Alexander "Sam" Fernald *was appointed assistant professor of watershed management at NMSU earlier this year. He received a B.A. in 1987 in international relations from Stanford University, an MEM in water and air resources from Duke University in 1993, and a Ph.D. in watershed science from Colorado State University in 1997. Sam was a Fulbright Scholar in Chile in 2000 where he taught classes in groundwater/ surface water interactions and conducted a study as part of an integrated watershed assessment of the agricultural Chillan River Basin. From 1997-2000, Sam held a National Research Council Postdoctoral position with the U.S. Environmental Protection Agency in Corvallis, Oregon. His major field of interest is water quality hydrology.*

GROUNDWATER/SURFACE WATER INTERACTIONS

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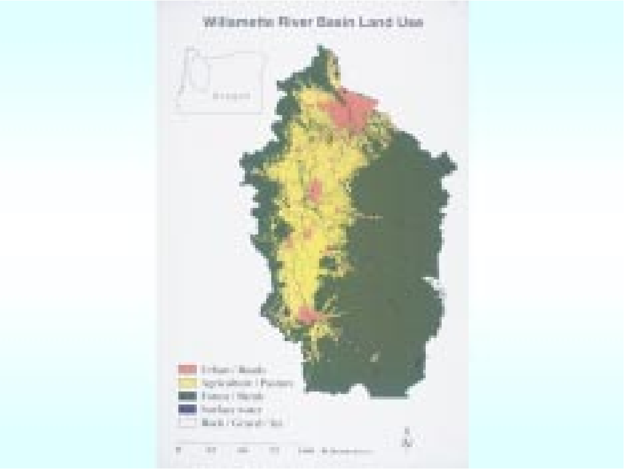
Thank you Karl. I will be talking about groundwater/surface water interactions. After a comment I got this morning, I'm afraid that this might be a dangerous topic so soon after lunch. The surface water people hear groundwater and their eyes glaze over, and when groundwater people hear surface water it's the same thing, and everybody snoozes. Well wake up, they are the same resource!

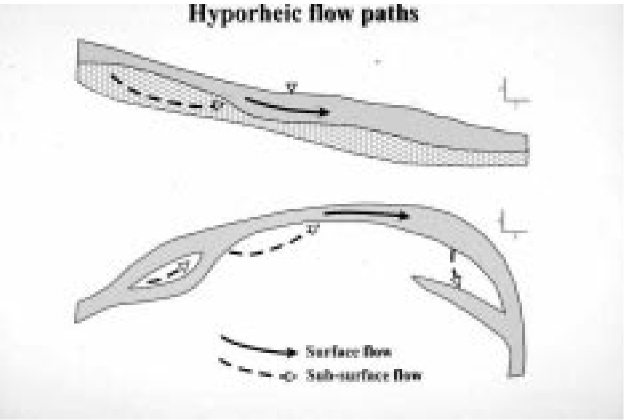
The figure to the right shows a gravel bar on the Willamette River in Oregon. The EPA in Oregon is particularly interested in side channel alcoves, the channel behind the gravel bar in the picture. They are important habitat for rearing and breeding salmon. We visited this site and saw cool and clear water bubbling out of the gravel into the alcove. This was hyporheic flow that started in the river, flowed through the gravel bar, and emerged into the alcove. Hyporheic flow is important for aquatic habitat and water quality.

In the Willamette River Basin water quality is a big issue. The Willamette River flows north from Eugene 200 miles to the Columbia River and out to the ocean. The orange areas in the figure are urban areas. Cities are looking to the river for municipal water supplies. With extensive agricultural areas in yellow, there are concerns about water quality from increasing agricultural chemical use since the 1940s. For example, at some locations, nitrate concentrations in groundwater exceed EPA standards for drinking water.



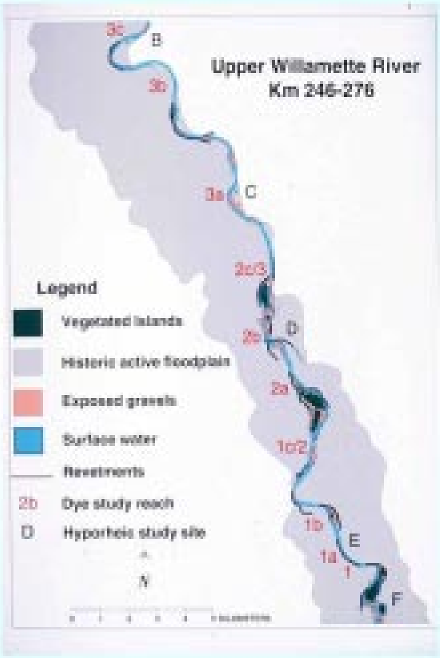
Aquatic habitat for threatened and endangered salmonids is also a big issue. Much of the historic habitat has been lost with channelization of the river. This picture shows a riprap bank with large boulders and concrete that create a straight channel and remove historic channel complexity.

This is a section of the river that still has room to move back and forth and create braided and anastamozing channel structure through the gravel deposits, with many side channels and alcoves. These are important aquatic habitat, and we hypothesized that hyporheic flow going through the gravels would be important for water quality of the river as a whole.



This shows a schematic of hyporheic flow paths where water starts in surface water, goes underground, and then reemerges to surface water downstream. Hyporheic flow occurs through islands, across point bars, and across the bar deposits that separate the river from alcoves. These alcoves are great spots to study hyporheic flow, because you can go out on the bar deposits, punch in wells, and measure the hyporheic flow easily.

We hypothesized that: 1) there is extensive surface/subsurface exchange along the Willamette River, mostly at sites where the river is able to create porous gravel deposits, 2) water quality changes along hyporheic flow paths, with cooling and loss of nitrate, and 3) reemerging hyporheic flow affects the water quality in the alcoves and the river. In a preview of our results, we found that nitrate actually increased in hyporhiec flow at most locations. A sub theme of this talk is that it is important to use the best scientific methods to get information about the specific site and resource that you want to manage.

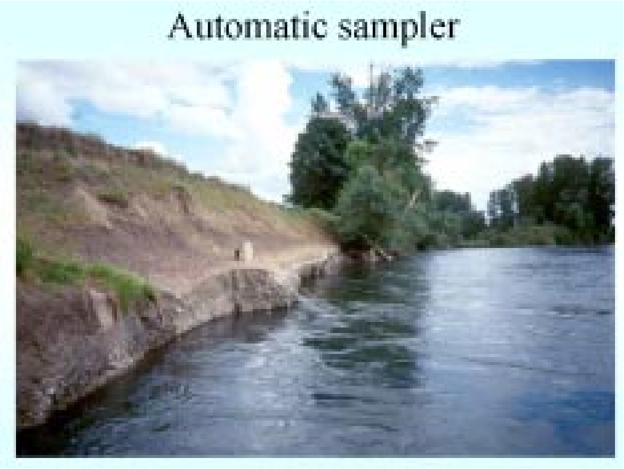


We set up two studies to test these hypotheses, using many of the same tools that we will be using here in New Mexico research. The figure shows a 30 km study section. Letters in red are the upstream and downstream ends of dye study reaches to look at surface/subsurface exchange over two to five kilometer reaches of the river. The bold dark capital letters represent sites where we studied in detail the water quality relationships of hyporheic flow.

Dye release

Starting with the dye study, we released Rhodamine WT upstream of each study section. This dye is non-toxic; even the fisherman standing on the bank believed it when we told them! Rhodamine WT is a great tracer because you can measure it in very small concentrations far downstream.

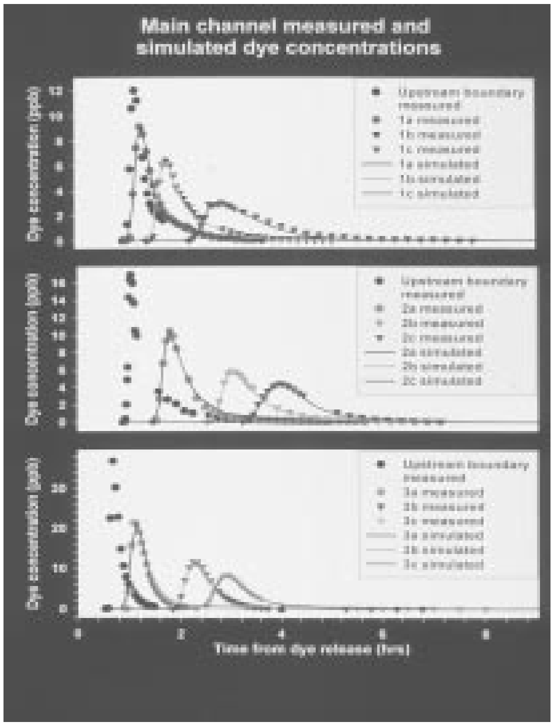
At four locations on each study section we measured the cloud of dye moving downstream with automatic samplers that took samples every five to ten minutes. We analyzed the dye concentrations with a Turner fluorometer.



We also sampled in backwaters and in wells for water that was captured in eddies or water that moved underground through hyporheic flow paths.

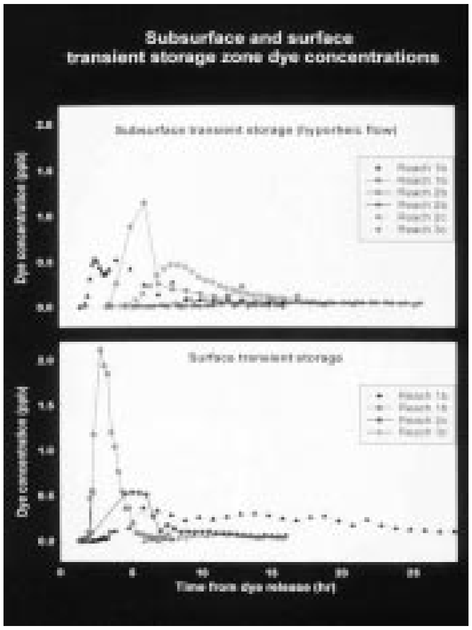
We used a one-dimensional solute transport model, coded in the program OTIS, to describe the dye movement and to determine transient storage. Transient storage is the amount of water that is temporarily restrained in surface backwaters or hyporheic flow before reentering the main channel and moving downstream. Water entering hyporheic flow and backwaters results in a delayed trailing limb in the dye curve.

This figure shows the dye curves measured in the main channel. The symbols are the measured values and the lines are the OTIS-modeled values. In the upper graph, the trailing limb is delayed, and this is actually the location with the most hyporheic flow.

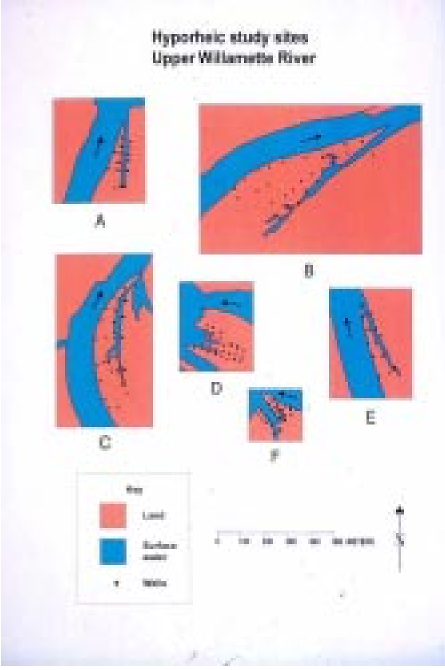


This figure shows the dye concentration versus time for hyporheic flow and backwaters. The important point here is that both types of transient storage were about the same in terms of peak concentration and time to peak. This shows there was a significant amount of hyporheic flow along the river in our study area.

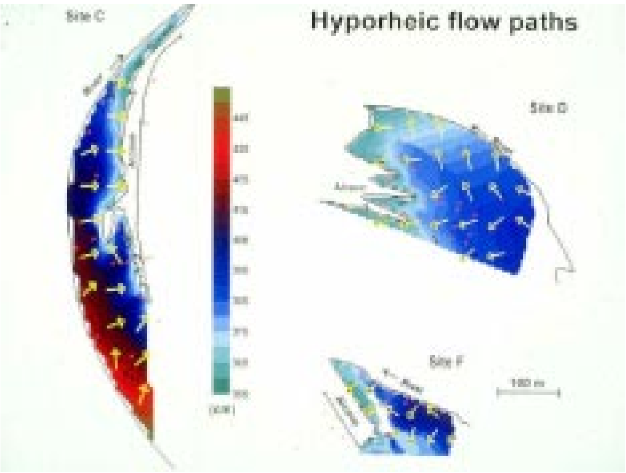
We concluded that: 1) there is a large amount of transient storage, 2) a large component of transient storage is hyporheic flow, and 3) 70% of the water over our study reach had passed through hyporheic flow paths. That is a lot of water moving underground back into the river, and we wanted to determine the water quality effects of hyporheic flow.



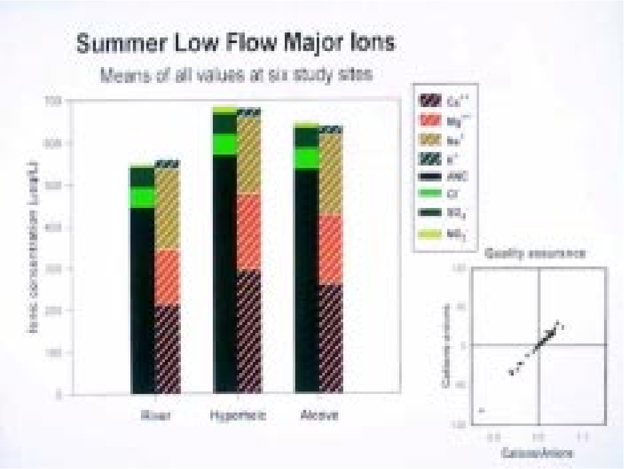
We set up six study sites for detailed study of water quality effects of hyporheic flow. In each figure, the arrow shows the river flow direction with an alcove behind a bar deposit. The little black dots are wells. In each well we measured water levels and physical water characteristics including temperature, specific conductance, pH, and dissolved oxygen. In transects of wells we took water samples for analysis of complete water chemistry. We selected representative sites including both recently reworked sites with high porosity gravel and mature sites with low porosity fine substrate.



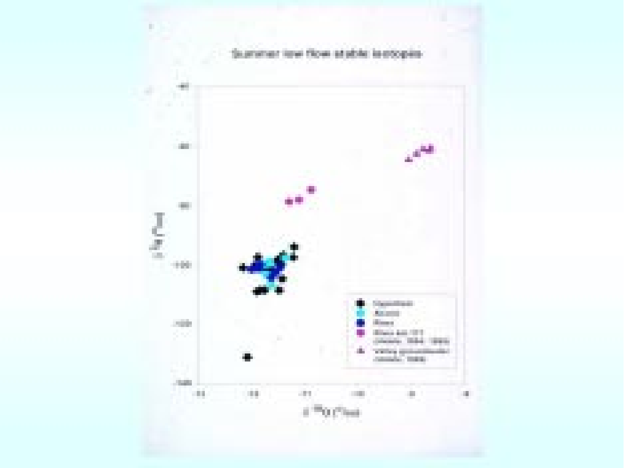
Using water levels, we were able to generate maps of flow path directions. This figure shows elevation of groundwater extending from the river, through the bar deposit, to the alcove. Using a simple application of Darcy's law with measurements of saturated hydrologic conductivity, we characterized hyporheic flow rate at each site. Site C had a steep gradient and fast hyporheic flow from river to alcove. Site D had medium hyporheic flow rate in the general direction of river flow. Site F had a low gradient at a mature site with very fine substrate and slow hyporheic flow.



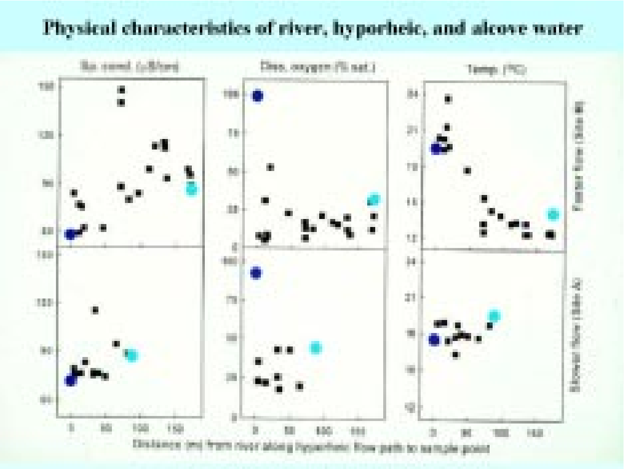
This figure shows the ion concentration in river water, hyporheic flow, and alcove water. The hyporehic water gained ionic strength from interaction with the interstitial material. The alcove water is a mix of river and hyporheic water.



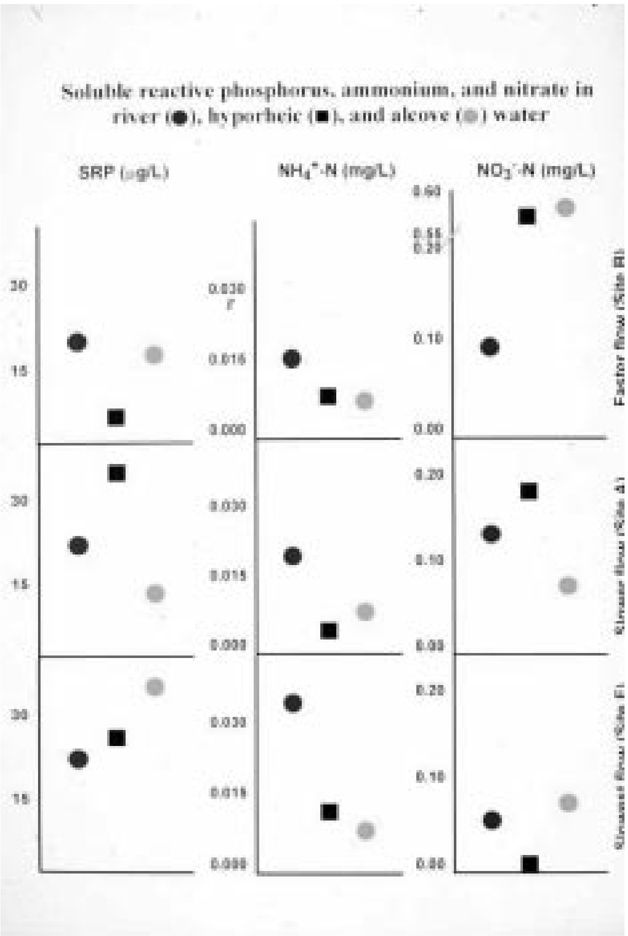
We used stable isotopes to determine if changes in water quality were from hyporheic processes or from mixing with deeper groundwater. The symbols in pink are from a site downstream of our study site. The river and groundwater at the downstream site have distinct signatures for deuterium and ^{18}O. If we had deep groundwater up-welling affecting water quality at our sites, we would expect a mixing line moving toward deep groundwater values, but all our of hyporheic flow values (in black) were clustered around the river values (in blue). Basically we had river water flowing through the gravel beds and back into the river without the influence of deep groundwater. We could attribute the water quality changes directly to hyporheic processes.



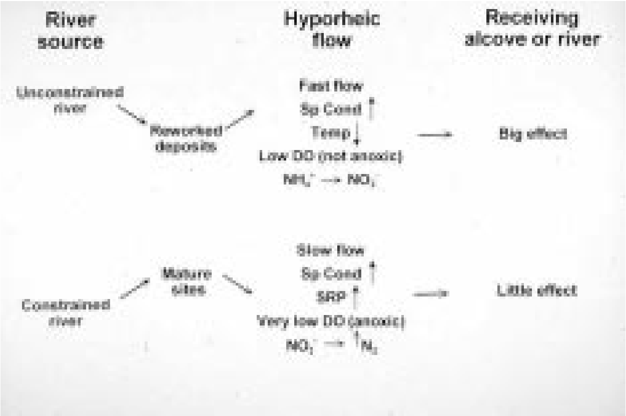
This figure compares fast and slow hyporheic flow rate sites. At all sites we saw increases in specific conductance. Dissolved oxygen dropped rapidly, but did not reach zero. At the fast sites, the water was cooled significantly (from about 20 to 13 degrees Celsius in the top graph). The slow sites did not show this cooling. With these results, we answered one hypothesis. Yes, there is cooling from hyporheic flow, but this only happens consistently where there is fast hyporheic flow rate.



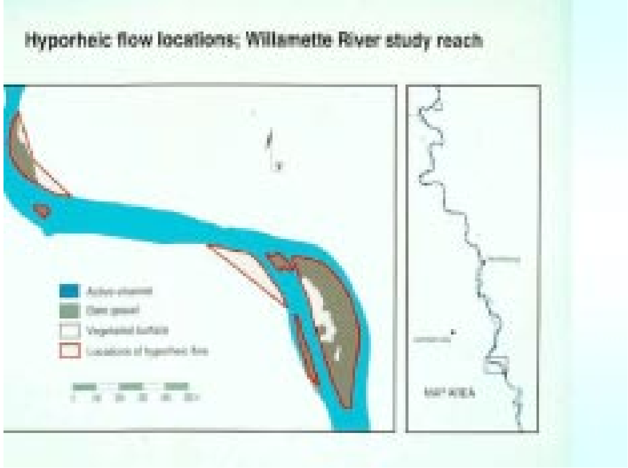
With nitrogen, we found close to the opposite of what we hypothesized. At all sites there was a loss of ammonium moving from river to hyporheic to alcove water. Nitrate, however, increased from river to hyporheic water in all but one site, which had anoxic conditions suitable for denitrification. Soluble reactive phosphorus generally decreased except for at the one anoxic site. We attribute the nitrogen changes to nitrification of ammonium in hyporheic flow, which was relatively high (for subsurface flow) in dissolved oxygen. The pattern we found reinforces the importance of going out and getting good data instead of relying on the literature (which suggested that we would find denitrification in hyporheic flow).



We developed a conceptual model that we used to estimate hyporheic effects river water quality. The top half of the figure shows unconstrained river sections with porous deposits and fast hyporheic flow. Here we have: increases in specific conductance, cooling, and increases in nitrate. The bottom half of the figure represents constrained river sections with fine substrate and slow hyporheic flow. Here we also find increases in specific conductance, but no consistent cooling and loss of nitrate.



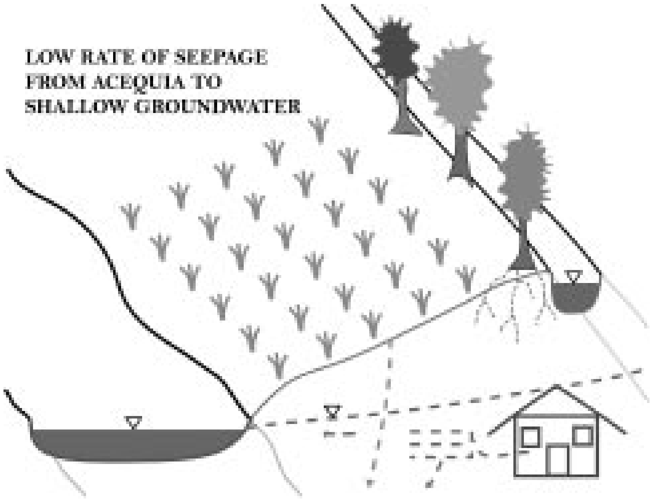
Using the conceptual model and vegetation as a surrogate for substrate type (and hyporheic flow rate), we were able to use GIS to characterize the hyporheic flow at all of the alcove, island, and point bar sites along our study reach. We used the specific conductance relationships that we measured in our water quality study to estimate the effects of hyporheic flow on river water quality over our 30 kilometer study reach. We found that 60% of the increase in specific conductance can be attributed to hyporheic flow. In a similar model we found that we could attribute to hyporheic flow one to one and a half degrees Celsius of cooling over our study reach. Even though the total volume of hyporheic flow at any one time is only 2% of river volume, since it goes in and out of the gravel many times, it affects the water quality of the entire river.



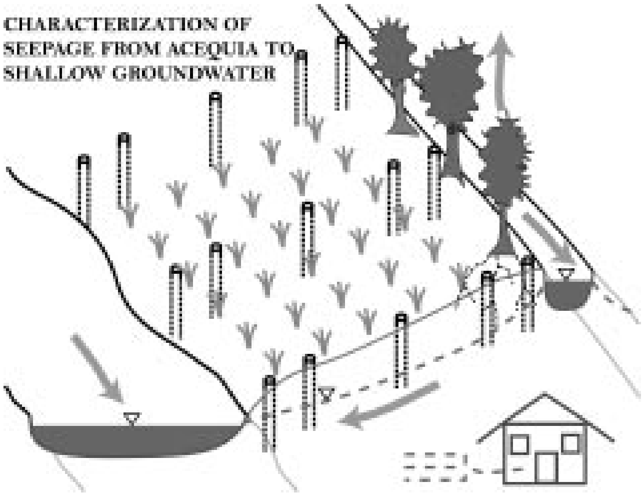
Surface water-groundwater interaction is important in New Mexico. This is an acequia, a community-operated irrigation ditch, just north of Española at the Alcalde Sustainable Agricultural Science Center operated by New Mexico State University. In many places, there is pressure to line earthen acequias with concrete to increase conveyance efficiency. To counter this trend, acequia associations point to possible benefits of acequia seepage such as: 1) support of riparian vegetation, 2) protection of deep groundwater by maintaining subsurface flows that move contaminants toward the river, and 3) supply of return flow that moves slowly back into the river after spring runoff season.

This is a picture of a very old walnut tree that relies on acequia seepage.

Lining acequias may lead to loss of seepage benefits. With a cement lining, seepage is cut off and the riparian trees die from lack of water. There is less return flow to the river, and agricultural chemicals or septic tank leachates may flow to deep groundwater. This is a conceptual model that sounds logical, but there are very few data from New Mexico to quantify seepage benefits.



We began a study in fall 2001 to characterize different components of the hydrologic budgets along irrigation ditches and to determine water quality effects of seepage. We are studying sites in northern, central, and southern New Mexico, trying to put numbers on these basic hydrologic processes. In the first phase we will quantify the arrows in the figure: evapotranspiration, acequia flow, seepage out of the acequias, return flow to the river, and river discharge. We will use many of the methods discussed earlier to estimate subsurface flow paths and flow rates. In the second phase we will look at the entire irrigation ditch scale, which might be three miles long. We will characterize the land use, the water consumption, and the return flow to get at the big issue of how much return flow is coming from ditch seepage.



Early on and throughout the project we are meeting with the mayordomo and members of the Alcalde Acequia Association. They are enthusiastic about helping us with the long-term part of the project because they would like to know more about water consumption and return flow for the whole ditch. We feel it is very important to make sure that our study results can be applied and useful. First, we are relying on good science and not basing our assumptions on the literature, and second, we are maintaining on-going contact with the people who are out there managing the resource.