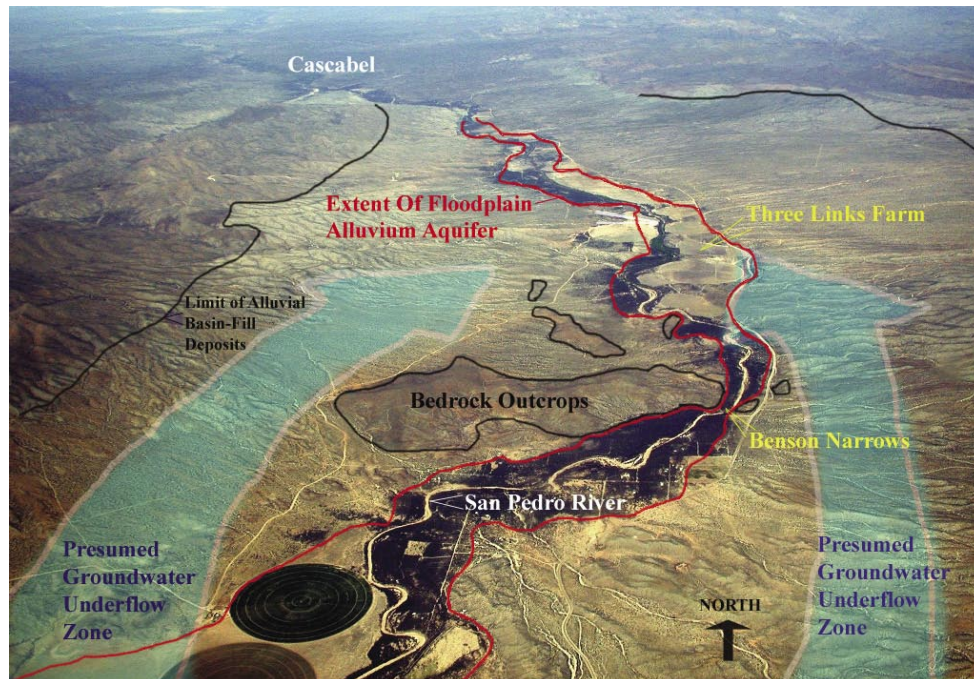


Interbasin Groundwater Flow at the Benson Narrows, Arizona

Jeanmarie Haney – The Nature Conservancy
and Jim Lombard – Consulting Hydrogeologist

The Nature Conservancy's (TNC) Three Links Farm stretches six miles along the San Pedro River in southeastern Arizona and contains a perennial flow reach and a cottonwood-willow riparian forest with a large variety of birds and other wildlife. TNC is working to re-establish ecosystem and hydrologic function in appropriate reaches of the San Pedro River, with an emphasis on protecting and restoring perennial streamflow and associated riparian habitat.

Understanding the hydrogeologic relations along the San Pedro River and source of groundwater underflow that supports the perennial flow at Three Links Farm is critically important to TNC's conservation efforts. The farm is located immediately downstream of the Benson Narrows, which marks the boundary between the Upper and Lower San Pedro basins. Previously, just 120 acre-feet per year of interbasin groundwater underflow were estimated to move through this area, based on the assumption that groundwater could move solely through the San Pedro River floodplain alluvium aquifer at the restricted slot canyon of the Benson Narrows (Heindl, 1952).



Groundwater flow at the Benson Narrows (figure from The Nature Conservancy).

Subsequent work, however, identified the possibility of groundwater underflow through the 800- to 1,000-foot thick alluvial basin-fill deposits flanking the bedrock outcrops of the Narrows (Montgomery, 1963; Halvorson, 1984).

Recent hydrogeologic investigations show that during the 2003 water year, about 3,500 acre-feet of groundwater passed through the floodplain alluvium aquifer at Three Links Farm. TNC hypothesized that most of this water originates as

groundwater underflow moving from the Upper San Pedro Basin through the alluvial basin-fill deposits at the Benson Narrows. Direct measurement of such underflow was not possible because wells of sufficient depth are lacking. Thus, new hydrogeologic work conducted at Three Links Farm included the following tasks:

- Fifteen existing wells at the farm were surveyed for location and altitude. Water level elevations were measured at each well during 2002-2003.



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- Groundwater altitude contour maps were constructed for different seasons, and groundwater gradients in the floodplain alluvium aquifer were calculated.
- Well records and new soils mapping by the USDA-NRCS Tucson Soil Survey Office were used to estimate the width and thickness of the floodplain alluvium.
- Aquifer testing was conducted using multiple observation wells. Based on analysis of results, a transmissivity of 40,000 square feet per day was estimated for the floodplain alluvium aquifer at one location on the farm.

From these new data, TNC researchers estimated that the average annual volume of groundwater underflow through the floodplain alluvium where aquifer testing was conducted was more than 3,500 acre-feet per year. Researchers then considered potential sources of water that could replenish the floodplain alluvium aquifer at that rate. Their analyses suggest that interbasin groundwater flow from the Upper San Pedro Basin is the primary replenishment source for the groundwater underflow observed at Three Links Farm, for the following reasons:

- No flood flows in the San Pedro River occurred at Three Links Farm during the monitoring period for which underflow estimates were made. Therefore, streambed recharge was ruled out as a source of groundwater.
- Irrigation at the farm had ceased more than a year before the monitoring period; therefore, irrigation return flow was not a source.
- Estimated average annual mountain front recharge is about 160 acre-feet for the small watersheds in the Little Rincon Mountains and the Johnny Lyon Hills flanking the southern end of the Lower San Pedro Basin (Goode and Maddock, 2000).
- Steady groundwater levels in the floodplain alluvium at the farm during

the monitoring period eliminated drainage from previously stored groundwater in the floodplain alluvium as a source.

- Existing groundwater chemical analyses in the aquifers north and south of the Narrows indicate that groundwater types do not change there: the types found in the Upper San Pedro Basin are also found in and near Three Links Farm.

This research indicates that substantial groundwater is moving through the floodplain alluvial aquifer at Three Links Farm and that most of this water originates from the Upper San Pedro Basin. This finding has significant implications, for in the neighboring Benson sub-area of the Upper San Pedro groundwater basin, deficit groundwater pumping was estimated to be 1,300 acre-feet in 2002 (Arizona Department of Water Resources, personal communication). Increased groundwater pumping in the Benson sub-

area could result in diminished interbasin groundwater flow to the Lower San Pedro Basin.

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The advertisement features a central image of a computer monitor displaying the Roscoe Moss Company website. The website header includes the company logo and the slogan "We Make Water Work Worldwide." Below the header, there are navigation links for "HISTORY," "MANUFACTURING CAPABILITIES," "RESEARCH & DEVELOPMENT," "CALCULATIONS & SPECIFICATIONS," and "FAQ's." A magnifying glass is positioned over the "CALCULATIONS & SPECIFICATIONS" link. To the right of the website image, a text box states: "Since 1926, the Roscoe Moss Company has been the leading manufacturer of water well casings and screens. They are marketed under the most respected brand name: Moss Well Products." Below this, it lists "New from Roscoe Moss Company" products: "STORM WATER SOLIDS REMOVAL DEVICE" and "ROSSUM SAND TESTER." To the right of the website image, a separate box lists three services: "NEW: Calculations & Specifications," "Rossum Sand Tester," and "Storm Water Removal Device." At the bottom of the advertisement, the Roscoe Moss Company logo is shown again, followed by the address "4360 Worth Street, Los Angeles, CA 90063" and phone/fax numbers "(323) 263-4111" and "(323) 263-4497." A copyright notice at the bottom right reads "© 2004 Roscoe Moss Company, All Rights Reserved."

New Approach to Address Acid Rock Drainage

Gregory J. Olson and Thomas R. Clark
– Little Bear Laboratories Inc., and Terry I. Mudder – TIMES Ltd.

Mine remediation costs are dramatically increased when acid rock drainage (ARD) is present. Consequently, mining engineers have learned it is best to inhibit ARD production before it begins through proper waste management and source control.

ARD results from uncontrolled oxidation of metal sulfides, primarily pyrite (FeS_2) in waste rock, tailings, and spent ore. Both oxygen and microorganisms are important in this process. Pyrite exposed to oxygen and water slowly oxidizes, producing ferrous sulfate and sulfuric acid. As the pH becomes more acidic, microorganisms greatly accelerate the oxidation of ferrous sulfate to ferric sulfate, a strong oxidant that readily oxidizes more pyrite and other metal sulfides. The end result is

production of drainage waters that have low pH, high concentrations of dissolved solids, and toxic metals.

With funding from the U.S. Environmental Protection Agency's Small Business Innovative Research Program and a consortium of eight international mining companies, Little Bear Laboratories Inc. and TIMES Ltd. are evaluating a method for ARD source control that focuses on stopping the growth of iron-oxidizing microorganisms and minimizing the chemical oxidation of pyrite and other sulfide minerals.

Controlling Biooxidation of Iron

Iron-oxidizing bacteria at low pH are extremely sensitive to thiocyanate



Placement of waste rock in test pits at Red Dog Mine, Alaska. A loaded and treated pit in the foreground shows wire leads from a thermistor placed in a vertical pipe for temperature measurements.

(SCN), with only a few parts per million in solution being lethal. Thiocyanate is a selective biocide, and is much less toxic to "normal" microflora and higher forms of life. It is relatively stable at low pH and under anaerobic conditions, and at neutral pH under aerobic conditions it is biodegraded to carbon dioxide, sulfate, and nitrate. Thiocyanate is a component of wastewater solutions at many precious-metal mines, therefore these solutions could potentially be used for ARD control following selective treatment to remove constituents other than thiocyanate, such as cyanide and metals.

Controlling Chemical Oxidation

Even if all biooxidation of iron is inhibited, pyrite and other metal sulfides may still be oxidized by oxygen and ferric iron. However, this chemical oxidation can be greatly reduced by adding phosphate to sulfidic mine waste. Phosphates neutralize acidity and precipitate ferric iron and aluminum ions as phosphates. The removal of iron and aluminum from solution as phosphates precludes acid production by precipitation of these metals as hydroxides.

Furthermore, iron phosphate precipitation may also coat unreacted pyrite, further preventing its oxidation. Phosphate is a relatively benign and inexpensive chemical available worldwide.

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