to the maximum allowable nitrogen application rate of 170 kg/ha of N with manure is only applied for or considered by Member States with larger regions with a substantial livestock density. Farmers are judged on the basis of their nitrogen use and use of other prescribed measures, not on water quality. Monitoring approaches: All Member States are required to monitor their groundwater, surface water and the effectiveness of their Action Programs. There are no regulations for monitoring; only (draft) guidelines have been published by the European Commission. Guidelines for four-annual reporting to the Commission have also been published. Member States are investing a lot of time and money in monitoring networks, with several Member States still extending their networks. There was an agreement on the general strategy for effect monitoring of the Action Programs and the fact that this does not imply that all Member States have to monitor in the same way. Some Member States use regular groundwater and surface water monitoring networks for effect monitoring, while others use quick response networks. Two different approaches of effect monitoring were defined: up scaling and interpolation. The up scaling approach uses the results of studies on effects of changes in agricultural practice on nitrate leaching (and water quality) on experimental sites (e.g. plots or parcels). Process models and data on national-scale change in agricultural practice are used to upscale the experimental-sites results to describe the effect of the Action Program on nitrate leaching and water quality on the national scale. Countries employing an approach that could be classified as up scaling include Denmark, Sweden and the United Kingdom. The interpolation approach uses the results of the monitoring of agricultural practice and nitrate leaching (and water quality) on a random sample of locations, e.g. farms. Statistical models and national-scale monitored changes in agricultural practice are used to describe the effect of the Action Program on nitrate leaching and water quality on the national scale. Countries employing an approach that could be classified as interpolation include Austria, Belgium, Germany, Ireland and the Netherlands.

Assessing Potential Nutrient Losses in Tile Drained, Macroporous Soils over an Annual Cycle through Conservative Tracer Tracking

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In agricultural settings that are subject to moderate to large seasonal temperature variation, such as where this work was conducted in southwestern Ontario, farmers often have a narrow window of time between crop harvest and snowfall for applying liquid manure. Although it is well known that liquid manure application in the fall may have associated risk, limited holding capacity often dictates that liquid manure storage structures are emptied before winter. By applying liquid manure to tile drained fields in the fall, there is increased likelihood that nutrients will become surface water contaminants due to reduced water storage capacity of the soil, minimal evapotranspiration and increased macropore flow. The focus of this research is to quantify the potential nutrient loss to surface water via tile drainage after a fall liquid manure application. Methodology involved the application of a NaBr tracer solution over a 2.3m by 6.1m strip of soil immediately adjacent to a tile drain before irrigating the area for nine hours to replicate the worst case scenario of heavy precipitation immediately after manure application. The tracer was applied in early November 2007 and Br concentrations in the tile discharge were subsequently monitored for 1 year. By September of 2008, Br was not regularly detected in the tile effluent and 16, 2m long soil cores were extracted from a 6m by 6m area parallel to the tile where the tracer had been applied. Soil pore water was sampled from each core in 0.1m increments and analyzed for Br concentration in order to quantify the residual mass of Br in the soil. Tile discharge was primarily measured with an electronic flow meter which was augmented by manual measurements during periods of high flow. Discharge measurements were supplemented by results from an empirical model that was developed to test the relationship between tile discharge and hydraulic head in groundwater monitoring wells at the site. A remarkably good correlation coefficient of .94 was obtained between the model and measured tile discharge values. Mass balance calculations indicate that all of the Br was ultimately accounted for, with approximately 98 percent contained in tile discharge and the remainder retained in the soil profile. Within 21 days of the tracer application 22 percent of the bromide mass had been discharged through the tile with 8 percent of the total mass arriving at the tile in the first 48 hours. By April 1, 2008 the majority of the bromide had been discharged, with approximately one quarter of the total bromide mass discharged during the hydrologic response to an early January winter melt event. Results from this work indicate that the majority of soluble nutrients applied close to tile drains, during fall liquid manure applications, will potentially be transported to surface water prior to the following growing season, and that winter and spring melt events are responsible for most of the soluble nutrient flux between tile drained agricultural land and surface water.

UNESCO-IHP and Groundwater: Recent Developments

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The UNESCO-UC Irvine-USGS Conference of December 2008 has identified key responses of groundwater management to water scarcity and global change. It has produced an Action Framework, presented at the World Water Forum of Istanbul in 2009, and which is now in its first phase of implementation. This first phase concerns the design and setting in Kenya of a UNESCO Category 2 Centre focused on groundwater and serving East Africa, as the first node of a world network of Groundwater Regional Knowledge Transfer Centers. Local nodes providing training and consulting support to local water managers and individual farmers in rural areas will complete each regional center. Several East African aquifers are transboundary, which naturally relates the Kenya project to the IHP activities concerning transboundary groundwater, such as the development of legal instruments and education and training, which will be briefly explained.

Sustainable Groundwater Management: The Role and Performance of Institutions in India

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Groundwater has rapidly emerged to occupy a dominant place in India's agriculture and food security. It has become the main source of growth in irrigation and now contributes over 60 percent of the irrigated area. About 70 percent of India's food grain production comes from irrigated agriculture in which groundwater now plays a dominant role. Despite this huge significance, groundwater is poorly managed and is heading for a crisis. Overexploited blocks are increasing at an alarming rate of 5.5 percent per year. A major problem is the lack of institutional development. A huge gap exists in institutional arrangements necessary to complement the technological change and demand growth. This would have serious implications for agriculture and poverty alleviation in India. In response to the acute water scarcity and declining water tables, local institutions have developed spontaneously in some area such as Gujarat to manage and use the resource. These include tube-well cooperatives and partnerships in northern districts, and rain water harvesting institutions in western districts. An approach based on new institutional economics and governance theories is developed to examine the nature, function and performance of these institutions. A large number of institutions and their members are surveyed and the data analyzed to identify determinants of performance including addressing scarcity/availability of water, environmental impact, equity of distribution, and economic viability. Derived features such as clear objectives, good interaction, adaptiveness, scale, and compliance, as well as technical, organizational and political rationality are examined through econometric analysis. The results indicate the usefulness of new institutional economics and governance theories in explaining performance on different counts. Objectives being clear to the members, management having expertise, management having authority to adapt the rules and systems, and the institution using its powers to bring compliance are important determinants of performance. The impact on the village as a whole is found to be better when the institution regularly makes and pursues plans towards achievement of its objectives, and the management has the necessary expertise, particularly technical expertise. Important implications emerge for policy and for the design of institutions.

Social Sustainability of a Groundwater Allocation Plan toward the Resolution of an Allocation Dispute Between Agricultural and Forest Water Users

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The 140,000 ha pine and bluegums plantations in the South East of South Australia are a major water user through both direct extraction in shallow water tables and rainfall and thus aquifer recharge interception. The land use change induced by the forestry expansion is therefore blamed for significant water table decline in the area. A proposed South Australian legislation plans the introduction of forestry water licensing, converting the water planning process and regulating users' water allocation into a highly disputed process dominated by the forestry debate. The review of the social sustainability of the water allocation planning process offers an in-depth consideration of its interrelated five principles: livelihood or quality of life, fairness, resilience, future focus and community engagement through a longitudinal analysis of the local values of the 5-year long planning period (from June 2004 and still ongoing). These values, collected with local newspaper reports of the issues and conflicts in drafting this regulation and revealed through its qualitative content analysis, enabled thorough examination of the community perceptions around this policy development. The forestry water licensing adversely impacts the long-term forestry employment if other plantations areas do not introduce similar regulations. But it also provides for equity among water users, including the environment. In particular, forestry, in being licensed, is recognized as a water affecting activity equal to other water users. The existing forestry plantations thus get a water license, but could also bear a share of the allocation reductions if any planned to address over-allocation and initially affecting only irrigators. Additionally, the secure water right promoted by the legislation and the formal diversification permitted by the new licensing favor resilience of the local community. However, the planning process itself endured significant pressure from all stakeholders and not only from the community engagement. Especially the difficulty to account for the intricate characteristics of forestry as opposed to irrigation water use level cannot be managed and reduced growth in dry periods still holds the plan adoption up. The social sustainability perspective applied to this groundwater allocation planning process removes some of the contested elements of the forestry water licensing towards a resolution of the dispute.

Unquenchable: America's Water Crisis and What To Do About It

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Deep in the Mojave Desert sits Las Vegas. The desert is a dry, torrid place that can quickly kill a person without water, but in Sin City a torrent of water flows freely in massive fountains, pirate lagoons, wave machines, and casinos. Meanwhile, across the country in places that are not particularly dry or hot, communities, farmers, and factories are struggling to find water, and even running out altogether. America's self-inflicted water crisis is coming. In a book that is both frightening and wickedly funny, acclaimed author and expert Robert Glennon has captured the tragedy and irony of water in America. From the Vegas Strip to faux snow in Atlanta, from our supersized bathrooms to mega-farms, from billion-dollar water deals to big time politics and personalities, *Unquenchable: America's Water Crisis and What To Do About It* reveals the heady extravagances and everyday waste that are sucking the nation dry. Our water woes will get worse before they get better because we are slow to change our ways, and because water is the overlooked resource. It s happening again: Washington's love affair with biofuels will turn to heartbreak once America realizes that thousands of gallons of water are required to produce one gallon of fuel. Glennon tells how a celebrated, new ethanol plant in Minnesota, The Land of 10,000 Lakes, is already sucking local wells dry. Glennon argues that we cannot engineer our way out of the problem with the usual fixes or the zany but very real schemes to tow icebergs from Alaska or divert the Mississippi River to Nevada. America must make hard choices and Glennon's answer is a provocative market-based system that values water as a commodity and a fundamental human right. Island Press is proud to take part in bringing Robert Glennon's thought-provoking expose on our water crisis to light. *Unquenchable* will illustrate the urgency of this problem and the need for action on multiple fronts to solve it. Robert Glennon is the Morris K. Udall Professor of Law and Public policy in the Rogers College of Law at the University of Arizona. He is the author of many articles and books, including the acclaimed *Water Follies: Groundwater Pumping* and *The Fate of America s Fresh Waters*.

Westlands Water District: Managing the Groundwater-Agriculture Nexus in the Largest U.S. Irrigation District

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Prior to the delivery of Central Valley Project (CVP) water supplies to Westlands Water District, the annual groundwater pumpage within the District ranged from 800,000 to 1,000,000 acre-feet during the period of 1950-1968. The majority of this pumping was from the aquifer below the Corcoran Clay causing the sub-Corcoran piezometric groundwater surface to reach the lowest recorded average elevation of 156 feet below mean sea level in 1967. The U.S. Geological Survey calculated that the large quantity of groundwater pumped prior to delivery of CVP water compacted water-bearing sediments, causing land subsidence ranging from one to 24 feet between 1926 and 1972. After CVP water deliveries began in 1968, the groundwater level within Westlands Water District rose steadily until reaching 89 feet above mean sea level in 1987, the highest average elevation of record dating back to the early 1940s. Between 1968 and 2006, with reliable delivery of CVP water supplies through the Delta, annual groundwater pumping within Westlands averaged about 200,000 acre-feet per year. Recently, groundwater pumping has increased tremendously because of reduced CVP water supplies caused by the extended drought and regulatory actions related to the Central Valley Project Improvement Act, the Endangered Species Act, and Bay/Delta water quality. Groundwater pumping for the past three years (2007-2009) has averaged about 420,000 acre-feet a year. With the Delta fix and a more reliable water supply many years away, Westlands' challenges will include effective management of the groundwater basin to supplement a smaller and less reliable surface water supply.

A National View of the Irrigation Resources to Grow Biofuel and the Groundwater Role

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Irrigated cropland and associated water supplies, including groundwater resources, are currently being used for biofuel production. This presentation provides a national view of water and land resources used for irrigation, with an emphasis on groundwater use. The focus of the data-driven presentation is on current biofuel production in the form of corn-based ethanol, but implications will be drawn for possible future cellulosic ethanol feedstock. The presentation utilizes secondary data sources from the U.S. Department of Agriculture and U.S. Geological Survey to provide a national view of the water (surface and groundwater) and land resource activities. State- and crop-level data are used to illustrate the consequences of ramping up biofuel feedstock production on crop water applications with implications for the utilization of groundwater resources.

Microbial Contamination of Groundwater under Agricultural Fields, Sources and Pathways

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The application of animal manure and human waste to provide nutrients to field crops has been widely practiced for centuries. Increased interest in recycling other organic materials, such as paper mill, distillery and vegetable waste from supermarkets, has broadened the range of possible sources of pathogenic bacteria applied to soil. In addition, on-site waste treatment systems, such as septic units, are more prevalent in rural than other areas. Grazing domestic and wildlife may also pose a threat. Whether or not pathogenic microorganisms, such as bacteria, viruses and protozoa, are able to travel through the soil and superficial rock layers to groundwater depends on the form and the way these organic materials are applied, the partitioning of precipitation into surface runoff and infiltration, survival and persistence of pathogens outside a suitable host, soil type, soil structure, and the type of flow that dominates water movement down through the soil. The same soil-focused considerations apply to the outflow from the weeping beds of septic waste systems. Solid organic materials act somewhat like mulch and encourage infiltration of water, whereas liquid and slurry forms can clog finer pores at the soil surface, thereby encouraging runoff, but the water entering the soil is likely to do so through large diameter pores that can facilitate rapid flow to depth. Once in the soil, bacteria from solid manure appear to be less able to compete with indigenous soil organisms that those from liquid manure. Bacteria and viruses are strongly adsorbed to metal oxides, clay and organic matter, and so are less likely to be removed from sandy soils. However, even though sandy soils are more permeable, unsaturated flow is more likely than movement under saturated conditions. Well surveys in Ontario, Canada showed much less contamination of groundwater under coarse textured soils than under soils with more clay and silt. Saturated flow conditions can occur in these finer textured soils, especially as they are often well structured. The presence of macropores, whether formed by soil organisms such as earthworms or larger burrowing animals, or produced by wetting-drying or freeze-thaw cycles, are very important for the rapid transport of viruses, bacteria and protozoa to depth (Fig. 1.) There is evidence that the walls of these pores are lined with organic matter and also more mineral nutrients are available than in the bulk soil, which will tend to enhance pathogen persistence. This paper reviews the processes important for pathogen transport and persistence in soil and considers the consequences for quantitative risk assessment and agricultural management practices that can enhance the protection of groundwater resources.

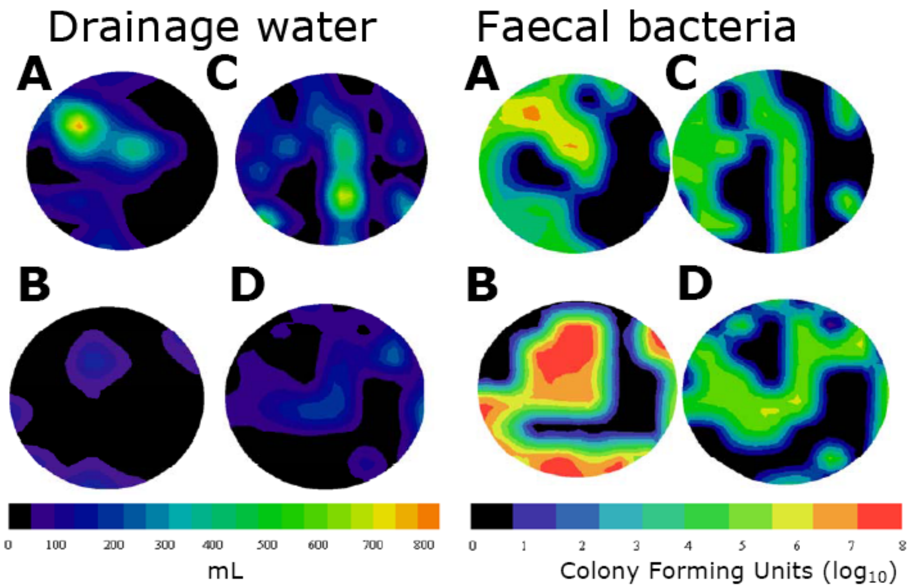

Figure 1. Location and contribution to drainage of flow paths exiting lysimeters and the concentration of Faecal bacteria in the water from each flow path.
Lysimeters A and C treated with liquid swine manure; Lysimeters B and D treated with solid manure from beef cattle.

Trends in Nitrate Concentrations in Agricultural Areas of the United States: Implications for Aquifers and Streams

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Use of industrially fixed nitrogen (N) fertilizer for agricultural purposes has increased more than 20-fold in the United States (U.S.) and more than 45-fold globally since 1945. As a result, there has been growing concern about the consequences of increases in the amounts of anthropogenic N circulating in the atmosphere, hydrosphere, and biosphere. The U.S. Geological Survey's National Water-Quality Assessment Program has collected groundwater samples along flow paths in more than 20 agricultural areas and across a variety of hydrogeologic settings to evaluate the trends and transformations of agricultural chemicals. Historical trends in N fluxes to groundwater were evaluated by relating the recharge dates of groundwater samples, estimated using tracer (e.g., chlorofluorocarbon) concentrations, with concentrations of the parent compound at the time of recharge, estimated as the sum of the molar concentrations of the parent compound and its transformation products in the age-dated sample. Results from this analysis indicate that the median concentrations of nitrate in recharging groundwater have increased markedly over the last 50 years, from 4 mg/L (as N) in samples that recharged prior to 1983 to 7.5 mg/L (as N) in samples that recharged after 1983. Nitrate concentration trends in recharging groundwater were related to increases in the amount of fertilizer applied. Estimates of the portion of applied N reaching the water table ranged from 4 to 49 percent among the sites, with a median value of 14 percent. Increasing nitrate concentrations in shallow groundwater pose a potential risk not only to these waters but also to deeper groundwater and streams. This risk will be reduced to the extent that nitrate is removed by denitrification along subsurface flow paths, a process that is directly related to the rates of reduction of dissolved oxygen. Dissolved oxygen reduction rates varied widely within and between sites, with higher rates (e.g., >0.13 yr-1) often found in riparian zones. However, in several watersheds, low dissolved oxygen reduction rates (<0.05 yr-1) were observed in both upland and riparian zones, indicating that denitrification rates may be too low at these sites to prevent increases in the concentrations of nitrate in groundwater and streams from legacy sources of nitrogen.

Assessing and Forecasting Nitrate Fluxes in Agricultural Aquifers

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Research on hydrogeochemistry of agricultural aquifers is important for sustaining water supplies and drinking water quality. As a part of the NAWQA Agricultural Chemicals Team (ACT), detailed studies were conducted of chemical fluxes and transformations in the unsaturated and saturated zones at seven sites in California, Washington, Nebraska, Iowa, Mississippi, Indiana, and Maryland, USA. Unsaturated zone water and groundwater samples were collected in vertical profiles along transects leading from farm fields to rivers for analyses of N species, stable isotopes of N and O in NO3, dissolved gases, and atmospheric age tracers. Mathematical models were applied inversely to concentration profiles of age-tracers and agricultural chemicals to estimate the hydrogeological and chemical properties of the subsurface, including unsaturated zone travel time, groundwater recharge flux, fraction of applied N lost to groundwater, denitrification rates, and vertical groundwater velocities. The sums of water application + precipitation are relatively uniform among sites, yet recharge to the water table varied by a factor of five as a result of unsaturated zone properties. The NO3 flux at the water table is variable and ranges from 0.1 to 0.6 of applied N at these sites. The rates of denitrification in recharging shallow groundwater are surprisingly uniform among sites, despite reports of many orders of magnitude difference in denitrification rates in previous literature. The consistency of denitrification rates among these sites likely relates to the use of consistent methods and scales of measurement as well as control of denitrification by solid phase electron donors in aquifer materials. Vertical groundwater velocities strongly affected differences in the distribution of redox conditions among these aquifers. Zones of NO3 reduction tended to be shallower at sites with lower vertical groundwater flux. Scenario testing illustrates the effects of vertical velocities, reaction rates, and N loading on future distributions of nitrate in these aquifers. In these shallow agricultural groundwaters, denitrification rates are too low to substantially mediate nitrate contamination, which will persist for decades to come.

Framework for the San Joaquin Valley Integrated Regional Water Management Plan

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The California Partnership (Partnership) for the San Joaquin Valley (Valley) was created by Governor Schwarzenegger in 2005 to focus attention on the challenges of the Valley in meeting the needs of its citizens and the entire state. The Partnership developed a strategic action proposal that included a mission to address water issues in the Valley. The Partnership then commissioned a Water Work Group and the California Water Institute (CWI) at California State University, Fresno to first develop a framework for a long-term San Joaquin Valley water management plan. Similarly, four Valley congressmen had previously asked CWI to develop a water plan for the Valley and the two efforts were merged. The cumulative effort is critical to identify the Valley water needs and determine water management solutions for a fifty-year planning horizon. The following is the framework summary findings: 1.) The California Water Code and the California Department of Water Resources have outlined a process for analyzing local long-term water needs and developing comprehensive water management solutions. The process involves creating integrated regional water management plans (IRWMP). The entire San Joaquin Valley should embrace this concept and adapt it further for its own purposes. 2.) The IRWMP process has three basic components: a. An assessment of conditions and water use preceding a 50-year planning time frame; b. An estimate (water budget) of water needs for the next 50 years; and c. A solutions process that analyzes every reasonable water management technique to meet various alternate futures as the technique becomes available. 3.) Significant amounts of information and integration will be required to develop and implement regional, inter-regional, basin-wide and Valley-wide plans. Information gathering and dissemination tools that outline core information needs for all participants at every level will be important. The report offers an example for consideration. 4.) The IRWMP process is a deliberative, long-term approach that will take time to develop and implement. Water crises and conflicts will continue to arise in the intervening years and may override the long-term effort. The Valley must recognize the importance of these events and be prepared to respond to them accordingly in a timely manner. An action team response approach to address such events would be useful. By example, a Partnership action team will continue to work on the Sacramento-San Joaquin Delta water export and statewide drought crisis. 5.) Two examples of how integrated assessment, planning and management solutions can work together are included within this report. They include solutions for groundwater recharge improvement that integrates land and water use and a rural water system assessment and solution strategy. Both of these water-related issues are rapidly approaching crisis level. Many good recharge soils are getting separated from surface water supplies. Access to Valley groundwater becomes more important should the lack of surface water supplies become more widespread. Rural water system operations that rely on groundwater are then faced with dwindling supplies and water quality issues and very often the local operators do not have the financial capacity to resolve the problems. Postponing resolution of these issues is not an effective option. 6.) The Partnership must engage all its members to make water an ongoing high priority if the Valley is to prosper and meet the commitments to its citizens. Water cannot be created. Its distribution is naturally uneven and cannot be moved or made available without significant social, environmental and economic cost. What we have must be treated with respect.

Interannual to Multidecadal Climate Variability Effects on Sustainable Groundwater for Agriculture

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Climate variability and change have important implications for recharge, discharge, contaminant transport, and the sustainability of groundwater resources for agriculture. Reliable predictions of groundwater sustainability due to climate change will require improved understanding of the climate forcings on interannual to multidecadal timescales. Climate variability on these timescales has been shown to partially control precipitation, air temperature, drought, evapotranspiration, streamflow, recharge, and mobilization of subsurface-chemical reservoirs. Thus, climate variability can augment or diminish human stresses on groundwater and the responses in storage can be dramatic when different climate cycles lie coincident in a positive or negative phase of variability. Understanding climate variability has particular relevance for management decisions during drought and for groundwater resources close to the limits of sustainability. Results will be presented from recent studies on two important agricultural regions of the United States, including the High Plains and Mississippi Embayment regional aquifers to quantify recharge and contaminant transport responses to climate variability on interannual to multidecadal timescales. Using singular spectrum analysis, the signal of groundwater pumping was removed and natural variations were identified in groundwater levels as partially coincident with the El Nino/Southern Oscillation (ENSO) (2- to 6-yr cycle), the Pacific Decadal Oscillation (PDO) (10- to 25-yr cycle), and the Atlantic Multidecadal Oscillation (AMO) (50- to 80-yr cycle). Recharge in both aquifers was most significantly correlated to the PDO. In the High Plains (450,000 km2), climate varying recharge rates (196 to 476 mm/yr) were found to be substantially larger than previous estimates of diffuse recharge (0.2 to 110 mm/yr), indicating the importance of preferential flow and downward displacement of chloride reservoirs during recharge to the High Plains aquifer. In the Mississippi Embayment aquifer (181,000 km2), future PDO and AMO shifts and continued groundwater-pumping trends are predicted to result in 25 to 50-meter declines in water levels. These studies support the conclusion that understanding natural climate variability is necessary toward predicting groundwater response due to climate change.

Aquifer Geometry and the Impact of Irrigation Water on Groundwater Level Changes in Main Ethiopian Rift

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The rise of groundwater levels has recently becomes a serious concern at the Wonji irrigation field, in the main Ethiopian Rift. An integrated study based on geophysical resistivity methods is conducted at the Wonji irrigation field aimed at understanding the link between irrigation water and the shallow aquifer system, a research intended to validate the current concern of groundwater rise and improve the uncertainty of understanding the extent and direction of groundwater-surface water interaction. The vertical and horizontal contacts between the different geological series of the Wonji area are resolved with two-dimensional high-resolution geophysical imaging. Result from both 1D sounding and 2D tomography show low in resistivity of layers with narrow ranges in resistivity variation (1-5m) which corresponds to a homogeneous layer saturated with saline water; salinity due to groundwater evapotranspiration. The geoelectric sections reveal two fault systems running NW-SE and N-S directions which impede lateral groundwater flow. Furthermore, groundwater is converged toward the Wonji irrigation site strained by these fault systems. The results of the geophysical survey show the strong hydraulic connection between irrigation water and the shallow unconfined aquifer as well as hydraulic link among the local and regional flow systems.

The Groundwater Surface Water Connection in California: Balancing Agricultural, Municipal and Ecosystem Needs in Groundwater Management

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The Nature Conservancy has developed and implemented many innovative freshwater conservation strategies, including protecting the headwaters of streams and rivers, managing forests sustainably, facilitating environmentally beneficial regional water planning, purchasing lands and conservation easements, and acquiring surface water rights to provide environmental flows. Practically all the rivers and streams in California, and the freshwater ecosystems that depend upon them, rely on groundwater for a significant portion of their water. Therefore, our success in aquatic ecosystem conservation is closely tied to effective management of our water resources; groundwater and surface water. In addition, given the highly stressed and intensely managed water resource setting of California, successful management of groundwater to support aquatic ecosystems is closely tied to agricultural and urban water uses. In an effort to move toward more truly integrated water management for people and ecosystems, The Nature Conservancy's California Water Program is evaluating the connection of groundwater and surface water at our conservation sites around the state. With improved understanding of the groundwater/surface water/ecosystem relationships, we are establishing groundwater management objectives that meet the needs of ecosystems and developing integrated water management strategies that provide multiple benefits for existing water users and for the environment. This presentation will highlight how historic and current groundwater management has affected aquatic ecosystems at some of the Conservancy's iconic conservation sites in California. In some cases, the ecosystem damage from poor groundwater management is severe and advanced, and recovery will be difficult and expensive. Other systems still have reasonably functional groundwater systems, and with fairly straightforward and painless precautions, the integrated groundwater / surface water relationships can be protected and maintained with very potent outcomes for conservation and sustainable water supplies for cities and farms. We will present examples of integrated water management strategies we are evaluating that blend environmental, agricultural and municipal water resource objectives. Collectively, our investigations highlight some important weaknesses in current groundwater management institutions and policies and suggest what changes must occur if further degradation of aquatic ecosystems is to be curtailed.

Analysis and Simulation of Conjunctive Water Use for Agricultural Settings with the Farm Process for MODFLOW

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MODFLOW with the Farm Process (MF-FMP) allows fully coupled simulation of the use and movement of water in the form of precipitation, streamflow and runoff, groundwater flow, and consumption by natural and agricultural vegetation that facilitates detailed analysis of conjunctive use. MF-FMP provides the ability to simulate natural and anthropogenic components of the hydrologic cycle and facilitates the supply-constrained and demand-driven simulation that accounts for all water throughout the simulated system. MF-FMP provides a dynamic allocation of surface-water deliveries, groundwater pumping, and return flows as runoff and groundwater recharge based on a requirement for crop irrigation necessary to satisfy the crop-water demand after using effective precipitation and root uptake from shallow groundwater. Simulation at different levels of spatial detail from individual farms (micro-agriculture) to aggregates of farms or irrigation districts (macro-agriculture) demonstrate the utility of MF-FMP to simulate and analyze conjunctive use at different scales. This includes the ability to simulate historical conditions as well as the ability to simulate the direct effect of future climate projections on estimated demand, surface-water deliveries, and groundwater pumpage. MF-FMP provides a tool to assess conjunctive use on local to regional scales within the context of a hydrologic cycle that includes natural and urban components. The ability of MF-FMP to dynamically analyze the supply and demand components of the water budget allows water managers to understand the potential effects of proposed conjunctive-use plans on the aquifer system and irrigated crops. This analysis could be difficult without embedding them in the simulation and these components of water use could be difficult to estimate independent of these dynamic relations a priori. Selected examples from across the western United States are used to demonstrate some of the unique features of MF-FMP.

For Want of Food: Groundwater and Agriculture

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Food, feed, fiber, and (bio)fuel production in agriculture consumes nine out of every 10 liters of freshwater consumptively used by humans - the remainder being consumptive water losses in industrial and domestic water uses. Irrigated agriculture produces 40 percent of the global food supply. In many irrigated regions throughout the world - Southwestern U.S., China, India, the Mediterranean region, Mexico - groundwater constitutes from one third to more than two thirds of all irrigation water. More importantly, groundwater provides a stable source of water against local and global climate variability. World population growth and increasing economic output not only in developed countries, but also in Latin America and especially in India, Southeast Asia, and China continue to heighten demands for food production. Water and especially groundwater use for food production has therefore seen tremendous increases over the past decades, first in the U.S. and in southern Europe, and over the past thirty years also in India, China, North Africa, the Middle East and elsewhere. In turn, groundwater overdraft and groundwater quality degradation in agricultural regions have become issues around the globe, and are now closely linked to global long-term food security in both irrigated and rain-fed regions. I suggest that long-term global food security, and with that the livelihood of the agricultural community must be considered as the driving rationale for sustaining agricultural groundwater resources for long-term food production. But the complexity of the link between sustainable groundwater resources and food security is challenging both, our understanding of its true global significance and our ability to develop comprehensive, adequate technical and policy solutions. Disciplinary scientific and legal isolation between watershed management, groundwater quality and quantity management, and agricultural management, disparateness between science, policy, and education, and the geographic and socio-political isolation of stakeholders that arises from the fact that groundwater is intrinsically a local or regional, common pool resource are major hurdles in working toward a global infrastructure that can efficiently support sustainable groundwater in agriculture at a global scale. Recently, much local, national, and global efforts have been initiated toward meeting these challenges, especially with respect to surface water. A broader initiative is needed to also establish a global network of regional and (trans-)national efforts that can effectively help formulate, assess, and meet the wide range of challenges in agricultural groundwater quantity and quality management as a critical part of managing our water resources in agriculture. Agricultural groundwater management and policy must also strike a balance with competing, but related needs for urban growth and environmental sustainability in a world of global change and limited land and energy resources.

Understanding the Effects of Agriculture-Driven Multiscale Groundwater-Surface Water Interactions on Scott River Baseflow and Stream Temperature in Support of Beneficial Salmon Habitat

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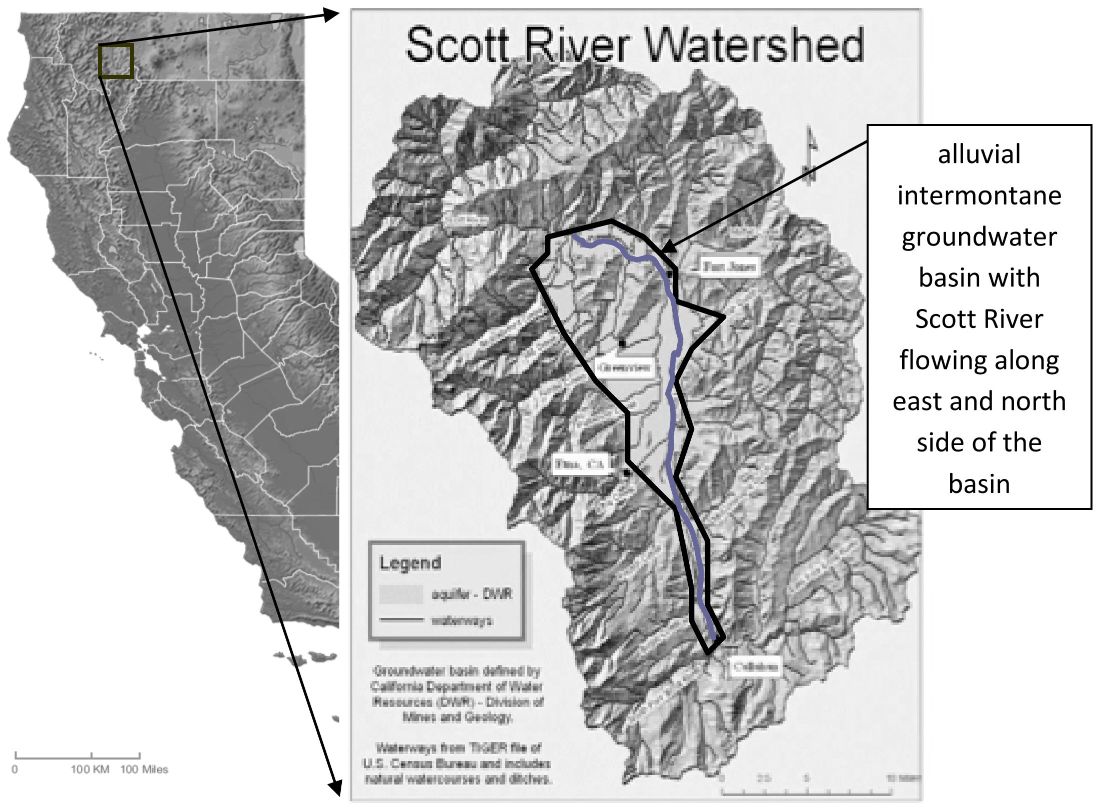
Regional scale surface water–groundwater modeling is employed to investigate the benefits of various agricultural land use management alternatives on mid- and late summer baseflow in the Scott River. Concurrently, high-resolution field measurements of stream temperature over an approximately 1,000-meter reach collected using Fiber Optic Distributed Temperature Sensing (DTS) indicate that groundwater discharge to the Scott River is highly localized throughout the Valley. Analysis of the data was able to identify areas of apparent groundwater accretion and hyporheic inflow based on the characteristics of the resulting temperature signals, including mean, amplitude, and phase. The high-resolution temperature measurements were paired with fish surveys in order to determine the correlation between areas of identified lower river temperatures, groundwater accretion and beneficial salmonid habitat. Our work suggests that understanding of local-scale groundwater-stream interaction and analysis of corresponding local-scale geologic and riparian vegetation controls are critical to understanding the basin-scale groundwater-stream interactions. This local-scale understanding is necessary if strategies aim for effective water resource management practices that will improve beneficial use habitat. A multi-scale field reconnaissance and modeling approach is suggested to develop water management practices that lead to better habitat protection throughout the watershed.


Scott River Watershed
alluvial intermontane groundwater basin with Scott River flowing along east and north side of the basin
Fort Jones
Etna, CA
Legend
aquifer - DWR
waterways
Groundwater basin defined by California Department of Water Resources (DWR) - Division of Mines and Geology.
Waterways from TIGER file of U.S. Census Bureau and includes natural watercourses and ditches.
0
100 KM
100 Miles

The Situation of Groundwater Quality and its Availability for Agriculture in Yemen

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Yemen is classified within the semiarid areas where the rainfall varies between 400-50 mm annually. Therefore, per capita of per year renewable water is estimated at 130 m3 per year. The water poverty line is 1000 m3 per year and Yemen is at the bottom of countries under this line. Yemeni agriculture has varying climatic characteristics resulting from the uneven rainfall and temperature, humidity, and different topographic conditions, which led to differing regions of plants and which help to diversify the production but that the adoption of many of the areas on the rain-fed agriculture impact on the sustainability of agricultural production. This also depends on other parts of groundwater pumping, groups of reservoirs and dams, irrigation and springs of water. According to scientific research, the problem of water in Yemen started in the mid-70s. This was when people started using excavators to dig deep wells and use pumps to extract large amount of water for agriculture use. More than 45,000 wells have been drilled. Among them are 5,000 wells in Sana'a where most of them are used for irrigation. This over-pumping of water led to a decline in water levels and in some cases it is more than 7 meters shortage per year. According to the agricultural census in 2007, 69,763 wells exist in Sana'a. Yemen suffers from a deepening crisis due to lack of groundwater and the depletion of water reserves to the extent that some water basins such as the Sana'a Basin (the capital) are threatened by drought in less than a full two decades. The paper reviews the most important issues and challenges related environment in reliance on the use of groundwater in agricultural development and maintain its sustainability in Yemen - one of the challenges to the problems of water scarcity.

New Developments for Conjunctive Management in Idaho: Why Our Expanding Understanding of Science Should Expand How We Address the Doctrine against Waste in Idaho Water Right Transfers

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Idaho, like all western States, is facing an impending water crisis due to a combination of unprecedented growth and extended drought. This is particularly true in southern Idaho's Snake River Basin, where a booming population has put particular stress on both the ground and surface water supply. As a result, the need for users to become more efficient with their water and water rights has become increasingly necessary. By Idaho statute, the user is allowed to keep any water that has been saved as a result of an increase in efficiency, allowing such a user to transfer that additional water to others who may need it. There are two competing legal doctrines at issue in such a situation. A water right does not include the right to waste water; however, a user is also not allowed to injure any other user in the process of completing a transfer. Before groundwater became a major source in Idaho, determining injury was a rather straightforward process. However, proving injury for groundwater is much more complicated because of the complexities of the substrate. This complexity seems to have caused the no-injury rule to be pushed to the backburner when transfers are requested. However, the no-injury rule cannot be ignored. It is part of the foundation of Idaho water law and serves the critical purpose of insuring that a single water user does not control the destiny of junior users. The purpose of this presentation is to argue that Idaho should adhere to the no-injury rule when dealing with issues of water transfer. It will go on to discuss how before this question of fact can be answered, a method of determination must be implemented. Namely, the Snake River Plain Aquifer Model must be modified to be able to determine the all-important question: will my transfer affect other users on a local level? Finally, this presentation will discuss how the state of Idaho is attempting to work around the complexities caused by groundwater and the no-injury rule with new incentives created through the state of Idaho's Comprehensive Aquifer Management Plan.

Legal Regimes for Groundwater Regulation: Effectively Managing an Increasingly Crucial Resource

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As surface water supplies dwindle, groundwater is becoming an increasingly important resource. Furthermore, given the cost and environmental impacts of building surface water storage facilities, groundwater basins have become crucial for water storage. Many jurisdictions have legal regimes governing groundwater use. California is almost alone among in the western United States in having no statewide regulation of groundwater use. Without a statewide permitting system regulation is left to ad hoc agreements, special legislation or lengthy and expensive litigation involving all water users in a basin. Currently only 24 out of over 400 groundwater basins have been adjudicated in California through litigation and very few are governed by special legislation. This presentation will compare different legal regimes governing groundwater and discuss the challenges faced by municipal and agricultural groundwater users that rely on unregulated groundwater basins. It will also discuss the difficulty of regulating uses after the waters of a basin are being fully utilized. The presentation will also discuss the increasing importance of groundwater management, including groundwater banking, in light of limits on current and future surface water supplies and environmental restrictions. Finally, the presentation will address the difficulties associated with the intersection of agriculture and municipal uses of groundwater.

Groundwater and Energy Emerging Challenges, Directions and Opportunities

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Water and energy are interdependent. Water is used extensively in energy development as cooling water in thermoelectric power generation, in oil and alternative transportation fuels refining and in biofuels production. At the same time, water and waste water pumping, treatment, and distribution is one of the largest energy use sectors in the country. At a time when fresh water availability is becoming limited in many regions from changing precipitation patterns, increased ecological and environmental water demands, and concerns over sustainable groundwater withdrawal, water demands by the energy sector could triple over the next two decades. Emerging competition for water from the energy sector could significantly impact and change how surface and groundwater resources are developed and utilized. This presentation will provide an overview of emerging trends in how the energy and groundwater development sectors are becoming even more closely linked due to new energy development trends and water needs. The presentation will also discuss some of the emerging energy and biofuels related issues that are expected to drive future groundwater development and utilization.

Groundwater Chemical Status in Denmark Based on Environmental Objectives for Ecosystems and European Water Directives and Guidelines

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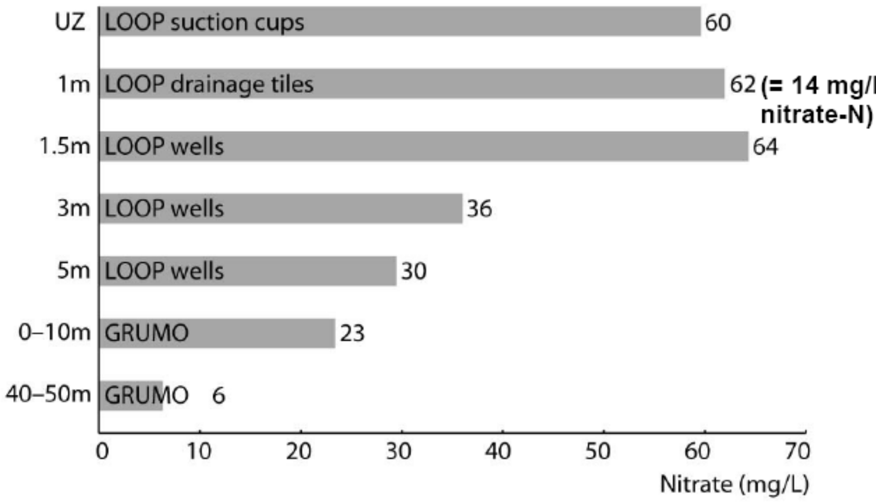
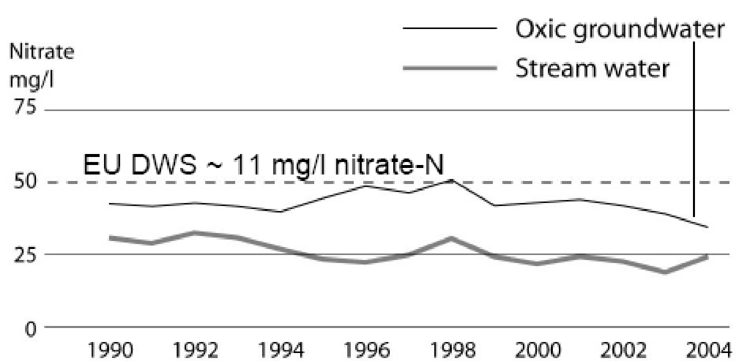
Nitrogen leakage from agriculture has severe consequences for the chemical status of the shallow oxic groundwater in Denmark. A recent assessment indicates that as much as 2/3 of the shallow oxic groundwater does not comply with the European Water Framework and Groundwater Directives (WFD and GWD), when the status assessment is based on groundwater nitrate concentrations and the environmental objectives for associated aquatic and dependent terrestrial ecosystems. Average nitrate-N concentrations in shallow oxic groundwater below agricultural monitoring sites is currently about 14 mg/l (Figure 1), but it has been slowly decreasing from about 25 mg/l since 1990 due to national Danish action plans to reduce nutrient leakage from agriculture. However, assessments of groundwater threshold values derived for the protection of specific aquatic ecosystems indicate that this value should be reduced to about 4 mg/l or less in order to assure good ecological status of these ecosystems, and probably even further, 1 3 mg/l nitrate-N, to assure good status for dependent terrestrial ecosystems. Hence, at the current rate of decrease in nitrate concentrations (Figure 2) it will be difficult to reach good status for shallow oxic groundwater in Denmark in 2015 as required by the WFD and GWD, and it may be difficult to reach this goal even in 2027, which is the ultimate deadline for complying with the good status objective. Regional climate models predict that winter precipitation will increase in Denmark. Consequently, integrated groundwater-surface water models estimate increased nutrient transport to streams via shallow oxic groundwater and drains. This must be considered when measures to reduce nitrogen leakage from agriculture are planned, and when designing monitoring and modeling systems for assessing the efficiency of the established measures. Results from a few recent Danish studies are presented to illustrate the current observed nitrate-N concentration distribution in Danish groundwater and surface water, and the modeled effects of increasing winter precipitation on nitrate leakage to groundwater and associated aquatic and dependent terrestrial ecosystems. Measures to reduce nitrogen (and phosphorus) leakage to groundwater and surface water are strongly needed as Danish coastal waters and the Baltic Sea are among the marine waters most affected by pollution globally, according to a recent review study.



Average nitrate concentrations at different depths and depth intervals in Danish monitoring wells. Data represented by the upper five bars are from the monitoring programme in agricultural watersheds with in total about 100 shallow wells at 1.5, 3 and 5 meter depths. Data represented in the lower two bars are from the national groundwater monitoring programme with totally 278 wells and 83 wells in the intervals 0-10 m and 40-50 m, respectively. The drinking water standard for nitrate is 50 mg/l nitrate or ~ 11 mg/l nitrate-N in Europe.



Annual mean concentrations of nitrate in oxic groundwater and streams in Denmark. The stream values are flow-weighted average of streams in 86 catchments (Kronvang et al. Env. Sci. Pol., 11, 144-52, 2008.

Both figures are from Hinsby, K. and Jørgensen, L.F. Groundwater monitoring in Denmark and the Odense Pilot River Basin in relation to EU legislation. In: Ph. Quevauviller et al. (eds) Groundwater monitoring, Wiley, 2009, pp. 209-224.

Groundwater in China: Development, Regulation and Farmers' Responses

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Despite the growing importance of groundwater in China's agriculture, there is a lamentable lack of systematic information on the groundwater economy, especially on the consequences of groundwater depletion on the agricultural sector. This paper makes an attempt to overcome this limitation with information and analysis on trends in the expansion of agricultural groundwater use, resource management challenges, and institutional and policy responses in the particular context of northern China. The results show that groundwater problems and their agricultural consequences in northern China are heterogeneous across space and changing rapidly over time. While the problems are serious, they do not present everywhere with the same severity. As a result, policies for their solution should be clearly discriminatory and carefully targeted. Even targeted policies will be difficult to implement, and government has had little success in controlling the extraction of groundwater or protecting its quality with the many formal laws and regulations now in existence. In contrast, farmers have been responsive to increasing shortages. Individual farmers (i.e. the private sector) have taken control of most well and pump assets, developed groundwater markets, changed cropping patterns and adopted water savings technologies. While market forces and economic incentives can change use, public initiatives for agricultural groundwater regulation to balance short-term economic efficiency with long resource sustainability are urgently needed.

Biofuel Production Effects on Gw-Sw Connection. Groundwater-Lake Interaction in Ag Settings (Quality and/or Quantity)

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Hydrologic measurements and models are well-suited for characterizing groundwater and surface water systems, but simple abiotic indicators may not answer the hydroecological questions related to changes in land use and climate. Thus, understanding how changes in the hydrological system might ripple to the biological system is a critical topic for understanding and protecting groundwater dependent ecosystems, both for present day and potential future conditions. In this work, the effect on the biotic system was evaluated using simulated changes in hydrograph shape metrics (also referred to as hydrologic indices or hydrologic condition metrics). In this approach, the hydrograph is characterized using many different criteria (e.g., low-flow duration, stormflow recurrence), which are then summarized into a set of statistical metrics. Others have shown that some hydrologic metrics responded to urbanization and related to both water quality and biologic field data, and that such relations held for watersheds evaluated in the conterminous United States and internationally. Such results are promising because climate change predictions are commonly reported in abiotic terms, yet societal concerns are often ecosystem focused. The USGS coupled hydrologic model GSFLOW was used to simulate two watersheds in Wisconsin, USA. Model results are processed using the Nature Conservancy Index of Hydrologic Alteration (IHA) software suite to assess possible biological response to present day and changed streamflow resulting from climate and/or land-use change. The low pulse frequency count, defined as the number of flow events where the flow drops below a low-flow threshold, related well to current climate biological field data. In one watershed the relation established between both macroinvertebrate abundance and richness and the low pulse frequency counts simulated using a current-conditions calibrated groundwater-surface water model was then extrapolated to change scenario conditions. The increased temperature scenarios resulted in decreases in expected invertebrate abundance, with the lowest expected quality at a stream site that was periodically dry during some change scenarios. Results from both watersheds suggest that hydrographic shape metrics hold promise for helping translate future changes in climate or land use to ecosystem health.

Sustainable Use of Groundwater Energy and Economic Analysis of Wheat Production under Raised Bed and Traditional Irrigation Systems

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The project's aim was to reduce Pakistan's groundwater use and its costs in crop production system by increasing knowledge of water use among farmer's community and target sensible solutions for optimizing groundwater use with the raised bed (RB) irrigation system. Pakistan uses intensive groundwater in its agricultural production sector. The large scale groundwater utilization from Indus Basin aquifer started 30 years prior when the quantity of tube wells was 14,000 (covering nearly 2.6 million ha of irrigated land) with an average capacity of 80 liter/sec., installed under the Salinity Control and Reclamation Project (SCARP). Presently the quantities of tubewells are over 600,000 in Pakistan (GOP, 2000; PWP, 2001; Qureshi & Akhtar, 2003a). Over 2.5 million farmers are estimated users present in irrigated areas that exploit groundwater directly or buy water from their neighboring tube well owners. The aim of this study was to analyze groundwater use as well as energy used in wheat production on raised bed (RB) and traditional agricultural systems in Pakistan in terms of water saving, energy and water productivity and benefit/cost ratio of the two systems. The water saving under the RB system was 35 percent as well as less pumping by 35 percent from groundwater. Pakistan, annually pumping 55 MAF from groundwater, in wheat season groundwater pumping is 20 MAF which will be decreased by using the RB farming system up to 7 MAF. The total energy requirement in RB farming on understudy sites was 3653 kWh ha-1, whereas 3910 kWh ha-1 was used under traditional farming, i.e. 6 percent higher energy inputs were used on conventional farming than the RB farming system. The average energy ratio of 6.3 was achieved under the RB and conventional farming systems. The final conclusion of the study is that in the RB farming system, water use, agricultural inputs and energies applied were properly utilized, but in the traditional (basin) system some parts of the applied energies were missing. The RB system can work better than basin for wheat production, and suction of groundwater also decreased, which is a dire need for the future of agriculture in Pakistan.

Sustainability of Groundwater for Agricultural Water Supply in the Southwest Region of Bangladesh

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The study area lies between latitude 23015N and 22055N and longitude 89024E and 89036E in the Southwest region of Bangladesh. The river system and the aquifer are subject to seasonal salinity intrusion due to tidal fluctuation and upstream withdrawal. The groundwater in the area is found in three separate aquifers; an upper aquifer of low permeability; an intermediate aquifer of moderate permeability, and a deeper aquifer of moderate to high permeability. The wells in the southern parts show evidence of high salinity. Agriculture is the dominant occupation but only 38 percent of the net cultivable area is presently under agriculture. The productivity is behind the national average. The current obstacle to bring more area under cultivation and to improve the productivity is the availability of water and the salinity intrusion in the river system. As a result, the use of groundwater is increasing and this demands an evaluation of its sustainability for future irrigation. The farmers in the Narail district abstract water from the intermediate aquifer for irrigation whereas the deeper aquifer is used for domestic use. The irrigation wells are privately owned, mostly by large farmers, and are installed without following any guideline. In the present study, the sustainability of the aquifers has been explored in terms of water quantity and quality. The changes of water levels in the aquifers and the Electrical Conductivity (EC) of groundwater are used as indicators for sustainability. An effort has been given to analyze the trend of groundwater withdrawal, the time variation of the maximum and minimum groundwater and river water level, surface water and groundwater interaction, aquifer recharge pattern, and salinity intrusion from rivers and the adjacent downstream coastal aquifers. The findings show that the intermediate aquifer water level is dependent on recharge from rainfall, rivers, and the upstream aquifers and the quality of aquifer is dependent on salinity intrusion from the rivers and the coastal aquifers. The findings further show that increasing the rate of water withdrawal from the intermediate aquifer is causing lowering of the dry season water level significantly. However, the aquifer is fully recharged during wet season and rainfall plays the most important role. The productivity of many of the Shallow Tube Wells is therefore reduced with increasing threat to abandon many of them during dry season due to combined effect of water withdrawal and improper installation of wells. The deeper aquifer has been found relatively stable in terms of water level. However, both the aquifers have been found marginally suitable in terms of salinity for crop production. But with increasing the rate of water withdrawal the salinity intrusion will increase and the aquifer will no longer be suitable to supply agricultural water. Therefore, for sustainable irrigation water supply the possibilities of development of the deeper aquifer for irrigation and with a provision for conjunctive use of fresh and saline groundwater by mixing them at crop tolerance level should be explored. Further, a guideline for installation of the irrigation wells should be incorporated in the government water policy and be strictly implemented.

Investigating Long-Term Effects of Manure Management Activities on Groundwater Quality in Alberta

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In January 2002, the Alberta Government assumed responsibility for the regulation of confined feeding operations (CFOs) when the Agricultural Operation Practices Act (AOPA) was amended. The Natural Resources Conservation Board (NRCB), the Provincial agency responsible for the administration of the AOPA, and Alberta Agriculture and Rural Development (ARD) are concerned that some manure storage facilities and associated activities, such as land application of manure, may be releasing manure constituents into shallow groundwater resources. An integral part of the administration of the AOPA is determining environmental risk, as outlined in a provincially adopted Risk Management Framework policy. This has led to the development and use of a risk screening tool and risk-based compliance initiative, both currently focused towards groundwater. Although the environmental risk-based policy being implemented utilizes the best available, current, and relevant science, limited Alberta-specific information exists on the impacts of manure storage and handling of groundwater quality, leading to uncertainty of the actual extent and risk that these activities pose to groundwater. As Alberta is home to almost 50 percent of Canada's beef cattle population, as well as a significant proportion of the national dairy, pork, and poultry populations, Alberta-specific understanding is important to the overall knowledge base. A multi-year groundwater research program has been initiated through the establishment and instrumentation of field-scale CFO pilot study sites to improve the understanding of impacts from manure handling and storage on groundwater quality in Alberta and the fate and transport of various inorganic, organic, and biological manure constituents in groundwater beneath CFOs. Long-term study sites were identified through site characterization, geological investigations, and monitoring well installation, and represent the primary typical hydrogeological conditions in Alberta affected by manure storage and handling activities. To date, activities have been specific to earthen manure storage (EMS) facilities at CFOs, but are also designed to examine the effects of manure land application on Alberta's groundwater. Although in the early stages of the research program, activities have and will continue to include the characterization of the contaminant (i.e., aqueous) source, characterization of the hydrogeological and physical controls on the transport of contaminants, characterization of the background aqueous and solids chemistry, characterization of aqueous and solids chemistry within the contaminant plume, and quantification of the geochemical controls on the fate of contaminants. Preliminary results and findings will be presented. By improving the scientific and practical understanding of the fate and transport of manure constituents in the groundwater in typical Alberta CFO settings, improved management, regulation, and protection of the groundwater and environment can be achieved. The results will also provide insights and understanding into the impacts of other point- and non-point-sources of manure associated contamination, particularly land application of inorganic and organic fertilizers and disposal of human waste, on Alberta groundwater. Instrumentation installed may also provide the opportunity to investigate the fate and transport of other emerging contaminants (e.g., pharmaceuticals, viruses, etc.) and thus assess their impact on groundwater.

Evaluating Agricultural Water Use with Crop Life Cycle Assessments

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Efforts to evaluate resource use by major row crops have advanced significantly in recent years thanks to the development of more robust and sophisticated life cycle assessments (LCA). However, life cycle modelers frequently wrestle with challenges that are unique to production agriculture. Modelers must consider the impacts of co-products, additional utilization of natural resources from non-agricultural elements within an ecosystem, and the ongoing challenge of obtaining high quality data. These challenges are often addressed by trying out different system boundaries and allocation models, but they can have varying effects on the results of the LCA. The United Soybean Board (USB) encountered several of these challenges when it initiated a life cycle assessment of soybean production in the U.S. three years ago. The now-complete LCA evaluated the consumptive water use for soybean production in the U.S., with results that were similar to other recent studies (The Keystone Center, Environmental Resource Indicators for Measuring Outcomes of On-Farm Agricultural Production in the United States, First Report, January 2009), showing that soybean water use efficiency has increased by 20 percent since 1987. The LCA also evaluated the impact of soybean production on more than 50 water effluents, and consolidated several of these values into a eutrophication potential for soybeans, measured in kg Nitrogen equivalent, per 1000kg soybeans. To address several of the modeling challenges mentioned earlier, the USB LCA incorporated ISO 14044 mass criterion in setting system boundaries (cut-off goal of 99percent material inputs) and used mass allocation to account for co-products, with economic allocation being used to assess the sensitivity of the modeling decision. When the results were run with the economic allocation, for the most part, the overall outcomes did not change too dramatically between the economic allocation and the mass allocation results. However, the actual ratio differential was almost 50 percent in some cases. This provides further evidence of the impact that modeling decisions have on the results of LCAs. While the results of the soybean LCA are certainly of interest, this presentation will primarily focus on the implications of the soybean modeling decisions and the impact they had on the final LCA results. This broader discussion has much more significant relevance to the evaluation of water use and effluents in other crops, and how those evaluations could be affected by other modeling decisions. Through a review of the results of the USB study, we will discuss key learnings and best practices that could help guide similar water use evaluations in other crops.

Field Verification of a Remote-Sensing Based Method to Quantify Irrigated Acreages in the Lower Rio Grande Valley in New Mexico

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(Poster presentation cancelled)

A field-verification study to assess and verify the accuracy of a normalized difference vegetation index (NDVI)-based method for quantifying irrigated acreage was completed for the 2006 growing season. The study area was the Lower Rio Grande Valley (LRG) in New Mexico from Elephant Butte Dam to the New Mexico-Texas state line. The purpose of the study was to collect field data for three periods during the growing season contemporaneously with satellite imagery collection in order to perform an accuracy assessment of an NDVI-based acreage quantification methodology. The multi-period approach allows analysis of temporal trends in irrigated acreage throughout the growing season. In addition, the results for all three seasons can be combined to produce a composite picture of irrigation over the entire growing season. The method is based on calculating the NDVI from satellite data. The NDVI provides a measure of the degree of vegetation at the land surface. In arid areas such as the LRG, where native vegetation is sparse, the NDVI methodology works well to quantify irrigated acreage, since the majority of healthy plant cover can be assumed to be irrigated. In addition, a masking technique was used to subtract riparian areas from the analysis so that these were not counted as irrigated. Of particular interest is the threshold at which the NDVI-based analysis begins to identify a field as irrigated with an actively-growing crop. Previously, that threshold has not been well-identified, and has in the past been selected based on visual inspection of natural-color satellite imagery. We also calculated crop coefficients (Kc) and correlated those with NDVI. The availability of field-collected cropping data greatly enhances our understanding of these issues. Results were compared with published values and allowed an independent check of those published values.

Groundwater Investigation and Modeling of Buchir-Homeyran Plain, Hormozgan Province, Iran

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Buchir-Homeyran plain, with a total area of 78.25 KM sq has a catchment area of about 378 KM 2 and is located 360 KM west of Bandarabbas port on the Persian Gulf. This catchment is the extension of the southern Zagross mountain range, covering the western boundary between Iran and its neighboring countries, Turkey and Iraq. The plain lies between 26, 57 and 27, 10 latitude and 53, 28 E to 53, 49 E longitude. Maximum elevation in the catchment is 1470 m in the northwestern direction and a minimum of 210 m in the southwestern corner (a palm growing region). About 10 percent of the area of the plain is covered with alluvial fan deposits in the northern sector, which are expected to contribute greatly to aquifer recharge. Depth of bedrock was estimated to vary between 70 and 125 meters. Of the total 132 wells constructed in this plain, 99 are actively in operation, 10 percent of which are used for domestic purposes and the rest for agriculture. Favorable climate and a long growing season, along with productive soils in the region, have created an increasing desire for agriculture development and hence, increased number of requests for water well drilling in the region. Present water supply from these wells amount to about a minimum of 1430 m3/year to a maximum of 530,000 m 3/year .Wells operate 186 days/year and have a depth of 14 to 75 m. In order to respond to the increasing number of well permit demands, groundwater investigation of the Buchir-Homeyran aquifer was initiated using PMWIN 5/ software. Calibration of the model was done under steady and unsteady state conditions using groundwater fluctuation data from 13 scattered observation wells recoded bimonthly from 2001 to 2008. Hydraulic conductivity, specific yield and recharge discharge estimates were created throughout the region with pest automatic calibrator and local experience and site investigation. Verification of the model made it possible to define a number of groundwater discharge and recharge management scenarios for the region and investigate the impact of the accomplishment of these scenarios. It was determined based on the findings from this model that in order to keep the water budget balance for this aquifer, current groundwater withdrawal and discharge must be decreased by 20 percent. A similar case study was done for the Jiroft plain in Kerman province with about 2000 production wells facing severe shortages in water supply due to increased withdrawals in recent years for agricultural and domestic use. The results from that study are given for comparison.

Groundwater Recharge in Eastern San Joaquin County Resulting from the Farmington Program

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Eastern San Joaquin County is dependent entirely on groundwater for agricultural irrigation. Agriculture sustains the economy of this region within California's Central Valley. It is a region that for a half-century has seen groundwater levels decline an average of 1.7 feet per year, with some areas dropping to 100 feet below historic levels. This drop in groundwater levels is resulting in significantly higher energy costs to lift groundwater from deeper and deeper levels within the aquifer up to ground surface. Coupled with this overdraft, it is estimated that the basin has lost up to 2 million acre-feet of storage capacity. As a result, water quality has declined as saline tainted water from the west has been moving eastward into the basin at a rate of up to 150 feet per year. This reduction in groundwater quality has resulted in the closure of three groundwater production wells operated by the city of Stockton to meet municipal water demands. More municipal well closures or costly wellhead treatment will be required if the critical groundwater overdraft is not reversed. To reverse this trend, Stockton East Water District, the U.S. Army Corps of Engineers and other local water agencies launched the Farmington Groundwater Recharge Program. With $33.5 million in available funds, the Farmington Program aims to partner with local landowners, businesses, growers and ranchers to save the region's water supply. The goal of the program is to directly recharge surface water to the groundwater aquifer on 800 to 1,200 acres of land and increase surface water deliveries in-lieu of groundwater pumping to reduce overdraft and establish a barrier to saline water intrusion. The objective of the program is to recharge an average of 35,000 acre-feet of water annually into the Eastern San Joaquin Basin. In addition to reversing groundwater overdraft, spreading water on agricultural fields and other recharge basins also provides seasonal migratory waterfowl habitat. Stockton East Water District and the U.S. Army Corps of Engineers have initiated a public outreach campaign to educated local landowners and encourage landowner participation in the program. The outreach campaign has been successful and groundwater recharge activities have begun on many sites. Each potential groundwater recharge site is evaluated in the following four stages: Stage 1: Initial Site Screening; Stage 2: Field Investigation; Stage 3: Demonstration Testing; and Stage 4: Long-Term O&M. This program implementation framework has been developed to choose the most feasible locations for groundwater recharge. The recharge method of choice is field-flooding, a practice where a small perimeter levee is built at the parcel, then flooded to a depth of up to 18 inches. Field flooding has the lowest impact on agricultural operations and provides a cost-effective and cost-efficient process for landowners to participate in short-term and long-term agreements and receive market-based compensation for the use of their land. It is an arrangement that essentially allows the rotation of groundwater recharge practices with traditional land use, making water a cash crop for Eastern San Joaquin County.

Factors Contributing to the Susceptibility of Public-Supply Wells to Agricultural Contaminants

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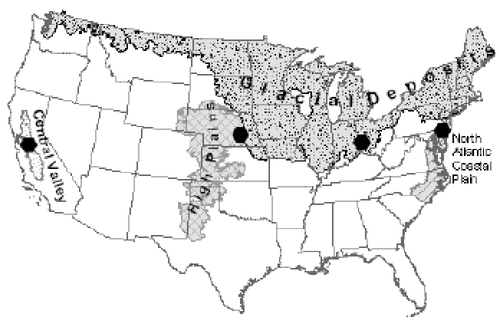
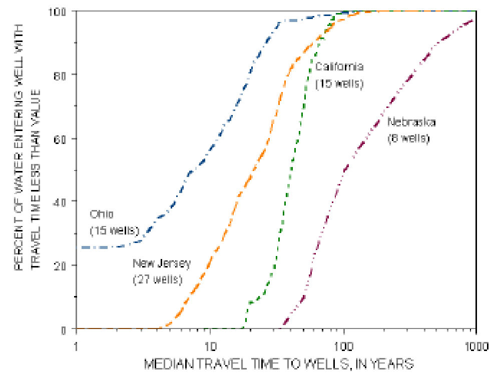
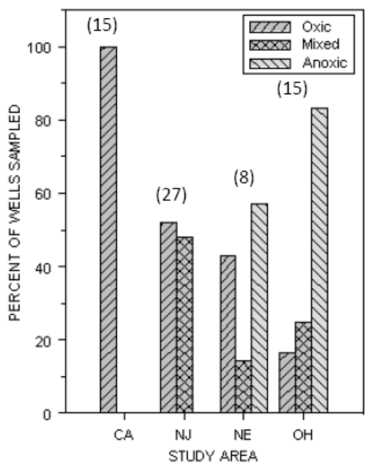
As part of the National Water Quality Assessment Transport of Anthropogenic and Natural Contaminants to Public-Supply Wells topical study, the U.S. Geological Survey investigated factors contributing to the susceptibility of public-water supply wells to contamination in different geologic and geochemical settings. This investigation included: sampling and analyses of water quality of wells; identifying redox conditions in the surrounding aquifers; and using numerical models to delineate areas contributing recharge to wells and to quantify the distribution of travel times through the groundwater systems. Wells are located in four study areas: (1) deltaic and marine deposits in the coastal plain of New Jersey; (2) basin fill deposits in California; (3) glacial valley fill deposits in Ohio; and (4) alluvial deposits in the high plains of Nebraska. These aquifers have areas contributing recharge that on average include more than 25percent agricultural land, leading to increased concern over agricultural-water quality problems. These four study areas are all in highly productive aquifers composed largely of sand and gravel with some smaller amounts of clay and silt. Differences in the aquifer geometry and materials as well as recharge amounts lead to differences in groundwater travel times to and redox conditions of public-supply wells in the areas. A dissolved oxygen value of 0.5 milligrams per liter was used to classify wells as oxic or anoxic, however when there was dissolved oxygen present above this threshold along with elevated levels of iron and (or) manganese, the well was classified as mixed. A natural attenuation factor for potential contaminants, based on travel time through each redox zone and the expected degradation rate of the contaminant in the redox zone, can be determined for each well. This natural attenuation factor was used as a measure of susceptibility of the public-supply wells to contamination. Well construction and the timing of pumping also can affect the susceptibility of wells to contamination by altering the travel time through and (or) redox conditions in the surrounding aquifers. Travel times are generally fastest in the Ohio and New Jersey study areas. Redox conditions in the water from public-supply wells are generally oxic in the California study area, oxic or mixed in the New Jersey study area and mixed or anoxic in the Ohio and Nebraska study areas. Nitrate is a useful indicator for agricultural contamination because it is applied over most agricultural land. Although travel times are fastest in Ohio, part of the paths are often through anoxic zones where the nitrate will readily degrade. In contrast, in New Jersey and California travel times are higher but the flow is largely through oxic zones where nitrate is persistent resulting in a lower natural attenuation capacity. Measured nitrate concentrations are highest in the California and New Jersey study areas corresponding to lower simulated values of natural attenuation capacity for nitrate. Other agricultural contaminants, such as pesticides might have different degradation properties related to the different redox zones so it is important to understand the natural attenuation capacity for a range of degradation rates.



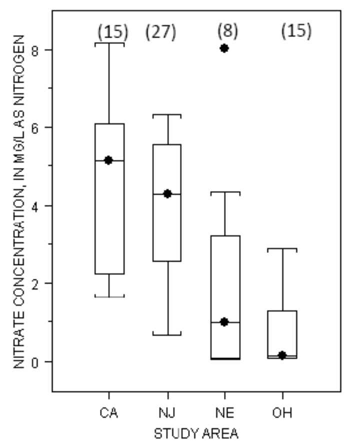
Locations of the four study areas with areas contributing recharge containing greater than 25 percent agricultural areas.



Median simulated distributions of travel times of water to wells. (The median distribution is calculated from the median percent of water for all the wells in a study area for each yearly increment.



Redox conditions measured in water from public-supply wells. The number of wells in each study area is in parentheses.



Distributions of nitrate concentrations measured in public-supply wells. The boxes represent the range of 25th percentile to 75th percentile with a line through the median. The whiskers extend to the maximum or 1.5 times the inter-quartile range. Outliers are plotted individually. The number of wells in each study area is in parentheses.

Sustainability Economics of Agricultural Groundwater Usage and Management

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The talk sets out general principles of economic sustainability and applies them to the groundwater management problem. The common Bruntland Commission sustainability definition is conceptually appealing but lacks sufficient specificity for quantitative policy analysis. Other definitions implicitly or explicitly define sustainability as maintaining existing resource stocks. However, as population and economic growth must inevitably draw down at least some natural resource stocks, this definition can also be limiting as it confuses means with ends, ignores substitution possibilities, and doesn't indicate how one determines the appropriate stock to maintain. Many studies don't define sustainability at all. Within the economic literature, there appears to be implicit agreement that sustainability involves a notion of intertemporal equity that future generations not be worse off than preceding generations. However, it would hardly make sense to have an equitable economy in this sense, but inefficient with productivity levels below what is possible. Thus we define sustainability as intertemporal efficiency formulated as Pareto-optimality, and intergenerational equity implied by non-declining utility. Furthermore, as this literature emphasizes, sustainability cannot be determined from analysis of the natural resource stock alone. One must also simultaneously consider accumulation of physical and human capital. Thus, sustainability does not lie solely in the natural science domain as often construed; rather it must be an amalgamation of the natural and social sciences. These ideas are applied to the groundwater management problem. The standard economic analysis of groundwater couples an agricultural production economics model with an aquifer model and analyzes both common property usage and economic efficiency. However, this model cannot be utilized directly for sustainability analysis. First, PV-optimality does not guarantee equity. Second, sustainability is defined over consumption paths, while groundwater extractions generate income streams which are not necessarily synonymous with consumption. Third, as previously noted, substitution possibilities exist as water supplies become scarce. Accordingly, we extend the standard model to include alternate objective functions as well as physical and human capital. We first consider common property usage of a lumped-parameter model in which pumpers extract freely from the aquifer as is commonly the practice in California, but they also invest in a capital stock. Aggregate production in the region is then a function of water extractions and the physical capital stock. The primary question addressed here is whether or not the region will experience continued growth over time, or whether there will be decline over time at some point. Next we consider a present-value (discounting) solution for economic efficiency of the entire system. While this leads to regional efficiency, it does not guarantee equity for future generations. Finally, we consider a model with a sustainability criterion of non-declining utility. While the economic approach to sustainability provides a rigorous and internally consistent definition of sustainability, a variety of issues inevitably arise in practice. These include analytical scale, benefit-cost and policy analysis, and sustainability in open regions. Finally, this analysis can be extended to consider population growth, spatial variability, water quality, conjunctive use, and ecosystem impacts.

Groundwater and Indian Agriculture: The Challenges

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Agriculture contributes about 22 percent of the GDP and is the mainstay of 70 percent of the population. Despite all the tall talk about the industrialization that has taken place since the country attained independence in 1947, agriculture retains its major role in INDIA' economy. For this, water has been the main contributor. India's total water resources have been estimated at 16, 45,000 million cubic meters while the total groundwater reserve is 37 million cubic meters down to a depth of 300 m meters. The present use comes to about 440x 10 cubic meters for a population of 900 million. The present population of the country is more than 1,000 million and the need has risen to 850 million cubic meters. The ultimate potential of development at the present precipitation phase is around l990 million cubic meters. The food grain production has to rise to 250 million tonnes to feed the population, apart from the drinking water requirements. 50 percent of the irrigation in the country is from groundwater; the overexploitation of which has already caused concern. The contribution from groundwater will be l9, 26, and 45 BCM (Billion Cubic Meters) respectively for the years 2010, 2025 and 2050. It will have to meet the needs of irrigation, domestic needs and municipal use, industries and power. This is bound to lead to overexploitation of this source by 2050 when the utilizable quantity would be only 396 billion cubic meters. It will become a critical source, unless proper plans are made to control its utilization. Steps have to be initiated to regulate its exploitation, devise recharge methods and prevent contamination by industries. Already there are reports of saline water intrusion in the coastal areas of the country, which is causing concern. The entire economy will suffer if this precious source of water is not protected well in time.

Can Electricity Pricing be a Tool for Efficient, Equitable and Sustainable Use of Groundwater in Indian Agriculture?

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Flat rate and heavily subsidized prices for electricity in the farm sector ruin both groundwater and energy economy in many groundwater-scarce regions in India. But, many scholars have theoretically argued that pro rata pricing of electricity in the farm sector is socio-economically unviable and politically infeasible. This paper analyzes the potential impacts of energy pricing on efficiency, equity and sustainability in groundwater use. The analyses use empirical data on water productivity in agriculture for crops, dairying and farms for north Gujarat, eastern UP and south Bihar. For north Gujarat, the analysis uses data from well owners who pay flat rate tariff, and well owners who pay pro rata tariff. For eastern UP and south Bihar, the analysis uses data from well owners and water buyers from diesel and electric well commands. Analysis shows that introducing marginal cost for electricity motivates farmers to use water more efficiently at the farm level through careful use of irrigation water; use of better agronomic inputs; optimize costly inputs; optimize livestock composition and carefully select crops and cropping patterns, which give higher return from every unit of water and grow low water consuming crops. It also shows that higher cost of irrigation water will not lower net return from every unit of water used as the farmers will modify their farming system accordingly. Further, change in the structure of power tariff from flat rate to pro-rata will not have any adverse effects on access and equity in groundwater use. Nor will it increase the monopoly power of well owners. The number of potential water sellers and not the number of potential buyers of water govern the price of water. Pro rata pricing reduces cost of groundwater pumping per unit of land. It also reduces aggregate pumping, which is disproportionately higher than the reduction in net returns per unit of land. This leads to more sustainable groundwater use. This means that in water scarce regions, it would be possible to introduce metering and higher electricity tariff without compromising on the economic prospects of farming. Raising power tariff in the farm sector to achieve efficiency, equity and sustainability in groundwater use is socially and economically viable.

Climate Change, Agriculture and Sustainable Groundwater Management: Developing a Strategic Groundwater Reserve to Buffer Extreme Droughts

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In California, it is predicted that climate change will increase extreme drought events, resulting in a need for proactive planning to cushion the effects of severe water shortages on agriculture. A significant problem is that California's drought planning process is centered on how to manage water shortages after a dry period occurs, and it does not provide for proactive and long-term measures to reduce vulnerability to a prolonged drought. Instead guidelines primarily focus on immediate reactive measures to be implemented during an actual drought occurrence, such as generating surface and groundwater data and preparing and implementing water shortage contingency plans. Moreover, if additional water produced through strategies such as surface storage, recycling, desalination and conservation, is used to support further agricultural development in water stressed regions during wet cycles, the result could actually be a future upsurge in overall water requirements along with a hardening of demand side conservation possibilities. This could actually increase vulnerability to water shortages for agriculture in the future. It is therefore vitally important to take advantage of wet years as an opportunity to recharge supplies and, most important, develop reserves. During critically dry years, groundwater is the lifeline for many rural and agricultural regions. Farmers and water districts greatly increase groundwater pumping to offset surface water shortfalls, and consumptive use of groundwater can rise to as much as 60 percent. Yet, even in normal rainfall years, the Department of Water Resources estimates that Californians overdraft 2 million acre-feet of ground water annually. Yearly overdrafts cannot continue indefinitely and only by conserving groundwater in normal and wet years can this essential resource be maintained. This paper examines water supply planning through the lens of a future drought. It is divided into two parts. The first discusses water supply planning in the state and elaborates on areas of disconnect between (1) planning for a severe drought and (2) planning to accommodate the state's burgeoning demand for water. The second part elaborates on the legal, institutional and management issues surrounding alternate strategies to augment supply- groundwater recharge and storage, and it focuses on an innovative strategy - the establishment of a strategic groundwater reserve that would serve as an important buffer during extended periods of drought. This would involve creating stronger incentives to (1) bring groundwater basins into hydrologic balance through recharge processes and promote the enhancement of groundwater storage, and (2) establish and maintain a baseline reserve of groundwater. The reserve would only be withdrawn and used during a severe dry period and is critical to conserving nature's capital for the inevitable long-term drought. The paper then outlines future research to identify physical metrics and institutional options to implement this goal.

Using Groundwater for Irrigation in Semiarid, Hard-rock Areas in Peninsular India and the Role of UNESCO-IUGS-IGCP Project GROWNET

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Most of the groundwater pumped from an aquifer for irrigation of crops is consumed by the crops for their growth and is lost from the liquid phase of the water cycle. Agricultural use is thus mainly consumptive. On the other hand, most of the surface water or groundwater used for industrial or domestic purpose remains as water, albeit of degraded quality, which could be improved by treatment. Reuse and recirculation of the resource is thus possible. In semiarid regions of Peninsular India, the annual rainfall of 350 mm to 500 mm during the monsoon season (June-September), takes place in the form of a few rainstorms. Recently, the climatic pattern is becoming more uncertain and erratic. Degradation of watersheds is causing fast runoff towards major streams and less recharge to groundwater. Surface water sources are meager in most of the watersheds and the hard rock aquifers yield only modest quantities of groundwater. When the sustainability of the groundwater resource is thus threatened, there is naturally a tendency to question the wastage of precious groundwater for irrigation. People often refer to the productivity or the contribution to the GDP of one cubic meter (Cu. M) of groundwater used for irrigation by the farmers and the same quantity used by a rural industry. In other words there is a conflict between the farmers and the industries which have been encouraged by the Government to leave the highly developed urban centers and move to rural areas. But groundwater is the life-line for farmers who wish to dig or drill wells and move away from the perpetual poverty of dry-land farming. Therefore, even amongst the farmers, there is an intense competition for getting more and more share of groundwater. The average size of farm is about 2 hectares per family. Those who are lucky to have a good yielding dug well or bore well in their farm pump as much supply of groundwater as possible and irrigate high value, water-intensive crops like sugarcane and bananas. Others continue their efforts to get more groundwater from several wells within their farm. The down-the-hole hammer type drilling machines have considerably reduced the cost and time for drilling a bore. A 150 mm diameter bore of 100 m depth costs only around $350 to $400 in the U.S. The number of trial bores is therefore increasing every year. The pumpage is increasing; the water table is depleting and so also the yields. Efforts for recharge augmentation are few and scattered. This paper examines the scenario of groundwater use in Peninsular India and suggests governance at village level and active involvement of farmers in recharge augmentation, as the management tools. It also emphasizes the role of UNESCO-IUGS-IGCP Project GROWNET in disseminating the Best Practices in groundwater management. The author is the Project Leader of GROWNET.

An Overview of Studies of Agricultural Contaminant Trends in Groundwater in the United States

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The U.S. Geological Survey (USGS), National Water-Quality Assessment (NAWQA) program began in 1991. As part of the NAWQA program, groundwater-quality data from several thousand wells across the United States has been collected, including pesticide and nutrient analyses and other data related to agricultural activity. Over the previous two decades, many study wells have been sampled multiple times. These data, along with groundwater age-dating results, present an opportunity to analyze trends in groundwater quality in many regions of the United States. The approaches to analyzing the groundwater-quality trends data vary depending on the goals of the analysis. Determining whether or not a constituent has increased in concentration on a decadal basis is the simplest question that can be answered; however, this is typically not the only relevant question. What caused the apparent trend or non-trend in concentration? Will the same trend continue into the future? What management practices could affect future trends? Answering some of these questions requires supporting data from a variety of sources within and outside of the USGS. The NAWQA program has formed a team of scientists to investigate groundwater-quality trends at national and local scales. Statistical approaches are utilized for data analysis at the national scale. Groundwater modeling and geochemistry are utilized in local- and regional-scale studies to gain additional insight into the factors leading to groundwater-quality trends, and to allow predictive modeling of groundwater-quality trends into the future. For example, data on age-dating tracers have been collected to improve the understanding of travel times and to reconstruct groundwater trends. These data are being used to evaluate trends in nitrate concentrations and to understand the fate of atrazine in the vadose zone and shallow groundwater in multiple aquifers throughout the United States. Additionally, the groundwater trends team is conducting detailed studies using flow and transport modeling methods to simulate the long-term fate of nitrate concentrations in agricultural regions. These efforts will include detailed analysis of the existing distribution of nitrate and accompanying nitrate-attenuation factors (such as oxidation-reduction processes) as well as forecasting of long-term trends in nitrate concentrations. The combination of data and studies from both within and outside of the NAWQA program are used in order to provide the best explanation of trends in groundwater quality.

Groundwater Vulnerability Assessments for the San Joaquin Valley

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Precious groundwater resources across the U.S. have been contaminated due to decade-long nonpoint source applications of agricultural chemicals. Assessing the impact of past, ongoing, and future chemical applications for large-scale agriculture operations is indeed timely for designing best management practices to reduce subsurface pollution. Presented here are results from a series of regional-scale groundwater vulnerability assessments for the San Joaquin Valley. Two relatively simple indices, the retardation and attenuation factors, are used to estimate groundwater vulnerabilities based upon the chemical properties of 32 pesticides (e.g., EDB, DBCP, Atrazine, Diuron) and the variability of both soil characteristics (e.g., water content, fraction of organic carbon) and recharge rates across the valley. The uncertainties inherit to these vulnerability assessments, derived from the uncertainties within the chemical, soil, and, recharge data, was estimated using first-order analyses. The groundwater vulnerability maps generated for the entire San Joaquin Valley, based upon deterministically-crisp applications of retardation and attenuation indices, show considerable variations in leaching potential for the 32 pesticides. In some cases the uncertainty within the vulnerability assessments is significant, thereby identifying serious limitations within the data. Assuming that these data shortfalls can be satisfied, revised estimates of groundwater vulnerability, in the spirit of those shown here, will be useful to those in the decision-management arena charged with regulating the future use of agriculture chemicals in the San Joaquin Valley. Furthermore, the areas/pesticides shown to have the greatest leaching potential, based upon a simple screen/rank approach, could be targeted for future measure and model investigation, driven by risk-adverse motives, with detailed field observations and comprehensive physics-based simulation (forensic or predictive) focused on individual events.

Groundwater Governance in Spain: Aligning Science with Policy

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The paper will provide an overview of the main challenges currently experienced in Spain in relation to groundwater governance. In particular, it will focus on the case of agricultural groundwater use in Spain in the context of the new requirements under the Water Framework Directive. The paper will analyze the boom in agricultural groundwater use in Spain, and the main management challenges generated by this intensive groundwater use. It will then offer some priorities in terms of public policy for the most effective use of groundwater as a strategic resource; in particular it will look at the concept of the water footprint, the key role of groundwater user groups as key mediators in management, and the need for increased flexibility in groundwater regulation and allocation mechanisms to correct the current gap between actual groundwater use and formal groundwater allocation. The policy measures discussed will be presented in relation to the general trends in Spain at the national level, and it will also zoom into a series of case studies in Spain. On purpose it will select a range of examples which have very different agricultural patterns, from the south east of Spain characterized by very intensive and highly profitable greenhouse agriculture, to mainland Spain where cereals, olives and vineyards predominate, to the orchards and fruit tree agriculture in the East of Spain. The paper will aim to combine and present data gathered from the new agricultural census in Spain, the new Hydrological plans due to be presented in 2010 within the Water Framework planning schedule, and from field work in the diverse case study areas. The policy implications of these data will be commented on.

Gendered Access to Shallow Wells and Riverine Alluvial Dugouts in the Upper East Region of Ghana

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The limit of rain fed agriculture is one of the major causes for poor agricultural performance in Sub-Saharan Africa, due to the prevailing climatic conditions. If these challenges are further juxtaposed with the climate change projections, irrigation then becomes a key solution to such agricultural challenges of changing rainfall amounts and seasonal rainfall variability in the Upper East region of Ghana. The extreme variability in rainfall, long dry seasons and recurrent droughts, floods and dry spells pose key challenges to food production and has resulted in hunger and poverty in the Upper East Region of Ghana. The practice of irrigated agriculture remains a key solution to hunger and poverty reduction in this area. As a result the area has seen a significant upscaling of irrigation using shallow groundwater and surface water with appropriate technologies within the past 15 years. This study used a gendered approach to assess how poverty alleviation through the use of shallow wells and riverine dugouts have differential access for men and women. Whilst it is often argued that water based interventions to reduce poverty need to be gender sensitive this research looked at whether the underground water irrigation technologies are accessible to both men and women. This paper is part of a hydraulic rights creation project in the broader Volta Basin. This study looked at how both men and women appropriate water resources for their benefit. This study concludes that shallow ground water technologies have to be grounded within the gendered production systems and tenurial arrangements which largely determine whether one benefits from water extraction technologies or not. In rural Africa where the majority of the poor households are de facto or de jure female headed, this paper proposes mechanisms for empowering women to benefit from ground water based irrigation.

Groundwater Monitoring in Big Valley in the Northeastern California Counties of Lassen and Modoc

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The Lassen Modoc Flood Control District (LMFCD) consists of members of the board of supervisors of Lassen and Modoc Counties with the responsibility of management of groundwater in Big Valley, a 92,000 acre basin in Northeastern California on the Pit River in Lassen and Modoc counties. About one-third of the district is in Modoc County and the full committee consists of all five members of the Lassen County Board of Supervisors, plus four members of the Modoc County Board of Supervisors. The most significant historic activity of the LMFCD was to guide the construction of Allen Camp Dam by the Bureau of Reclamation, which was authorized by the US Congress in 1976, but never funded and finally determined not feasible in 1981. Modoc County adopted a groundwater ordinance in 2000 and Lassen County adopted a Groundwater management plan in 2007. Modoc does not contain any groundwater districts and Lassen County has three groundwater districts, Long Valley (1980), Honey Lake (1989), and Willow Creek (1994). Big Valley is not a groundwater district. The budget of the tax supported LMFCD is small, only $45,250 in 2009-10, and the District relies heavily on a community-based advisory committee for advice on groundwater decisions. Groundwater development has steadily increased following demands for agricultural production and export raising concern about sustainable management of the water resource. In 1995, the LMFCD contracted with Professor L.T. Grosse of Colorado School of Mines for a hand drawn hydrogeologic map of Big Valley. In 1999, the Lassen County Board of Supervisors established a permit process for export of water. In 2003, the LMFCD began putting meters on wells to develop information about the actual pumping in Big Valley. To date, 100+ meters have been installed to measure groundwater extraction. We report groundwater the LMFCD summaries for extraction volume and depth measurements through 2009. Separate from the LMFCD, the Department of Water Resources samples 18 wells in Big Valley.

Central Valley Groundwater Requirements for Dairy Farms

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In 2003 the Central Valley Regional Water Quality Control Board adopted Waste Discharge Requirements General Order for Existing Milk Cow Dairies (General Order). Many provisions of the General Order relate to the protection of groundwater resources. One of the most vexing of these provisions to dairy producers is the requirement to install groundwater monitoring well systems on all dairies at an estimated rate of 100 to 200 dairies per year. Installation of monitoring wells at this scale represents a severely high outlay of dairy capital, anticipated to be over one-half of the total compliance costs of the General Order, with little in the way of improved performance. Producers would much rather spend their limited resources on practical applications for improving groundwater quality. However, recognizing the high cost, at the same time that the waterboard adopted the General Order, they also passed a second motion giving direction to board staff, dairy and other stakeholders to explore alternatives to the original dairy-by-dairy monitoring well program. Thus far, compliance with the requirements of the General Order by the valley dairy farmers has been exemplary, with submissions meeting deadlines at rates far beyond what anyone expected. The dairy farming community has earned the respect of regulatory staff. Work is progressing on the development of an alternative to the original monitoring well requirements that should provide a better analysis of the performance and groundwater implications of various manure management practices. Rather than wells on each dairy facility, the proposal seeks to identify areas that can be used as representative of similar conditions and install monitoring wells system in clusters. Implications of manure management practices in these representative areas will provide a clearer interpretation of the effectiveness of the General Order and either validate or discredit the manure management practices in use. Dairy farming is the only agricultural sector that is subject to such a program. Producers remain concerned regarding groundwater nitrate source determination and accurate assessment of background contributions as they do not believe that responsibility lies solely with them. Additionally, the environmental justice community continues to express frustration with poor groundwater quality. Much of this discontent justified or not, is directed at dairy farms.

Groundwater and Climate Change: Forcing, Feedbacks, and Integrated Hydrologic Response

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While anthropogenic climate change is significantly altering the hydrologic cycle at global and regional scales, climate change impacts on water resources will ultimately depend on interactions and feedbacks between groundwater and surface water processes, the land surface water and energy balance, and regional climate processes. Here we use ParFlow, an integrated watershed model that includes three-dimensional variably-saturated subsurface flow, overland flow, and land surface processes, to analyze watershed response under observed and perturbed climate conditions. Streamflow response to changes in temperature and precipitation is shown to differ significantly between predominately energy-limited (direct runoff) conditions compared to moisture-limited (baseflow) conditions. Similarly, the evapotranspiration response to changing climate conditions is shown to depend on feedbacks between groundwater and the land surface water and energy balance. Notably, our results demonstrate not only that local and watershed response to climate change depends on feedbacks between groundwater, surface water, and land surface processes, but that the magnitude of these feedbacks is sensitive to changes in climate. Developing effective strategies to mitigate the impacts of climate change on water resources will therefore require an improved understanding of interactions and feedbacks across the hydrologic cycle at local, regional, and global scales.

Ag-Groundwater in AUS, U.S., GB and Globally

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Sustainable development law is the incorporation of the Rio principle into the laws of the relevant jurisdiction. The Rio principle of sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This principle has been inserted in Australia in the water allocation laws of each state and is a requirement of the water plans to set out regionally relevant strategies to achieve this. Over the last 18 years there have been many plans created and these legal documents have been interpreted by many state judges to uphold severe water allocation reductions. The strategies in the plans to reduce water have been subject to judicial review and the elements and decisions will be reviewed. There are some particularly innovative plans in some regions to regulate the interception of water by forestry. The sustainable development requirement is now also in the new Federal Water Act and is also a component of the new overarching Basin Plan for the transboundary Murray Darling Basin (covers four states). The Basin Plan also has requirements for a new sustainable Cap to be set, incorporating the inter-linkages between surface and groundwater systems. The Water Act also requires the national interest and relevant international agreements to be a factor in making decisions to promote sustainability. Hence Australia has a vertical system of cascading plans, all of which aim to achieve sustainability but which have various regional foci. All of the above will be discussed and the problems of integration of these requirements. The future implications of these processes are considerable. The implications are for legal processes and administration which will have substantial social and economic impacts. The implications are not limited to Australia but help to develop international law (draft convention on transboundary aquifers) and the laws of the U. S. and the EU.

Water, People, and the Future: Water Availability for Agriculture in the United States

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With a projected 25 percent and 50 percent increase in U.S. and world population, respectively, by the year 2050, substantial increases in freshwater use for food, fiber, and fuel production, as well as municipal and residential consumption, are inevitable. This increased water use does not come without consequences. Already, the United States has experienced the mining of groundwater, resulting in declining water tables, increased costs of water withdrawal, and the deterioration of water quality. Long-term drought conditions have greatly decreased surface water flows. Climate change predictions include higher temperatures, decreases in snowpack, shifts in precipitation patterns, increases in evapotranspiration, and more frequent droughts. Not surprisingly, conflicts over water use are continually emerging. As one of the largest users of water in the United States, agriculture will be impacted significantly by changes in water availability and cost. Approximately 40 percent of the water withdrawn from U.S. surface and groundwater sources is used for agricultural irrigation. Although the proportion of available freshwater used in agriculture varies widely among geographical areas, it is a major proportion of total water use in every area. Increasing responsibilities are being placed on agricultural water users at a time when available water resources are decreasing. Additionally, increasing industrial and residential water use will continue to limit the water available to agriculture. Since agriculture faces a future with less available water supply, substantial efforts will be required to make irrigated agriculture more efficient. It is important to the economic vitality of the United States including agriculture that policymakers, water managers, and water users work collaboratively to achieve sustainable water resource management. Multiple issues require attention: water quality, environmental water needs, municipal demands for water, water resource availability, and agricultural water use. No issue can be addressed individually. This paper discusses the diverse demands for water resources past, current, and future using the impacts, regulations, challenges, and policies of specific U.S. states as examples. The authors indicate that the reliability of water quantity and quality deserves the attention of all levels of government and that private and public sector leadership will be critical.

Deteriorating Food Security in India

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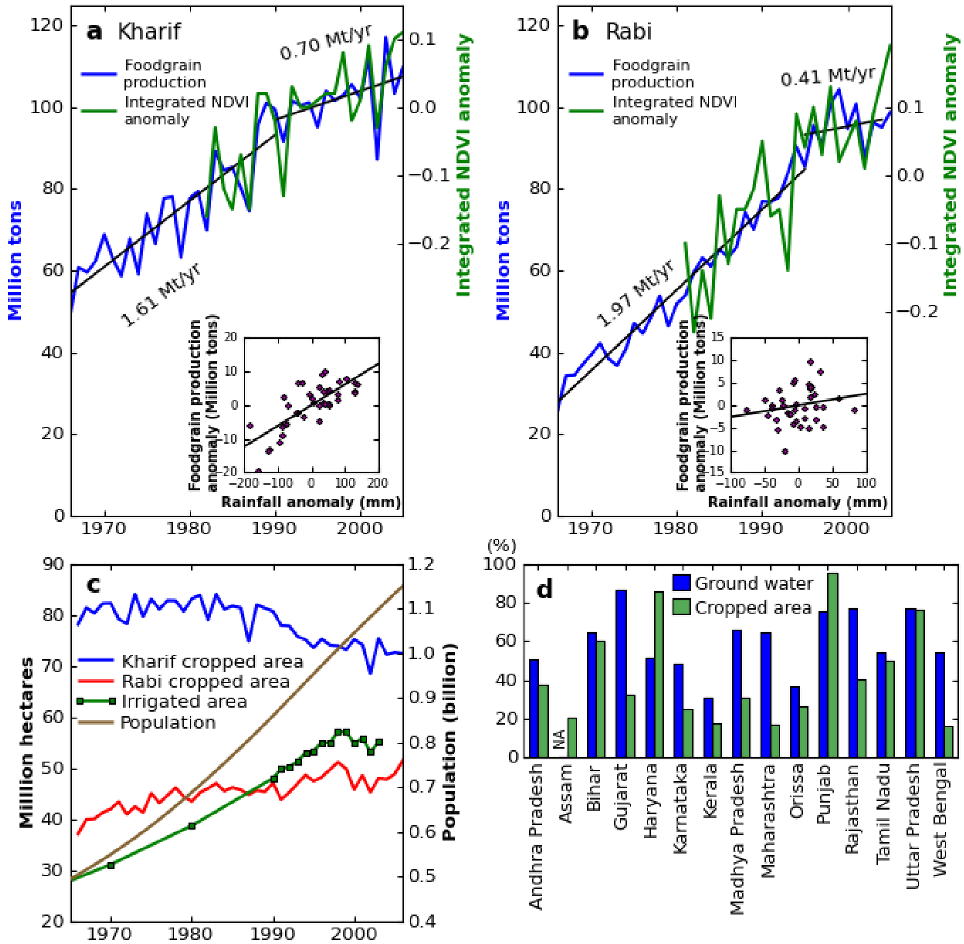
One of the major challenges we face on our planet is increasing agricultural production to meet the dietary requirements of an additional 2.5 billion people by the middle of the century while limiting cropland expansion and other damages to natural resources. This problem is even more challenging given that nearly all the population growth will take place where the majority of the hungry live today and where ongoing and future climate changes are projected to most negatively impact agricultural production, the semiarid tropics (SAT). The SAT contain 40 percent of the global irrigated and rain-fed croplands in over 50 developing countries and a growing population of over a billion and half people, many of which live in absolute poverty and strongly depend on agriculture that is constrained by chronic water shortages. Rates of food grain production in many of the countries of the SAT have progressively increased since the mid-1960s aided by the Green Revolution and relatively favorable climatic conditions. However, aggregated agricultural production statistics indicate that the rate of food grain production has recently stalled or declined in several of the countries in this region, escalating the concerns over matters of food security, that is availability of food and one's access to it, in a region where many people live in extreme poverty, depend on an agrarian economy and are expected to fare increasingly worse climatic conditions in the near future. In this presentation we will analyze the agricultural deceleration and some of its drivers over the country of India, which faces the daunting challenge of needing a 50-100 percent increase in yields of major crops by the middle of the 21st century to feed its growing population. We analyze the long term (1982-2006) record of the Normalized Difference Vegetation Index (NDVI) from the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer (NOAA/AVHRR) together with climate, land use, and crop production statistics. We shows that while there are no significant changes in long-term precipitation, there are geographically matching patterns of enhanced crop production and irrigation expansion with groundwater, initially, but both of which have leveled off in the past decade. In addition to increasing pressure on water resources, a decline in expansion of cropland area, a warming climate and increasing air pollution compound to challenging long-term food security in India.



a Kharif
Foodgrain production
Integrated NDVI anomaly
0.70 Mt/yr
1.61 Mt/yr
Million tons
Integrated NDVI anomaly
Foodgrain production anomaly (Million tons)
Rainfall anomaly (mm)
b Rabi
Foodgrain production
Integrated NDVI anomaly
0.41 Mt/yr
1.97 Mt/yr
Million tons
Integrated NDVI anomaly
Foodgrain production anomaly (Million tons)
Rainfall anomaly (mm)
c
Kharif cropped area
Rabi cropped area
Irrigated area
Population
Million hectares
Population (billion)
d
(%)
Ground water
Cropped area
NA
Andhra Pradesh
Assam
Bihar
Gujarat
Haryana
Karnataka
Kerala
Madhya Pradesh
Maharashtra
Orissa
Punjab
Rajasthan
Tamil Nadu
Uttar Pradesh
West Bengal

Calibration and Validation of the FAO AquaCrop Model for Irrigated Rice Grown in Goa, India

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Rice (Oryza saliva L) is the principal crop and staple food of Goa, India. It was being cultivated over an area of 171,000 hectares until some years ago. However, at present the gross cropped area for the rain-fed or kharif crop include only 36,000 hectares and that of irrigated or rabi/vaingan crop is around 17,500 hectares. The fact that the share of agriculture in the state GDP, which was around 17 percent until two decades ago, has come down to about 6 percent, indicates that agriculture is declining in Goa. One of the reasons for this decline is the lack of proper irrigation facility. In order to make rabi crop cultivation profitable in Goa, adopting proper agronomic practices and efficient use of water would prove to be handy. To address this need, FAO's new crop-water model called AquaCrop was applied. It focuses on simulating the attainable yield in response to water, which is the key driver for agricultural production. This study attempts to calibrate and validate the model for the site-specific conditions for rice production in Goa. Both rain-fed and irrigation water management scenarios were examined. Applicability of the model as a decision-making tool for best water management practices was verified.

Feeding the World to 2030 and Beyond: The Role of Groundwater

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Compared to the previous decades, the current trends in world commodity prices for food seem remarkably different in character, and appear to break the secular decline in real price levels that had previously been the expected norm. Looking forward into the future, a number of researchers project the continued elevation of world prices for agricultural goods above past historical trends, despite a leveling off in the near-term period from the current highs. The medium-term projections generated by the joint OECD-FAO modeling effort show that a prevailing tightness remains in most major agricultural markets, so as to keep price levels significantly above historical trends. While some see the reversal of historically declining real prices of agricultural commodities as an opportunity for the agricultural producers in both developed and developing countries, others remain concerned about the implications of high food prices and increased volatility in food markets on the welfare and well-being of vulnerable populations who consist of mostly net consumers of these products, and who largely reside in the poorest regions of the developing world. The challenges and increased stresses that face global food production and distribution systems, in the present economic climate, are particularly acute and pressing for Sub-Saharan Africa, where persistent levels of food insecurity already exist. To illustrate, roughly thirty-three percent of the population of Sub-Saharan Africa lives with insufficient food supplies and an even greater proportion, forty-three percent, lives below the international dollar poverty line. In this paper, we examine the role that groundwater plays in supporting agricultural production in key food-producing (and consuming) regions of the world (such as India and China), and the implications of scarcity-driven declines in production on food availability in those regions, as well as the rest of the world. We treat the increasing pressure on groundwater resources as one of several key drivers of change in a highly-globalized world food system, and examine a number possible entry points for policy intervention (both within and outside the water sector), in order to determine their effect on food prices and other market-driven outcomes. By comparing a baseline set of demand and supply projections to one in which we have simulated groundwater crises in key food-growing regions, we illustrate the contribution that groundwater plays in supporting the world food economy, and the dangers of delaying concerted policy action, in terms of its effect on future food prices and levels of malnourishment and hunger.

Exploring the Behavioral Dynamics of Groundwater Usage in India: Evaluating the Potential Effectiveness of Community-Based Management Schemes

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The varied landscape, hydrogeological profiles and agro-ecological conditions across India make for a wide range of environments in which irrigated agriculture is practiced. The importance of irrigation for agriculture is fairly uniform, however, and high levels of dependency on groundwater for irrigation can be found in many regions. The hydrogeological characteristics of the hard rock aquifers that are found in many parts of India complicate the picture, and create very different hydrological conditions from what would be found in other groundwater basins of the world, where large bodies of groundwater storage exist in the form of extensive alluvial aquifers. The added complication brought by national and state-level agricultural policy, which seeks to provide subsidies to farmers in the form of low-cost (or free) electricity, provide perverse incentives, in some cases, and make the implementation of certain instruments more difficult than they would be in an environment free of such distortions. In this paper we address the groundwater resource management issues in the regions of India with hard-rock aquifers, and take the case of Andhra Pradesh, to examine the dimensions in which user behavior can lead to water-saving behavior under community-based groundwater schemes. We illustrate the nature of the water resource management problem facing Andhra Pradesh, and point to ways in which groundwater users might react to different policy regimes, with the use of an economic model that is calibrated to observed data on farmer production and water usage behavior and is linked to a simplified representation of the characteristic hydrology. By illustrating the resource management problem within the context of the policy and natural environments that exist, the paper explores the scope that well-designed economic instruments could have in correcting the perverse incentives that exist for groundwater conservation, in regions of India like Andhra Pradesh, while also improving human welfare. In doing so, we hope to better clarify the role of policy instruments in addressing common pool resource management problems in India, the potential effectiveness of community groundwater management schemes, and provide guidance to researchers and policy makers on how they can further explore these cases and provide better guidance for policy.

Farmers' Willingness to Adopt Agricultural Best Management Practices to Control Nonpoint Source Pollution in the Lower Bhavani River Basin, India

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The role of stakeholders and their voluntary participation in agri-environmental management in general, and water resources conservation in particular, is a new area of research, at least for a developing country like India. This study attempts to understand the factors influencing farmers' willingness to adopt agricultural Best Management Practices (BMPs) to protect groundwater from nonpoint sources of pollution. Based on long-term groundwater nitrate concentration and source(s) of irrigation, six villages selected in the Lower Bhavani River Basin, Tamilnadu and detailed questionnaire survey (face-to-face interviews) has been carried out among 395 farm households. The results of binary choice Probit models show that socio-economic characteristics, perceptions about environmental impacts of agricultural practices, prior knowledge of BMPs, sources of agricultural information, memberships in social participatory institutions, prior experience of participation in agricultural training/workshops significantly influence farmers' decision to adopt BMPs. Government provision of agricultural training and education programs (extension services) are effective to induce farmers to adopt BMPs. Farmers from villages having better access to irrigation are willing to adopt BMPs as compared to relatively water-scarce villages. Workforce participation rate plays a crucial role in the adoption of BMPs and availability of family-based labor encourages adoption of BMPs.

Groundwater Laws in India: Of Content and Intent

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One of the most significant developments in India in the last four decades has been the quiet ascendancy of groundwater as the main source of irrigation. While this boom in groundwater started in late 1960s and preceded the Green Revolution in India, law making in groundwater started in India only in the 1980s and reached its peak in the 2000s. In this paper, we reviewed over 70 water laws (and legal documents) from India with a special focus on groundwater laws. It analyzes the content of these groundwater laws and examines whether they meet their intended goals and whether they are suited to the agro-ecological realities and development needs of different Indian states. It was found that groundwater featured in 20 of the 25 instruments assessed for India for the 1990-2009 period, with 15 classified as having either a primary or substantial focus on groundwater. However, while this quantitative observation confirms the significant attention given to groundwater, the review of the content of relevant instruments identified a substantial degree of similarity in content (and language) between several of the more recent instruments. This was most prevalent amongst the three federal draft Groundwater Bills (1992, 1996 and 2005) and the close resemblance to the 2005 Bill of the groundwater legislation of West Bengal, Bihar and Himachal Pradesh. Paradoxically, the groundwater laws of water abundant states like West Bengal and Bihar are far more restrictive than groundwater laws in the water-scarce state of Andhra Pradesh. This, to some extent, highlights the mismatch between groundwater resource realities and groundwater policies in India. Analysis of water laws in India shows two important trends in terms of content. The first is the gradual move towards regulation of groundwater use. The need for limiting extraction within recharge limits was recognized by the National Water Policy of 1987. This was followed by the proposed introduction of permits for and registration of new and existing wells, as well as the regulation of commercial well digging in the Draft Groundwater Bill of 1992. The Bill also envisaged the creation of a Groundwater Authority with the power to advise the State/Union Territory Government to declare any area to be a notified area for the purposes of controlling the extraction or use of groundwater in any area. Concerns over groundwater overuse emerged in the National Water Policy of 2002, which states that overexploitation of groundwater resources in certain parts of the country have raised the concern and need for judicious and scientific resource management and conservation (Section 6.1).The second trend and a significant addition in the 2005 Bill is the emphasis placed on enhancing the supply side through groundwater recharge systems. Thus the Bill envisages permits for digging new wells to include the mandatory provision requiring artificial recharge structures to be built as part of the well (Article 6.3). The proposed Groundwater Authority would also be charged with identifying areas needing recharge, and issuing guidelines for adoption of rain water harvesting in these areas (Article 19.1).

Identification and Quantification of Nitrate Transport in Agricultural Area

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As fertilizer is applied to agricultural area, it introduces a large amount of nitrate into aquifer and stream. Therefore it is necessary to identify the nitrate transport and to estimate its loads, in order to establish a proper water quality management. This study investigates the nitrate transport and estimates its loads in the HoengGaeRi area, South Korea, which causes severe eutrophication in the DoAm Lake, located downstream. It consists of four major components: estimation of pollution load to aquifer, development of data transforming interface, identification of nitrate transport, and estimation of pollution load to stream by flow separation. The SWAT model, the quasi-distributed watershed model, is employed to estimate the pollution load to aquifer by fertilizer application. According to its estimation and sensitivity analysis, the pollution load to aquifer is sensitive to the amount of fertilizer, the vegetation type and the infiltration rate. So as to import this estimated pollution load data into the MODFLOW and MT3D model, the fully distributed groundwater model, a GIS-based interface is developed to transform the output data from hydrologic response units of SWAT model to input data for finite-different grid of the MODFLOW and MT3D model. Nitrate transport in aquifer is described using the MODFLOW and MT3D model. The pollution load to stream is driven by two types of flow, which are direct flow affected by precipitation and base flow maintained all the year round. In order to consider both of nitrate transport mechanism and this temporal difference in water quality management, a tool is developed to estimate pollution load by base flow as a post-processor of the MODFLOW and MT3D model. Thus the pollution load by base flow is calculated using this tool and the pollution load by direct flow is calculated as the difference between total pollution load calculated by the SWAT model and the pollution load by base flow. This separation of pollution loads indicates the flow that has larger portion and has to be controlled. The approach suggested in this study shows the nitrate transport in aquifer from land surface to stream and estimates its loads to aquifer and stream. It would be useful to implement water quality management, especially when the agricultural area is located in riparian zone.

Offsetting Allochthonus Salinity Increases Threatening Irrigated Agriculture with Managed Recharge

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Where the salinity of master streams is increasing, recharge may also become more saline. The choices and yields of crops are becoming more limited in numerous agricultural basins in central and southern California, requiring management of recharge quality to keep high-value agriculture sustainable. Dilution with waters of lower salinity is often the simplest and preferred alternative. Four sources of fresher water are available in many such basins: 1.Low salinity storm runoff captured in reservoirs; 2. Low salinity storm runoff captured in recharge facilities, such as former quarries; 3. Deeper groundwater of lower salinity, typically available from clastic continental deposits of Pleistocene or recent age; 4. Treated effluent, which often is of substantially lower salinity in subarid California than is the master stream, due to water imports or selection of lower-salinity local sources for drinking water quality. As salinity of master streams continues to increase, planning recharge for salinity control will also become increasingly necessary, and should be incorporated in many groundwater basin planning efforts. The Pajaro Valley is used as one example of how low-salinity dilution from each of these sources - singly or in combination - can lead to maintaining the high-value agriculture for which the region is known. Pajaro Valley results suggest that it may be necessary to respond sooner than we think to inhibit salinity increases in at least some alluvial valleys.

Food Security under a Changing Environment: Sustainable Management of the Groundwater Resources of India

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Impacts of climate change and environmental degradation on groundwater resources pose a serious threat to food and water securities in India. Groundwater contributes to nearly 80 percent of the agricultural production and domestic water supply in rural areas and about 50 percent of the urban and industrial uses. These resources are under threat from the depletion of quantity and quality, as the dependency on them increases sharply with changing climate, rising population, agricultural expansion and industrial and urban developments. India is heading towards a food crisis, demanding another major revolution in agriculture. The country is on the path of globalization and rapid industrial development. Industrial overuse and misuse of groundwater is tremendous. Urbanization and expansion of urban limit led to encroachment into wetlands, affecting groundwater recharging. Unsustainable use of groundwater has caused considerable depletion of water table during the past two decades. The number of open and bore wells for domestic and irrigation purposes has rapidly and indiscriminately increased. There is an increasing gap between the use and recharge. Sea level changes, storm surges and over-extraction contaminate coastal aquifers, affecting agriculture in coastal zones. The ongoing national river linking project may alter the current scenario and the impact may be serious. Extremes in temperature and rainfall and change in rainfall seasonality affect the groundwater recharge. Higher temperatures produce more evaporation from surface water bodies and also make the soil dry, reducing the recharging of underground resources, especially in the dry interior parts. Rainfall is becoming highly seasonal in parts of western and southern India, allowing wasteful runoff and reducing the timing of surface water available for groundwater recharge. With the current rate of melting of Himalayan glaciers, groundwater extraction will deplete fast and maintaining food security will become difficult. Setbacks in agriculture will affect national economy and may create serious social issues like rural unemployment, competition for resources, disputes and migration. Present study assesses the impacts of climate change and environmental degradation on the groundwater resources of India and its reflections in the agricultural sector. A review of the existing policies and management strategies related to water and agriculture and of the climate change adaptation measures have been made. The study reveals a sharp decline in surface and groundwater availability in almost all parts of India. Better management and conservation practices can help overcome the crisis. Since the total amount of rainfall does not show significant trends, control of runoff and adequate measures for storage and recharge can improve the groundwater condition. Reviving the traditional environment-friendly mechanisms for groundwater recharge could minimize the water scarcity in the rural areas. Existing policies and their implementation often fail because of the typical socio-economic, bureaucratic and political setup in India. India has to develop appropriate policies for food and water and an efficient strategy for climate change adaptation. Suggestions for this have been provided.

Autonomous Smallholder Shallow Groundwater Irrigation Development in Upper East Region of Ghana

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In sub-Saharan Africa in general, and in Ghana in particular, groundwater resource is associated with domestic use. There is paucity of information on groundwater resource potentials and the limited information that is available based on data from specific aquifers indicates a pessimistic view about the groundwater resources in Ghana. Moreover, the agricultural use of groundwater is not reflected in the country's water and irrigation policy. Contrary to the official knowledge, farmers have started using shallow groundwater to produce horticultural crops. In Upper East region, the groundwater infrastructure is developed using extremely rudimentary digging/drilling technologies banking on the abundant human labor during the long dry season. This paper analyzes: (1) the economics of smallholder groundwater irrigation; (2) food security and poverty outreach of access to groundwater resource; and (3) constraints and opportunities of smallholder groundwater irrigation systems. The paper is based on data generated from 420 farmers in 35 communities distributed in three micro-watersheds of the White Volta basin in the Upper East region of Ghana. These communities are divided into 2,085 compounds harboring 4,576 households and 20,962 people. Of the total 4,576 households found in the area, about 61 percent are practicing irrigation of one sort or the other. Of those practicing irrigation, about 89.9 percent are using shallow groundwater. The rest are using small dams, river and drainage water. Even though the agricultural use of groundwater had significant positive livelihood impacts, further development and productivity is constrained by complex land tenure issues, lack of access to efficient drilling technology, marketing challenges, and the general lack of official support services such as extension and micro-credits.

The Impact of Irrigation on Groundwater Quality in Northern Kuwait

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Kuwait is an arid country with an average annual rain fall of 132mm and evaporation of 4,015mm (central statistical office, 2007). There are three main farm areas in Kuwait: Al Wafra, Sulaibia and Al Abdally, which are located south, middle, and north (resp.) of Kuwait. The main irrigation water for all areas is derived from the brackish to slightly saline groundwater from the unconfined Kuwaiti group aquifer. This study deals with the northern part of Kuwait (the Al Abdally farm area), where farming activities started in the early 1960s. Now there are 1,012 farms that cover about 300 km2 (PAAFR, 2009). The expansion of the farm areas was associated with an increase of groundwater consumption for irrigation and other purposes. The groundwater is being extracted very heavily from more than 1,515 wells. In 1963, 1989, 1998 and 2006 studies were conducted in this area for the quality of the groundwater used for irrigation. The average water extraction was 40-45 MGD, in which 30 percent is lost due to evaporation (J.Al-Sulaimi, 1996). The present study is to compare the TDS concentration with the previous studies. Groundwater samples were collected from 1,017 wells and a TDS contour map was produced. It was found that in 1963 the TDS ranged from 2,000 mg/l in the central part of Al Abdally farm area to 8,000 mg/L in the outer border of the area. In 1989 it ranged from 6,000 mg/l from the central part to more than 10,000 in the outer border of the area. Because of excessive pumping, in 1998 the 10,000 contour line intruded to the middle part of the farming area and the TDS concentration dropped in the northeast part of Abdally to 6,000-7,000 mg/l. In 2006 there was not a great deal of change in the TDS concentration for the area if compared to the TDS map of 1998. This study shows a slight improvement in TDS concentration, in which the 10,000 contour line regressed to the outside edges of the farm area. This could be attributed to the utilization of low salinity (80mg/l) treated wastewater in irrigation, which has been provided by the Kuwaiti government to the farms since 2004. In conclusion, after 43 years of pumping, the TDS concentration of groundwater in the middle of the study area was increased from 2,000 mg/l to 10,000 mg/l and decreased to 9,000mg/l during the last 3 years.

Till the Wells Run Dry? Dealing with Groundwater Depletion in Victoria, Australia, and California, USA

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This study contrasts the regulatory experience of California, USA with that of Victoria, Australia in preventing and responding to groundwater depletion by controlling groundwater extraction. California and Victoria share a Mediterranean climate, concerns about how climate change will affect water availability, increasing groundwater use, and common roots in relation to water law. Groundwater regulation is a live political and legal issue in both jurisdictions. In the face of these ongoing policy discussions in both jurisdictions, this study analyzes empirically how key groundwater control mechanisms are presently established and implemented under contrasting regulatory approaches. On its face, Victorian law provides for close control of groundwater extraction, whereas Californian law takes a more laissez-faire approach. This study seeks to examine how groundwater controls are implemented in practice, an issue which is yet to receive significant study in both jurisdictions. The study focuses on five key aspects of groundwater legislation and its implementation in practice: (a) the collection of groundwater information to support management; (b) management planning; (c) different methods of dealing with groundwater depletion, including export restrictions, extraction limits, replenishment and conservation; (d) enforcement of groundwater controls; and (e) the identity of key decision-makers. The study also seeks to determine how these elements vary with the characteristics of the situation regulated, for example, the specific problems caused by groundwater extraction, the resources available to the managing agency, and the gravity of groundwater depletion. First, content analysis is carried out in relation to the documents that constitute the relevant regulatory mechanisms in Victoria and California, to systematically code the elements of interest. These documents include management plans, ordinances, legislation and regulatory declarations. Second, interviews with key stakeholders are carried out in relation to a small number of individual regulatory control mechanisms, which are selected to illuminate key patterns revealed by the content analysis. This two-step method seeks to show how groundwater regulations are used in practice to control groundwater extraction in two regions suffering from water scarcity, thereby seeking to inform ongoing debates over groundwater policy and legal reform.

Probabilistic Predictions of Groundwater Recharge Under Climate Change Scenarios in a Dryland Cotton Region of the Southern High Plains

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The IPCC (2007) reports that climate change will likely bring an intensification of the hydrological cycle. Droughts will likely become more frequent, while precipitation events could become heavier and more concentrated. This would reduce reliability of precipitation and increase dependence on groundwater for agriculture. However, aquifers will likely also be impacted by climate change through effects on recharge. Making predictions of recharge under climate change in agricultural regions is thus critical. Unfortunately, in dry environments where groundwater resources are often most important, low recharge rates are difficult to resolve due to high sensitivity to modeling and input errors. Water resources management requires understanding the full range of possible outcomes for recharge This work assesses future climate change impacts on recharge - and its uncertainty - for a dryland cotton region in the semiarid southern High Plains (SHP) using a probabilistic framework. In the SHP, negligible diffuse recharge occurs below perennial native vegetation (~ 6 mm/yr); yet rain-fed crops allow notable amounts of drainage (median 24 mm/yr) below shallower annual crop rooting depths. These elevated post-land use change recharge rates could now be subject to further alteration under new climate conditions. Some recent studies on climate change and groundwater examined recharge under a suite of general circulation model (GCM) climate predictions, an obvious and key source of uncertainty. This work extends beyond those efforts by also accounting for uncertainty in other land-surface model inputs in a probabilistic manner. Acknowledging these uncertainties is critical for assessing terrestrial responses to the climate. Our simulations showed that using a range of unconstrained literature-based model parameter values produce highly uncertain and often misleading recharge rates. Thus, distributional recharge predictions were found using soil and vegetation parameters conditioned on current unsaturated zone soil moisture and chloride concentration observations. For most climate change alternatives, the range in predicted changes in mean recharge (- 75 percent to +35 percent) are larger than the corresponding range in predicted changes in mean precipitation (-25 percent to +20 percent). This suggests that amplification of climate change impacts may occur in groundwater systems. Predictions also include varying changes in the frequency and magnitude of recharge events. Our predictions showed that the temporal distribution of precipitation change (over seasons and rain events) explains most of the variability in predictions of recharge totals and episodic occurrence. In particular, the timing of precipitation changes relative to crop development played an important role in determining recharge. Our work provides a probabilistic sensitivity analysis of recharge under potential climate changes in semiarid agricultural regions, which will be critical for managing water and land resources.

Modeling Agricultural Impacts on Groundwater at Contrasting Spatial Scales

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Models were developed at two contrasting spatial scales to assess the vulnerability of groundwater to agricultural impacts. First, a nonlinear regression model (GWAVA) was developed at the national scale (R-squared = 0.80) to predict nitrate concentration in shallow groundwater (typically < 5 m deep). GWAVA is empirical but is more physically realistic than typical regression approaches. It has a structure that separates nitrogen (N) sources from factors that enhance or restrict nitrate transport and accumulation in groundwater. Input data were spatially averaged to minimize small scale variability so that the large scale influences of N loading, climate, and aquifer characteristics could be examined. Second, a mechanistic model (the Root Zone Water Quality Model or RZWQM2) was used to predict unsaturated zone N fluxes for the San Joaquin Valley of CA. RZWQM2 is a one-dimensional unsaturated zone fate and transport model that also simulates crop growth and the effects of agricultural management practices. The model was used to predict daily nitrate concentration in deep seepage so that responses at the water table to weather, irrigation, and other factors could be evaluated. The model was calibrated by inverse modeling to data collected throughout the unsaturated zone and yielded an index of agreement (d) value of 0.60 (d is interpreted like R-squared but is more sensitive to differences between predicted and observed values). RZWQM2 predicted that 67 percent of the N loss from the unsaturated zone occurred through plant uptake (144 kg N/ha-yr) and that the remainder occurred primarily through deep seepage (71 kg N/ha-yr). Pulses of nitrate at the water table were predicted to occur in response to irrigation. The two modeling approaches are complementary. Whereas GWAVA is primarily a spatial tool to compare levels of contamination in areas, RZWQM2 predicts changes in contaminant fluxes in response to changing conditions at the land surface. Empirical models such as GWAVA require fewer inputs and are easily applied at large spatial scales to identify impacted areas for monitoring and/or more detailed mechanistic modeling. The latter require more input data and typically are applied at the field scale. Because they have an explicit temporal component, mechanistic models can be used to determine the time required to realize potential effects from alternative management practices. Additionally, mechanistic models can help identify variables for potential incorporation into empirical models, such as soil hydraulic properties and plant characteristics.

The Use of Reserve Determination in Assessing Groundwater Quantity

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South Africa is a water-scarce country and the pressure on the water resources are increasing. South African National Water Act (Act 36 of 1998) provides a means by which water resources can be managed. The Act created a mechanism that allowed the South African Department of Water Affairs to review all water uses in an area. The Act makes provision for water required for basic human needs and the water required to maintain ecosystem functioning. In order to manage the available water resources in an efficient, effective and sustainable manner, the quantity of water being used, available and the Reserve need to be known. All water users who do not receive their water from a service provider, but are using water for irrigation, mining, industrial, and feedlots are required to register their water use. This registration sometimes requires a water use license. This applies to both surface and groundwater. Before the Act, the management of water was haphazard and not well coordinated. There was, therefore, a need to develop some tool with which water can be managed in sustainable manner. This study looks at a set of tools formulated in order to evaluate the groundwater quantity and quality when assessing for a water use license. The country was divided into quaternary and data from among other things, groundwater component of the reserve, the registered water uses, the maximum and minimum harvest potential, exploitation potential and recharge were collected. These data sets were computed for each quaternary, the volume of water available were estimated. The results show that these set of tools have helped in assessing groundwater quantity and quality in a particular area, thereby improving the management of groundwater in a more efficient and effective manner. Although these are estimates, the tool can be used to quantify up to more than 75 percent of the quantity of water available for use. The developed tool has demonstrated that it can be used to estimate the quantity of water available.

Assessment of the Influence of Geology on Groundwater Quality: A Case Study of Kutama and Sinthumule Areas in Limpopo Province

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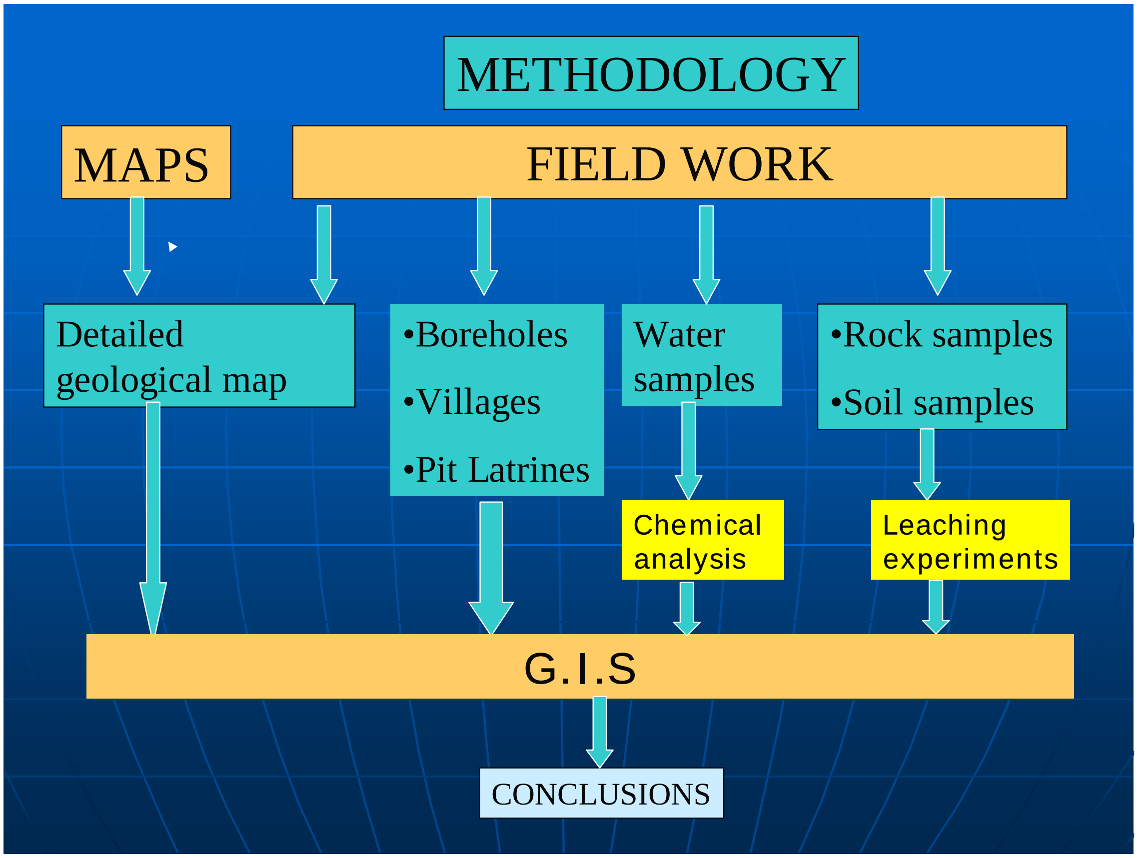
In rural areas in South Africa, just like most rural areas in developing countries, people tend to rely very much on groundwater in form of wells and boreholes for domestic use. In most cases the water is not treated before use and this is based on the assumption that since the source is of natural origin, it should be safe. However, this is not always true because some geological changes can introduce substances into water systems. For example, it is known that fluorite which is found in granite can be leached from bedrocks into groundwater causing elevated fluoride and when such water is consumed, it could lead to the browning of teeth among other effects. The browning of teeth, particularly among the elderly is very prevalent in the case study area of Kutama and Sinthumule. This study was, therefore, carried out to assess the influence of geology on the groundwater within the study area with the aim of determining the fluoride content, among other anions and cations, in the groundwater. Groundwater samples were collected from boreholes in the study area during the winter and summer periods in order to evaluate any seasonal changes. Both physical and chemical parameters were determined using appropriate analytical methods. Detailed study of the geology of the study area was also undertaken. The results of the chemical analysis of the borehole water samples showed that the concentration levels of fluoride (no detection-0.25mg/l), chloride (93.56-219mg/l), magnesium (59.25-113.50mg/l), potassium (1.95-8.10mg/l) and sodium (65.80-241.34mg/l), were all within the acceptable limits for drinking water except nitrate. The concentration of nitrate as nitrogen in the groundwater ranged from 41-231 mg/l compared to the recommended level of 44 mg/l. From the geology of the study area, the presence of nitrate in form of nitrogen is very low and therefore, the observed high level of nitrate could not have come from the bedrock. A closer analysis of the results indicated that the observed high nitrate level may have come from the pit toilets which are, in most cases, not properly constructed. The type of soil and the underlying geology may have enhanced the movement of nitrate from the pit toilets to the groundwater. No significant difference was observed between the levels of the parameters determined in the winter and summer months and the physical parameters, pH and conductivity were found to be within the acceptable limits for drinking water. This study has indicated that the suspected high level of fluoride in the groundwater within the study area was within the acceptable limit. However, the level of nitrate was unexpectedly high and this has been attributed to the land use activities in the area. The browning of teeth among the elderly people may be due to other factors.


METHODOLOGY
MAPS
FIELD WORK
Detailed geological map
•Boreholes
•Villages
•Pit Latrines
Water samples
•Rock samples
•Soil samples
Chemical analysis
Leaching experiments
G.I.S
CONCLUSIONS

Management of Groundwater in California through an Integrated Regional Water Management Plan

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California's thirst for water supplies to support population growth, food production and enhancement of environmental resources has stretched surface and groundwater supplies to unsustainable conditions in many areas of the state. A significant percentage of California's groundwater basins are being over-drafted to address these demands and compensate for reduced reliability of surface water supplies due to inadequate storage and conveyance infrastructure, hydrologic conditions, and changes in state and federal policy. Local management solutions are being encouraged and developed to support sustainability of these important resources. The California Legislature has conditioned financial support for regional projects with a requirement that Integrated Regional Water Management Plans (IRWMP) be prepared and implemented by local public agencies to promote creation of regional water supply strategies to improve water supply sustainability. The Legislature recognizes that integration of local planning activities can lead to politically acceptable solutions that expand regional water supplies to meet urban, agricultural and environmental objectives. IRWMPs also provide a framework for coordinated management and monitoring of groundwater supplies and quality. The California Legislature has established local groundwater management criteria that must be developed with the IRWMP framework. Enacted in 2002, Senate Bill 1938 (SB1938) amended sections of the California Water Code defining process and terms for adoption of a local groundwater management plan. In order to meet the requirements of SB1938, a local public agency must conduct a stakeholder-driven process to establish basin management objectives for groundwater elevation (supply), quality, subsidence, and interrelationship with surface water flows. The local agency must also establish monitoring programs that assess performance of these objectives. Traditionally prepared and implemented by individual water agencies, cities and counties, the IRWMP structure requires coordination of these groundwater management plans to meet regional objectives. The Comprehensive Water Package signed by Governor Schwarzenegger in November 2009 included Senate Bill 7x 6, amending the California Water Code and establishing provisions requiring the development of a statewide groundwater monitoring framework by the California Department of Water Resources. IRWMPs can play a key role in development of the monitoring and reporting framework utilizing the structure of the SB1938 groundwater management plans. Water agencies, cities, counties, local community interests and several non-governmental agencies have come together in the central San Joaquin Valley of California to develop and implement the Upper Kings Basin Integrated Regional Water Management Plan. The Plan covers over 600,000 acres in portions of three counties that lead the State in annual agricultural production, have rapidly growing urban centers, and are dissected by the Kings River, one of California's significant remaining riparian corridors. Plan participants have developed a vision, objectives, governance structure, project lists, an interactive groundwater model, and an open process for discussion of regional resource management issues and potential solutions. Plan participants are currently discussing further coordination of member agency groundwater management plans and monitoring strategies to meet basin management objectives and legislative requirements.

Cycling of Organoarsenicals Released from Poultry Litter: Results from a Field Experiment in an Agricultural Watershed

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The use of organoarsenicals in poultry feed has a wide variety of benefits which range from improved feed efficiency and pigmentation to weight gain. However, the compounds are not taken up in tissue and are instead excreted from the animals, resulting in elevated concentration (15-77 mg/kg) in poultry litter. When poultry litter is land applied as fertilizer, there is a potential for arsenic to leach from the litter into hydrologic systems. Laboratory studies on the biotransformation of roxarsone (3-nitro 4-hydroxybenzene arsonic acid), the dominant organoarsenic feed additive for poultry, have been conducted; but to date, there is little information on its environmental fate and transport within agricultural watersheds. This study examines the pathway of roxarsone released from poultry litter from the land surface to soil and groundwater and finally surface waters. The main objective is to determine how geologic (e.g. aquifer mineralogy, stratigraphy) and geochemical (e.g., redox) conditions impact arsenic mobility and to what extent arsenic is transported through hydrologic systems after poultry litter is land applied. To address the research objectives, we have installed monitoring wells, lysimeters and continuous monitoring equipment at a field site in the Delmarva Peninsula, a region of intense poultry production. Prior to this study, the site had not been litter-applied for more than five years. After collecting several sets of background samples, we conducted a poultry litter application (2 tons per acre) in October 2009. Results thus far show that water-soluble species from poultry litter are mobile, but so far, impact has been limited to soil water. Further sampling will continue to determine the arsenic form and species available in ground or surface waters at the site.

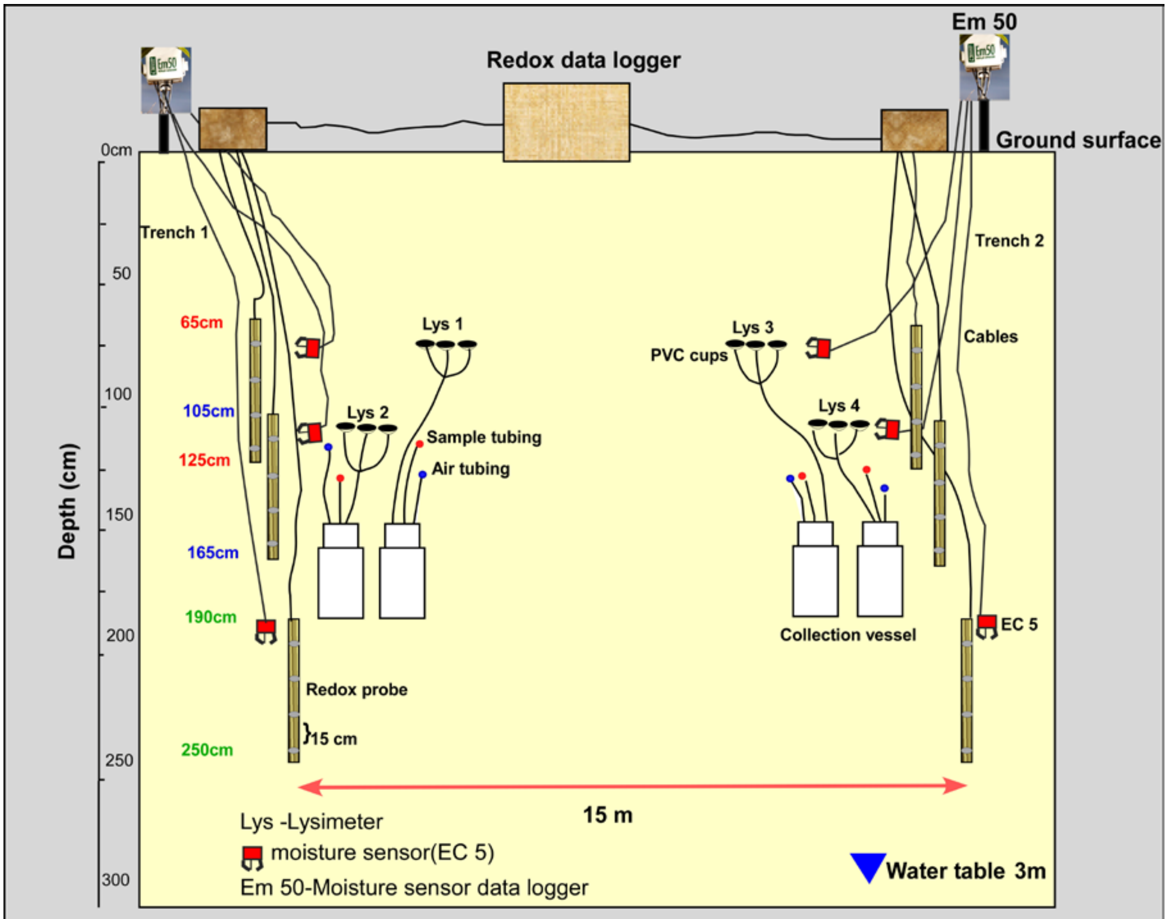

Figure 1: A schematic plot of site instrumentation

Addressing Groundwater Overexploitation - Large Scale Success of Community Management Approaches in Hard Rock Aquifers of Southern India

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India is the largest groundwater user in the world, accounting for more than a quarter of the global groundwater abstraction. There has been a phenomenal growth in the exploitation of groundwater over the last four decades, largely through the construction of millions of private wells, aided by cheap drilling and pumpset technologies, as well as public subsidies for electricity. However, 30 percent of the aquifers in India are now at unsustainable levels of exploitation. With more than 60 percent of irrigated agriculture and urban and rural water supplies dependent on groundwater, addressing groundwater overexploitation has emerged as a critical challenge for India. The broad range of economic and regulatory models attempted across the globe for groundwater demand management has a limited applicability to Indian settings because of unusually high (approx. 20 million) number of individual users, preponderance of informal institutions, and deeply entrenched populist policies in energy, irrigation, and agriculture which discourage groundwater demand management. Self-regulation of groundwater use by communities is often presented as a solution but the existing examples of community management are based on charismatic local leaders, and therefore have not been replicable at large scale. We present an assessment of successful experiences from southern India which indicates that certain models of community groundwater management may be viable at large-scale in hard-rock areas, even in those cases that are characterized by the perverse incentives of cheap power and crop support prices. Under the FAO-supported Andhra Pradesh Farmer-Managed Groundwater Systems (APFAMGS) program, tens of thousands of farmer households in drought-prone areas of southern India have been trained and engaged in participatory hydrological monitoring, aimed at building their understanding of the dynamics and status of groundwater in the local aquifers. Farmers are provided with the equipment and skills to collect and analyze rainfall and groundwater data. They measure and keep daily track of rainfall, water levels, and well yields, calculating groundwater recharge from monsoonal rainfall, and estimating their annual water use based on planned cropping patterns. The project is transforming farmers into barefoot hydrogeologists, and also facilitates access to information about water-saving techniques, improved agricultural practices, and ways to regulate and manage farmers' demand for water. In contrast with most community-based approaches, the project does not seek collective decision-making nor does it offer any incentives in the form of cash or subsidies to the farmers. Assessments show that these communities have achieved a closer alignment of water availability and water use, and reductions in groundwater use have been realized by farmers without sacrificing profitability. With an outreach of more than a million farmers, these achievements of the project posit it as the first global example of large-scale success in community-based demand management of groundwater. It shows that the key determinant of success in community groundwater management is the focus on developing local capacity to adapt dynamically to the annual hydrological variability, through non-formal learning, innovative social engineering, and aligning water management objectives with the individual farmer's rational behavior instead of collective action.

Development and Pilots for a National Groundwater Monitoring Network in the United States

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The Office of Management and Budget established the Water Information Coordination Program (WICP) to foster collaboration and improve water information for decision-making related to natural resources management and environmental protection. The Department of the Interior through the U.S. Geological Survey acts as the lead agency and works together with other federal agencies and the non-federal sector, collectively under the Advisory Committee on Water Information (ACWI), to help implement WICP and to identify water information needs, evaluate the effectiveness of water information programs and recommend improvements. A subgroup of ACWI, the Subcommittee on Ground Water (SOGW) has the charge to develop a framework for a long-term, national groundwater-monitoring network and encourage its implementation. The SOGW developed and ACWI approved in late 2009 the report *A National Framework for Ground Water Monitoring in the United States*, which proposes the National Groundwater Monitoring Network (NGWMN). The overall goal of the national-scale groundwater monitoring network is to provide the data necessary for the planning, management, and development of groundwater supplies to meet current and future water needs, including ecosystem requirements. A key component of the network is the development of a prototype, web-based data portal, which will serve data from the participating groups (state, regional and local) to the analysts requesting network data. NGWMN pilot projects including Indiana, Illinois, Minnesota, Montana, New Jersey, and Texas were initiated at the beginning of 2010. These pilot projects were selected to represent single-state programs with different levels of intrastate-agency coordination, and multi-state collaborations monitoring multi-state aquifer(s). Pilot projects are intended to serve to test the concepts outlined in the NGWMN, and produce information with which to evaluate the feasibility of a nationwide network. Information gained from the pilot projects will be incorporated into the Implementation Phase of the NGWMN. Pilot projects will be used to evaluate the distribution of existing wells within principal and major aquifers, well measurement, sampling frequency, field practices, data elements stored in their environmental database(s), data management procedures and documentation, and overall network costs. Pilot programs will also be evaluating the efficacy of sharing data through the data portal. This presentation will provide an overview of the NGWMN and the pilots.

Modeling Seasonal Risk of Deep Drainage for Different Regions of Ontario: Implications for Source Protection Guideline Development

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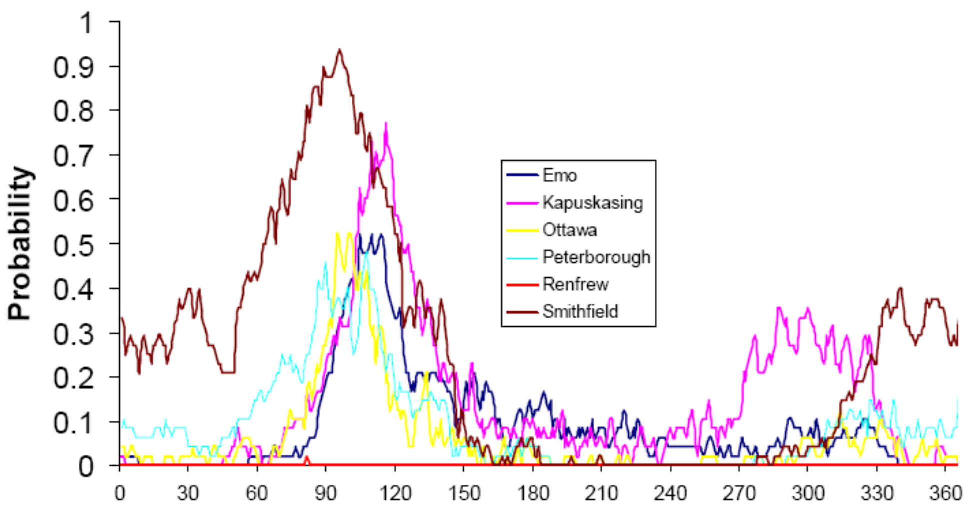
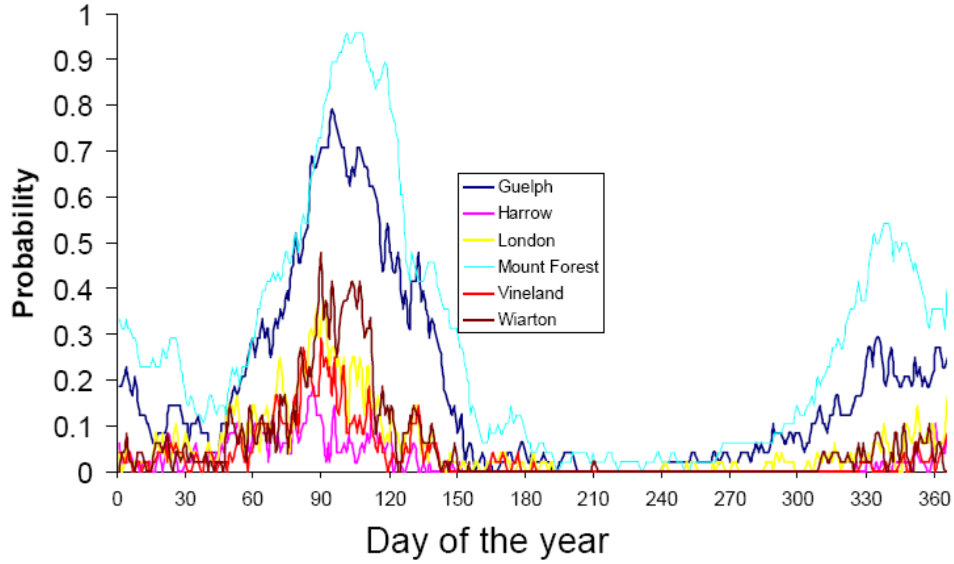
Deep drainage (DD) is the main driver for leaching and potential groundwater contamination from non-point sources such as farm fields; therefore, DD should be considered when developing source water protection strategies across a large geographic area such as the Province of Ontario, Canada. To investigate this issue, the DD for 12 different regions of Ontario was estimated using the model DRAINMOD. The model was run on a daily basis using climate data from each region over the 1954-2001 time period. Soil textures selected to represent each region ranged from sand to clay, and along with large differences in climatic regime between regions, resulted in a large range of estimated average annual DD from about 20 mm to over 300 mm. The month with the greatest risk of drainage across all regions was April. In Ontario this is the month with the most snowmelt and, in general, soil conditions are changing from frozen to thawed, leading to a high probability of wet soil conditions and drainage. The two regions with the greatest probability of drainage occurring on a single day over the 48-year model period had the greatest amount of snowfall and the coarsest-textured (sand) soil. For the region with the sandy soil the greatest probability of drainage of 0.94 occurs on Apr. 6 for any given year. For the region with the highest snowfall, the greatest probability of drainage of 0.96 occurs on both Apr. 11 and Apr. 16 for any given year. In terms of guiding policy for source water protection, there are two main issues that arose from this study beyond the spring-season timing of the greatest risk of deep drainage. First of all, some regions have peak risk as low as 0.17 and most regions have peak risk less than 0.5. Although soil texture does influence DD probability, it appears that climatic differences between regions have an even greater impact. In summary, the model estimates of DD from this study indicate that policy on source water protection in relation to the amount and timing of DD should not be developed at a Province-wide scale across Ontario; including regional climatic variability and to a lesser extent different soil textures should be considered when developing source water protection strategies.





Estimates of probability of deep drainage greater than 1 mm occurring on any given day of the year for 12 regions of Ontario, Canada using DRAINMOD.

Collaborative, Stakeholder-Driven, Water-Energy-Agriculture-Ecosystems Modeling and Planning for Long-Term Resource Sustainability

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Water, energy and food systems, and the ecosystems in which they all occur, make the foundation for human social, economic and political systems. The decline of these systems represents a threat to human security, stability, and to the overall sustainability of the human enterprise in general at all scales. Since all these systems are interwoven, attempts to understand and manage any of them individually must occur in the context of them all. This is a complex task, hindered by historic academic and professional specialization, and by the inability of the human mind to accurately evaluate the consequences of complex and dynamic resource management activities as they ripple across systems over time. We use a collaborative, stakeholder-driven approach to bring together experts from across disciplines, elicit information and develop conceptual models of interacting systems, gather data from across sectors and disciplines, build computer simulation models, and then use the models to evaluate the possible consequences of competing resource management strategies as they are projected into the future. The collaborative, stakeholder-driven process assures that all important disciplines and sectors are represented, that the model is the most accurate possible representation of the system, and that the model is owned and trusted by the stakeholders. The collaborative process results not only in a technical tool but in a stakeholder team much more well informed about system dynamics and the feedbacks, time lags, and consequences of actions, both intended and unintended. This approach has been applied in numerous projects in the U.S. and around the world. The presentation will include a brief demonstration of a model.

Legal Instruments for Dealing with Agricultural Groundwater Management in the United States

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Groundwater supplies roughly a fourth of the water used in the United States, and roughly two-thirds of the groundwater is used in agriculture. Groundwater reserves vary in type of formation, quality, and location. The law of groundwater allocation and management is primarily left to individual states, and state law and practice vary greatly. After providing an overview of groundwater resources and law frameworks, the presentation will focus on four specific areas of the U.S. as examples: California, Texas, Florida, and the states overlying the High Plains Aquifer in the center of the country. In addition, interstate issues including an interstate groundwater dispute between Tennessee and Mississippi will be discussed. Individual states have adopted one of several groundwater allocation doctrines or combinations of those doctrines, as well as special groundwater management strategies. Texas uses the absolute ownership doctrine, in which landowners own the groundwater underneath the surface, need not have a permit, and can pump without regard to impairment of neighbors. California has adopted the correlative rights approach, which provides a sharing of the groundwater among overlying landowners. Florida uses consumptive use permits in a regulated riparian approach, which authorizes state-issued permits, limited to a prescribed time period and based on the reasonableness of the proposed use of the water. Most of the states overlying the High Plains Aquifer use prior appropriation, which requires permits and holds that first in time, is first in right. In addition to these various doctrines, some states have other laws that provide for prospective management of groundwater withdrawals and attempt to curtail groundwater mining when that situation arises. Kansas enacted legislation in 1972 to enable the formation of groundwater management districts, which aid the state's chief engineer in setting well-spacing rules and limiting issuance of new permits, when to do so would exceed goals regarding rates of depletion or safe yield. Additional legislation has given states authority through both judges and water administrators to shut down users, partially or entirely, to achieve safe yield in an aquifer. Evaluation on the success of these management techniques varies: supporters think these practices have worked, while critics claim they have been unsuccessful. Cooperation among neighboring states overlying common aquifers has been rare. While interstate compacts covering apportionment of interstate rivers have been common, no compact exists that focuses entirely on groundwater, although a proposal exists for a model interstate groundwater compact. Recent U.S. Supreme Court cases involving interstate river compacts have concluded, however, that even though river compacts fail to mention alluvial groundwater expressly, the compacts cover groundwater, and the Court has ordered upstream states to curtail alluvial groundwater pumping. Recently, the state of Mississippi sued the state of Tennessee in the U.S. Supreme Court, alleging impairment of its groundwater by the city of Memphis, Tennessee. These two states share a common groundwater aquifer, but they have not signed an interstate water allocation compact.

Groundwater Management Program for Yuba County Water Agency: A Conjunctive Use Pilot Project

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The Yuba County Water Agency (YCWA), an independent, stand-alone government organization created in 1959, aims to develop and promote the beneficial use and regulation of the water resources of Yuba County. Over the last two decades, YCWA and its Member Units (currently eight Member Units) in cooperation with stakeholders and local, state, and federal agencies have made significant planning efforts to improve both local and statewide water supply reliability. In 1984, YCWA started surface water deliveries to the North Yuba Subbasin and South Yuba Subbasin from the New Bullards Bar Reservoir. Following the surface water deliveries, groundwater elevations in the South Yuba Subbasin, which declined substantially (estimated 100 ft. at some locations) between 1948 and 1981 due to groundwater overdraft, returned to near historical levels. In addition to supplying highly reliable water to its local Member Units, in 1987 YCWA began transferring surface water and groundwater to other parts of the state to increase statewide water reliability. In 2001, the Conjunctive Use Pilot Project was designed to formalize the historically successful management of Yuba County's groundwater resources and to develop a framework for implementation of future activities. Funded by the California Department of Water Resources, this ongoing project is a part of a comprehensive watershed and groundwater management effort in Yuba County. YCWA has recently developed a collaborative agreement, known as the Lower Yuba River Accord (Yuba Accord), working with a broad coalition of agricultural, environmental, and fisheries interests, including state and federal agencies. The Yuba Accord, proposed in early 2005 and implemented in late 2006, improves river habitat conditions and provides YCWA with a source of revenue for activities, including an active surface and groundwater conjunctive use program. Through the past groundwater management and resource use activities, YCWA has proven its leadership role in progressively embracing the concept of sustainable groundwater management. Resource management operations implemented under the Yuba Accord further demonstrate YCWA's dedication to providing highly reliable local and statewide water supply.

Evidence for Denitrification Processes in Nitrate Polluted Groundwater (Catalonia, NE Spain) Using a Multi-Isotopic Approach

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An understanding of the origin and fate of nitrate, as well as of the biogeochemical processes controlling nitrate attenuation in aquifers, is crucial for improving water resources management, and preserving the quality of groundwater supplies and groundwater-dependent surface waters. Six vulnerable areas to nitrate pollution from agricultural sources in Catalonia (NE Spain) (Maresme, Osona-Lluçanès, Baix Empordà, Selva and Garrotxa) have been studied by coupling conventional hydrogeochemical data with a multi-isotope approach (D, 18OH2O, 15NNO3, 18ONO3, 34SSO4, 18OSO4, 13CDIC and, for the Baix Empordà samples, 11B) in a research project focused on tracking the sources of nitrate pollution and assessing the chemical reactions affecting the solutes involved in denitrification processes (NO3-, SO42- and HCO3-). According to dissolved nitrate and sulfate isotopic compositions, the main origin of nitrate pollution in the different areas are: synthetic fertilizers (Maresme; Vitòria et al., 2005), animal manure (Osona-Lluçanès, Baix Empordà), and a mixed source in Selva and Garrotxa areas. The use of boron isotopic composition (Widory et al., 2005) in the Baix Empordà demonstrated that sewage is not a potential pollution source in this area. Moreover, the coupled use of nitrogen and oxygen isotopes of dissolved nitrate confirmed active denitrification in the Osona-Lluçanès, Baix Empordà and Selva areas, being not significant in the Maresme and Garrotxa areas. The isotopic composition of the ions involved in denitrification reactions indicated a relationship between pyrite oxidation and nitrate attenuation in the Osona area. On the other hand, in the Baix Empordà, Selva and Lluçanès areas, denitrification is mainly linked to organic matter oxidation.

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Groundwater In Situ Biodenitrification Pilot Test in Fractured Media

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Nitrate pollution is one of the main concerns of the European Water Framework Directive, seeking a challenging concentration reduction goal by 2015. Many regions in Spain, some of them in the Catalan Inner Basins where this project is developed, have already reached nitrate concentrations of above the 50 ppm threshold (10 ppm N-NO3-), and nitrate pollution may currently affect 33 percent of the groundwater bodies in the Catalonia area. Therefore several management and remediation strategies are being tested in order to (a) decrease the amount of N entering the system and (b) recover groundwater resources for drinking water quality standards. Enhancing natural attenuation by applying active technologies will not only help groundwater remediation processes, but also provide data for decision-making and groundwater management. However, to apply correctly these methodologies it is necessary to have a good knowledge of the hydrogeological media. In this sense, fractured environments add an extra complexity to apply these kinds of technologies as bioremediation. We present an in situ pilot test conducted in a fractured aquifer in Osona, a hotspot for nitrate non-point source pollution located in Catalonia (NE Spain). This area is characterized mainly by fractured marls with negligible primary porosity with preferential flow through fractures. Prior to installation, a hydraulic characterization was developed at the site. Pumping test carried out with several observation wells indicate good connectivity between boreholes (S= 10-3-10-4) and a nearly similar effective hydraulic conductivity of 5 m/day. Tracer test under inducted a natural flow indicate low porosity (m= 10-3-10-4) and high velocity (30 m/day). Then, borehole and field data indicates a heterogeneous but isotropic media with low porosity and relatively high velocity. Biodenitrification system design included one extraction well (for carbon and nutrient addition), an injection well and 5 monitoring wells. Multilevel sampling points were installed at monitoring wells to determine vertical geochemical profiles prior to and during system operation. Lab-scale experiments were developed previously to determine the amount of C source and nutrients needed. The pilot test ran in natural flow conditions for 7 months by weekly addition of carbon source and phosphate. After the start-up period, nitrate levels were reduced to below drinking water standards (and later on below detection levels) in all monitoring points and all sampling levels, with vertical differences observed only in monitoring wells closed to the injection point, results that were consistent with preferential flow paths. Nitrite was temporarily detected at the site, although concentrations decreased over time. N2O was also detected. An injection event was followed for 48 hours and characterized for geochemical and isotopic analytes. Observed patterns showed an immediate decrease of nitrate levels following C and P amendment, with small vertical differences and some nitrite production, but always below drinking water standards.

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Spring Water Nitrate Content as Indicator of Hydrological Response to Agricultural Fertilization (Osona Region, NE Spain)

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Natural springs usually reflect the hydrological processes that occur at the upper subsurface layers. They are valuable indicators of the water cycle dynamics at the subsoil as well as of the response to fertilizer application to crops. In this study, we evaluate nitrate concentration in 131 natural springs of the Osona region (Catalonia, NE Spain) for a sampling period of about five years. We seek a relationship between nitrate pollution, geological setting and land use. The Osona region (1260 km2) has intensive livestock and agriculture activities, and manure production is used as fertilizer. Consequently, high values of nitrate are found in groundwater. Natural springs have been classified according to their geological setting: crystalline rocks, prequaternary sedimentary rocks, quaternary sedimentary rocks, and regional fault zones. Land uses (agricultural, forested, and urban) in the recharge areas have been considered, as well as meteorological data. Results show that nitrate concentration in spring waters ranges from <1 mg/L to 256 mg/L, with an average of 75.7 ± 67.1 mg/L. More than half of the collected samples (52.7 percent) have average nitrate concentrations higher than 50 mg/L. The highest nitrate concentrations are found in springs located in agricultural areas on prequaternary and quaternary sedimentary rocks. Flow paths through fractures or coarse-grained alluvial layers permit an effective transport from manure application areas to springs. In addition, springs in crystalline (igneous and metamorphic) rocks drain surface weathered formations as well as the underlying fractured material. As manure is seldom applied in these areas, springs are less affected by nitrate pollution. In average, nitrate concentrations decrease after drought periods, and they are particularly high when rainfall has been intense in the preceding months. This indicates that water storage on the soil plays a significant role on the spring water chemistry. High nitrate levels point out a complete transformation of organic nitrogen to nitrate, suggesting some time delay between the rainfall event and the spring response. A nitrate background concentration lower than 10 mg NO3-/L has been calculated using statistics methods This threshold value indicates that larger nitrate concentrations are due to anthropogenic sources. This project reveals the importance of spring hydrochemistry long-term databases to evaluate the effects of anthropogenic activities on groundwater quality, and the vulnerability level at specific locations. New policies on nitrate management and land-use control can be inferred to prevent spring water as well as groundwater pollution.

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Hydrological Data as a Farm-Level Decision Making Tool: Experiences from a FAO Groundwater Project in Andhra Pradesh, India

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Long-term data covering all key elements of the hydrological cycle including groundwater fluctuations and water level trends are essential for keeping track of changes and managing groundwater resources in a sustainable manner. Notwithstanding, the lack of sufficient hydrological data as a major constraint in many countries, including India, data or information generated is best put to use when the direct groundwater users have access to it, as decision making is done at the field level by individuals. Inability to access data/information encourages inaction or incorrect action. Additionally, models based on reliable hydrological data can play a central role in conflict resolution between various water users. The Andhra Pradesh Farmer Managed Groundwater Systems (APFAMGS) Project of the Food and Agriculture Organization (FAO) in India successfully innovated the idea of local groundwater governance. The project empowered groundwater users (about 15,000) in seven drought prone districts of Andhra Pradesh to rationalize the pumping to suite to the annual groundwater recharge in a given drainage basin or Hydrological Unit (HU). While data collection is carried out by trained volunteers at village level under the supervision of the Groundwater Management Committee (GMC), data storage and analysis is done at the HU level by members of the Hydrological Unit Network (HUN). Data storage is in the form of a Hydrological Monitoring Record (HMR) at the village level and at the HU level all HMRs are compiled together. The ultimate field level action is triggered by an exercise at the HU level referred to as Crop Water Budgeting (CWB) which is conducted once a year at the beginning of winter cropping season. All groundwater users in the HU are invited to participate in the exercise. Data/information sharing is done at different levels. At the village level it is in the form of wall paintings of information boards which display information on daily rainfall received, static water level and pumping rates in the wells. At the HU level (for a set of villages) boards are erected to display physical features of the HU, sections showing sub-surface strata, and results of CWB. At the district/sub-district level, data is shared with governmental departments free of charge. At the state level, data is priced for research institutes and national/international agencies to generate income for HUN to meet the expenses of operation and maintenance of data generating assets. HUN is a legally registered community-based institution built up with the membership of all groundwater users of constituent villages and hence is the owner of the data generated. As a result of project intervention, positive changes are witnessed in the groundwater balance as farmers empowered with hydrological data/information took several farm level actions to reduce pumping including: crop diversification, efficient water use, energy saving, etc. The project shows how well-trained farmers in the community not only produce reliable data (accessed even by research institutions), but also address the issue of data scarcity. The initiative resulted in unlocking of a data treasure chest of conventional data providing agencies as there is a mutual sharing of data and respect. The FAO-APFAMGS approach also addresses the issues of understaffing of data-generating agencies (because farmers collect the data) as well as regulatory authorities (farmers are informed about the spirit and need of legislation to control over-exploitation of water resources).

Green Water Management to Sustain Agricultural Production in a Changing Climate

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Agricultural production is increasingly water limited in many semi-arid to sub-humid regions. In these regions, climate change is often projected to reduce water availability further, while increasing evaporative demand, variability and extremes, as well as uncertainty in agricultural water management. Conventional blue water solutions and adaptation practices can no longer maintain productivity. In particular further intensification of groundwater pumping and irrigation is not sustainable in many regions of India, China, US and MENA. In order to produce more food for a growing and partially undernourished population, green water solutions have to receive more attention and investment. Green water productivity can be increased by improved land management and well-known practices and interventions that offer multiple benefits, such as conservation agriculture, soil and water conservation, rainwater harvesting and supplementary irrigation. Many of these solutions are more decentralized, smaller in scale and more affordable for the poor than conventional blue water options. With that they can increase diversity and resilience to climate and other disturbances. True integrated water resources management will simultaneously address green and blue water management, e.g. by integrating improved soil and land management with water harvesting and managed aquifer recharge. Finding a way to nest green water management opportunities within the development of blue water management plans is a critical challenge that will be explored.

Opportunities and Constraints to Community Regulation of Groundwater: Lessons from a Grass-Roots Project in Andhra Pradesh, India

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The pilot project "Social Regulation of Groundwater Management" was started in late 2003, almost the same time when the Andhra Pradesh Water Land and Trees Act (APWALTA 2002) came in to force. As the name says, the primary focus of the project is on community regulations, unlike the APWALTA's approach of government regulations. When the project was started, major issues of concern were 1) groundwater over-exploitation (including failure of wells and loss of investments) and 2) inequity in access to groundwater. In essence, over-exploitation by about 60-70 percent of people, while 30 percent remain as rain-fed farmers, risking crop losses in the event of droughts. Over-exploitation and inequity are two interrelated issues that clash with each other. Attempts to address one issue will have negative impact on the other. For example, when the new tube wells are restricted farmers not having wells, we are increasing inequity. Conversely, if new wells are encouraged to address inequity, over-exploitation increases. This predicament drives one normally to address only one of these two aspects separately. For example, projects like Andhra Pradesh Micro Irrigation Project (APMIP) that addresses over-exploitation by promoting micro irrigation systems but does not address inequity. APWALTA, follows the principle of Doctrine of Prior Appropriation and reinforces inequity by banning further drilling of wells in over-exploited areas. Addressing both aspects together, over-exploitation and inequity, is the challenge. In this pilot project, in 10 villages, small groups of farmers (2-3 farmers in each group) were formed. In these groups, one tube well-owning farmer shares water with his neighboring farmers, who do not have access to groundwater. Each group uses sprinkler system to save water. This saved water is shared among the new members. By and large, groundwater extraction remained the same or reduced compared to pre-project status. APMIP subsidizes sprinklers and the project provides partial support, say, Rs.2000 (approx. $40) per group to acquire sprinkler sets. Major investments are on education, training and capacity building of farmers towards a change in mind-set. In a way, the project interventions start where APWALTA stops – and goes beyond. They are not alternatives but supplementary to the law. APWALTA restricts small farmers from accessing groundwater, due to well-spacing restrictions imposed. This project confronts the Doctrine of Prior Appropriation and created rights on groundwater to all those deprived families. This is a small scale pilot, and for up-scaling of these elements at lesser costs, APWALTA needs to make a paradigm shift from this illogical and unjust approach. Integration of groundwater management into existing water management programs, such as watershed management projects, is the best way to address the issue holistically.

Socio-Economic Impact of Groundwater Pollution Due to Disposal of Textile Effluent – A Case Study from India

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The dependency on groundwater, particularly in the developing countries like India, has been increased to a great extent due to increase in population, industrialization and new agricultural practices. However, domestic and industrial wastes disposed both in liquid and solid forms in land and water bodies percolate into the groundwater and get transported in the direction of groundwater flow. As a result, different pollutants reach into the groundwater system and pose a threat to groundwater quality, which ultimately affects the socio-economic life of the people, who depend on groundwater for various purposes. The people living in a village downstream of Tiruppur have been taken as a classic example. There are about 750 dyeing and bleaching units located in Tiruppur, which discharge around 85 mld of untreated or partially-treated effluents into the Orathupalayam reservoir, constructed in 1992 across the river Noyyal and around 30 kilometers downstream of Tiruppur. In time, this reservoir continuously received textile industrial effluents from the Tiruppur area and became highly polluted. The water stored at the reservoir was rendered unfit for irrigation and fisheries owing to the high TDS and other pollutants. Hence, a study was carried out to study the socio-economic consequences of the groundwater pollution, particularly the poor and the socially-deprived communities. The quality of groundwater was analyzed in and around the reservoir which revealed that it falls under highly polluted zone. The socio-economic impact due to groundwater pollution was analyzed through focus group discussion and questioner survey. The analysis indicated that groundwater pollution has affected rural economic activities like agriculture, livestock, fisheries, unemployment and migration.

Looming Impact of Groundwater Quality Degradation on our Rural Municipal Water Supply and Ag Lands: Not a Technical Issue but a Political and Financial Issue

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For a rural community in the fruit basket of the world, its groundwater and surface water resources are critically important for both the municipal government and the agricultural economy supporting the community. The drinking water system of the city of Firebaugh in western Fresno County depends on groundwater and surface water. Groundwater quality is degrading while access to surface water is becoming increasingly more difficult because of natural droughts and man-made droughts (regulatory droughts). Political and financial issues severely limit our ability to implement technical solutions to the water shortage, which has caused the fallowing of thousands of acres and 40 percent unemployment. The drought further compounds an ongoing water crisis in this region, including agricultural drainage impacts to water quality, land subsidence, flooding, water quality degradation, groundwater recharge, and surface water conveyance issues. In addition, energy costs associated with pumping, conveyance and water treatment are burdens on the community. Our region produces 10 percent of the nation's crops and if these issues are not remediated our country will indeed face national food security worries and communities like this one will dry up.

Implications of Past Agricultural Practices on Mobilization and Transport of Selenium and Nutrients from Groundwater to Surface Waters

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The former Tustin Marine Corps Air Station (MCAS) is located in the coastal alluvial plain of Orange County California. The air station is situated in an area that historically was a swampland and ephemeral lake known as the "Swamp of the Frogs." This area was a large natural retention area that would occasionally overflow to the ocean during periods of high rainfall. Highly reducing conditions in the swamp provided an environment for long-term accumulation of selenium and other minerals that were leached and washed down from marine deposits in the surrounding hillsides. In the late 1800s, the swamp was drained by creating a series of drainage channels and the area was converted to orchards, grazing and other types of farming. Orchards were planted along the margins of the former marshland, and associated fertilization resulted in high nitrate levels in the shallow soils and groundwater. Additionally, drainage of the swamp increased the oxidation state, which promotes conversion of selenium from reduced forms (e.g., selenite) to oxidized forms (selenate). The oxidized forms of selenium are more soluble and more easily transported to drainage channels. The aquifer surrounding the drainage channels in the former "Swamp of the Frogs" is a shallow pluvial aquifer that is highly responsive to precipitation. Groundwater elevations typically peak in the spring following winter rains, and are lowest in the fall at the end of the dry season. Groundwater flows are a major source of dry weather base flows in the drainage channels which flow downstream to Newport Bay. The dry weather base flows are impaired by elevated levels of nitrate and selenium, and TMDLs have been established. Discharge of shallow groundwater to the drainage channels within the historical swamp region is the primary source of elevated levels of nitrate and selenium. The Tustin MCAS is a former 1600-acre naval installation location in the historic swamp region. It was established in 1942 to support navel blimp operations and was later converted to a Marine helicopter base. During its operation the Navy leased about 500 acres to farmers for commercial crop development, and for many years, agricultural lands surrounded the facility. Beginning in the 1980s residential and light industrial/manufacturing areas developed adjacent to the station. The Tustin MCAS was slated for closure in 1991 and operational closure occurred in July 1999. Much of the area has been conveyed to the city of Tustin, and is being redeveloped with residential, commercial, educational, and recreational land uses. Runoff management planning for the base redevelopment was constrained by elevated levels of selenium and nitrate, a byproduct of legacy agriculture, as well as flat topography and the presence of shallow groundwater. A main objective was to design and manage the storm drain facilities in a manner that does not exacerbate discharges of nitrogen and selenium to the impaired receiving streams. To accomplish this goal the following principals were used to guide design of storm drain facilities and treatment BMPs: 1) Use distributed treatment BMPs that will treat runoff before it enters the storm drain system. 2) Avoid infiltration BMPs and groundwater recharge to the extent possible. 3) Use at-grade vegetated systems such as swales, bioretention, flow-through planters that provide effective treatment, aesthetics, and avoid ponding.4) Avoid infiltrations into storm drain facilities.

Nitrate Reduction in a Groundwater Dominated Catchment: How Good are Our Models?

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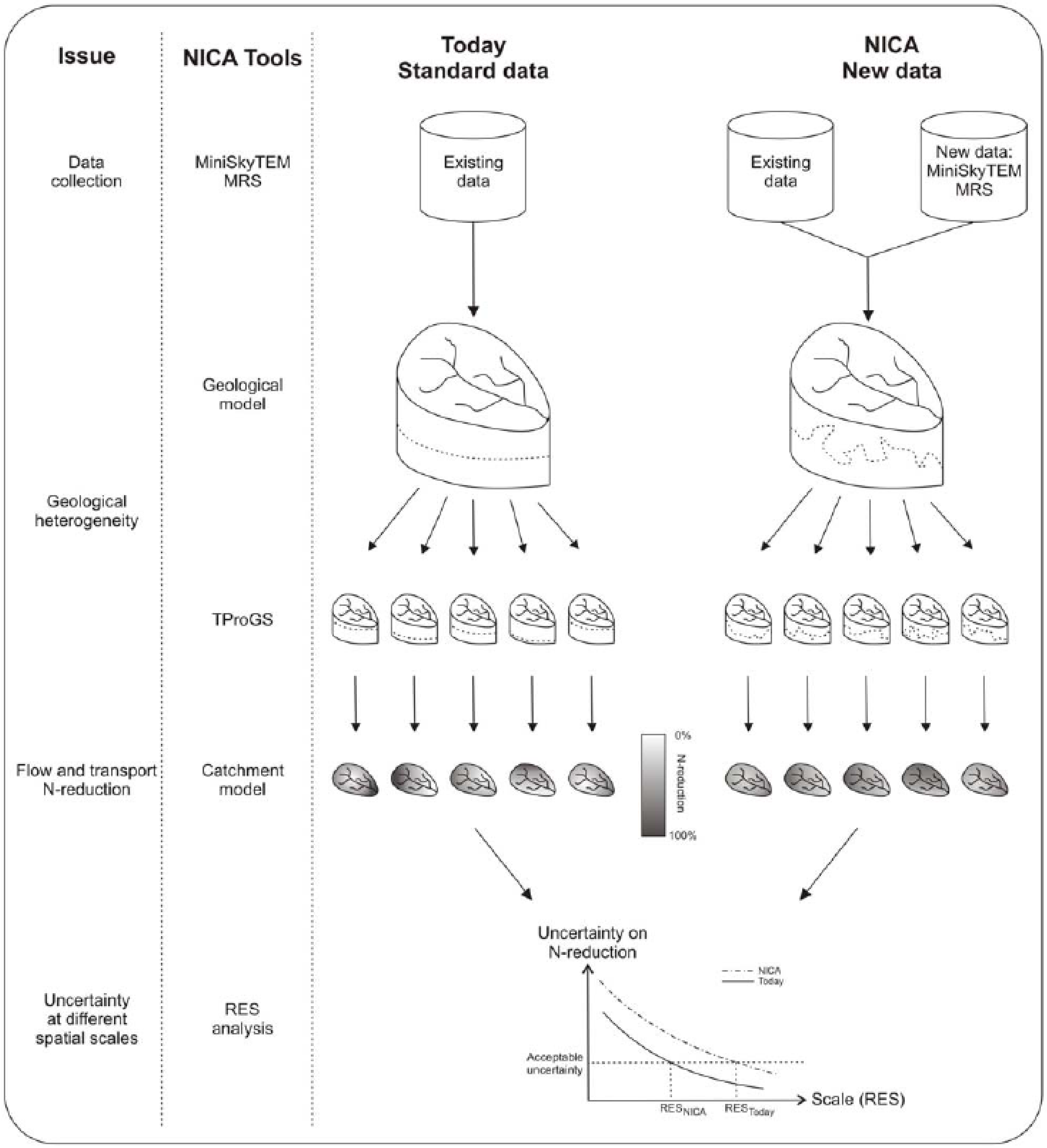
The nitrate load from agricultural land to lakes and coastal water in Denmark has, during the past 20 years, been reduced by about 50 percent by government regulations imposed on agricultural practice. The EU Water Framework Directive (WFD) requires that good ecological status be achieved for all water bodies by 2015 and prescribes that surface water and groundwater resources are managed in an integrated context. This will require an additional reduction of nitrate load by 50 percent, which economically will be very painful for the agricultural sector. The regulations imposed until now have been general, i.e. the same restrictions for all areas independent on the subsurface conditions. Studies have shown that on a national basis about 2/3 of the nitrate leaching from the root zone is reduced naturally in the subsurface before reaching the streams. This implies that if a general agricultural regulation reduces nitrate leaching by 100 kg N, the nitrate load to surface water will only be reduced by 33 kg N. Therefore it is much more cost-effective to identify robust areas, where nitrate leaching through the root zone is reduced in the saturated zone before reaching the streams, and vulnerable areas, where no subsurface reduction takes place, and then only impose restrictions on the vulnerable areas. Distributed hydrological models can make predictions at grid scale, i.e. at much smaller scale than the full catchment. Hence these models have a potential for being able to differentiate between robust and vulnerable areas. However, in all previous studies we have seen, distributed models do not have predictive capability at scales much smaller than the catchment scale. A constraint in this respect is that distributed models often do not include local scale hydrogeological heterogeneities that are known to be important for reactive transport. NICA (Nitrate reduction in geologically heterogeneous catchments) is a new research project that will develop tools for assessing nitrate reduction in the subsurface between the root zone and the streams and methodologies for assessing at which spatial scales such tools have predictive capabilities (see the enclosed figure). A new instrument will be developed for airborne geophysical measurements, MiniSkyTEM, dedicated for identifying geological structures and heterogeneities in the upper 30 m. State-of-the-art hydrological models (DAISY, MIKE SHE/MIKE11, HydroGeoSphere, RWHET) will be applied and the effect of geological heterogeneity will be analyzed by use of stochastic geological realizations such as TProGS. A new concept, Representative Elementary Scale (RES), will be developed for assessing the minimum scale at which models, with a given data input, potentially have predictive capabilities. The studies will be conducted in a 10 km2, densely instrumented catchment and tested in a 101 km2 catchment, where farmers and authorities will be actively involved in evaluating possible measures for reducing the nitrate load to surface water in a cost-effective manner. The economic gain from a cost-efficient location of the measures will be evaluated. The talk will present the policy background, the methodology, the case areas and preliminary results.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Standard data
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Scale (RES)

Relationship between Farm Management, Nitrogen Surplus, Nitrate Concentrations and Economic Performance of Dutch Dairy Farms on Sandy Soils

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The production process of milk on a dairy farm is inevitably associated with losses of nitrogen (N) to the environment. These losses can compromise the quality of groundwater and surface water. Actual losses of nitrogen in the field are determined by many factors in which the management decisions of the farmer play a decisive role. In the Dutch Minerals Policy Monitoring Program (LMM), data are collected on both farm management and water quality at farm level. During the period of 1991-2006 this program has collected data for approximately 250 dairy farms (1500 year measurements) in the sandy region. In the current study, linear regression analysis was used to study to what extent nitrogen surpluses and nitrate concentrations on dairy farms in the sandy region of the LMM program are affected by differences in farm management. Also the relation with the economic performance of the farms was investigated. The results of the study are summarized in Table 1. This table gives the effect of all farm management characteristics that were included in the Fixed Effects regression model for the explanation of the variation in nitrogen surpluses and nitrate concentrations. The FE model uses the variation within the firms. The results show that farm management explains 67 percent of the variation in nitrogen surpluses. Decreasing the fertilization level, both in terms of organic and artificial fertilizer and increasing the yield of fodder crops have the largest effects on the nitrogen surplus. For nitrate concentration 51 percent of the variation could be explained by farm management. Reducing the fertilization level on grassland (especially artificial fertilizer) had a significant effect on the nitrate concentrations but also other management characteristics such as the percentage of land that is used as grassland, the milk production level per cow, the percentage of grassland that is mowed, the concentrate use per kg milk produced and the manure storage capacity (expressed in months) affected nitrate concentrations. Management practices that increase the efficiency of manure, either by reducing the fertilization level or by increasing the yield of the fodder crops, appear to be not only environmentally attractive but also economically, as the effects on economic performance have the same direction.

Farm management		Environmental performance*		Economic performance*	
Management characteristics	Range 5-95%	Nitrogen surplus	Nitrate concen-tration	Gross margin	Net result
Farm size (DSU**)	34-192		-18	-5.3	+10.8
% LSU pigs/poultry of total LSU**	0-49.7	+13			-6.0
% market crops of total area	0-15.7		-16		-3.9
% grassland of total area	50.3-100	+57	-41	-2.1	
Capacity manure storage in months	2.8-12.8		-12		-6.9
Kg N-artificial fertilizer/ha grassland	87-375	+170	+31	-1.7	
Kg N organic fertilizer/ha	198-436	+132	+6	-0.9	+3.4
Kg milk per cow per year	5245-9394	+20	-34	-1.2	+12.9
Feed units concentrates/100 kg milk	21-45	+32	+26		
Mowing percentage	113-424		-22		
Yield in feed units/ha fodder crops	6234-12914	-102		+4.7	+4.7
R^2 of the FE model		67	51		

* the green color indicates a positive effect of increasing the specific management characteristic on the performance, the red color indicates a negative effect.
** DSU = Dutch Size Units. LSU = Livestock Size Units

Table 1 Explaining variables for nitrogen surplus per ha, nitrate concentration in mg/l in the upper groundwater, gross margin and net result in € per 100 kg milk, with the range 5-95% and the effect over the range according to the Fixed Effects (FE) model: dairy farms on sandy soils

Evaluation of Numeric and Integrated Models for Applications in Texas

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Previous studies have demonstrated the efficiency of optimizing surface and groundwater use in conjunctive strategies, particularly in agricultural regions. However, because numeric models have not typically been used to assess the overall efficacy of conjunctive use, this study evaluates conjunctive use/management in a new light by examining physical water system models and providing insights for future conjunctive management efforts, particularly in regions with limited or no conjunctive management programs. Models can play a significant role in planning and operating conjunctive water management programs. Previous models and programs include physical systems, water balances, numeric multi-objective algorithms for decision-making and integrated models. Optimization approaches for addressing sufficient water supply distribution, storage, and/or economic target issues also were assessed. This evaluation provided a summary of each model considered, study goals, model components, optimization criteria, and major results. Model selection for this study was based on two primary criteria: (1) emphasis was placed on evaluation of water resources as a system; and (2) the project or model must explicitly recognize conjunctive surface water and groundwater applications. Based on these criteria, 15 models were assessed. Evaluation and comparison of the physical water balance models highlighted the following (see attached table): "Model areas and programs are found in differing geographic locations, ranging from the tropics to arid climates with associated precipitation variations;" Model evaluations indicated a range of physical settings and surface water and groundwater characteristics; and "Interconnections between stream-aquifer systems, alluvial water systems, and shallow, unconfined groundwater systems were common to many models and programs. This study also evaluated the optimization targets and overall goals of each model or program. Of the 15 models and programs, 11 recognized improved water management goals from including conjunctive strategies. While these study results indicate a wide applicability of conjunctive surface water and groundwater management, a more detailed assessment of integrated models, economics and legal frameworks for water management suggest historic limitations on conjunctive use in Texas may be based on factors other than water use efficiency. Accordingly, existing Texas programs also were examined. Their long-term success, combined with these study results regarding models and programs from other regions and the economic efficiencies of groundwater storage to buffer water stresses, indicate conjunctive use will become a viable water management strategy in specific regions of Texas, as well as other areas that previously utilized only limited conjunctive programs.

Study Area			
Model / study locations	Aral Sea, Arkansas River (2), Central Valley, CA (4), China (1) India, east coast (1), West Sumatra, Indonesia (1), Rio Grande Basin (2)		
Data Set	**Low Range**	**High Range**	**Unit**
Historic flow data	6	> 100	years
Area of study	49	8,784	km^2
Regional precipitation	10 - 25	120 - 290	cm / yr

Water uses in modeled systems:

Predominant - agriculture, municipal/urban, flood control

Other: environmental, fish hatcheries, hydropower, domestic, livestock, coal washing, thermal power, forestry

Surface Water Systems			
Data Set	**Low Range**	**High Range**	**Unit**
Number of rivers/streams	1	>20	
Average flow rate (seasonal)	0	2,650	m^3/s
Infiltration	0.59	0.74	m^3/s
Stream-aquifer connectivity		12 of 15	studies
Groundwater Systems			
Data Set	**Low Range**	**High Range**	**Unit**
Number of GW basins	1	>28	basins
Recharge *	0.03	250,000	m^3/s
Saturated thickness	0	200	m
Hydraulic conductivity *	61	243	m/d
Specific yield	0.1	0.3	[dimensionless]
Storage coefficient	10^{-4}	10^{-1}	[dimensionless]
Water table evaporation		5 of 12	studies
Pumping yields	0.006	10.2	m^3/s
Total annual pumping	1.92	703	Mm^3 / yr

* Models did not typically report between lateral and vertical components.

Table 1. Data Ranges from Selected Conjunctive Use Models

In-stream Bioreactor for Agricultural Nitrate Treatment

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Nitrate from agricultural activity contributes to nutrient loading in surface water bodies. This study describes ongoing monitoring of a novel in-stream bioreactor that uses carbonaceous solids (woodchips) to promote denitrification of agricultural drainage. The reactor (40 m3) was trenched into the bottom of an existing agricultural drainage ditch in southern Ontario (Avon site) and a cobble riffle was used to induce flow through the reactor. Monitoring in the second and third years of operation and a comparison of laboratory measured reaction rates for the Avon media and other woodchip bioreactors that have been in operation for up to eight years, suggests that such reactors have the potential to sustain removal rates on the order of 25-250 mg N m-2 hr-1 over decadal timeframes. These removal rates substantially exceed those reported for constructed wetlands. Stream channel narrowing using cobble rip-rap eliminated a siltation problem experienced during the first year of operation. Recent monitoring shows that such in-stream bioreactors can generate greenhouse gases, N2O and CH4, at rates similar to other N-rich agricultural and aqueous environments and can generate methyl mercury at rates similar to other wetland environments. However, production of these potentially undesirable secondary constituents can be reduced or eliminated by control of the redox condition within the reactor. This is easily done at the Avon site using an adjustable height outlet pipe which allows flow through the reactor to be controlled. In-stream bioreactors are simple to install and maintain, they can utilize existing agricultural drainage networks and they could be suitable for larger scale applications. They could also work well in combination with other nitrate control methods such as the use of constructed wetlands.

Restoring and Maintaining a Lake's Oxygen Supply Using the RezOX gPRO H2O Oxygenator

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As a result of warm and stratified lake conditions in the summer, lakes become anoxic and result in algae blooms, which create unsightly lake conditions including taste and odor problems, and increased filtration costs for treating the lake water for municipal drinking water. The drop in dissolved oxygen levels in lakes as the summer temperatures increase further reduces the area for fish habitat and increases the dissolution of toxins and minerals into the water. Traditional methods of using chemicals such as copper sulfate are costly and can be ineffective. The use of floating water pumps to mix the water is not only slow but ineffective at addressing the root of the problem as they also tend to increase nitrogen levels in the water. The natural loss of oxygen in the lake water needs to be replaced by the addition of pure oxygen and not other methods such as mixing, or chemical means to bring the dissolved oxygen levels back up to a healthy lake conditions. Injection of air or oxygen has traditionally been costly due to ineffective means to deliver the oxygen to the reservoir. However, the patented gas infusion technology from iNVentures Technologies has been used for years in the aquaculture industry and has been adapted for restoring lakes to healthy habitats where fish and wildlife can thrive, while maintaining the lake's ecosystem to deliver water for drinking water purposes without extensive filtration and addition of chemicals due to poor lake conditions. This paper presents the technology and benefits of maintaining a lake's water quality using the patented gas infusion technology.

Quantifying the Performance of Regional Scale Reductions in Nutrient Applications for Source Water Protection through Vadose Zone Monitoring

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In some agricultural areas in Ontario, Canada, excessive application of nutrients have negatively impacted underlying groundwater quality and associated municipal water supplies. Source Water Protection strategies have included the implementation of Beneficial Management Practices (BMPs) involving regional scale reductions in nutrient applications to reduce the risk to municipal water supplies. Assessing and quantifying the effectiveness of these region-scale BMPs, both spatially and temporally, have been problematic due to lengthy response times and multivariate heterogeneity. We have developed a novel approach for rapid assessment of BMP performance by tracking spatial and temporal variability in stored nitrate mass within the vadose zone beneath agricultural lands where significant reductions in nutrient application have been implemented. The project was based on field activities conducted in the vicinity of the Thornton Well Field near Woodstock, ON. Groundwater from several of the production wells at the site have chronically high levels of nitrate, likely as a result of the leaching of excess nitrate from the surrounding agricultural lands. Local county officials purchased land within the wellhead protection area of this municipal drinking water supply in 2002 and implemented a nutrient management plan that involved an average reduction of between 40 percent and 50 percent in total applied nitrogen. To monitor the influence of the reduced nutrient loadings, continuous cores were extracted from a series of locations (field stations) throughout the study site. The cores were sub-sampled and analyzed for nitrate pore water concentration and soil moisture. Cores were repeatedly collected at each of the stations over a period of four years to track changes in subsurface nitrate soil concentrations. At the end of four-year period, the average nitrate concentrations within the vadose zone were initially 22 mg NO3--N/L and subsequently decreased to 8 mg NO3--N/L, a reduction of over 60 percent. Overall total stored mass was documented to have decreased between 20 percent and 60 percent over the field site. Estimated point-scale nitrate mass flux values over the time period show an average 45 percent reduction which compares well to the estimated 40 percent to 50 percent reduction in nitrogen application. Regional-scale flow and transport modeling suggests that a 20 percent decrease in the average municipal well nitrate concentrations will ultimately be achieved, however, the full benefit of the BMPs will not be realized at the wells for between five and 10 years after the initiation of the nutrient reduction. Overall, these field and modeling results indicate that the implementation of BMPs in selected areas within municipal capture zones is a promising strategy to reduce the impacts of agricultural nutrients at supply wells. This approach can be applied to other well fields to provide insight with respect to the magnitude and timing of water quality changes and assist in water resources management decisions.

Agricultural Irrigation Management in Semi-arid Areas

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The aim of soil salinity control is to prevent soil degradation by salinization and reclaim already salty soils. The primary man-made cause of salinization is poor agricultural irrigation practice and water conservation. River water or groundwater used in irrigation contains dissolved salts, which remain behind in the soil after the water has been utilized due to crop evapo-transpiration. The primary method of controlling soil salinization is to waste up to 20 percent of the irrigation water to leach salt from the soil. This leachate has to be drained and discharged through an appropriate drainage system or it percolates to the ground water. The salt concentration of the drainage water is up to 10 times that of the irrigation water. If this practice is utilized, salt export matches salt import and it will not accumulate. Obviously, irrigation conservation practices such as drip irrigation only accelerate this problem. However, the sink for this evaporite suffers the consequences of either salt buildup or substantial salinity increase in the receiving water body. Based on the FAO/UNESCO Soil Map of the World, the magnitude of poor salinity control is demonstrated by a real impact on the World's soils that already exhibit salinization as follows: Region Salinized Area (10^6 ha)Australia 85Africa 70Latin America 60Middle East 50Europe 20Far East 20North America 15. To address a problem of this magnitude, the preparation of salt and water balances for distinguishable sub-areas under irrigation and the use of agro-hydro-salinity models is critical to minimizing the impacts of and extent/severity of salinization. This paper discusses the soil/water chemistry of irrigation and the use of agro-hydro-salinity models in the management of modern irrigation practice, especially when combined with food plant processing wash water disposal. Practical guidance will be provided based on the experience of the author at over 100 types of agriculture and food processing facilities located through the world.

Can Groundwater Protection and Agricultural Production Co-Exist Over Vulnerable Aquifers?

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The Abbotsford Aquifer is a vulnerable water supply aquifer whose average nitrate concentrations have exceeded drinking water standards for more than 15 years. The long-term groundwater nitrate monitoring shows little overall trend with time, although shorter-term fluctuations in the shallowest monitoring points suggest management can affect groundwater nitrate concentrations locally. Soil nitrogen budgets show excess nitrogen is available for leaching. Although there is consensus that agricultural management practices have changed in the past few decades, there is no objective assessment of their extent or whether they are affecting change in the aquifer. It is unclear if adoption of best agricultural management practices alone will be sufficient to protect water supplies in this vulnerable aquifer. Contaminated groundwater flows south across the international border, making it a long-term transboundary issue. We have been working towards delineating and monitoring groundwater nitrate leached from a particular field in order to directly link soil management with groundwater impacts. This work, and complementary numerical modeling efforts, will provide insights into the agricultural management and climatic controls on nitrate leaching. However, there is currently little effective policy or legislation to deal with the ongoing situation. If groundwater protection requires changes to management practices that put growers at an economic disadvantage in global markets, how then do we move forward?

Satellite and Ground-based Approaches for Monitoring Impacts of Agriculture on Groundwater Resources

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Increased intensity of the hydrologic cycle predicted by climate change models should reduce reliability of precipitation, soil moisture, and stream flow because of longer-term droughts interspersed with intense droughts. As a result, reliance on groundwater may increase in the future. Irrigated agriculture is the dominant consumer of global groundwater resources. Sustainable development of groundwater resources requires quantitative estimates of the rates that groundwater is being renewed or groundwater recharge rates. Impacts of land use change and climate variability/change on groundwater recharge need to be considered. In addition, water quantity and water quality issues need to be addressed to fully assess water availability. This presentation will focus on various techniques that can be used to assess groundwater resources with examples from different regions globally. The Gravity Recovery and Climate Experiment (GRACE) provides a valuable tool for monitoring changes in total water storage (TWS), including surface water, soil moisture, and groundwater at 10 d to monthly timescales. By comparing GRACE TWS with output from the Global Land Data Assimilation System, temporal variations in groundwater storage can be estimated. Use of GRACE to monitor seasonal changes in groundwater storage in the U.S. High Plains related to irrigation will be compared with groundwater depletion estimates from NW India published recently. In addition, uncertainties related to GRACE processing and GLDAS modeling will be examined. Groundwater hydrographs provide valuable information on changes in groundwater storage in response to land use change. Increasing groundwater levels in response to changes from natural grassland/shrubland ecosystems to rain-fed agroecosystems in the U.S. High Plains will be described. Large scale groundwater level declines (? 1.4 m/yr) have also been recorded in areas of irrigated and indicate that irrigation pumpage is not sustainable in some parts of the High Plains aquifer. Groundwater solute hydrographs also record changes in water quality in response to cultivation with increasing salinity and nitrate levels in the High Plains aquifer. Unsaturated zone profiles provide a time-integrated record of past impacts of land use change on recharge and solute fluxes at decadal to millennial timescales. Lack of recharge under natural ecosystems in the U.S. High Plains is shown by bulge-shaped accumulations of chloride in the subsurface in response to changing climate from Pleistocene to Holocene times about 10,000 to 15,000 years ago. Increased recharge after conversion to cropland is recorded by downward displacement of these salt bulges and development of nutrient bulges. Irrigation in this region results in accumulation of salts and nutrients that are similar in magnitude to those beneath natural ecosystems but accumulated over decades rather than the millennia represented by bulges under native vegetation. Unsaturated zone data provide an extremely valuable record of water, salt, and nutrient fluxes that link land surface practices and groundwater quantity and quality. The various approaches for monitoring groundwater quantity and quality cover a range of space and timescales and can be used to determine approaches toward sustainable management of groundwater resources. Recharge estimates under different land use settings can be used to determine what level of irrigation application is sustainable in semiarid regions.

Comparison of Irrigated Agriculture in the U.S. High Plains and North China Plain

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Irrigation is widespread in the U.S. High Plains and the North China Plain (NCP) with large scale depletion of groundwater resources during the past few decades. Comparison of these two regions can provide insights into controls on water quantity and quality issues related to irrigation practices and paths toward sustainable irrigation management. Irrigation in both regions consumes up to 90-95 percent of the water supply. Irrigation in the NCP was primarily supplied by surface water originally in the late 1950s and early 1960s. Groundwater-fed irrigation has been expanding since the 1960s and currently supplies up to 80 percent of irrigation water in some regions. Groundwater level declines 0.7 m/yr were recorded in many regions, resulting in stream channels drying up. Irrigation in the U.S. High Plains is derived primarily from groundwater with water table declines 1.4 m/yr in areas of intense irrigation where the aquifer was originally thick. Soil water salinity in the NCP is generally low and is attributed to relatively high quality irrigation water and application of sufficient water to flush salts. Irrigation water is applied in the winter to wheat whereas most precipitation occurs during the summer monsoon; therefore, precipitation can also flush salts that accumulate from irrigation. In contrast, irrigation water in the southern High Plains, the area of most intense groundwater depletion, has a relatively high salt load and large salt bulges (Cl, ClO4, SO4) are accumulation in the soil profile. These salt bulges are accumulating much faster, at decadal timescales, than the rate of salt accumulation under natural ecosystems, at millennial timescales. The accumulation of salts is attributed to poor quality irrigation water, deficit irrigation, and lack of flushing from precipitation which is coincident with crop growth and irrigation in the summer. Both the NCP and the High Plains record a large accumulation of nitrate in the soil profile, which is attributed to over-application of fertilizers and failure to account for nitrate in irrigation water. Both systems are evolving from initially open systems with discharge to rivers to more closed systems with declining water tables and reduction in groundwater discharge to rivers and springs. Groundwater quality is projected to degrade much more in the future with mobilization of salts and nutrients that are currently measured in the soil profile into the underlying aquifer. Declining groundwater tables will reduce the assimilative capacity of the aquifer, further exacerbating water quality problems. Groundwater quantity and quality issues will have to be considered when developing more sustainable irrigation practices in the future.

Impacts of Rain-fed and Irrigated Agriculture on Soil Water and Groundwater Salinity

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Cultivation can have large-scale impacts on accumulation and mobilization of naturally occurring contaminants in semiarid regions. Therefore, agricultural management needs to consider both soil water and groundwater quality, in addition to quantity, when developing sustainable management programs. Natural ecosystems accumulate salts, including chloride (Cl), perchlorate (ClO4), sulfate (SO4), and fluoride (F), and sometimes nitrate (NO3) from meteoric sources in soil profiles over millennia due to lack of recharge since past glacial times 10,000 to 30,000 yr ago in the SW US and SE and SW Australia. Conversion of natural ecosystems to rain-fed agroecosystems increased recharge in many of these semiarid regions, mobilizing these salts into underlying aquifers. Examples of groundwater salinization from this process are found in the Murray Basin in Australia and in the High Plains aquifer in the U.S. Some salts are not readily mobilized by this process because of sorption, including F. Cultivation can also create N reservoirs by mineralization and nitrification of soil organic nitrogen, as in the southern High Plains. Groundwater-fed irrigation can also impact salinity and nutrients by further mobilizing salt inventories that accumulated under natural ecosystems into underlying aquifers. Irrigation practices can also redistribute salts from aquifers to the soil zone. Soil profiles under irrigated agriculture in the southern High Plains show that large salt bulges have been accumulating since irrigation began. Development of these salt bulges is attributed to the similarity of evapotranspiration (ET) and desalination processes, with most salts being excluded during ET. The residual drainage or percolation from irrigation is highly concentrated in salts. For example, irrigation systems that are 50 percent efficient with respect to drainage would result in doubling of salt concentrations in drainage water. Systems that are 95 percent efficient, the upper limit of sprinkler systems, would result in increases in salt concentrations by a factor of 20 in drainage water. Inventories of Cl under irrigated agroecosystems are similar to those under natural ecosystems but accumulated over 50-60 yr from irrigation relative to 10,000-15,000 yr under natural ecosystems from precipitation. Perchlorate behaves similar to Cl with high correlations between the two. Sulfate mobilization lags that of Cl because of sorption onto soils. Fluoride is generally not mobilized and accumulates near the soil surface because of strong sorption. Large NO3 bulges are also found under irrigated cropland because of over application of fertilizers. Although groundwater systems are originally open systems with discharge to springs and streams, irrigation pumpage lowers water tables and ultimately results in closed groundwater basins with all discharge occurring through groundwater pumpage. Therefore, salts cannot be discharged from the groundwater system but are instead recycled through the system. Artificial drainage systems cannot be used to remove salts from the soil zone because flow is unsaturated. Groundwater quality is projected to degrade much more with future mobilization of the salt inventories currently measured in the soil zone. Declining groundwater levels caused by irrigation will further exacerbate the salinity problems by reducing the assimilative capacity of the aquifer. Soil water and groundwater quality need to be considered when developing sustainable irrigation practices.

Water Supply Enhancement Project for the Poso Creek Integrated Regional Water Management Plan Region

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This paper provides an overview of the Water Supply Enhancement Project (Project) for the Poso Creek Integrated Regional Water Management (IRWM) Region (Region). The Project involves implementation of both non-structural and structural measures identified in the Poso Creek IRWM Plan. A combination of local, private, state, and federal funding sources are being utilized to fund the implementation measures. The Region is located in north Kern County and southern Tulare County of the Southern San Joaquin Valley, California, and contains predominately agricultural districts with 347,000 irrigated acres out of 500,000 gross acres. The managed water supplies for districts within the Region include: Local: Kern River, Poso Creek, and the common groundwater basin; State: State Water Project (SWP) via the California Aqueduct; Federal: Central Valley Project (CVP) via the California Aqueduct and the Friant-Kern Canal. Court-ordered actions and hydrologic droughts in California are causing a decrease in available surface supplies to agricultural, urban, and environmental water users. Implementation of the Project is needed to off-set existing and projected losses to surface supply reliability and to conserve groundwater. Since the Region is located at the crossroads of the California Aqueduct, Friant-Kern Canal, and the Kern River, it is an ideal location for conjunctive management

Managed Aquifer Recharge as Tool for Sustainable Management of Ground Water Quantity and Quality in Agricultural Basins

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Managed aquifer recharge (MAR) is used to augment water supplies and limit the adverse impacts of groundwater overdraft in many basins. As groundwater demands continue to increase and MAR projects become more common, it is increasingly difficult to secure pristine sources for MAR throughout the year. Instead, resource managers must explore options for using MAR sources such as stormwater runoff, treated wastewater, and supplies influenced by agricultural activity. Many such sources are impaired by elevated nutrient concentrations and thus there is a need to understand the conditions under which the quality of managed recharge can be improved. In this study, we quantify the rates and controls on denitrification during MAR with an emphasis on the load reduction that occurs during infiltration. Our study site includes a 3 hectare percolation pond located in central coastal California into which excess flows are diverted from a nearby wetland during the rainy season. Recharged water passes through a 20 to 30 m thick vadose zone below the pond and enters a perched aquifer from which it is recovered and distributed to local growers. The concentration of nitrate in diverted wetland water is generally between 10 µmol and 100 µmol but values over 1000 µmol have been observed. Major element and stable isotopic analyses of infiltrating water and groundwater in combination with point measurements of infiltration indicate considerable spatial and temporal variability in hydrologic and geochemical conditions beneath the recharge pond. Nitrate concentrations are consistently reduced by 50-90 percent during infiltration. Nitrate isotopic analyses suggest that most of this reduction in nitrate concentration results from denitrification. The average rate of denitrification during infiltration was 30 µmol N/L/d, although rates as high as 200 µmol N/L/d were observed. While denitrification rates were highest at high infiltration rates, denitrification was most efficient at reducing nitrate concentration when the rate of infiltration was between 0.2 m/d and 0.5 m/d. At most sample locations denitrification was not observed when the rate of infiltration exceeded 0.75 m/d. Despite high concentrations of dissolved organic carbon (DOC) in the recharge water, modest reductions in DOC during infiltration suggest that solid phase materials may also supply electron donors for denitrification in this system. Integration of physical and chemical data indicates that denitrification may result in a 50percent reduction in the nitrate load delivered from the pond to the underlying aquifer. Collectively, these data suggest that denitrification during managed aquifer recharge may be an effective tool for achieving regional nutrient load reduction goals.

Groundwater Overdraft in Mexico: Climate, Energy, and Population Drivers

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Over 100 of Mexico's principal aquifers are overexploited, up from one-third of that number in 1975. This paper assesses data for 288 aquifers across Mexico and considers the groundwater balance implications of changing climate, electrical energy supply, and growing population. Climate change and variability of surface water intensify groundwater use by increasingly shifting consumptive demand to groundwater while the impacts of climate change on recharge are poorly understood. Electrical energy supply and pricing are primary enabling factors behind groundwater pumping for irrigation – the largest user of groundwater in Mexico. Three of the four states with the highest energy demand for irrigation pumping are located along Mexico's border with the United States, where energy and groundwater demand continue to rise. The rise in commercial export-oriented agriculture raises questions about trade policies with the U.S. that appear to increase agricultural water demand in Mexico. At the same time, groundwater is an important source of urban water supply, placing cities in competition with agriculture for groundwater. Policies to make an impact on groundwater overdraft must focus on the water-energy nexus. Off-peak (night-time) energy use for pumping has increased significantly since time-of-day metering and differential tariffs were introduced starting in 2003, with significant negative implications for groundwater sustainability. Assessments of groundwater titling and user-based groundwater management initiatives suggest that awareness of groundwater depletion is increasing; however, groundwater sustainability remains an elusive goal.

Strategies for Efficient Irrigation to Protect Groundwater Resources

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Agricultural practices can affect groundwater most directly by over-drafting aquifers and percolating contaminants. Both of these possibilities are mitigated by irrigation practices. We discuss the role of irrigation system operations and maintenance in the broadly observed contamination of aquifers with agriculturally-source nitrogen. Though rarely addressed in the literature, system maintenance is shown to be pivotal to groundwater quality protection. Benefits of such efforts include substantial economic cost reductions and yield increases. New soil distributed moisture measurement methods are presented which point the way to ever more precise management of irrigated lands. Examples of the issues discussed are drawn from field projects conducted over the past 10 years in Oregon.

Groundwater Irrigation and Small-holder Agriculture: India's Experience and its Implications for Sub-Saharan Africa

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This paper argues that making available 3-5 million small-scale, mechanized groundwater irrigation structures can revolutionize small-holder farming in Sub-Saharan Africa. Instead of fancy canal irrigation systems, small-scale groundwater development can quickly improve food and livelihood security for Sass poor and make droughts history without posing any significant environmental threat. Groundwater irrigation using small pumps and boreholes has revolutionized small-holder farming in South Asia. For a long time, it was widely thought that intensive groundwater irrigation is confined to rich alluvial aquifer systems of the Indo-Gangetic basin; as a result, the South Asian experience was thought irrelevant for small-holder agriculture development in Sub-Saharan Africa, which is mostly underlain by a variety of low-yielding hard-rock formations. Hard-rock areas, 65 percent of the Indian land mass below the Vindhyas too have low groundwater yield, unsuitable for large-scale resource development. However, in India, these have experienced a veritable boom in groundwater irrigation which has emerged as the mainstay of its small holder farming livelihoods. The likely reason is that while low-yielding hard rock formations may be unsuitable for producing a large volume of water at a point in space, they are amenable to small-scale development in a dispersed format. The question is: if low-yielding hard rock formations have served small holders in India well, why should they not be developed for supplemental irrigation in Sub-Saharan Africa which has a comparable rainfall regime. The stock response is: the "precautionary principle"; that Sub-Saharan Africa will face the same problems of over-exploitation of the resource as is increasingly evident in hard rock areas of India. We suggest this is unlikely to be the case; that the pressure on groundwater resources in India is determined by the high ratio of farming to total areas (at 50 percent or more) which in turn is the outcome of high population density. Sub-Saharan Africa has less than 5 percent of its landmass under plough; moreover, small-holder farming in tiny pockets is spread thin over a vast terrain resulting in a moderate non-point demand for groundwater. If anything, SSA's groundwater resource will come under threat from municipalities or large-scale commercial farmers that represent high point-demand. Small-scale groundwater development would be an ideal, low-cost alternative for quickly uplifting small-holder agriculture in SSA, where developing canal irrigation is expensive because of low population density.

Impact of State Regulation on Groundwater Exploitation in the 'Hotspot' Region of Punjab, India

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Groundwater resources, believed to have played an important role in Green revolution-induced agricultural productivity rise in India, is under serious threat due to overdraft, especially in the food basket states. Continued unregulated exploitation of this limited resource brought Indian Punjab into a state of acute water crisis, with 90 percent of the area experiencing falling water tables. Homogenized cropping (rice-wheat) followed in the state, with water-guzzling rice being the highly favored crop in the hot summer season (kharif) along with free energy supply to the farms, is the most to blame for this resource crisis. The plunging water levels and near-bankrupt energy supply utilities led the state government to regulate groundwater use by direct and indirect measures. The Punjab Preservation of Sub-soil Water Act-2009 is such an effort to conserve groundwater resource by mandatory shifting of the transplanting date (beyond the 10th of June) of paddy to periods of low evapo-transpiration (ET) demands. The Act also has a penalty clause (imposition of fine and recovery of the cost of uprooting the crop) for the non-adhering farmers. The present paper investigates the potential of the act in bringing about anticipated real water savings. It also looks at the impact of this water management option on agricultural energy consumption. The analysis showed that a net ET gain of 14 mm to 90 mm could be obtained by a delayed transplanting of 1 to 6 weeks. ET demand of the crop reduces by 1.8, 2.4, 3.5, 6.1, 8.6 and 9.3 percent through shifting of transplanting dates by 1 to 6 weeks (Fig. 1). When the whole rice cropped area (2.62 M ha) of Punjab followed the late transplanting by the 10th of June, the net water savings of 2,180 million cubic meter were achieved resulting in a saving of 7 percent in annual groundwater draft. This would potentially check the water table decline by 60 to 65 percent. This shall also lead to a saving of about 175 million KWh of energy used for pumping with no loss in rice productivity. Poor and marginal farmers are likely to have relatively higher economic benefits by this saving in electricity, as they spend a higher proportion of their household income on purchase/ renting of pumps. Although, it is still early to evaluate the impacts of such a novel act in a democratic setup, there are prima facie reports citing effective implementation with only 0.6 percent early transplanters up to end of May 2008 when the Act was introduced as an Ordinance. The study further recommends that rather than a single way of responding; delayed transplanting ought to be integrated with other demand management options for added gains.

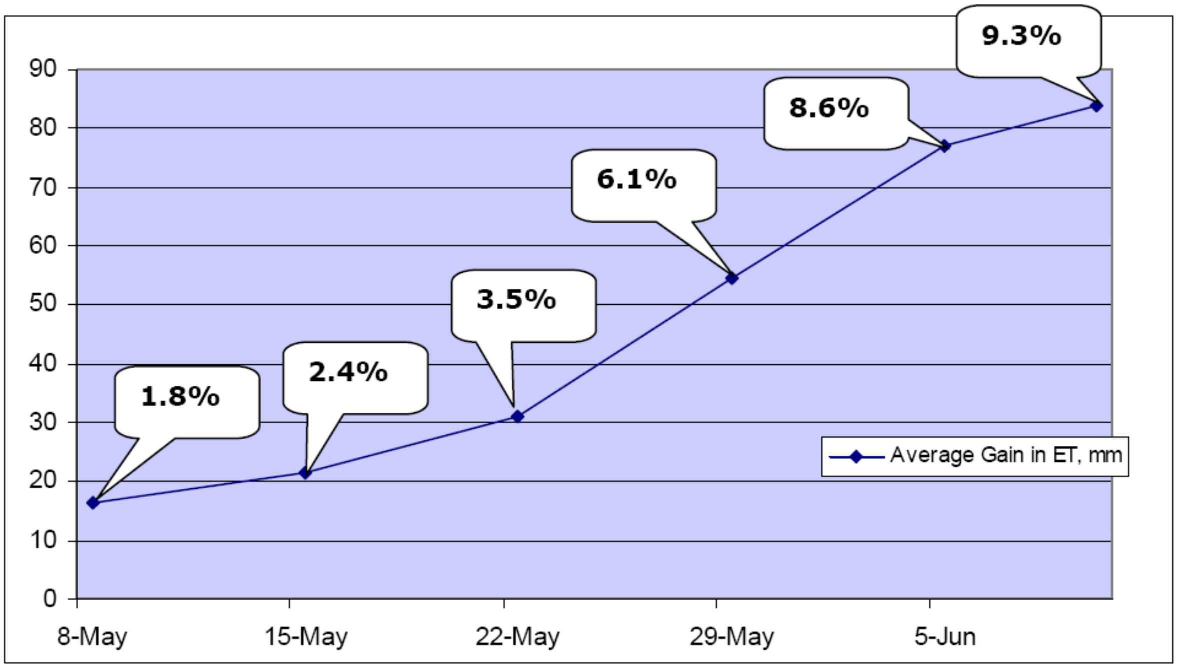

Figure 1: Average gain in ET and the percentage reduction in ET demand by delaying the transplanting date from 01 May to 10 June (for PR113 rice variety).

The California Almond Sustainability Program: An Ag Community's Proactive Approach to Sustainable Water Management

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The California almond farming community has experienced unprecedented growth in acreage over the past decade. Success has brought with it new challenges and opportunities, as farmers new to almonds bring both a learning curve and a willingness to try new ideas long-time almond farmers might not. New regulatory, resource, and marketplace pressures on agriculture also challenge the farming community. In response, the Almond Board of California has developed the California Almond Sustainability Program with SureHarvest Inc. to encourage almond farmers to assess their resource use and help the statewide almond community benchmarks its best management practices. The effort began in 2009 with a module on irrigation efficiency and crop nutrient management. Farmers assess their practices and water and fertilizer use against a list of best practices as identified by university research and extension faculty, growers, and cropping experts. Dr. Daniel Sonke of SureHarvest will present on this innovative program and share some initial data on what has been learned about almond irrigation best practice adoption.

Regression Model for Predicting the Concentration of Atrazine Residues in Shallow Agricultural Groundwater across the Conterminous United States

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Tobit regression methods were used to develop a model for predicting the summed concentration of atrazine and deethylatrazine (referred to as atrazine residue) in shallow groundwater. Atrazine residue concentration data were collected from more than 1,000 monitoring wells located in various agricultural settings across the conterminous United States between 1993 and 2001 as part of the U.S. Geological Survey's National Water Quality Assessment Program. Explanatory variables in the model describe the source and transport of atrazine residues in the subsurface and include the (1) intensity of atrazine application for agricultural purposes (kg/km2), (2) permeability of the least permeable soil layer and the average available water-holding capacity, (3) amount of artificial drainage (trenches and subsurface drains), (4) rate of recharge, and (5) subsurface residence time. The model, which explains about 50 percent of the variability in atrazine residue concentrations measured in shallow agricultural groundwater, was used to predict atrazine residue concentrations in unmonitored areas as well as the probability of exceeding a specified concentration threshold.

A Mass Balance Approach to Evaluating Salinity Sources in the Turlock Sub-Basin, California

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This presentation describes a mass balance approach for evaluating salinity sources in a key hydrologic sub basin in the Central Valley of California, the Turlock Sub-basin. The objective of the study was to evaluate if the primary salinity contributions can be assessed using a mass balance approach based on publicly-accessible data. This approach, intended to be straightforward and transparent to scientists and non-scientists alike, can serve as a practical first step to effective salt management and regulation in the Central Valley. A mass balance approach is proposed as a tool to help identify what DWR describes as "salt management's low hanging fruit," facilitating coordination among stakeholders and identifying productive avenues for policy development. The overall goal would be to promote regulatory efforts without the need for prolonged additional study or detailed groundwater flow and solute transport modeling.

Evaluation of Legacy Contamination at the Urban/Agricultural Interface Using Publicly-Available Data

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Groundwater quality at the urban/agricultural interface is monitored by both public and private parties. The monitoring well networks used for these various monitoring programs do not often overlap and the findings of these monitoring programs can offer differing views of groundwater quality conditions. In California and other states, results of groundwater monitoring at the urban/agricultural interface are available to the public, in a number of databases or in repositories. This presentation discusses groundwater quality data from the urban/agricultural interface information that is available to the public; where it is located; the scale and monitoring wells used; how the results of the monitoring programs compare and contrast; and how the differences can be used to. Included in the presentation are the past, current, and future potential issues related to emerging agricultural chemical contaminants.

Model Development for Analysis of Nitrate Leaching and its Field Application in a Rural Area

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Unsaturated/saturated groundwater flow and solute transport model, VSFRT2D (Variable Saturated Flow and Reactive Transport model) was developed considering effects of pumping, irrigation, and denitrification. VSFRT2D employed Richards equation as governing equation for groundwater flow and previously existing unsaturated models modified by including computational procedure of evapotranspiration at surface using Thornthwaite method when precipitation doesn't occur. Bioremediation processes based on monod kinetics are described using four nonlinear contaminant transport equations and three nonlinear microbes transport equations. The developed model was applied to field data in Hongsung area contaminated with nitrate. In order to identify the effect of precipitation, pumping, evapotranspiration, irrigation, fertilizer application, and various bioremediations on groundwater flow and contaminant transport, individual processes were separated and simulated. Then all results obtained from the individual processes are compared with each other. The simulation results show that bioremediation had a negligible effect on nitrate concentration change. However, pumping for irrigation, precipitation, and nitrogen fertilizer application showed profound influences on nitrate concentration change.

Monterey County Agricultural Water Sustainability in the Salad Bowl of the World Generations of Innovation & Conservation

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Extensive agricultural groundwater and fertilizer use began in the arid, mild climate of the Salinas Valley, Monterey County, California in the late 1940s. A transformation occurred from dry crop farming and dairies in the early 1900s, to sugar beets, then later to the current multibillion dollar industry that utililizes high tech irrigation practices to grow, among other crops, coastal cool-season vegetables and strawberries. As a result of this agricultural productivity and sustainability, the Salinas Valley has emerged as the Salad Bowl of the world. This title can be attributed to the multiple generations of family farmers who, through their own innovation and good business practices coupled with advancements and implementation of new technology, have achieved economic viability in Monterey County as a 3.8 billion dollar industry in 2007. The Monterey County Flood Control and Water Conservation District (District) was created from a California Legislative Act in 1947 and charged to monitor flood and coastal seawater intrusion. The District name was later changed in 1990 to Monterey County Water Resources Agency. Seawater intrusion has been monitored in coastal aquifers since 1944. The historical, 1944-2007, Pressure 180-Foot Aquifer intrusion front, 500 mg/L chloride contour, is represented in Figure 1. The District, with financing from the Monterey County taxpayers, built two reservoirs in the late 1950s and early 1960s in the Salinas Basin. The primary benefits of the reservoirs were for flood control in the Salinas Valley, and to halt intrusion through conservation releases to the Salinas River for recharging the multiple Pressure Aquifers for maintaining water levels at or above sea level. Later, in the 1980s, after extensive long-term groundwater monitoring and in a drought situation, it was concluded that groundwater used both for agriculture and urban/domestic use continued to be impaired in the coastal area by high chloride from seawater intrusion, and, in the entire Salinas Valley, by elevated nitrate. Water quality monitoring data analysis and groundwater investigations concluded that nitrate sources included confined animal operations, septic systems, and commercial fertilizer. The Salinas Valley utilizes 95 percent groundwater for all water uses, which caused concern for long-term impacts to drinking water. Well construction integrity was also found to have a bearing on aquifer water quality. See Table 1 for results of the 2007 nitrate monitoring effort in the Salinas Valley indicating that many wells are over the Primary Drinking Standard for nitrate (as NO_3).This paper presents four components of agricultural groundwater sustainability to inform others of 50 years of challenges and more to come in the Salinas Valley. Progression and productivity of agriculture in the Salinas Valley over multiple generations; impacts of urban and agricultural land use on groundwater quality, water levels, and extractions; successful measures taken by agricultural land owners and well operators, water resource managers, outreach and education cooperative partners, and regulators in the Salinas Valley Basin; discussion of what constitutes success to sustain agriculture and improve groundwater quality and quantity in the Salinas Valley; and how that success is measured by water resource managers, cooperative outreach partners, and regulators.

Hydrologic Subarea	Number of Wells Sampled	Mean Nitrate as NO3 (mg/L)	Median Concentration Nitrate as NO3 (mg/L)	Minimum Concentration Nitrate as NO3 (mg/L)	Maximum Concentration Nitrate as NO3 (mg/L)	Number of Wells Greater than DWS*	Percent of Wells Greater than DWS*
Pressure 180-Foot Aquifer	28	49	20	1	284	9	32%
Pressure 400-Foot Aquifer	44	12	3	1	143	3	7%
Pressure Deep Aquifer	5	1	1	1	2	0	0%
Pressure All	77	25	3	1	284	12	16%
East Side	15	106	63	3	502	9	60%
Forebay	41	79	54	1	290	22	54%
Upper Valley	19	90	78	3	425	13	68%
Locations Without 400-ft and Deep	103	77	47	1	502	53	51%
All Locations	152	56	20	1	502	56	37%

Data Source: Monterey County Water Resources Agency, June 10, 2009.
The majority of wells represented in this summary table are agricultural production wells.
*DWS-Drinking Water Standard

Table 1 - 2007 Summary of Groundwater Nitrate (as NO_3) Concentrations for 152 Water Quality Study Wells Salinas Valley, CA (Monterey County Water Resources Agency)

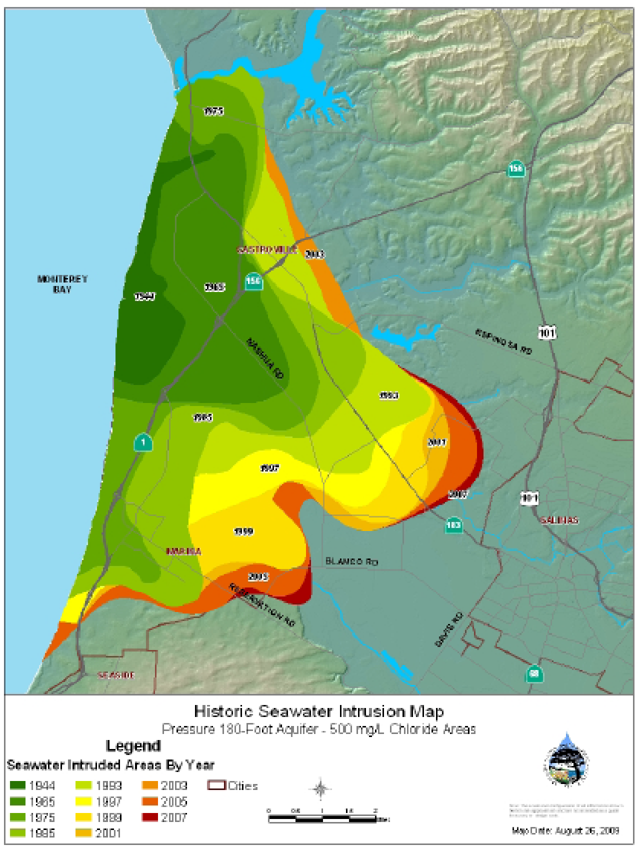

Figure 1 - Historical Seawater Intrusion Advancement Coastal Salinas Valley, CA Pressure 180-Foot Aquifer1944 – 2007 (Monterey County Water Resources Agency)

Monitoring Groundwater for the Effectiveness of Action Programs in Denmark, 1988-2009

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The National Monitoring and Assessment Programmed for the Aquatic and Terrestrial Environment (NOVANA) was established in 1987 when the first Action Plan for the Aquatic Environment was passed by the Danish Parliament. The core objective of the monitoring program was to follow the effects of different measures to mitigate nutrient impacts on the environment. Measures included enhanced wastewater treatment, stricter rules on manure storage, optimization of manure application/plant uptake, an increase of green fields, fallowing, raised levies on inorganic fertilizers, etc. During the years, further Action Plans have been introduced with the aim of meeting national goals as well as the requirements of the EU Directives and other international agreements. Consequently, the monitoring program and objectives have been adjusted regularly. Currently the whole program is undergoing a revision to agree with the monitoring strategies of the EU Water Framework Directive. The NOVANA program covers all aquatic environments, such as agricultural catchments, streams, lakes, groundwater, coastal and marine waters plus air and terrestrial environments. The program is carried out in cooperation between the Environmental Protection Agency and the Agency for Spatial and Environmental Planning, the Geological Survey of Denmark and Greenland (GEUS), the National Environmental Research Institute (NERI), and seven Environment Centers under the Agency for Spatial and Environmental Planning. The groundwater part of the monitoring program focuses on assessing the status and development of groundwater quantity and quality. It consists of a network of approximately 1,500 permanent monitoring points located in 73 dedicated groundwater monitoring areas, each covering a catchment area of a drinking water abstraction well (Figure 1). Each area has about 24 screens, from which a broad range of quality aspects of the aquifers, from the youngest upper groundwater to the deeper layers used for abstraction can be accessed. The areas are representative for the variation in geological setting and land use in Denmark. In addition, detailed monitoring is carried out in five small agricultural catchments, with focus on conventional agricultural practices, and fluxes of nutrients in soil and the uppermost groundwater. Time series of approximately 20 years are now available for nitrate and other major ions as well as pesticides, trace metals, and a range of organic pollutants. Groundwater dating with CFC in the monitoring areas has proved to be a strong tool when interpreting the collected data. An example is given in Figure 2, where nitrate is linked to the time of the groundwater formation as found by CFC and compared to agricultural use of inorganic nitrogen fertilizers. The reduction in use of inorganic fertilizers is an effect of the Action Programmes. The average nitrate concentration in Danish groundwater shows a downward tendency during the last years of monitoring. Future focus is on statistical trend analyses, as prescribed by the EU Groundwater Directive.

Ref: L. F. Jørgensen & J. Stockmarr, 2009: Groundwater monitoring in Denmark: characteristics, perspectives and comparison with other counties. Hydrogeology Journal 17: 827-842R. Grant, L. Thorling & H. Hossy, 2010: Developments in monitoring the effectiveness of the EU Nitrates Directive Action Programmes on the Environment: Denmark. Workshop report paper in Press: RIVM: 2nd Mon NO3 workshop, Amsterdam 2009

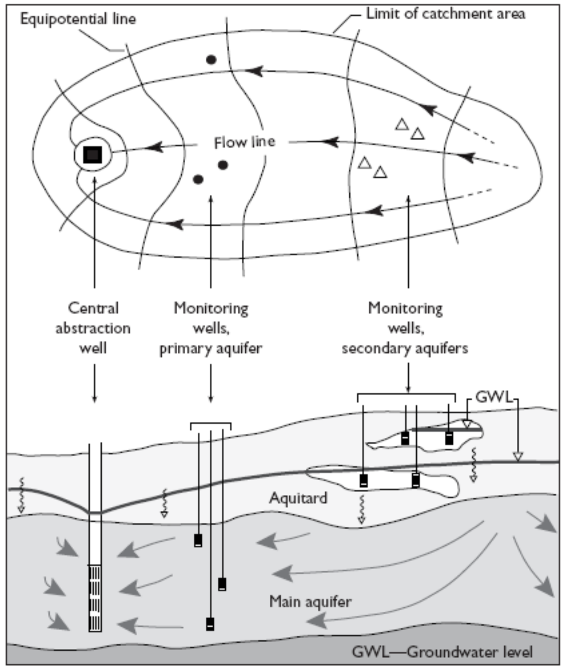

Figure 1. Concept for groundwater monitoring areas in Water works recharge areas of 5- 50 km^2.

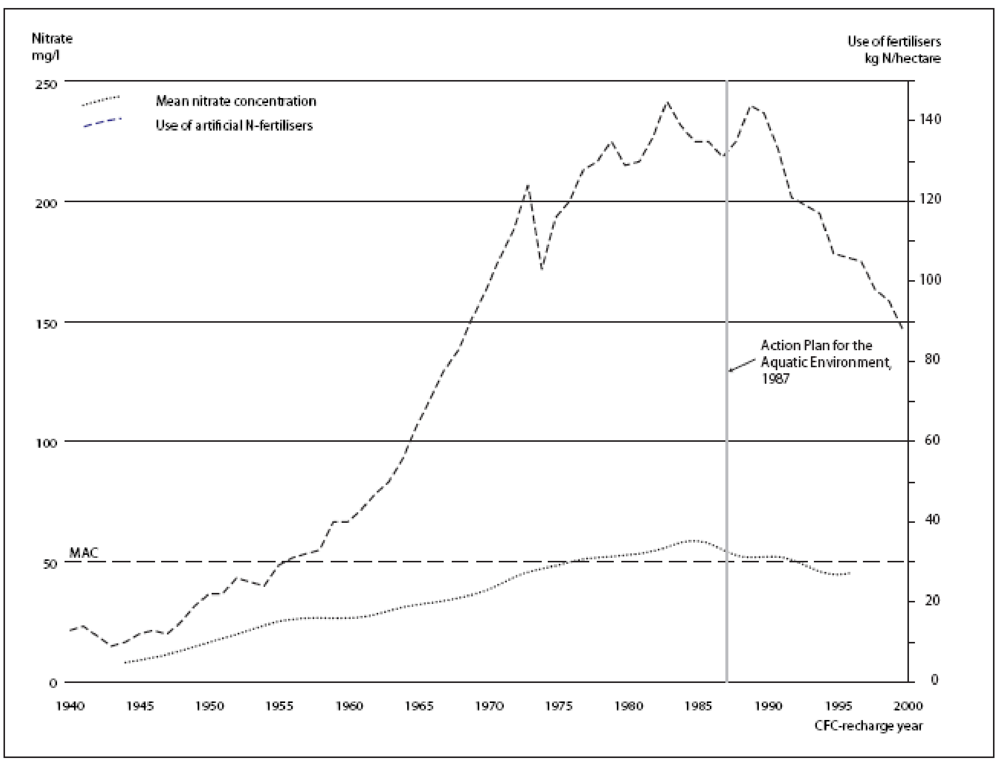

Figure 2. Mean nitrate in groundwater at the year of recharge, as found by CFC-dating in oxic groundwater, using the CFC age for each monitoring point on all data collected 1988-2005 from the groundwater monitoring networks. Also shown is the annual use of artificial nitrogen fertiliser. (Modified from Jørgensen, 2008)

Managing the Operational Cost of Ground Water Production to Sustain Profits

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Sustaining ground water for production encompasses myriad technical, legal, administrative, and socioeconomic measures. Perhaps forgotten in the discussion of this topic is the simple fact that the agricultural industry must be profitable. While it is obvious that sustaining groundwater is important to agriculture, it is also important that the farmer's business ledger show a positive result. Profitability is understood by all agriculturalists. However, sometimes forgotten is that the cost of groundwater production is an operational expenditure which can be and should be controlled. The cost of pumping any well is manageable and its management begins when the well is designed, not when the well is put into operation. Understanding key factors in well design, such as well efficiency, is imperative if one intends to sustain effective controls on ground water production costs. Choices made when any well is designed are certain to have long-term consequences that will directly impact the cost of water. Once the well is constructed, there is no turning back....no second chances. Therefore, every agricultural well should be designed with careful consideration of its efficiency just as are municipal supply wells. In so doing, the agricultural well will be operated so that each unit volume of water is delivered to the field at the lowest sustainable cost.

Rural Water Supply Drought Vulnerability Assessment in the Desert Southwest

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Groundwater is the sole source of water supply for many rural agricultural communities in Arizona. Groundwater age dating has characterized most regional aquifers as containing waters that had originally recharged the system thousands of years ago, under the colder and wetter climate of the Pleistocene. For aquifer waters thousands of years old, planned depletion of this non-renewable resource appears the norm. Several communities in Arizona, however, are sustained by groundwater of recent age, having fallen as rain or snow within the conditions of our modern climate. These younger aquifer systems are more vulnerable to drought as recharge rates decrease, but this vulnerability could be offset by the opportunity to change future water resource management strategy to increase drought preparedness and community resilience. The isolated aquifer system of the Arivaca (Pima County) groundwater basin supports more than 200 wells, lush riparian habitat, perennial streamflow and a cienega in the midst of the southern Arizona Sonoran Desert. Initial age-dating suggests groundwater is approximately 40 to 50 years old with apparent monsoonal recharge. Sufficient climate, streamflow, and groundwater elevation data exist to allow for the determination of climate-groundwater relationships, allowing us to characterize the relationship between drought and aquifer sustainability over the past 50 years. Armed with this vulnerability characterization and assessment approach, we are assisting in identifying opportunities for the community to initiate management strategies for the future to address climate change. Expanded sampling for isotopic signatures and metering of selected water wells, coupled with time-series analysis of existing climate data, has allowed us to refine our understanding of water supply vulnerability in the arid desert of the southwest. This study has allowed us to expand fundamental knowledge of climate-groundwater relationships in young arid aquifers and proposes an innovative approach to quantifying water supply vulnerability based on groundwater age and recent climate data. As a result of this drought vulnerability assessment, recommendations as to future resource management options are being implemented, and this vulnerability assessment tool is being applied to other rural communities across Arizona.

Predicting and Mapping Ground Water Vulnerability to Nitrate in Arizona

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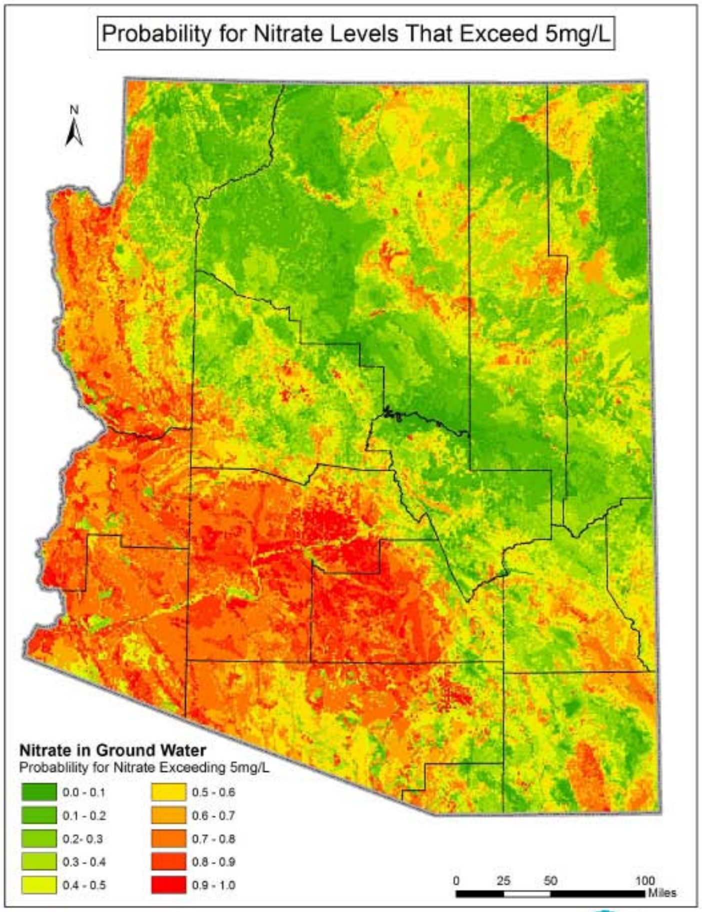
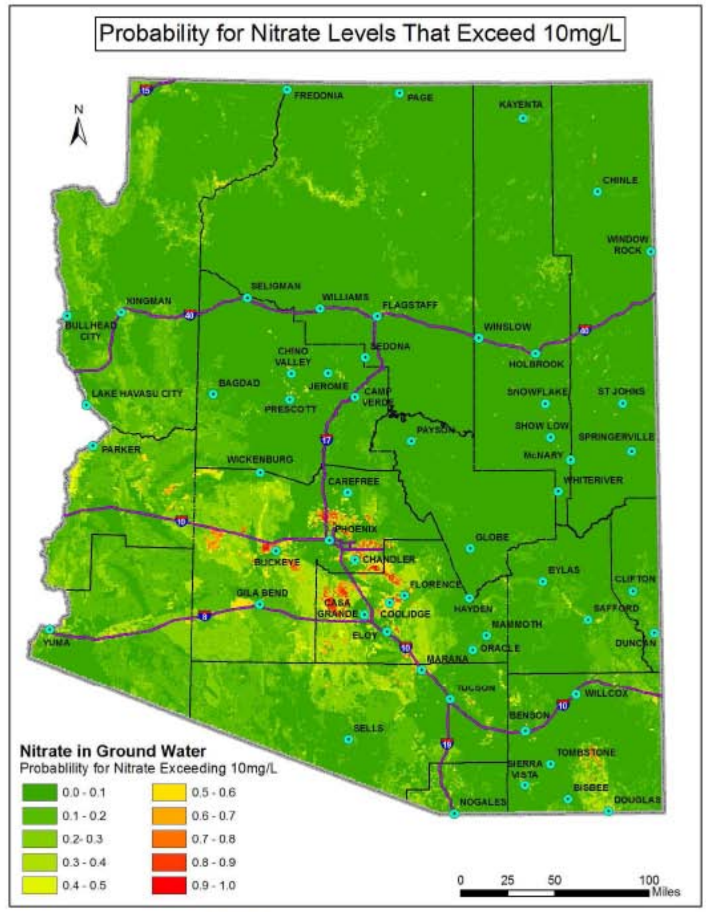
Nitrate is a common contaminant in groundwater in Arizona, exceeding maximum contaminant levels (MCL) in many regions the state. Recently, the Arizona Department of Environmental Quality (ADEQ) bolstered the Aquifer Protection Permit (APP) rules with provisions intended to reduce or eliminate sources of nitrogen pollution to ground water. For example, for areas with existing or potential contamination that will contribute to exceeding nitrate thresholds from the Aquifer Water Quality Standard, ADEQ has established a process to designate Nitrogen Management Areas to authorize controls and regulations for nitrogen sources. To support implementation of this important regulatory approach and other management strategies, the University of Arizona developed a multivariate logistic regression model to predict the probability of nitrate contamination in groundwater. Drinking water and other ground water quality data was joined directly with well location data, with a final data set of 6,802 wells across the state with unique locations, IDs, and associated nitrate data. Working within a GIS platform, well location data was used to map and attribute a table of hydrogeologic and anthropogenic characteristics from existing data sources for each location. Multivariate logistic regression was used to relate the probability of nitrate concentrations exceeding pre-specified threshold values of nitrate-N, with potential explanatory variables representing the well attributes. The statistical analysis identified statistically significant predictors of nitrate exceeding pre-defined threshold values. To map the state, we created a polygonal grid at 1,500 meters (approximately 0.9 square mile) and attributed the grid with the various data sets that were used in the analysis, for a total of 274,945 points across the state. Using predicted probabilities we generated three maps of the state, showing aquifer vulnerability to nitrate contamination at 3, 5, and 10 mg/L nitrate-N. The GIS and logistic regression analysis described in this study quantifies the magnitude, extent, distribution, and uncertainty of current and anticipated nitrate risks. We have predicted the vulnerability of groundwater to nitrate contamination in the areas of state where nitrate information is not available. This work is assisting ADEQ and local water managers protect water supplies by targeting land-use planning solutions and implementing monitoring programs where groundwater may be vulnerable.





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Constraints to Smallholder Livelihoods in Irrigated Agriculture in Groundwater-Dependent Parts of Asia

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Groundwater is of paramount importance as resource input to smallholder irrigated agriculture in many parts of Asia today, both for securing subsistence farming as well as part of economic livelihood strategies. It is estimated that 1 billion farmers across India, China, Pakistan, Bangladesh and Nepal are reliant on groundwater for their farming. However, despite and in some places because of effective and widespread technologies for accessing and utilizing groundwater, the farmers often encounter constraints in their further development and benefit optimizing of this resource. As part of devising policies and programs that contribute towards sustainable farming systems, integrated land use planning, effective use of water resources, increased food production, and adaptation to global changes in climate, demography, and economic conditions, it is key to understand the realities of farmer interaction with and impediments for utilizing groundwater in these parts of the world. Data and results are presented from action research carried out in the alluvial sedimentary basins of the Indo-Gangetic and Yellow River systems (Fig. 1) as part of a major training and research capacity building effort for groundwater professionals from these five Asian countries. A subsidiary objective to the capacity building aim was to gain insight into and collect key figures and comparative descriptions of the physical, the agricultural, and the household economic conditions for the poor farmers to engage in groundwater irrigation. Major constraints for groundwater use relate to exhaustion of the resource (Yellow River Basin, the North China Plains and western India) and to lack of reliable or affordable energy sources for the pumping of groundwater (eastern India and Bangladesh). Agricultural production levels are relatively low in a global context, particularly in the poorest areas, reflecting other constraints, such as lack of other production inputs and supporting market and service infrastructure. Nowhere is groundwater managed actively and directly, though few examples of local and social schemes for management were encountered. Adaptation or coping strategies of the farmers varied from drilling deeper wells and implementing more efficient pumps in over-exploited areas to substituting expensive diesel fuels with the subsidized cooking oil kerosene in areas with plenty of groundwater but poor energy sources (Table 1). In most places, farmers respond by diversifying crops and livelihood income sources. Migration is also practiced but not always to the effect of relieving further stress on groundwater. General recommendations are provided for addressing the groundwater-related constraints in the diverse landscape of groundwater based economies.

Fig. 1. The eight study sites across the Indo-Gangetic and Yellow River basins/North China Plains

	1	2	3	4	5	6	7	8
	Rechna Doab, Punjab	Hoshiarpur, Punjab	Vaishali, Bihar	Murshidabad West Bengal	Madaripur	Morang and Jhapa	Zhengzhou, Henan	Baoding, Hebei
	Pakistan	India	India	India	Bangladesh	Nepal	China	China
Responses or adaptation strategies of the poorest farmers	Conjunctive use of GW and surface water, water buyers crop intensively and grow more water saving crops or cash crops	Crop diversification, income diversification, non-farming enterprises, hired labour	Rain-fed farming, leasing out land to tube-well owners, use of kerosene to replace diesel, rental market for pumps	Shift away from summer paddy to low water consuming crops, use of fuel-efficient pumps, use of plastic pipelines, and mixing of diesel with kerosene	The poor continue to cultivate rain-fed crops only or *Boro* paddy on crop sharing basis, diversify livelihoods and work for larger farmers	Group formation to obtain loan, water buying from well owners, switch to high-value crops	Install deeper tube-wells, change to more efficient pumps, grow more high value crops, diversify livelihoods, some move to the cities	Change to private ownership of wells, change the cropping pattern, drilling deeper tube-wells, some simple water saving techniques

Table 1. Adaptation, and coping strategies of the poor farmers in the study areas. Data from Mukherji *et al*. (2009).

Support to Capacity Building within Integrated Groundwater Management in Africa

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Groundwater is of critical importance to water supply for rural and urban areas and also increasingly to agriculture in Africa. Groundwater is continuously being developed to meet the 2015 UN millennium development goals and as such to secure health, livelihoods, food production, industrial growth and drought and other natural and conflict-derived disaster mitigation. African Groundwater Network (AGW-Net) was set up in July 2008 with the aim to increase continental, but also local, national and international attention to groundwater issues in Africa. An important component of its mandate is to support capacity building for groundwater management across Africa of water professionals as well as institutions. A preliminary focus has been on Sub-Saharan Africa. AGW-Net works under the umbrella of the global initiative for capacity building within water management, Cap-Net, from which core funding is received. The AGW-Net has a small secretariat with the Institute of Water and Sanitation in Harare, Zimbabwe, is coordinated by Dr. Richard Owen, and embraces an open membership of individual water and groundwater experts from the African as well as international groundwater resource base. AGW-Net collaborates and networks with a host of groundwater-engaged initiatives and organizations, incl. BGR (German Federal Institute for Geosciences and Natural Resources), GW-MATE (Groundwater Management Advisory Team under the World Bank program), SADC Groundwater Management Project, Water Resources Commission - Ghana, GWP (Global Water Partnership-West Africa), Splash (European Union Water Initiative Research Area Network), German Federal Ministry for Economic Cooperation and Development, Swiss Confederation, BGS (British Geological Survey), GEUS (Geological Survey of Denmark and Greenland), and IAH (International Association of Hydrogeologists), who have provided both financial and technical support for the activities. During its time of existence, AGW-Net has grown to a membership of 110 members. Its activities so far have focused on development and implementation of integrated groundwater management training programs for water professionals across Africa and development of associated freely available lecture notes and information materials (in English and French) on integrated groundwater management. Four short courses have been conducted in collaboration with other regional water capacity building networks, such as WaterNet, Nile IWRM-Net, WA-Net, and NBCBN (Nile Basin Capacity Building Network) (Table 1). New courses in 2010 are scheduled for Lome, Togo and Addis Ababa, Ethiopia. An important target audience for the courses includes river basin organizations, catchment councils, and the surface water sector in general, in order to enhance the inclusion of groundwater management aspects in already established water management institutions. In the future, AGW-Net will develop further support to in-country groundwater related training initiatives and more thematic training sessions and material, e.g. related to cost-effective borehole drilling and groundwater development, effective data capture, borehole maintenance practices, and gender aspects. Finally, AGW-Net plans to liaise with the African Groundwater Commission (AGWC) under the African Ministerial Council on Water (AMCOW) on topics related to capacity building related to integrated management of groundwater.

Table 1. Courses conducted on Integrated Groundwater Management in Africa by AGW-Net and partners

Location, Dates	**Host organization**	**No. of participants (no. of females)**	**Facilitators**	**Funding sources**
Dakar, Senegal May 25 - 29, 2009	University Cheikh Anta Diop, Geology Dept.	30 (10)	Moustapha Diene (*AGW-Net*), Friedrich Hetzel and Vanessa Vaessen (*BGR*)	CapNet, BGR
Johannesburg, South Africa Jul. 6 -10, 2009	Witwatersrand University, Geology Dept.	13 (5)	Tamiru Abiye (*Wits / AGW-Net*), Hans Klinge (*BGR*), Karen Villholth (*GEUS*), Torleif Dahlin (*Lund University, Sweden*), Richard Owen (*AGW-Net*)	CapNet, Splash
Accra, Ghana Jul. 27 – 31, 2009	Water Resources Commission of Ghana	23 (7)	Paul Taylor (*CapNet*); Richard Owen, Muna Mirghani and Moustapha Diene (*AGW-Net*), Albert Tuinhof (*GW-MATE*)	CapNet, BGR
Dar es Salaam, Tanzania Nov. 16-19, 2009	SADC Groundwater Management Project	16 (5)	Albert Tuinhof (*GW-MATE*), Richard Owen, Daniel Nkhuwa, Martin Eduvie (*AGW-Net*), Willi Struckmeier (IAH)	CapNet, SADC, BGR, GWMATE

An Investigation of Polices for Controlling Groundwater Pollution from Confined Animal Feeding Operations

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Animal waste from confined animal feeding operations (AFOs) is a significant contributor to the nitrate contamination of groundwater. Some manures also contain heavy metals and salts that may build up either in cropland or groundwater and cause crop production to decline. To find efficient policies for pollution reduction at the farm level, an environmental-economic modeling framework for representative animal feeding operations is developed, where the owner of the operation is a profit-maximizer subject to environmental regulations. The model incorporates various components such as herd management, cropping systems, water sources, irrigation methods, waste disposal options, nitrate cycling, and pollutant emissions. Policies such as pricing emissions to groundwater, or emissions to downstream groundwater basins, are compared with the standard approach of limiting the amount of manure that may be applied to fields.

Can We Determine Background Nitrate Concentration in Groundwater?

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The background concentration of nitrate in groundwater is a threshold value above which influence by anthropogenic sources is indicated. This value provides the lowest threshold for modeling the vulnerability of wells to nitrate contamination and can be used to identify areas where the nitrate concentration may be increasing. Relative background concentration within a regional aquifer system can vary depending, in part, on land-management practices, hydrogeology, and climate. We needed to determine the background nitrate concentration for the purpose of assessing nitrate in private wells in the unconsolidated glacial aquifer system in the United States. Nitrate concentration and distribution were characterized in private wells of the glacial aquifer system based on data collected over the last 20 years by the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program. Reference monitoring wells were installed, as part of the NAWQA program, in areas minimally affected by human activities, including two to three monitoring wells in each of 15 studies, and these wells have been sampled to assess the background nitrate concentration. The mean nitrate concentration in these reference wells is 1.2 mg/L as N but the median is only 0.13 mg/L as N, indicating substantial variability across the aquifer system. Nitrate concentrations in 75 percent of the reference wells are below 0.49 mg/L as N. The background nitrate concentration in the glacial aquifer system ranged from 0.14 to 4 mg/L in previous studies. Based on this analysis, the background concentration of nitrate in the glacial aquifer system is low compared to other regional aquifer systems in the United States.

Trends and Alternatives to Ag to Urban Water Transfers in Colorado

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Water transfers from agricultural to urban and environmental uses are increasingly common worldwide. In most cases in the intermountain West, municipal water providers seek outright purchase of senior agricultural surface water rights, with subsequent permanent agricultural dry-up provisions. In Colorado, this trend has manifested in a decline of irrigated acres from a high of 3.3 million acres in the 1980s to less than 2.8 million acres today. It has been estimated that up to an additional half million irrigated acres in Colorado may be transitioned to dryland within the next 25 to 30 years as water is transferred to meet urban, environmental and recreational demands. Many irrigated areas in the Great Plains and West utilize groundwater for supplemental or full irrigation water supplies. Irrigated agriculture relies heavily on tributary groundwater in Colorado, extracting some 2.5 million acre-feet annually on average, but there are institutionally driven retractions in irrigated acres occurring in virtually every major groundwater basin in the state due to past over-appropriation, recent intrastate litigation, and resolution of interstate compact disputes. Surface water transfers out of agriculture and increased reuse of municipal effluent will further increase the pressure on irrigated agriculture as recharge in these basins is reduced. This presentation will review the current trends in the loss of groundwater irrigated lands in Colorado, the mechanisms causing this dry-up and the application of alternative institutional methods to permanent dry-up such as rotational fallowing, water banks, interruptible supply agreements and deficit irrigation approaches.

Groundwater Quality Monitoring and Compliance Checking According to WFD and GD

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The Netherlands has set up a program to monitor groundwater in order to reach compliance with the formal requirements of the European Water Framework Directive (WFD) and Groundwater Directive (GD). To this end, several aspects of this WFD Monitoring Program Groundwater quality (KMG) were evaluated. There is a need to develop a conceptual model which describes the interaction between surface runoff, groundwater and ecosystems. Surveillance and operational monitoring should be expanded to the upper few meters of groundwater for those locations where the upper groundwater interacts with the surface water and ecosystems. In addition, monitoring wells in the Netherlands should be distributed spatially on the basis of soil type, land use and hydrological situation in order to obtain a representative distribution of the measurements. Finally, the reliability of the assessment of the water quality can be improved by expanding the number of existing monitoring wells. These are the conclusions of a study carried out by the RIVM and Deltares by order of the Ministry of Housing, Spatial Planning and the Environment (VROM).The European WFD sets goals. One of these is that in 2015 there will be sufficient water in Europe with a good chemical status. This goal implies that the concentrations of pollutants should not exceed the standards and that the concentrations present should not cause a significant deterioration of the ecological or chemical quality of the groundwater body. In addition, these concentrations should inflict damage on groundwater-dependent ecosystems. The current assessment method for determining the chemical status of groundwater has been based on measurements taken at 10 and 25 m below the soil surface. The recommendation to also use groundwater quality data from the upper few meters concerns both surveillance and operational monitoring. Surveillance monitoring is applied in areas where the risk of pollution in 2015 is low, and operational monitoring is applied in areas where there is a higher pollution risk. In terms of operational monitoring, this recommendation has the advantage that effects of environmental policy measures can be observed at an earlier stage.

Groundwater Quality in the Netherlands, 1984-2008

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Since the early 1980s the Dutch National Institute for Public Health and the Environment (RIVM) has coordinated the National Groundwater Quality Monitoring Network (Dutch: LMG). The objectives of the network are: inventory and diagnosis of groundwater quality in relation to soil use, soil type and hydrogeological conditions; indication of human influence on groundwater quality; identification of long-term changes in groundwater quality; provision of data for groundwater quality control and groundwater management. The network is used to report about the state and trends in groundwater quality to the national government and to the European Commission to fulfill the obligations of the Nitrates Directive and the Water Framework Directive. The network presently consists of about 350 monitoring sites. Around two-third of the sites is under agricultural land use, around one-quarter of the sites is in nature areas. At each site, samples are taken at two depths: 10 m and 25 m below surface level. Samples are collected every 1, 2 or 4 years depending on the characteristics of the site. Samples are analyzed for the following components: Cl, pH, SO4, Al, N-total, NO3, NH4, P-total, K, As, Cr, Ni, Cd, Zn and Cu. Tritium contents were measured at the start of the network. Observations are grouped by sampling depth, soil type, land use and region. Results will be presented for the groundwater quality in 2008 and the trends for 1984-2008. The observed concentrations will be compared with environmental quality objectives for groundwater, expressed as the percentages of observations exceeding target values in 2008.

Monitoring the Effects of Emission Reduction Policy: Groundwater Quality in Forests and Heathland in the Netherlands

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The National Trend Monitoring Network Acidification (Dutch: TMV) was established in 1989 by the Dutch National Institute for Public Health and the Environment (RIVM). The purpose of the network is to study the impacts of government policies on acidification and large-scale air pollution on the quality of groundwater in the Netherlands. The network records the effect of changes in atmospheric deposition specifically, the deposition of acidifying and eutroficating substances on the quality of the upper 1 m of groundwater under forests and heathland in the sandy areas of the Netherlands. The groundwater under these areas is not affected by any notable pollutants other than atmospheric deposition. In addition, sandy soils have a limited capacity to neutralize the impacts of acidification. For these reasons, the impacts of atmospheric deposition on groundwater quality are most clearly detected under natural terrains with sandy soils. In other monitoring networks, the effects of atmospheric deposition are difficult or impossible to distinguish from other sources of pollution. In agricultural areas, for example, the impacts of fertilizer application on groundwater quality eclipse those of other sources of pollution. From the 1980s onwards the Netherlands have had a strong and successful policy in reducing emissions to air, soil and water. Results of the monitoring network clearly indicate that reduced atmospheric deposition is reflected in improved groundwater quality: nitrate concentrations in groundwater under forests and heathland have fallen significantly over the past 20 years.

Assessment of Pesticide Leaching to Groundwater in Germany: Comparison of Indicator and Metamodel Approaches

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In order to estimate the risk of groundwater contamination by surface applied pesticides, the fate of pesticides in the unsaturated zone needs to be evaluated. Process models that describe relevant processes such as transport of dissolved pesticides, sorption, degradation and root uptake, in combination with water and heat fluxes in the soil have been developed and used for regulatory purposes. Regional assessments are required to identify regions with higher risks of groundwater contamination. A major problem for the application of process models for a regional, EU-member state, or EU-scale assessment of pesticide leaching risk is the availability of regional databases of input parameters and boundary conditions that are required to run these models. Therefore, procedures that can assess pesticide leaching risk based on databases with regional coverage are required. In this presentation, we compare two different approaches for a regional estimation of pesticide leaching risk to groundwater in Germany. The first method uses an indicator approach to evaluate the risk of pesticide leaching as a function of a number of categorized soil, climate and pesticide properties. The result is a map of categorized risks. In the second approach, a metamodel is used to estimate the leached pesticide concentrations based on nation-wide available data of yearly average precipitation, temperature, soil organic matter content, soil texture, and pesticide parameters. The metamodel represents a synthesis of relations between climate, soil, and pesticide properties on one hand and leaching concentrations that are simulated by a more detailed process model on the other hand. The obtained maps of leaching risks and leaching concentrations were compared with the locations of anomynized pesticide findings in groundwater. The use of databases of pesticide findings in groundwater for the validation of leaching risks assessments is discussed.

Forecasting the Effects of EU Policy Measures on the Nitrate Pollution of Groundwater Based on a Coupled Agroeconomic Hydro(geo)logic Model

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The fundamental objectives of the European Union-Water Framework Directive and the EU Groundwater Directive are to attain a good status of water and groundwater resources in the member states of the EU by 2015. For river basins, whose good status cannot be guaranteed by 2015, catchment-wide operational plans and measurement programs have to be drafted and implemented until 2009. In the river basin district Weser, Germany, which comprises a catchment area of ca. 49.000 km2, the achievement of the good status is unclear, or rather unlikely for 63 percent of the groundwater bodies. Inputs from diffuse sources and most of all nitrate losses from agriculturally used land have been identified as the main reasons for exceeding the groundwater threshold value for nitrate (50 mg/l) and for failing the good qualitative status of groundwater. The achievement of good qualitative status of groundwater bodies entails a particular challenge as the complex ecological, hydrological, hydrogeological and agro-economic relationships have to be considered simultaneously. We used an interdisciplinary model network to predict the nitrogen intakes into groundwater at the regional scale using an area differentiated approach. The model system combines the agro-economic model RAUMIS for estimating nitrogen surpluses from agriculture and the hydrological models GROWA/DENUZ/WEKU for describing the reactive nitrate transport in the soil-groundwater system. In a first step the model is used to analyze the present situation using N surpluses from agriculture for the year 2003. In many region of the Weser basin, particularly in the northwestern part which is characterized by high livestock densities, predicted nitrate concentrations in percolation water exceed the EU groundwater quality standard of 50 mg/L by far. In a second step the temporal and spatial impacts of the common agricultural policy (CAP) of the EU, already implemented agri-environmental measures of the Federal States and the expected developments of agriculture were assessed with regard to both, groundwater quality in 2015 and the regional agricultural income. On average for the whole Weser basin, the reduction of nitrogen surpluses for agricultural areas leads to a decrease of nitrate concentrations in the leachate by about 10 mg NO3/L. In the agricultural-intensive used regions much higher reductions in the order of 40 mg NO3/L may be expected. Using the environmental target value for groundwater, i.e. a concentration of 50 mg NO3/L in the leachate as a target for groundwater protection, the model results were used directly to identify those regions where additional agro-environmental reduction measures are required. There, a backward calculation allows the quantification of maximal permissible nitrogen surplus levels, which was used as a reference for the derivation of additional nitrogen reduction measures. It could be shown that a further reduction by ca. 20.000 t N/a (19 percent) is necessary to reach a nitrate concentration in groundwater of 50 mg/l. The related costs sum up to ca. 75 Mio ¬/a.

The research work was carried out in the framework of the AGRUM Weser project which was funded on behalf of the German Federal Ministry of Food, Agriculture and Consumer protection (BMELV) and the River Basin Commission Weser (FGG).

A Summary of Laws and Regulations Related to Agricultural Chemicals and Groundwater

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Anthropogenic chemicals are widely used in agriculture to increase crop yields and prevent crop damage by pests. Chemicals of concern in groundwater include fertilizers (primarily nitrate) and pesticides (insecticides, herbicides, fungicides, nermaticides, rodenticides, etc). In 2000, U.S. farmers used approximately 12 million tons of nitrogen and applied more than 1.2 billion pounds of pesticides (active ingredient). There are more than 20,000 pesticide products registered for use in the U.S. Protecting groundwaters from contamination by agricultural chemicals has proven to be difficult. Nitrate contamination of shallow groundwater is a widespread problem in agricultural regions within the U.S.; in fact nitrate is the most widespread groundwater contaminant in the country. Nitrate (an inorganic ion) is not readily attenuated and is very mobile in groundwater. Pesticides are synthetic organic chemicals and are attenuated to some degree by degradation and sorption to soil. However some commonly used pesticides are highly toxic and known carcinogens. Fertilizer use is not regulated at the state or federal level. However the U.S. EPA, pursuant to the SDWA has established a maximum contaminant level of 10 mg/l for public drinking water supplies. A suite of best management practices (BMPs) have been developed to prevent or minimize leaching of fertilizers to the underlying water table and to streams. The effectiveness of these BMPs, with respect to the design and application/maintenance is not clear. The U.S. EPA is responsible for regulating the sale and use of pesticides. EPA's authority is derived from the Federal Insecticide, Rodenticide, and Fungicide Act (FIFRA). Under FIFRA, EPA is responsible for registering or licensing pesticide products for use in the U.S. Registration decisions are based on assessments of affects on human health and the environment and require strict adherence to label direction. Pesticide use that is not in accordance with label directions is subject to civil and/or criminal penalties. FIFRA regulations are typically implemented through State Departments of Agriculture. Maximum contaminant levels have also been established for some pesticides. Many states have statutorily authorized classification systems for groundwater. Classification is typically based on existing and future potential uses and provides a basis for assigning groundwater standards. Agricultural use is a common classification and many states have promulgated agricultural use standards which may include standards for nitrogen and selected pesticides. Other approaches that have been utilized to minimize or mitigate groundwater contamination from agricultural chemicals include differential management, which, in the case of agricultural chemicals attempts to identify and map areas, soil types and hydrogeologic conditions which result in high vulnerability to contamination from agricultural practices. Based on recent data from around the U.S. it is clear that regulatory, voluntary and programmatic efforts to reduce nitrate contamination have not been as successful as intended. It is time for the agricultural community working with State and Federal government agencies to take a new look at current regulations and practices, assess the effectiveness and explore new approaches.

Characterizing Groundwater Dynamics in Western Victoria Using Menyanthes Software

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Water table across much of western Victoria have been declining for at least the last 10-15 years, and this is attributed to the consistently low rainfall for these years. But over the same period of time there has been substantial change in land use, with grazing land replaced by cropping and tree plantations appearing in some areas. Hence, it is important to determine the relative effect the climate and land use factors on the water table changes. Monitoring changes in groundwater levels to climate variables and/or land use change is helpful in indicating the degree of threat faced to agricultural and public assets. The dynamics of the groundwater system in western Victoria, mainly on the basalt plain, have been modeled to determine the climatic influence in water table fluctuations. Previously, linear regression analysis was used to estimate trends in individual bores in the study area and thereby predict areas most at risk from shallow or rapidly rising groundwater [3]. In this study, a standardized computer package Menyanthes [4] was used for quantifying the influence of climatic variables on the groundwater level, statistically estimating trends in groundwater levels and identifying the properties that determine the dynamics of groundwater system. This method is optimized for use on hydrological problems and is based on the use of the continuous time transfer function noise model, which estimates the Impulse response function of the system from the temporal correlation between time series of groundwater level and precipitation surplus. In this approach, the spatial differences in the groundwater system are determined by the system properties, while temporal variation is driven by the dynamics of the input into the system. The results of 75 time series models are summarized in Table 1, with the model output parameter values characterized by their moments. The zero-order moment Mo of a distribution function is its area and M1 is related to the mean of the impulse response function. The relation is M1/Mo. It is a measure of the system's memory. It takes approximately three times the mean time (M1/Mo) for the effect of a shower to disappear completely from the system. Overall, the model fitted the data well, explaining 89 percent (median value of R2) of variation in groundwater level using the climatic variables (rainfall and evaporation) left without significant trend (-0.046 m/yr, on average),which is within the range of variable input standard error. The average estimated system response (memory to disappear) is 5.2 years which is less than by 1/10th of the previously estimated time using Ground Water Flow System approach [1]. The average Mo is 1.45 m, which means that a precipitation of 365 mm/yr will eventually lead to a groundwater level rise of 1.45 m on the location. The Menyanthes result is compared with HARTT (Hydrograph Analysis and Time Trends) method [2]. The trend and Mo estimate using Menyanthes and HARTT show comparable result. From a time series analysis there is no indication that the groundwater table was rising/falling due to changes in land use, at least not during the observation period.

Policy and Economic Drivers in California which Affect Groundwater Management and Sustainability in Agricultural Regions

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A number of significant policy drivers within California influence the ability of water districts and overlying groundwater users to sustain agricultural and rural economies. Changes to state laws, whether driven by the legislature or voter initiative, have altered the state water policies and the groundwater management environment in the state, creating both opportunities and constraints for local water managers and growers. This presentation will describe some of the recent changes to local and state laws in California that serve as policy ”drivers” that can positively and negatively impact agricultural districts when seeking to implement conjunctive use to optimize available surface and groundwater resources and keep agricultural water costs affordable. Trends in special district and local government funding; changes in environmental and land use laws; requirements to coordinate land use and water supply decisions to allocate water; and opportunities for integrated planning all need to be understood by local water managers if they are to work within their communities to optimize the management of available groundwater resources, keep water costs down, prevent overdraft and avoid conflicts and litigation.