Final Report
June 2011
Rio de Las Vacas Wetlands Restoration Project
Assistance Agreement #CD-966016-01-0

Rio de Las Vacas

Project Description and Location

The Rio de Las Vacas is located in the Jemez Watershed (HUC #13020202) in northern New Mexico and flows into the Rio Guadalupe, Figure 1. In the middle section of the Rio de Las Vacas (hereafter referred to as the Vacas), the canyon opens up to a valley floor with many private in-holdings and in the Cuba Ranger District, Santa Fe National Forest (SFNF) property. A perennial stream, Rito Peñas Negras, is above the project area, and Wolf Creek (intermittent – mostly wetland) is mostly privately owned.

The “Rio de Las Vacas Wetlands Restoration Project” is the first of a phase of projects to restore the Rio de Las Vacas. This project restored 39 acres of wetlands and approximately 2.53 miles

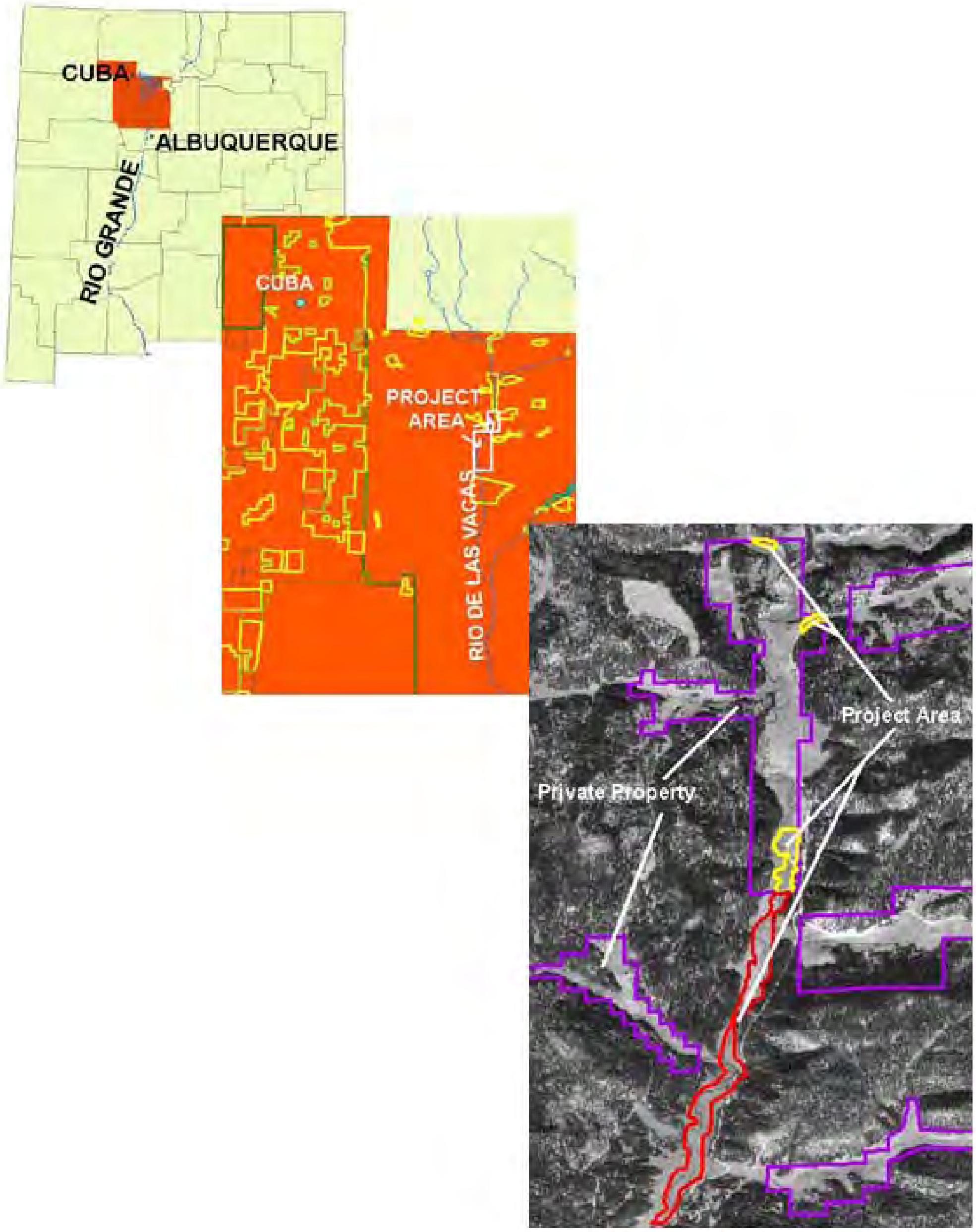


Figure 1. Map of Rio de las Vacas Project Area

of riparian area using the following methods and best management practices (BMPs): bio-engineering the stream and wetlands; planting native wetland vegetation; repairing fencing and building cattle and elk mini-exclosures; and installing innovative hemi-exclosure fences. The bio-engineering of the stream included building instream vanes and baffles, instream and wetland one rock dams and media lunas in wetlands for erosion control and grade control, as well as to slow down and spread out the water in small areas where degradation was evident. All of these structures have been planted with willows to enhance and strengthen the structures. This provides more stable streambanks and in time will reduce the stream bed width/depth ratio.

In additional to on-the-ground restoration activities, the project also included a significant information and technology transfer component through two beaver workshops worked on specifically through this project. SWQB also partnered in a third beaver workshop that resulted in a training DVD. Participants learned about the Rio de Vacas project; they gained appreciation for the positive correlation between beavers and healthy riparian areas; especially in the southern rocky mountain streams. They learned techniques to support beaver populations even in areas of human habitation. Landowners, people with cattle permits, NM Game and Fish wardens, and recreational users learned how to construct Beaver Deceivers™ and learned about the benefits of beaver on a river. Additional education and outreach value was gained by volunteer participation and labor on the project. Volunteer work crews, guided by restoration contractors, were directly responsible for much of the labor of planting woody vegetation, checking fences, and hand-placing rocks for erosion control structures.

The Rio de las Vacas, through this project, is moving towards a naturally functioning, self-sustaining wetland ecosystem because it is improving conditions for beaver, the most natural wetland engineer. Improving riparian habitat will encourage beaver to return and help sustain the project. We are addressing the impacts from the grazing component; however, sustainability can only occur with buy-in from the people who use the area. This is the reason for the workshops, so that recreational, grazing and other uses of the land will not discourage the presence of beaver.

Project Goals and Objectives

The primary objective of the project was to restore wetlands in the area by improving the condition of the stream. The wetlands will strengthen the density of the native vegetation. The wetlands and riparian corridor will provide a buffer protecting water quality on the Vacas. The Vacas is listed on the New Mexico Surface Water Quality Bureau (SWQB) Clean Water Act (CWA)§303(d) list of impaired streams. The Rio de las Vacas is listed as impaired for its designated use as a High Quality Cold Water Aquatic Life. An earlier listed probable cause of impairment, stream bottom deposits, was removed; however temperature continues to be impairment and nutrient impacts was added from information in the 2008 SWQB stream survey. The restoration will also improve shade and increase the number of pools in the rivers, which are issues of concern for the SFNF and SWQB. As the wetlands improve, so will habitat for fisheries, amphibians and mammals, especially the beaver.

A second objective was to increase awareness of wetland function and the beaver (*Castor Canadensis*) as wetland implementers and gain more support by private landowners for the next phase. Creating a more resilient habitat will improve the function of the stream increasing biodiversity as well as allow for traditional uses such as grazing. The watershed will become more productive and with proper management can become a "win-win" situation. Specifically, improved habitat will increase populations for state and Federal listed species: Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis*) and New Mexico jumping mouse (*Zapus hudsonius luteus*). The project also improved habitat for Rio Grande Chub (*Gila Pandora*) and Rio Grande sucker (*Catostomus plebeius*) and most importantly the beaver. Two new beaver dams were established during this project. Increased wetland acreage was a specific project goal and an important focus of this project. Wetlands provide many assets, not in the least, increased productivity of vegetation. The outcomes were accomplished by delivering the final products of recovering riverine wetlands, more pools in the river, less erosion, restored streambank; an increased wetland and riparian plants, and installed exclosures and hemi-exclosures to divert wildlife and cattle from the streambanks. As part of the headwaters to the Jemez River, the Vacas is a popular fishing locale. Many fishermen target the large game trout including the Rainbow (*Oncorhynchus mykiss*) and Brown (*Salmo trutta morpha fario*) that are present in this stream. That said, we have seen evidence of destruction to our exclosure fences if they are a barrier to recreationalists. The hemi-exclosure fences address this problem.

Of the above outcomes, I would like to emphasize the demonstration aspect of the hemi-exclosure fence. The hemi-exclosure was a new technique conceived and designed by Bill Zeedyk, Zeedyk Ecological Consulting, Inc. to protect riparian areas from grazing and trampling and minimizing our costs of ever inflating price of metal. The style of fence has advantages over traditional exclosures because they are economical, shorter in length and will require less maintenance especially crossing the stream. The design of the fence, Figure 2, is simple. Observation shows that riparian and wetland vegetation is the first to 'green up' in the spring and provide nutrients to grazing animals including smaller species such as rabbits and prairie dogs. The wetland/riparian components are often grazed heavily if there isn't any management to move stock. Exclosures, whether they are large as in pastures, or riparian restoration boxes, function to protect riparian/wetland vegetation thereby strengthening the stream banks. This type of fence protection requires maintenance since the fence crosses the river two places. So the 'hemi- exclosure fence' takes advantage of the cow behavior to only forage on the terrace side of the river. We fenced the outside curve on a meander. Pools develop on the inside curve of the meander if the stream banks are stable. By protecting the riparian component, the pool has increased shade and bank stability.

Also an important component of the project, the beaver workshops were innovative because many New Mexico landowners view beavers as a nuisance. Disseminating information about the positive benefits of beavers and practical ways to coexist with beavers served to create momentum for beaver habitat projects. The workshops cast a positive light and changed some attitudes about beavers.

This project contributed progress towards achieving the following approved SWQB Wetland Program Plan objectives:

1) Develop two new restoration sites per year and demonstrate innovative designs and techniques for restoring wetlands. A project to continue work in this area was approved for CWA §319 (h) funding in FY 2012. Using hemi-exclosure fences and natural channel design we demonstrated as successful new and innovative process for restoration on this stream.

2) Create technical materials and disseminate information to private landowners, tribes, and others on incentives, methods and trainings to restore and protect wetlands, and coexist with beaver.

Original Timeframe

The original timeframe for the project was October 2005 through October 2008.

Cooperators Involved

1. The Santa Fe National Forest, Cuba Ranger Districts arranged for State Historic Preservation Office requirements to be completed on private land and NM Forestry Camp.
2. Animal Protection of New Mexico along with SWQB staff developed and co-sponsored two beaver workshops, “Beavers Belong!” and “Coexisting with Beavers by Preventing Damage.”
3. Zeedyk Ecological Consulting, Inc. performed restoration design, and was technical advisor for restoration and monitoring.
4. Rangeland Hands, Inc. did restoration implementation: specifically using heavy equipment in placing instream ‘natural channel’ design structures and overseeing fence work. They worked with Keystone Restoration Ecology, who conducted vegetation monitoring.
5. Cuba Soil and Water Conservation District provided discussion of private land problems and information for the CWA 401/404.
6. Private landowners assisted with restoration and wetland protection and attended workshops.
7. Albuquerque Wildlife Federation and New Mexico Trout unlimited provided volunteers for restoration implementation.
8. Several organizations sponsored the beaver workshop: Beaver Toyota in Santa Fe; Cid’s Market in Taos; the Eugene V. and Clare E. Thaw Charitable Trust; Far Flung Adventures; Taos Land Trust; Trader Joes; Vigil Law Firm; and private landowners John Brown and John Miera.
9. Sherrie Tippie of Wildlife 2000 gave technical presentations at both beaver workshops.
10. Barbara Coulter and Josh Rector from New Mexico Department of Game and Fish gave technical presentations at the beaver workshops.

11. Dr. Paul Polechla, Jr. of the University of New Mexico Biology Department gave a technical presentation at the first beaver workshop.
12. Wildlife biologist Skip Lisle of Beaver Deceivers International gave technical presentations at the beaver workshops.
13. Dave Foreman of the Rewilding Institute gave a presentation at the second beaver workshop.
14. The Gallup Youth Conservation Corps (YCC) provided labor to build fencing.

Funding (Federal and Final Match Balances)

Grant Award	Federal funding – EPA 152,335	Match 50,793
Drawdown FY 06	0.00	100.00
Drawdown FY 07	7,215.00	15,000.00
Drawdown FY 08	27,871.00	26,250.00
Drawdown FY 09	45,586.00	20,300.00
Drawdown FY 10	2,769.04	13,348.00
Drawdown FY 11	68,883.33	0.0
balance	10.63	(24,205.00)

Describe Major Project Highlights, Products and Completion Dates

Task 1. Hemi-Exclosure fence implementation. Twenty hemi-exclosure fences were constructed in the summer of 2008. These fences were an innovative design concept conceived by Bill Zeedyk. The hemi-exclosure fences are less expensive to construct because they take fewer materials and less labor. They also are less likely to be subject to vandalism by people or destruction by animals because the stream can still be accessed, however the more vulnerable cutbank side of the stream is protected. Also, the fence does not cross the stream, which reduces the need for maintenance following flood events. Photo 1 below shows a hemi-exclosure fence one year after construction. Note how the alders have been grazed on the right side of the photo, the stream terrace side. In contrast, Photo 2 shows previous attempts at fencing along Rio de Los Vacas, where the traditional barbwire fence is broken down and is in effective at excluding cattle. Photo 3 shows cattle in the stream and riparian area demonstrating the need for riparian exclosures. Note the paucity of woody vegetation in the riparian area. Another important facet of this fence design is that vandalism (cutting fence wire) is less likely to occur because the fences do not present an obstruction to people, they are usually short enough to walk around.

The hemi-exclosure fence design was presented at two conferences, the New Mexico Watershed Forum in Albuquerque – September 2008 and the Wetland Program Capacity Building Conference in Bozeman, Montana, September 2010. The hemi-exclosure fence design has subsequently been adopted by the Natural Resource Conservation Service (NRCS) as an approved agricultural best management practice for excluding livestock fencing. (May 2010)

See Attachment A- The Hemi-Exclosure: A New Tool for Riparian Protection and can also be found on the NRC website at http://www.nm.nrcs.usda.gov/technical/tech-notes/range.html

Besides the hemi-exclosure and mini-exclosure fences, four modifications of pre-existing USFS riparian pasture fences were planned and implemented. This strengthened already existing riparian protection, including a better water gap than was in place. Part of the modification was to put in access points so that the fence wouldn't get cut. A drift fence (perpendicular to a steep slope) was implemented to remove a cattle trail.

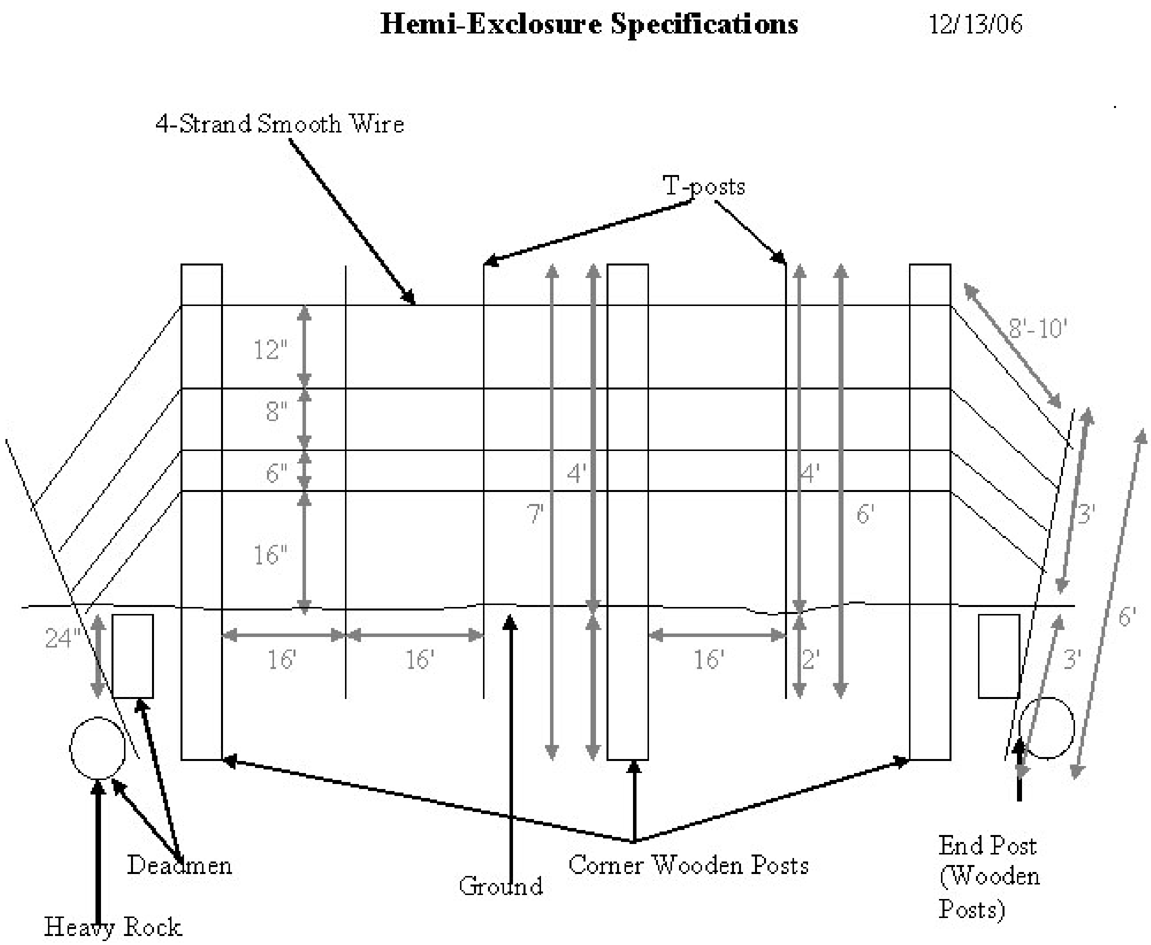


Figure 2. Hemi-exclosure fence design.

Photo 1. Hemi-exclosure fence exclosure, an innovative installation along the Rio de las Vacas.

Photo 2. Damaged and down barb-wire fence along the Rio de las Vacas.

Photo 3. Cattle grazing on the flood plain of the Rio de las Vacas. Note lack of riparian species.

Task 2. New Mexico State Historic Preservation Compliance for Rio de Las Vacas and Wolf Creek.

This task was completed in Fall 2007 for the Santa Fe National Forest property. The NM Historical Preservation Division issued a discovery clause allowing restoration to occur on the private property. However, in the process of creating a landowner agreement, the private landowners with the largest parcel communicated that he wished to do a land swap with the US Bureau of Land Management or the US Forest Service. He and through advise from his lawyer were unwilling to sign the landowner agreement. They were acquainted with the project BMPs and were amenable to protecting their wetlands, but not agreeable to signing a project landowner agreement. He said it would complicate future actions such as subdividing the land. One of the four participating landowners was willing to sign the agreement, but didn't want to provide match. His property also had the least impacted section of Wolf Creek. Therefore the restoration on private lands has become an evaluation and recommendation process. Each of the property owners was provided with specific restoration steps recommended for the property, based on site specific conditions.

Task 3. Design Riparian Restoration for Rio de Las Vacas and Wolf Creek.
The Rio de las Vacas Wetlands project was surveyed using the Rosgen Level II protocol during May 2006 by Bill Zeedyk, Zeedyk Ecological Consulting, LLC. Van Clothier, Stream Dynamics, SWQB staff. The surveyed channel length was 13,400 feet or 2.53 miles. Based on acquired date, the area was divided into 3 reaches, upper, middle and lower. The upper reach, Rosgen E-4 had a channel length of 4000 feet. The middle reach, Rosgen B-3 had a channel length of 5,300 feet ending at station 9,300. The lower reach is a Rosgen C-4 channel type and is 4,100 feet in length. Key morphological and cultural features (riffles, cutbank erosion, tributaries and springs) were documented and used for the restoration design. Based on survey results, proposed instream structures were sited and designed by Zeedyk during June 2006. Concurrently with the channel design, wetland structures or other treatments (fencing) for restoration were completed.

Survey work was performed on the 3 wetlands tributaries, Telephone Canyon, Turkey Canyon and School Section drainage. Wolf Creek and the private land portion of Rio de Las Vacas in completed during the summer of 2006. The design was completed in approximately January 2007.

The proposed structures were as follows:
Upper reach: 2 boulder vanes, 4 post vanes, 1 boulder baffle, 1 cross vane – total 8 structures.
Middle reach: 1 rock weir, 2 boulder vanes, 6 post vanes, 24 baffles and 1 cross vane – total 34 structures.
Lower reach: 5 post vanes, 7 boulder vanes, 2 log vanes, 6 baffles – total 20 structures.

In addition to instream structures for the main stream reach, at least 9 structures were designed for tributary streams, springs, gullies and wetlands. This inventory was later expanded based on additional information and study.
Attachment B– Restoration design and survey

Task 4. National Environmental Policy Act and Endangered Species Act Compliance for the Rio de Las Vacas on Santa Fe National Forest Property.
Data was summarized, including dredge/fill estimates, and material needs inventory. The data were used as a basis for the CWA §401/404 permit application. A Nationwide 27 §404 permit was obtained April 2007 and subsequently the USFS issued its Decision Memo, as Categorical Exclusion in August 2007.

Attachment C–NEPA decision memo.

Task 5. Threatened and Endangered Species Analysis for the Rio de Las Vacas and Wolf Creek.
The Threatened and Endangered Species Analysis was included in the NEPA for the SFNF project area. The analysis on the private section was discussed with US Fish and Wildlife, but as the participants wouldn't continue their participation, the analysis was not finalized.

Task 6. Clean Water Act Section 404/401 Compliance for Rio de Las Vacas.
Data was summarized, including dredge/fill estimates, and material needs inventory. The data were used as a basis for the CWA §401/404 permit application. A Nationwide 27 §404 permit was obtained April 2007 for the Santa Fe National Forest portion, and became un-necessary for the private land as the property owners opted out of the project. The 401/404 permit was renewed in April 2010. A copy is included in Attachment D.
Attachment D – 401/404

Task 7. A Series of Workshops.
A free workshop titled "Beavers Belong" was sponsored by Animal Protection of New Mexico on May 30, 2006. Various experts from around the country gave presentations to approximately 25 attendees in the morning. The afternoon was spent in the field learning hands-on how to construct a "beaver deceiver," watching a tree-wrapping demonstration, and observing the use of live beaver traps. Speakers included Sherrie Tippie of Wildlife 2000; Skip Lisle of Beaver Deceivers International; Paul Polechla, research associate professor at the Museum of Southwestern Biology of the University of New Mexico; Josh Rector of NM Department of Game and Fish; Sid Goodloe, rancher and conservationist. Talks focused on human and beaver coexistence, relocating beavers, mitigation methods, how beavers enhance rivers and wildlife, rules and regulations of trapping beaver, and beaver biology. SWQB attended and had a booth at the event.

Photo 4. Participants of the Beavers Belong! workshop.

Photo 5. Making a Beaver Deceiver

Photo 6. Left: Sherrie Tippie demonstrating live traps. On the right, Skip Lisle is protecting a tree using fencing material.

A second free workshop titled "Coexisting with Beavers by Preventing Damage" was conducted by Animal Protection of New Mexico (APNM) and the SWQB staff on May 20-21, 2008. The workshop focused on the benefits of beavers in riverine conditions and how a nuisance situation can be abated with other than lethal means. Over 50 people attended the two day workshop. The first day of the workshop was on-site field training of construction of devices in the Santa Fe River to mitigate beaver damage (Beaver Deceivers ™) and live-trapping instruction. Skip Lisle, nationally known for his innovative methods of protecting and coexisting with beavers was the instructor. Day 2 included six speakers with varying focus, including funding resources to protect beaver habitat, and why it is important to do so.

Photo 7. Coexisting with Beavers by Preventing Damage Workshop participants

A video was produced by APNM of another beaver training workshop in south-central New Mexico on an acequia off of the Rio Grande. Skip Lisle, who invented the Beaver Deceiver ™ and the Castor Master™ showed how to build them. These structures provide a viable way of deterring dams from where they are undesirable. This workshop was also sponsored by the US Fish and Wildlife with the specific target audience of Game Officers with the New Mexico Game and Fish Department. Others were also invited. The event was recorded onto a 5 hour DVD. SWQB, through this grant, shortened and edited the video to 41 minutes, to encourage more use with the public.
Attachment E –Video Beaver Dam Flow Device Training, agenda for two workshops.

Task 8. Dispersed Camping Restoration.
During the 2008 work weekend, Albuquerque Wildlife Federation volunteers and members from New Mexico Trout, constructed 2 check or one-rock dams and 5 Zuni bowls (drop structures to reduce headcut energy) and 2 media lunas, (which act as a flow dispersal mechanism) on the

wetlands of Telephone Canyon as it drains to the Rio de las Vacas, which has been subject to erosion damage from dispersed camping. Other problems that contributed to erosion and drainage of wetland areas include ruts that are created during driving activity on seeps or during wet weather. A legacy road that was turning into two rutted trenches was treated to keep it from turning into an arroyo. The trenches were filled in and drains were put in the road to disperse and drain water off the roads.

Photo 7. Media luna on Telephone canyon.

Photo 8. Left - road restoration, Right - Zuni bowl with C. Cook, USFS Fisheries Biologist and Bill Zeedyk

During the 2009 work weekend, the work focused on the main dispersed camping area at the confluence with Turkey canyon. This area was treated with 3 Zuni bowls, and 3 one-rock dam structures. This is a popular recreational site. There are several roads and we have suggested that the USFS minimize road density here. The structures will be effective to reduce the erosion from seeps that have been both overgrazed and/or have headcuts associated with them. There are many seep and springs in the Turkey Canyon area. The one-rock dams and Zuni bowls will stabilize and slow down the surface drainage on the wetlands adjacent to the Rio de las Vacas and make it difficult for cattle to trod on.

Photo 9. Turkey Canyon springs. One rock dam

Photo 10. Roads on dispersed camp site, Turkey Canyon

While not used heavily as a dispersed camp site, the drainage from the School Section Canyon was a focus for the work weekend in 2010. It was treated with 6 Zuni bowls on headcuts, 6 one-rock dams, and work on the road to keep trenching or headcutting from occurring in the ruts. A short channel was excavated by Rangeland Hands, Inc., to link School Section Canyon tributary to a former wetland site on the Rio de las Vacas left terrace, upstream from present wetland flow. This was planned to create a new wetland approximately 2 acres in size. The flow splitter was stabilized with a boulder flow splitter and four cobble channel liners. The function of this structure will split flow specifically during snowmelt.

Photo 11. Flow splitter on School Section Canyon

An earthen berm was built along the edge of the river channel in order to contain flows to the wetland surface.

Eight check dams (one-rock dams) and 3 drop structures (Zuni bowls) were installed by volunteers at various unnamed springs and seeps in the project area. The purpose of the structures was either to stop headcutting or sequester sediments, promote dispersed and slower flow and enhance the growth of riparian and wetland vegetation.

Task 9. Implementation of Rio de Las Vacas and Wolf Creek Restoration.
The 20 hemi-exclosure fences and the 4 mini-exclosures were installed in June 2008. The work was done by Steve Carson, Rangeland Hands, Inc., and the Gallup YCC. The hemi-exclosure fence design is unique and will hopefully require minimal maintenance. Cattle and other ungulates tend to avoid deep pools within the river where the banks are high and will not eat the riparian vegetation, especially shrubby species if fenced on the terrace side of the stream. The Rio de las Vacas has a temperature impairment and has had in the past a sediment/siltation impairment. It is part of our goal to protect the riparian species and create more wetlands. The area contained in these hemi-exclosure fences has responded and sedges, rushes and woody vegetation are now growing. By fencing the outside of a meander the animals are unable to graze the vegetation, but the stream is still available for recreation as well as a watering opportunity for stock on the riffles. Fences in the public land have a history of being cut. The Gallup YCC crew worked on the project under Rangeland Hands Inc. supervision. This was a positive experience for the young adults and teens to earn money, learn how to make a fence and why, and stay in a beautiful area in the SFNF.

Four mini-exclosures were also completed; this “box-like” fenced design generally may require maintenance as the fence crosses over the stream two times. Then mini-exclosures literally encloses the stream banks on both sides, however, cattle and wildlife can get under the fence where it crosses the river. The fence where it crosses the river more vulnerable to debris and other material catching on it during a flood event, whereas the hemi-exclosure fence ends at the banks of a river.

Photo 12. Mini-exclosure in upper reach

The project workplan was amended in December 2009. In June 2010, Rangeland Hands Inc. installed 8 boulder vanes, 12 log vanes, 5 post vanes, 2 boulder baffles and 1 boulder bankful bench on the lower reach. The upper and middle reaches had responded well to the exclosures and were getting vegetation on the banks, to stabilize and reduce width/depth ratio of the stream and to provide shade. The lower segment was more vulnerable to impacts and the project focused here to primarily decrease the width/depth ratio so as to reduce temperature, create better pool structures and reduce the occurrence of nuisance algae. The implementation of the restoration project was greatly assisted during the three Albuquerque Wildlife Federation work weekends in the summers of 2008, 2009 and 2010. Oversight was provided by contractor, Bill Zeedyk and SWQB staff. Volunteers plan to continue to come up to this project site and continue maintenance and planting around these structures. The Albuquerque Wildlife Federation has a work weekend at the Rio de Las Vacas planned for June 2011, and would like to continue to work in this area.

Photo 13. An example hemi-exclosure fence.

Recommendations on the Wolf Creek Restoration

SWQB staff, Steve Carson and Bill Zeedyk met with the three potential landowners, Larry Allred, Terry Bass, and Peggy Ohler. Recommendations included filling a headcut with a drop structure such as a Zuni bowl, discontinue cattle trailing alongside a property boundary fence and install drain structures on the dirt roads leading to their homes. In particular, we suggested rotational grazing for the horses that were frequently on site.

Task 10. Wetland Planting and Protection.

Volunteers from Albuquerque Wildlife Federation (AWF), New Mexico Trout (NMT), and staff from Respect the Rio (USFS) planted willow cuttings on three occasions, two days each during June 2008, 2009 and 2010. Willow cuttings were planted along one or both streambanks within the perimeters of all mini-exclosures in the upper reach and within the hemi-exclosure fences of the lower reach. The middle reach had a good stand of willows that were harvested and planted. Another willow stand that provided resource material was at the end of the project area where the canyon narrowed. Several thousand of at least three different species of willow wands were planted during the volunteer work days.

Photo 14. Albuquerque Wildlife Federation group photo, 2008. Photo by Pat Hestor, courtesy of AWF.

Several Zuni bowls were constructed to reduce headcuts and sedge material was harvested and incorporated into these structures. The media lunas on the wetland canyons were constructed to disperse the sheet flow and allow for more vigorous wetland species growth, and have shown a fast recovery for plant growth of grasses and forbes. A single volunteer planted willow cuttings at all sites disturbed by the installation of streambank structures in the lower reach during 2010 resulting in a contribution of 40 hours of time.

Photo 15. left - AWF volunteer Nathan Canaris planting willow, 2009. Photo by Peter Callen. Right - The littlest helper carries harvested willows, 2009. Photo by Pat Hester. Both photos courtesy of AWF.

Additionally, volunteers associated with AWF and NMT performed routine fence maintenance or modification of all project exclosure fences during 2008, 2009 and 2010. The fences are instrumental to the protection of wetland planting. A new District ranger had been assigned to the Cuba Ranger District in 2008. The SFNF was more attentive to reducing trespass cattle grazing and more willows were seen sprouting than had been observed in the past. We also enjoyed one year of a wet growing season, for example, rain fell during the 2009 work weekend, which was advantageous for the willows to take root. The method used to plant willow whips is to cut a stem about 0.5 inch to 2.5 inch in diameter by 2 – 2.5 feet in length. Using a digging bar or sharpshooter shovel, put about 1 foot length of the whip in the ground where the soil is moist. Do this in groups of three whips. Using three stems per hole reduces the wind damage that could occur to fragile roots. The alders in particular, and other species including willows and sedges were shown to be more vigorous within the hemi-exclosures, in fact we were so pleased with the results of one growing season that a poster was presented at the New Mexico Watershed Forum to share this novel approach to protecting wetland/riparian areas during the first growing season.

Task 11. Continued Monitoring of Project.
Pre-and post-implementation monitoring was conducted in accordance with the approved QAPP. The Rio de La Vacas Wetlands Restoration Project Pre-Monitoring Report was received October 27, 2008. The Post-Monitoring report was received by SWQB in December 2010. The project showed an increase of species growth and species diversity especially associated with the hemi-exclosure fences. The structures have not had enough time to show a great deal of change, however we are hoping to capture some of the changes with a follow up Rosgen Level II survey in the lower reach.

A special project was started by graduate student Andrew Robertson to study the influence of groundwater on temperature. He submitted his initial project report for SWQB review and consideration. Mr. Robertson was unable to continue with the project and his Masters program because he was deployed to Iraq and was unable to find another student interested in pursuing this information. It is however an interesting study, and in the future he or someone else may be able to continue with his work
Attachment F. (3)

Task 12. Grant Administration and Oversight.
Project staff changed during 2008 when Julie Arvidson Walker left employment with SWQB. The project was assigned to Nina Wells who was familiar with the project site and with the watershed. However, she already had 7 projects and staffing levels were down. We were unable to replace the wetlands staff position. The Wetlands Action Plan was started and is currently under development. The Rio de las Vacas headwaters are in the San Gregorio Wilderness and ends with confluence of Rio Cebolla to make the Rio Guadalupe. This is an ongoing task and will be completed this year. Invoices were checked and processed. Ten reports were submitted, permits and other regulatory requirements were obtained and followed. This document constitutes the Final Report. Although the change in staffing resulted in project delays and heavier workloads, the project implementation was very successful.

Task 13. Attend a Wetlands Training.
SWQB Project Officer Julie Walker attended a training provided by Natural Channel Design, Inc. entitled "Inventory and Assessment of Natural Channels in the Arid Southwest". This was a five day intensive training on inventory and assessment of rivers and streams specific to the southwest US, taught by Tom Moody. The training focused on assessing stream channel functions in the southwestern United States combining David Rosen's Natural Channel Classification System and methods adopted and regional relationships developed by Natural Channel Design, Inc. to gear assessment to streams in the southwest. The specific methods included assessing sediment transport, channel profile and pattern, riparian plant zones, regional bankful curves, and a larger entrenchment ratio for southwest streams.

As there were funds still in this category, SWQB staff Nina Wells, attended the Wetland Program Capacity Building Conference in Bozeman, Montana in September 2010. She presented a poster on the "Hemi Exclosure" – A New Tool for Riparian Protection and it was very well received.

Explanation of Delays or Milestones not Met

The project was modified throughout the course of implementation. The original workplan included the installation of trick tanks as part of the project, but this was precluded by an increase in the price of steel. The 10,000 gallon size tank needed became was expensive and would only meet our goals if the upland fences, where the trick tanks would be situated, would hold. The hemi-exclosure fence concept was developed and implemented as an innovative alternative to the trick tanks. This reduced variables that would affect the success of our project, and fit well to the goals of this project.

The project location area was also modified because of issues with implementation on private land. As Figure 1 shows, there was initial interest from people on the Rio de las Vacas upstream of the SFNF area. Although we surveyed the project site, they put their land up for sale. It still has the "For Sale" sign. The private land component became primarily a consultation and recommendation process for restoration activities that should occur on the private properties.

A Wetlands Action Plan for the Rio de las Vacas is not complete. Staff discussed this plan during meetings of the Jemez Watershed Restoration Action Strategy. Local individuals as well as agency staff were contacted but did not provide much commitment or participation. SWQB staff has developed an outline for the Plan, but time has run out for submitting this deliverable with the final report.

The overall project time period was extended from October 2008 to December 2010 because of requested changes in the first task, from trick tanks to hemi-exclosure fences and to review and correct the earlier workplan.

Performing work on private properties was originally a part of the project. The private property work was eliminated because ultimately the property owners were unwilling to sign the landowner agreements, and were unwilling to provide match for the work on their property. Nevertheless, the project was somewhat successful in educating landowners about wetlands, riparian restoration and beaver habitat, and provided local landowners with specific recommendations about low cost restoration actions for their properties. The landowners followed up by managing grazing and improving the drainage on their roads.

Project Chronology

- The project workplan was approved in November 2005.
- The project site was surveyed for design reconnaissance in 2006.
- Meeting with private property owners started with Sandoval County record research and was ongoing during the life of the project
- A beaver workshop titled “Beavers Belong!” was held in Taos on September 30, 2006.
- The QAPP was approved by EPA Region 6 on September 2007.
- The federal NEPA analysis and decision was completed in Summer 2007.
- Zeedyk Consulting, Inc. developed and implemented the innovative hemi-exclosure fences in 2008 as well as constructing other traditional grazing exclosures.
- Hemi-exclosure fences, mini-exclosure fences and other non-traditional fences were constructed in 2008.
- Albuquerque Wildlife Federation conducted a three day workshop on June 20-22, 2008; over 40 people volunteered to plant willows, work on structures on Telephone Canyon, modify constructed fences where needed and fix USFS fences.
- A second beaver workshop titled “Coexisting was Beavers by Preventing Damage” was held in Santa Fe on May 20-21, 2008.
- SWQB representatives took EPA Region 6 representatives on a site tour in 2009.
- SWQB worked with EPA Region 6 in 2009 to amend the work plan, wherein the hemi-exclosure fence task replaced the trick tank task and the budget was adjusted among tasks.
- Albuquerque Wildlife Federation conducted another three day volunteer workshop on June 19-21, 2009: forty-nine volunteers planted willows, repaired fences, and built or augmented rock structures to divert water flow or reduce erosion especially in the upper and middle reaches of the Rio de las Vacas project area.
- In-stream Natural Channel Design structures were constructed in early June 2010.
- Albuquerque Wildlife Federation conducted a third volunteer workshop on June 18-20, 2010: thirty-three volunteers planted willows and built rock structures to improve wetland drainage on School Section Canyon and Telephone Canyon.
- NMED Project Officer Nina Wells and Bill Zeedyk presented information about hemi-exclosure fences at conferences on September 2008 at the New Mexico Watershed Forum
- NMED Project Officer Julie Arvidson attended a wetland training session at western Arizona on April 2007
- NMED Project Officer Nina Wells attended a Wetland Conference at Bozeman, MT on September 2010, also presenting a poster on the hemi-exclosure fence.

List of Major Deliverables

1. Installation of 20 hemi-exclosure fences. Hemi-exclosure fences are riparian fences that protect only the landward side of the streambank. The design of the fences minimizes cost and likelihood of vandalism while protecting vegetation from grazing animals, especially cattle.
2. State Historical Preservation Division permit. This included completing an archeological survey for historic artifacts in the project area, report writing, and obtaining the permit. This was done through the NEPA analysis.
3. Completed design documents for riparian/wetlands restoration.
4. Completed documents for NEPA and ESA requirements.
5. Clean Water Act Dredge and Fill permit obtained, to comply with Clean Water Act Section 404/401.
6. Workshops conducted (2), DVD of our involvement in a third workshop.
7. Implementation of project, including increase in area of riparian and spring wetlands, more pools in the river, less erosion, improved shade, increased meanders, sinuosity and channel length, and restored streambank to begin planting wetland/riparian vegetation.
8. Riparian and wetland vegetation planted.
9. Monitoring reports.
10. Semi-annual and final reports.
11. SWQB staff attendance at wetlands training.

Monitoring Report

The final monitoring report is included as Attachment F.

Lessons Learned

This project was a delight to work on the ground, but there never seemed to be enough time to take care of all the details, including the reports. Staff has spent many hours working with private landowners, but the end result was that some did not wish to participate due to potential or perceived limitations on how their land was managed. Some were outright uninterested in restoring their land. Others, while passively interested did not want to participate in helping with the required permits. We are hoping that the neighbors have followed the process used in the SFNF public land. As the land becomes more productive and healthy, they may wish to improve their lands. It was also an important lesson to keep communication open with the Cuba Ranger District, especially Range staff, to address trespass cattle issues. The ability to compromise has been our biggest asset in moving forward with this project.

Technical Transfer

Staff planned and co-hosted two beaver workshops and participated in a third workshop with Animal Protection of New Mexico. New methods to coexist with beaver were presented as well as discussion of the benefits as well as the perceived nuisance this animal that can arise from having this animal on your property. Seriously misunderstood, the beaver is a keystone species, especially in southwestern watersheds where water runoff is prevalent.

A poster and white paper was presented at the NM Watershed Forum, during which time NRCS State Conservationist was interested in the design and use of the hemi-exclosure fence, NRCS adopted hemi-exclosures as BMP. The New Mexico Watershed Forum was attended by approximately 300 people and whereas we do not expect everyone to have looked at our poster, there was sufficient interest in the hemi-fence exclosure.

We held 3 work weekends with volunteers from Albuquerque Wildlife Federation, New Mexico Trout and others – showing how to build rock structures by hand, fencing maintenance and taught how to plant willows and transplant sedges. The Gallup Youth Conservation Corps were young adults that learned fencing techniques and some stone structure projects and the reason for building them.

Future Activity Recommendations

1. Monitoring.
   A. Staff will continue to conduct repeat photo monitoring at select photo points.
   B. Vegetation monitoring should be conducted annually for the next 2 years. Without funds this may be a little more difficult to achieve, however a new Section 319 project will be continuing to work on the next phase of Vacas restoration.
   C. Beaver occupancy. Continue trend of carrying capacity for beavers. The project area should be inspected annually during mid-Fall (October) to confirm presence/absence of beavers.
   D. Geomorphological. Channel morphology should be repeated every 5 years using Rosgen Level II survey techniques to ascertain channel response to structural and vegetative treatments.
2. Maintenance and repair of fences and structures.
   A. Mini-exclosures and Hemi-exclosures
   B. Minor maintenance of instream structures and erosion control structures
   C. USFS riparian exclosure pasture fence
   D. Install new cross fences and water gaps between the upper and middle reach to minimize trespass cattle movement.
3. Revegetation
   A. Continue to plant willows: Willow cuttings should be planted at favorable sites in al hemi and mini-exclosures. Second priority is to plant willow cuttings at al instream structure sites installed during 2010. Third priority is to plant willows at protected cutbank in the USFS riparian exclosure pasture.
   B. Revegetation of the School Section wetland should be considered if natural vegetation does not occur. Use select species of sedges and rushes.
4. Wet Meadow restoration (in order of priority)
   A. School Section and Telephone Canyon. Maintain existing structures; install additional structures as appropriate.
   B. Install erosion control to protect/restore slope wetlands, springs and spring seeps in valley right tributaries including and especially Turkey Canyon.
5. New instream structures (confirmation of future funding and volunteer labor)

A. Install the crossvane to provide grade control for the upper meadow. Crossvane at Station 3952.
B. Install planned hand built structures (28 baffles) in the middle reach or "B" section of the Vacas between Stations 4000 and 9000.
C. A new 404/401 permit would be required.

6. Other – volunteer. If the two recommended riparian cross fences are installed, the existing riparian fences on the east side of the Vacas between Stations 5000 and 9000 could be removed to enhance recreational value of the river for camping, fishing, wading, etc. Riparian fence on the west side should be maintained as "drift fence".

Any Supplemental Information

During the life of this project two unlikely and unfortunate events occurred. In while we were walking the stream length it was observed that the fish were dead. Further investigation showed benthic die off and the algae was discolored.

Photo 16. Fish kill 2006

The second event was an asphalt spill approximately 4 miles upstream. This occurred in August 2010 and remediation still continues.

Photo 17. Asphalt spill August 2010

From Albuquerque Wildlife Federation's July 2008 newsletter:

June project — Rio de las Vacas

Despite the wild Saturday afternoon storm of marble-sized hail that briefly interrupted planting, fencing, and rockwork, and caused those close to camp to make a mad dash for vehicles and a handy canopy, project leaders Bill Zeedyk and Steve Carson were pleased with the results of the weekend at Rio de las Vacas, AWF's first venture there. One crew collected cuttings of two types of willows, which were then planted along the river near camp to restore native vegetation, stabilize banks, and provide shade for a cooler trouthabitat. Others carried and placed rocks in headcuts to forestall further erosion. Another crew refined the newly-dubbed "hemi-exclosures" designed for creeks with high banks: cows won't graze on a high creek bank, so Bill and Steve developed a technique of fencing off valuable vegetation only on the flood plain side of the river.

Article from the Albuquerque Wildlife Federation July 2009 newsletter

Project Recap: Rio de las Vacas — Year Two

Despite the on-again, off-again rain showers on Saturday, the crew that assembled June 19-21 for our second year at Rio de las Vacas—our largest group ever—persevered and planted hundreds of willow cuttings, repaired human-cut holes in fencing exclosures, and built or augmented rock structures to divert water flow or reduce erosion. This lovely locale in the Santa Fe National Forest southeast of Cuba, NM, had obviously benefited from moisture during the year between our visits: grasses were tall and lush, especially evident around the media luna rock structure built in 2008 to spread out the water flow for increased infiltration into the meadow.

Coordinating close to 60 people was a challenge for task leaders Bill Zeedyk and Gene Tatum, and for camp managers Michael Scialdone and Patricia Hester. Nevertheless, project work was completed, and meals were enjoyed, with the help of many willing hands. So what if those hands were often muddy? ...there was plenty of hot coffee in the mornings and no one went hungry, and many of the willow planters hope to revisit their work to evaluate the success of their efforts. Thanks to everyone for a great weekend.

(In case you're speculating about physical niceties...the camp area was made more comfortable by deployment of four canopies and the rental of two portable toilets. We do, after all, try to make things civilized for our friends.)

ATTACHMENTS

Attachment A. Hemi-Exclosure Design
Attachment B. Survey Map and Survey data
Attachment C. NEPA Decision Memo
Attachment D. 404 reapplication request and original letter
Attachment E. Beavers Belong! Workshop cover, Coexisting With Beavers by Preventing Damage Workshop Agenda and DVD.
Attachment F. Monitoring Reports

Attachment A

United States Department of Agriculture

NRCS
Natural Resources Conservation Service
6200 Jefferson NE, Room 305
Albuquerque, New Mexico 87109
Phone: (505) 761-4400 Fax: (505) 761-4462
Web site: www.nm.nrcs.usda.gov

October 29, 2009

RANGE TECHNICAL NOTE NO. NM-105

SUBJECT: ECS – The "Hemi Exclosure" a new tool for Riparian Protection.

Purpose: To distribute information to area and field offices.

Effective Date: Effective when received.

Filing Instructions: File in office reference library also maintained on New Mexico NRCS web page.

Bill Zeedyk of Zeedyk Ecological Consulting located in Sandia Park, N.M & Nina Wells who is an Environmental Scientist with New Mexico Environment Department, Surface Quality Bureau located in Santa Fe, N.M. developed a new technique for protecting riparian vegetation from livestock impacts. This new technique is called the Hemi Exclosure after its hemispherical shape as installed on the outside edge of stream meanders.

Attached is the technical paper authored on the topic as installed on the Rio De Las Vacas near Cuba, NM. This technology is offered as a lower cost option as compared to complete riparian corridor fencing to promote vegetation recovery and protection. In addition to lower cost, access to other portions of the channel and banks can be maintained.

In adapting this design to other locations note the details of the area that are important to insuring function of the structure. They are; mean depth of channel at 1.5 feet. Bank heights, cutbank side of meander bends range from 2.5 to 4 feet. Distance from top of streambank to fence ranged from 10 to 25 feet depending on site characteristics.

If you have any questions on this information please contact John Tunberg, State Rangeland Management Specialist at (505)761-4488 or Marcus Miller, State Wildlife Biologist at (505)761-4432 or Steve Lacy, Geomorphologist at (505)761-4439.

GEORGE CHAVEZ
State Resource Conservationist

Helping People Help the Land

The "Hemi-Exclosure" – A New Tool for Riparian Protection

By Bill Zeedyk & Nina Wells

Introduction

Fourteen 'hemi-exclosures" were installed during June, 2008 along two miles of the Rio de las Vacas, Cuba Ranger District, Santa Fe National Forest to control livestock browsing on woody shrubs. Significant reduction in browsing intensity was apparent by September, 2008 as compared with unfenced streambanks. Hemi-exclosures are riparian fences that protect only the landward side of the streambank. The effectiveness of hemi-exclosures was tested along the cutbank edge of meander bends where pool depths generally exceeded one foot at base flow.

The Concept

The concept of the hemi-exclosure is based on observations by Bill Zeedyk, Nina Wells and Julie Walker that cattle tend to browse woody streambank vegetation while approaching from the terrace side rather than by approaching from the channel. Cattle tend to avoid the deeper pools with high banks, thus intense browsing pressure is focused on vegetation available from the terrace edge and on lower inboard banks at meander bends and riffle areas. Exploiting this behavioral trait of cattle offers an opportunity to protect a riparian component while accommodating other uses.

Stream Characteristics

Rio de las Vacas is a fourth order, Rosgen C or E channel type with a bankful width of 20 feet and a mean depth of 1.5 feet. Bank heights, cutbank side of meander bends range from 2.5 to 4 feet. Dominant woody vegetation consists of thin-leafed alder, three willow species, Wood's rose and narrow-leafed cottonwood.

Fence Construction

Cedar posts, 6" by 8' were set at bank's edge and exclosure corners, with 6' T-posts placed at 16-foot intervals between cedar posts. Post holes were drilled with track-mounted power auger. Posts were set using "dead – men" for supports to avoid use of guy wires. Fencing consisted of 36-inch field wire suspended 18" above ground level yielding a fence height of 4.5 feet. Distance from top of streambank to fence ranged from 10 to 25 feet depending on site characteristics. Above-ground height permits overbank flows to pass under fence with minimal damage. Where possible, end posts were set among alder clumps to discourage cattle from gaining entrance around the tips of exclosures.

Advantages

Use of hemi-exclosures avoids the need to string wire across the stream, avoiding potential loss during flood events and reducing both construction and maintenance costs. Riparian fences are often cut or vandalized where stream access for recreational use is blocked. When hemi-exclosures are used in lieu of full exclosures, streambanks remain open to easy access by fisherman and others, thus reducing the temptation to vandalize the fences. Livestock and people can easily cross the stream at riffles, avoiding the deeper pools.

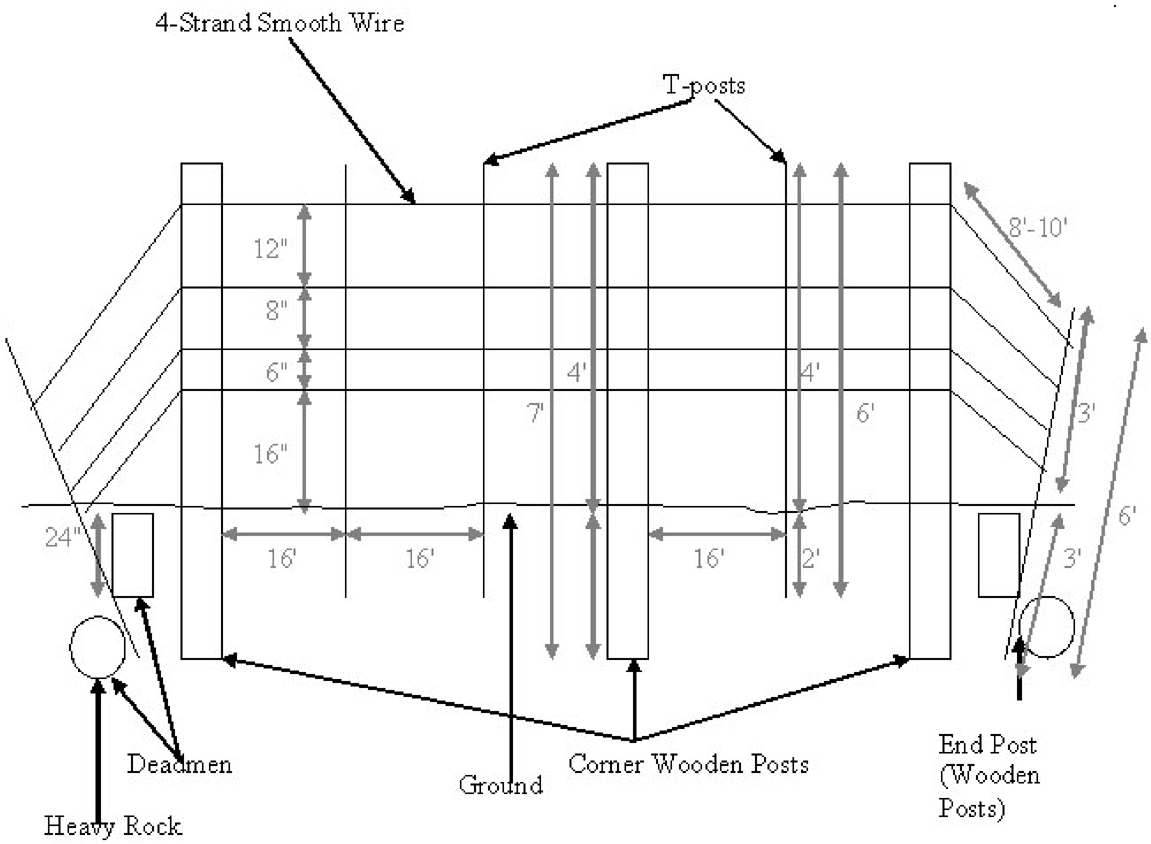
Acknowledgements
This experiment was conducted by Zeedyk Ecological Consulting, LLC. under contract with New Mexico Environment Department, Surface Water Quality Bureau. Fencing was installed by Steve Carson, Rangeland Hands, Inc.

Initial maintenance and supplemental planting were performed by Albuquerque Wildlife Federation, New Mexico Wilderness Alliance and New Mexico Trout. Authors wish to express appreciation to USDA Forest Service, Santa Fe National Forest for their support and cooperation in the project.

Authors
Bill Zeedyk, Riparian Restorationist,
Zeedyk Ecological Consulting, LLC

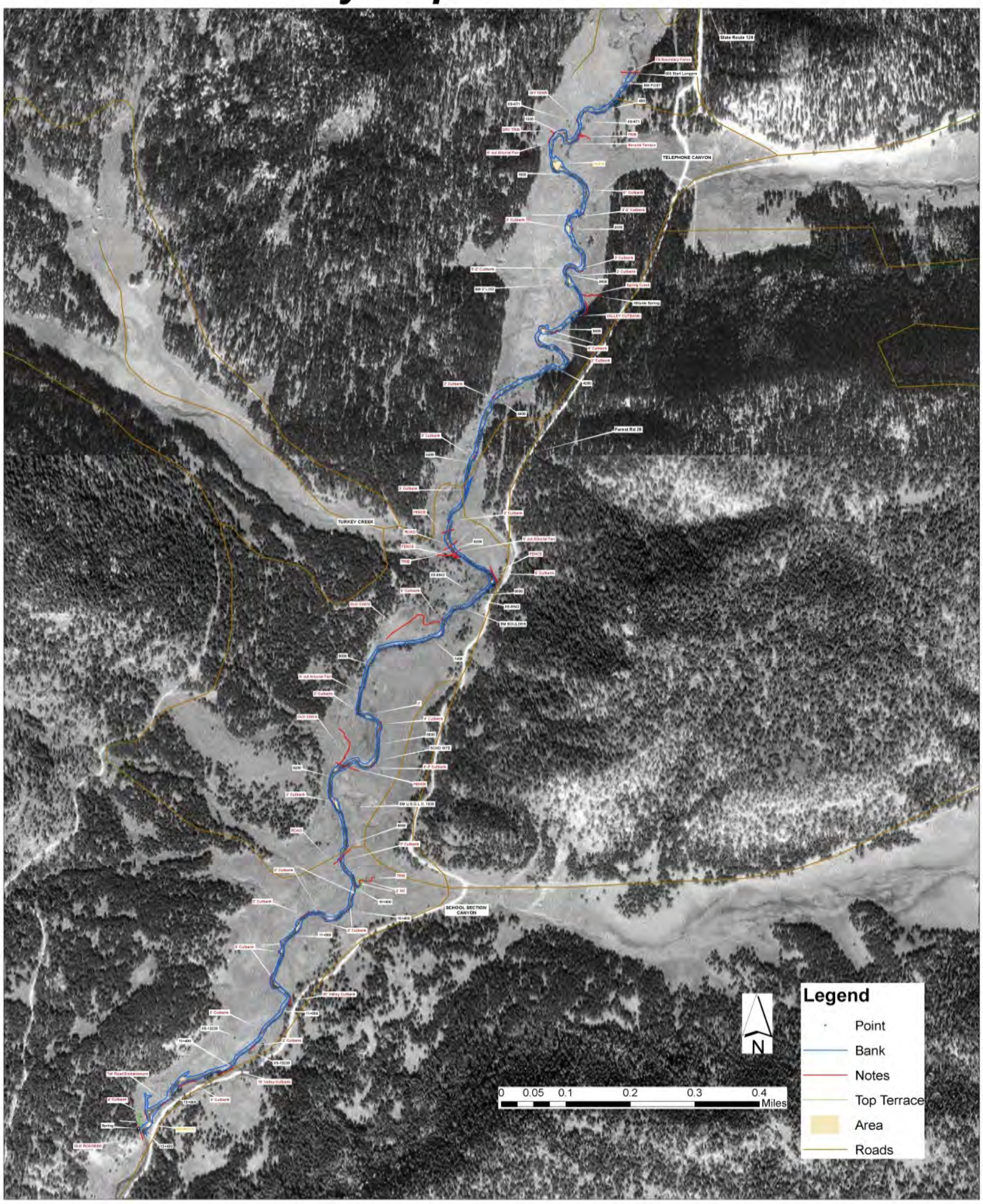
Nina Wells, Specialist/Scientist
New Mexico Environment Department, Surface Water Quality Bureau

Hemi-Exclosure Specifications 12/13/06

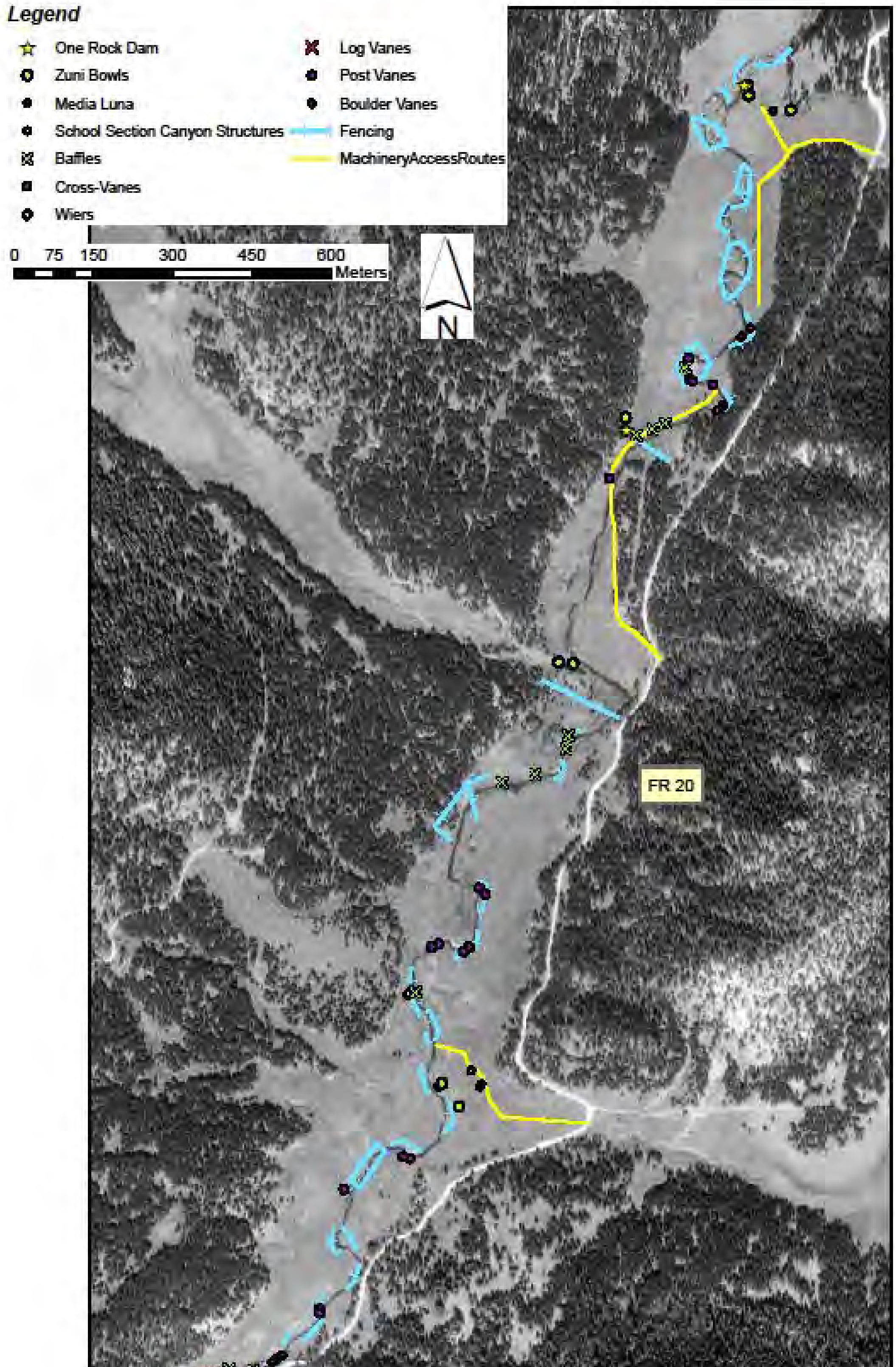


Attachment B

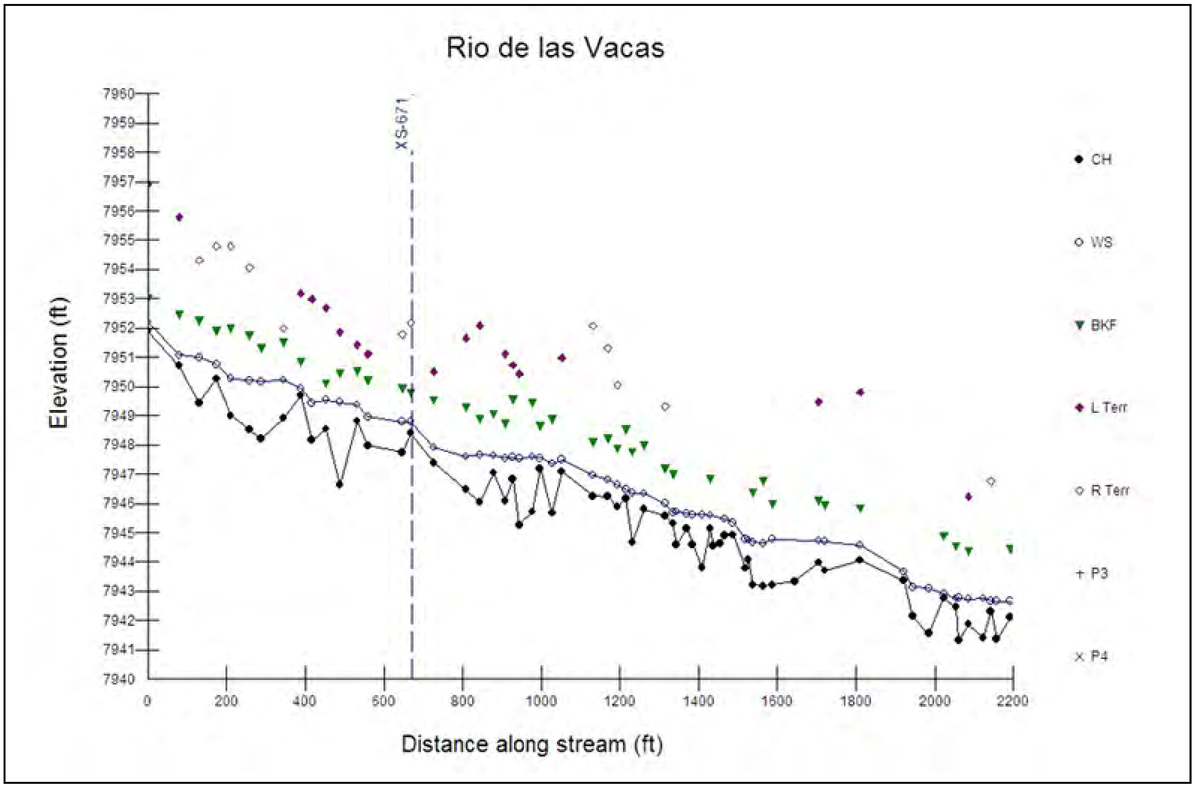
Rio de Las Vacas Geomorphic Survey Map on USFS Land

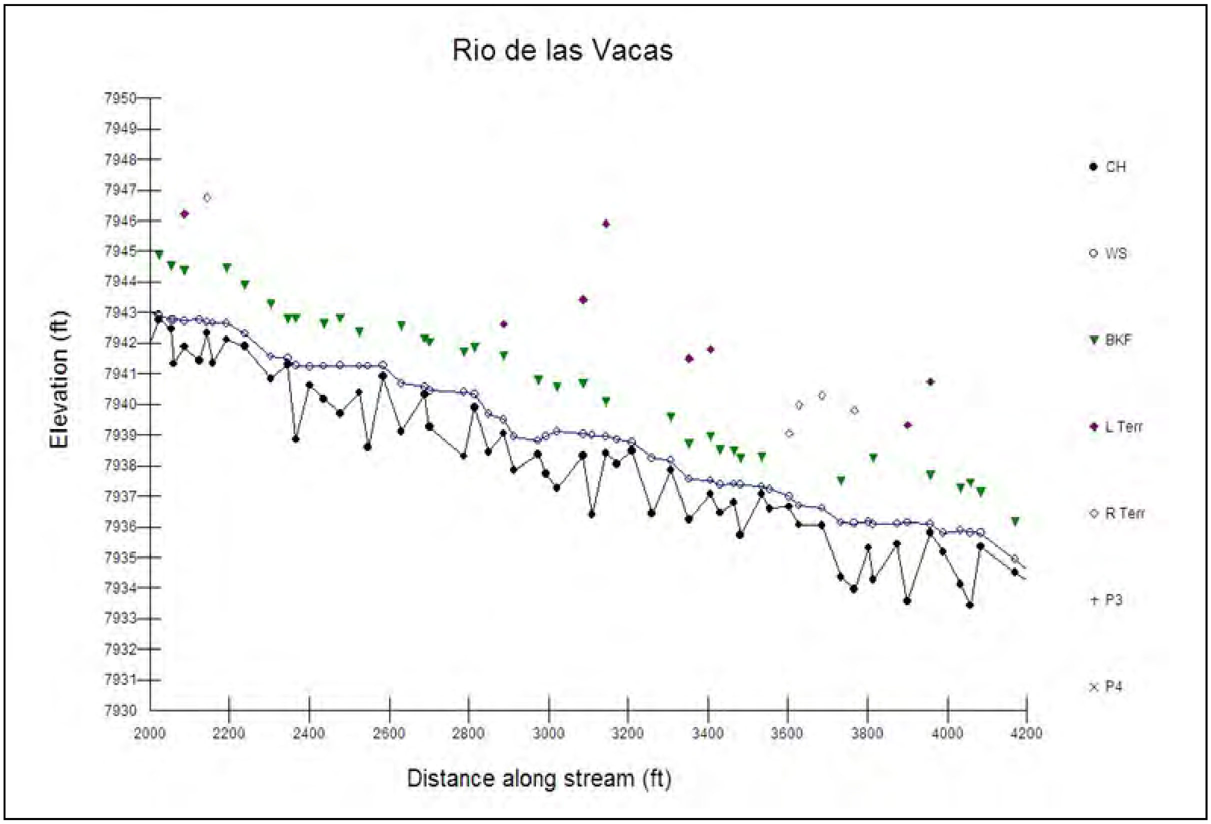


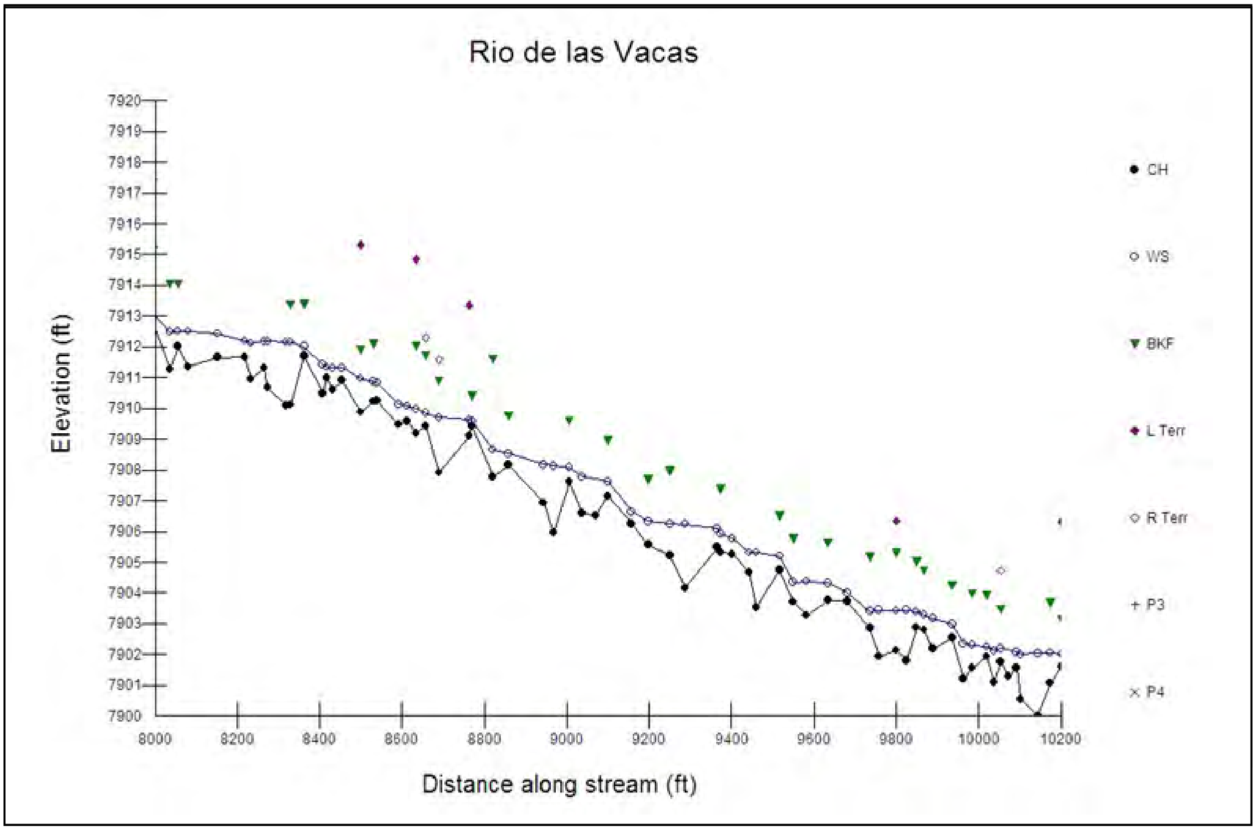
Rio de Las Vacas Wetland Restoration Project on U.S. Forest Service Land

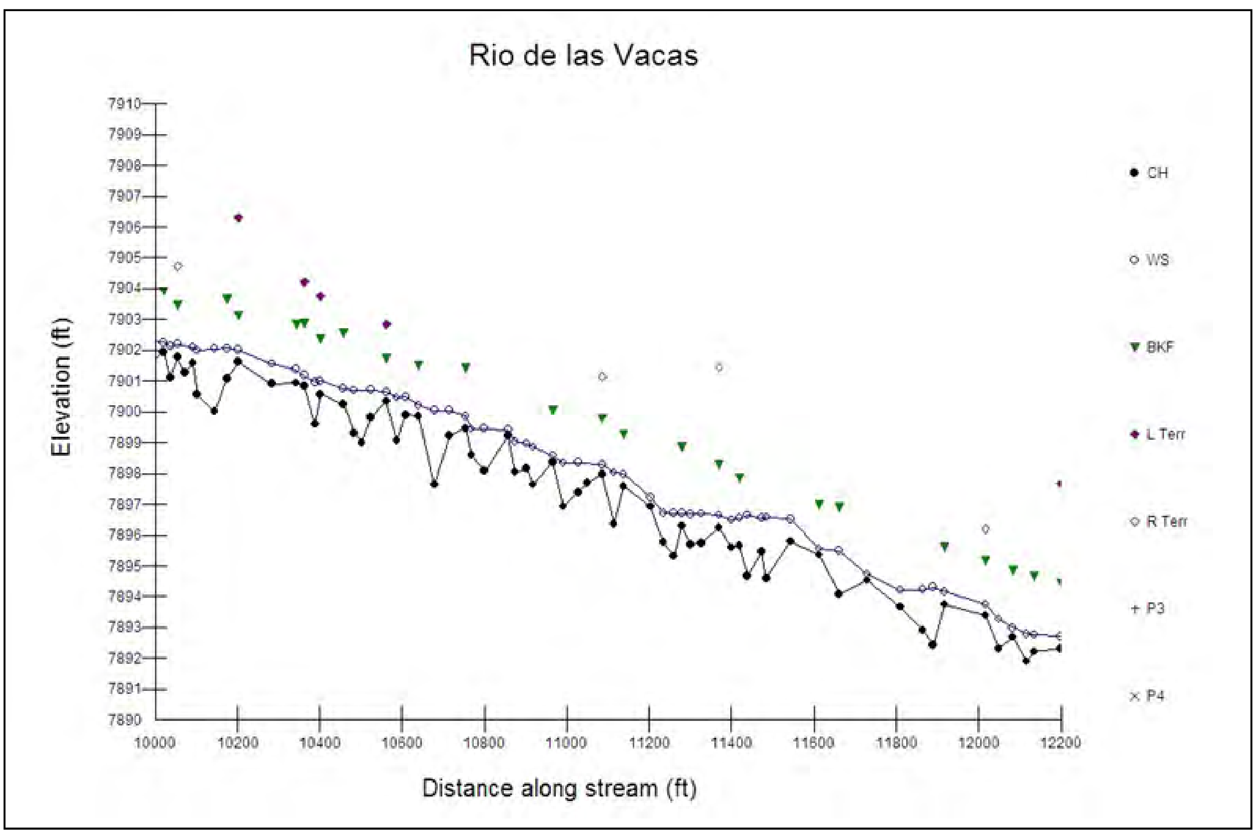


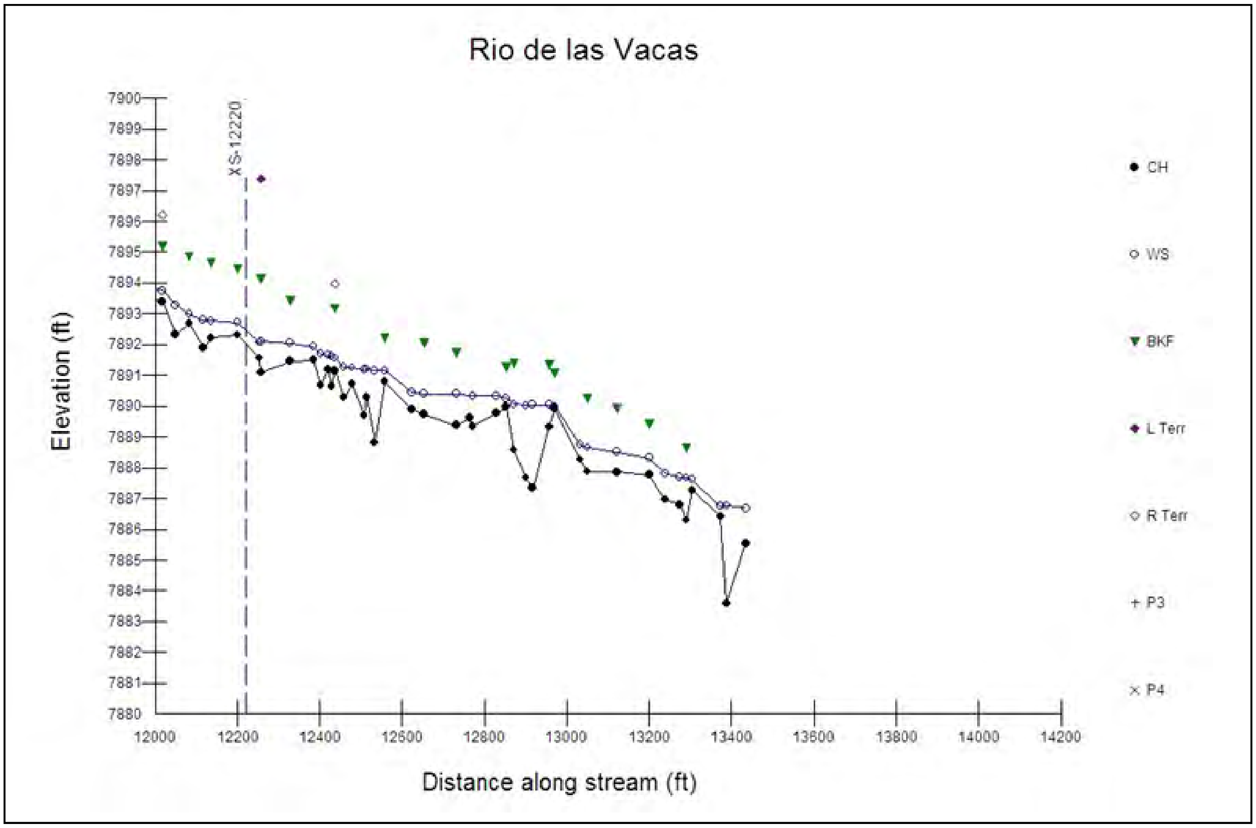
Rio de Las Vacas Forest Service Property Rosgen Level II Study
May 2006, Van Clothier, Julie Arvidson, Nina Wells, and Danielle Shuryn

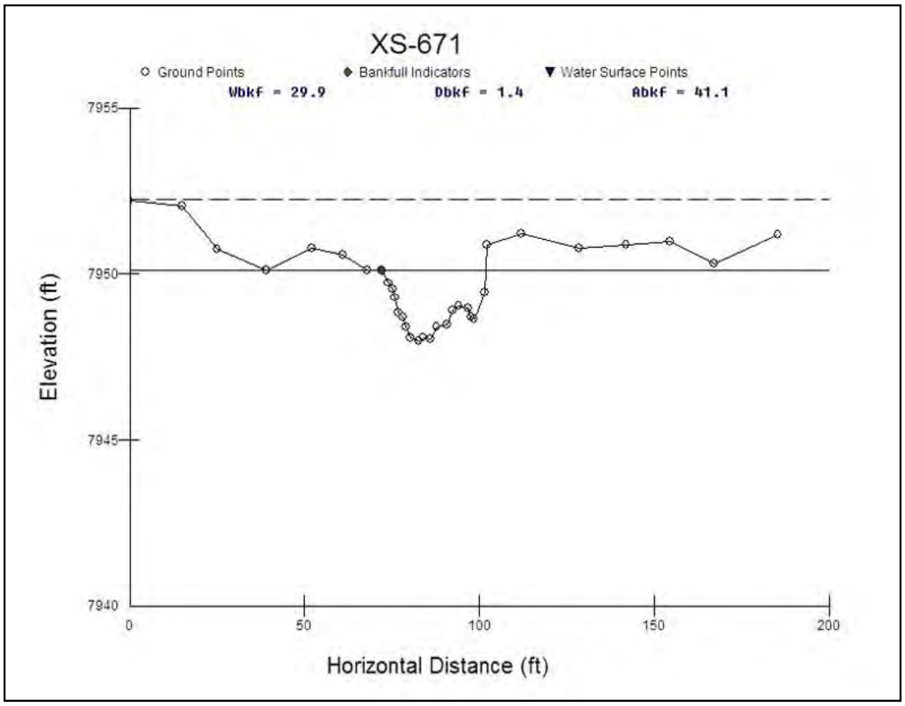


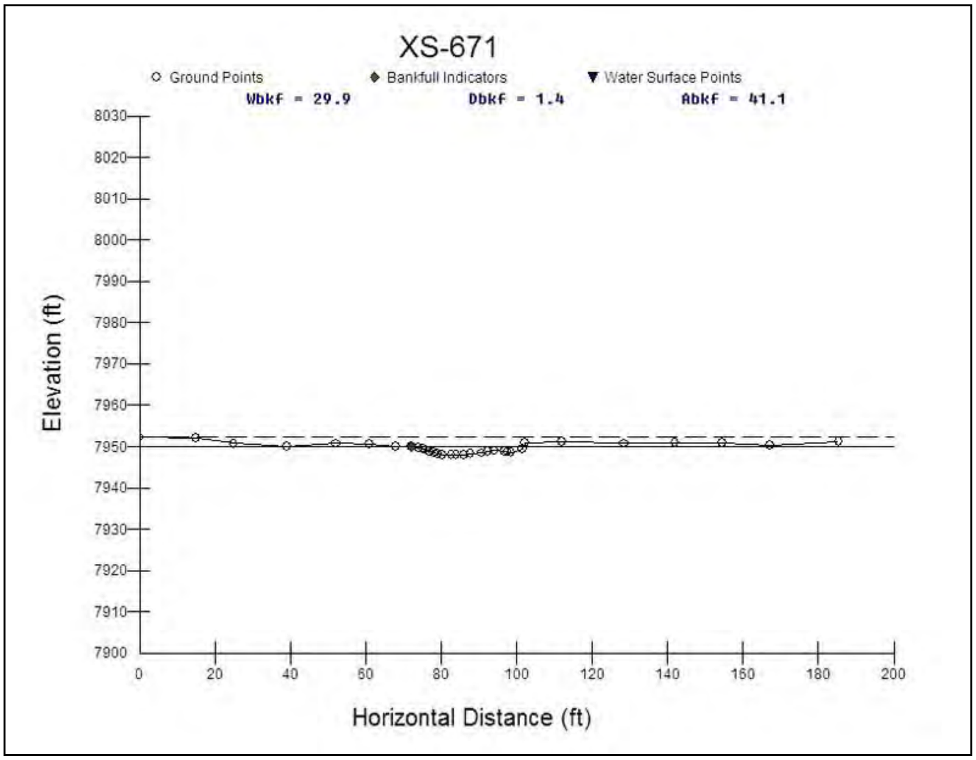

Rio de las Vacas
Elevation (ft)
Distance along stream (ft)
7950
7949
7948
7947
7946
7945
7944
7943
7942
7941
7940
7939
7938
7937
7936
7935
7934
7933
7932
7931
7930
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
CH
WS
BKF
L Terr
R Terr
P3
P4


Rio de las Vacas
Elevation (ft)
Distance along stream (ft)
7920
7919
7918
7917
7916
7915
7914
7913
7912
7911
7910
7909
7908
7907
7906
7905
7904
7903
7902
7901
7900
8000
8200
8400
8600
8800
9000
9200
9400
9600
9800
10000
10200
CH
WS
BKF
L Terr
R Terr
P3
P4


Rio de las Vacas
Elevation (ft)
Distance along stream (ft)
7910
7909
7908
7907
7906
7905
7904
7903
7902
7901
7900
7899
7898
7897
7896
7895
7894
7893
7892
7891
7890
10000
10200
10400
10600
10800
11000
11200
11400
11600
11800
12000
12200
CH
WS
BKF
L Terr
R Terr
P3
P4


Rio de las Vacas
Elevation (ft)
Distance along stream (ft)
XS-12220
CH
WS
BKF
L Terr
R Terr
P3
P4


XS-671
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 29.9
Dbkf = 1.4
Abkf = 41.1
Elevation (ft)
Horizontal Distance (ft)



RIVERMORPH CROSS SECTION SUMMARY

River Name: Rio de las Vacas
Reach Name: Reach 1
Cross Section Name: XS-671
Survey Date: 05/09/06

Cross Section Data Entry
BM Elevation: 7948.55 ft
Backsight Rod Reading: 9.35 ft

TAPE	FS	ELEV	NOTE
0	5.69	7952.21	LEP
15	5.84	7952.06	
25	7.16	7950.74	
39	7.78	7950.12	
52	7.11	7950.79	
61	7.32	7950.58	
68	7.78	7950.12	
72	7.79	7950.11	BKF
74	8.17	7949.73	

75.2	8.36	7949.54	
75.9	8.61	7949.29	
76.7	9.05	7948.85	
78.1	9.2	7948.7	
79	9.49	7948.41	WS
80.3	9.82	7948.08	
82.7	9.92	7947.98	TW
84	9.81	7948.09	
85.9	9.87	7948.03	
87.8	9.5	7948.4	
90.8	9.43	7948.47	WS
92.4	8.98	7948.92	
94	8.87	7949.03	
96.7	8.92	7948.98	
97.5	9.18	7948.72	
98.5	9.25	7948.65	
101.6	8.46	7949.44	
102.2	7.03	7950.87	
112	6.7	7951.2	
128.4	7.12	7950.78	
142	7.03	7950.87	
154.5	6.91	7950.99	
167.2	7.59	7950.31	
185.3	6.72	7951.18	REP

Cross Sectional Geometry

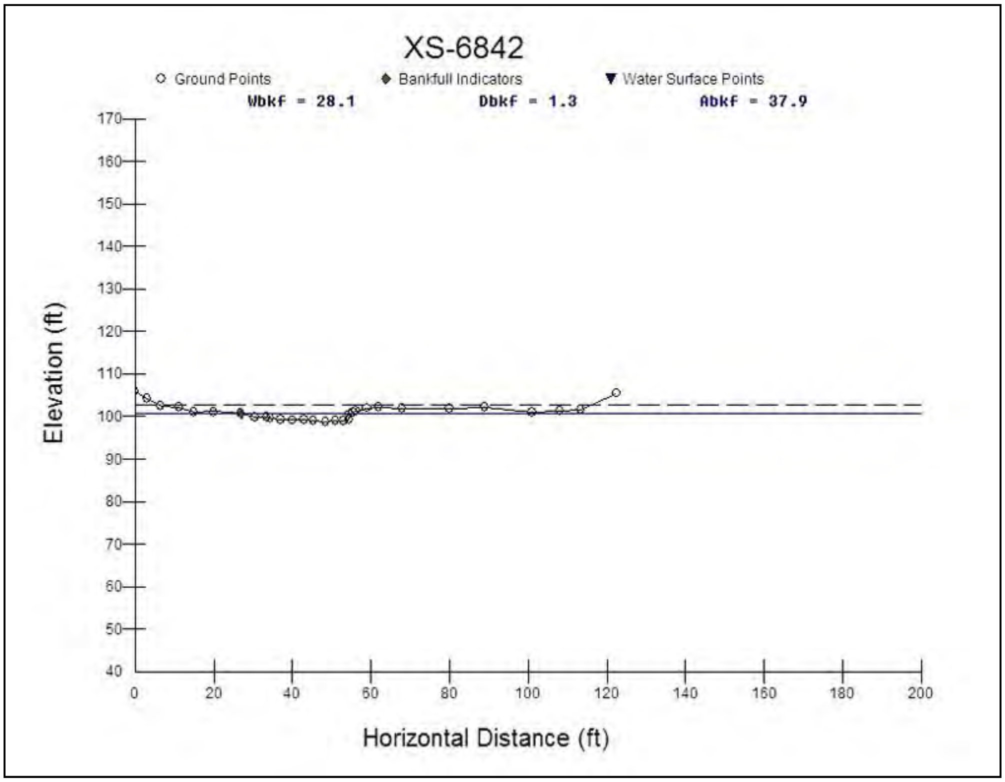
	Channel	Left	Right
Floodprone Elevation (ft)	7952.24	7952.24	7952.24
Bankfull Elevation (ft)	7950.11	7950.11	7950.11
Floodprone Width (ft)	185.3	-----	-----
Bankfull Width (ft)	29.88	16.42	13.46
Entrenchment Ratio	6.2	-----	-----
Mean Depth (ft)	1.37	1.47	1.25
Maximum Depth (ft)	2.13	2.13	1.7
Width/Depth Ratio	21.74	11.14	10.74
Bankfull Area (sq ft)	41.06	24.2	16.86
Wetted Perimeter (ft)	30.88	18.46	15.81
Hydraulic Radius (ft)	1.33	1.31	1.07
Begin BKF Station	72	72	88.42
End BKF Station	101.88	88.42	101.88
Slope	0.4%		

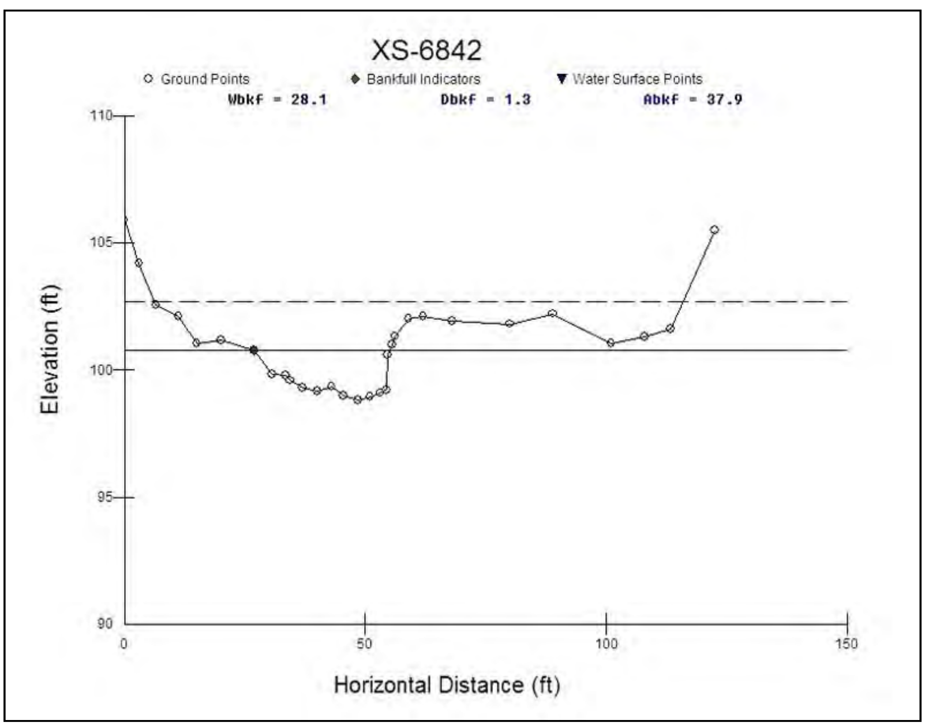
Note this riffle is below the grade of the riffles upstream and down, and therefore difficult to interpret the correct riffle-riffle slope

----

Entrainment Formula: Rosgen Modified Shields Curve

	Channel	Left Side	Right Side
Slope			
Shear Stress (lb/sq ft)			
Movable Particle (mm)			





RIVERMORPH CROSS SECTION SUMMARY

River Name: Rio de las Vacas
Reach Name: Reach 1
Cross Section Name: XS-6842
Survey Date: 05/10/06

Cross Section Data Entry
BM Elevation: 100 ft
Backsight Rod Reading: 10.34 ft

TAPE	FS	ELEV	NOTE
0	4.44	105.9	LEP, BM is big rock on L bank @ 6980
3	6.15	104.19	Cow Trail
6.5	7.78	102.56	
11.2	8.24	102.1	cross section partially obscured by 7' boulder, sta 12-19,
15	9.29	101.05	we shot ground surface ds of rock.
20	9.19	101.15	
26.9	9.59	100.75	BKF
30.6	10.5	99.84	
33.5	10.54	99.8	
34.4	10.75	99.59	WS
37	11.05	99.29	
40	11.18	99.16	
43	10.99	99.35	
45.4	11.35	98.99	
48.5	11.52	98.82	
51	11.4	98.94	
53.1	11.24	99.1	
54.4	11.11	99.23	WS
54.6	9.76	100.58	
55.5	9.37	100.97	
56.1	9.02	101.32	
59	8.33	102.01	
62	8.24	102.1	
68	8.42	101.92	
80	8.53	101.81	
89	8.13	102.21	
101	9.3	101.04	
108	9.04	101.3	
113.4	8.71	101.63	
122.5	4.85	105.49	

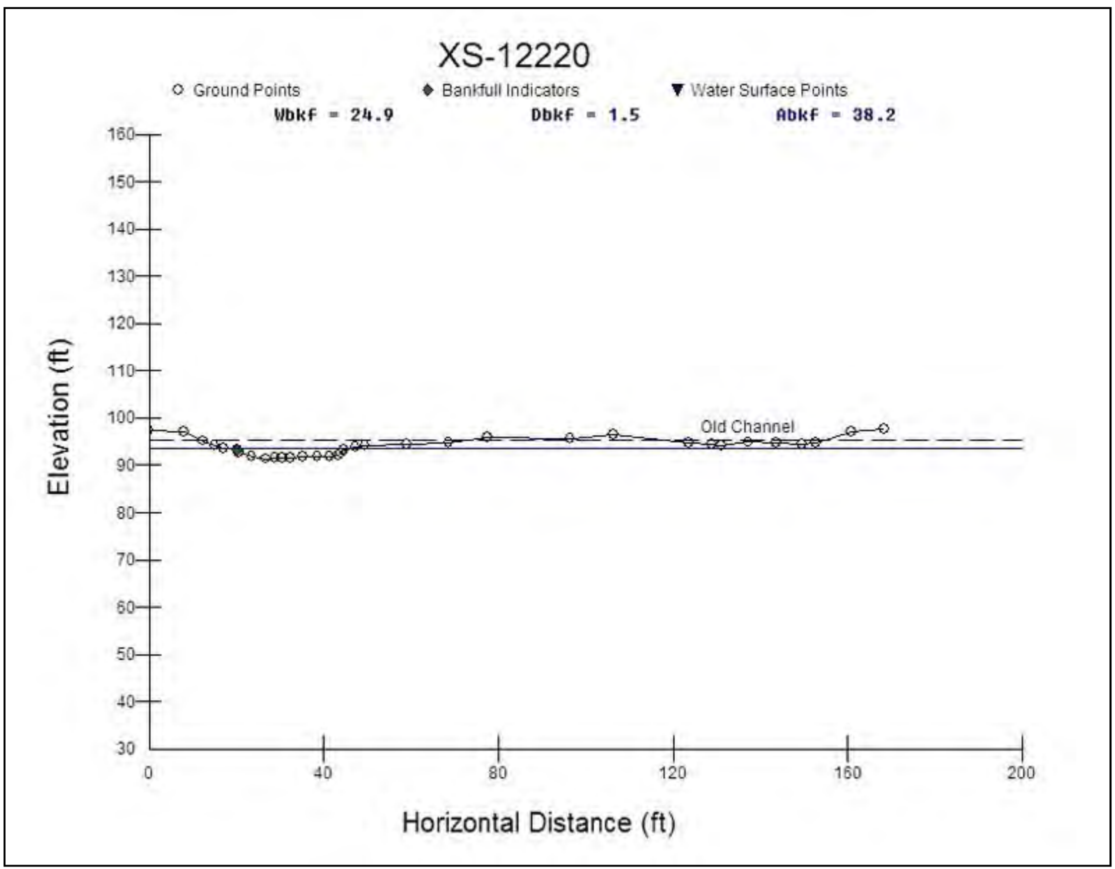
Cross Sectional Geometry

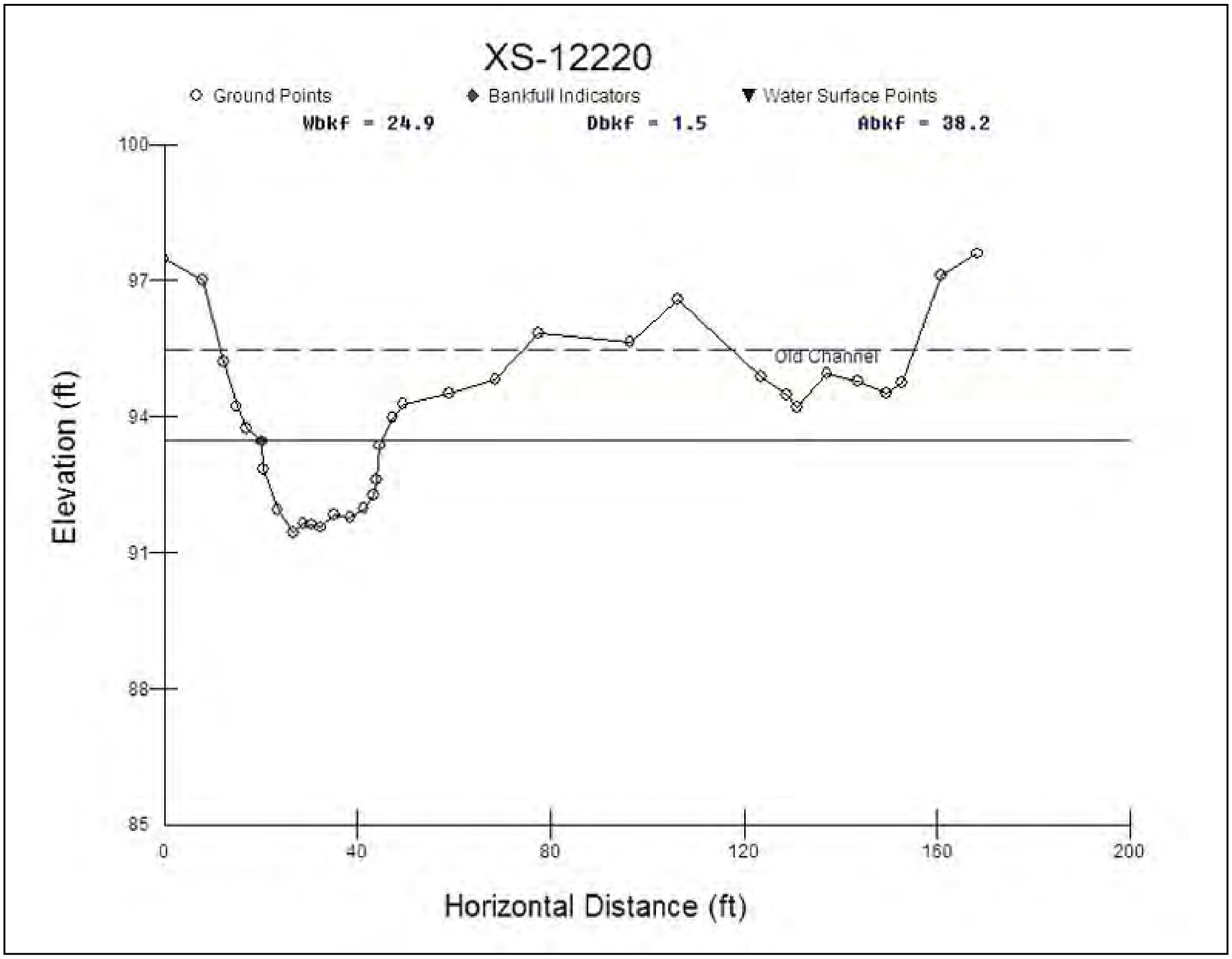
	Channel	Left	Right
Floodprone Elevation (ft)	102.68	102.68	102.68
Bankfull Elevation (ft)	100.75	100.75	100.75
Floodprone Width (ft)	109.63	-----	-----
Bankfull Width (ft)	28.09	14.05	14.04
Entrenchment Ratio	3.9	-----	-----
Mean Depth (ft)	1.35	1.05	1.64
Maximum Depth (ft)	1.93	1.59	1.93
Width/Depth Ratio	20.83	13.34	8.54
Bankfull Area (sq ft)	37.88	14.79	23.09
Wetted Perimeter (ft)	29.5	15.74	16.82
Hydraulic Radius (ft)	1.28	0.94	1.37
Begin BKF Station	26.9	26.9	40.95
End BKF Station	54.99	40.95	54.99
Slope	0.5%		

Note this riffle is below the grade of the riffles upstream and down, and therefore difficult to interpret the correct riffle-riffle slope

Entrainment Formula: Rosgen Modified Shields Curve

	Channel	Left Side	Right Side
Slope			
Shear Stress (lb/sq ft)			
Movable Particle (mm)			





RIVERMORPH CROSS SECTION SUMMARY

River Name: Rio de las Vacas
Reach Name: Reach 1
Cross Section Name: XS-12220

Survey Date: 05/12/06

Cross Section Data Entry
BM Elevation: 100 ft
Backsight Rod Reading: 0 ft

TAPE	FS	ELEV	NOTE
0	2.52	97.48	LEP
8	3	97	
12.3	4.8	95.2	
15	5.77	94.23	
17	6.25	93.75	
20.17	6.54	93.46	BKF
20.5	7.16	92.84	
23.5	8.06	91.94	WS
26.75	8.56	91.44	
28.75	8.35	91.65	
30.55	8.38	91.62	
32.3	8.44	91.56	
35.25	8.17	91.83	
38.45	8.23	91.77	
41.35	8.02	91.98	WS
43.33	7.72	92.28	
44	7.39	92.61	
44.67	6.64	93.36	
47.33	6.02	93.98	
49.5	5.72	94.28	
59	5.49	94.51	
68.5	5.2	94.8	
77.58	4.15	95.85	
96.5	4.34	95.66	
106.3	3.42	96.58	
123.6	5.12	94.88	
129	5.51	94.49	
131.2	5.8	94.2	
137.2	5.06	94.94	
143.75	5.23	94.77	
149.6	5.48	94.52	
152.8	5.26	94.74	
161	2.89	97.11	
168.4	2.4	97.6	REP

Cross Sectional Geometry

	Channel	Left	Right
Floodprone Elevation (ft)	95.48	95.48	95.48
Bankfull Elevation (ft)	93.46	93.46	93.46
Floodprone Width (ft)	100.62	-----	-----
Bankfull Width (ft)	24.93	11.51	13.42
Entrenchment Ratio	4.04	-----	-----
Mean Depth (ft)	1.53	1.59	1.49
Maximum Depth (ft)	2.02	2.02	1.9
Width/Depth Ratio	16.26	7.25	9.03
Bankfull Area (sq ft)	38.22	18.28	19.94
Wetted Perimeter (ft)	25.95	13.94	15.77
Hydraulic Radius (ft)	1.47	1.31	1.26
Begin BKF Station	20.17	20.17	31.68
End BKF Station	45.1	31.68	45.1
Slope	0.5%		

Note this riffle is below the grade of the riffles upstream and down, and therefore difficult to interpret the correct riffle-riffle slope

----

Entrainment Formula: Rosgen Modified Shields Curve

	Channel	Left Side	Right Side
Slope			
Shear Stress (lb/sq ft)			
Movable Particle (mm)			

Attachment C

Cuba Ranger District, Santa Fe National Forest

DECISION MEMO

Middle Rio de Las Vacas Restoration

USDA FOREST SERVICE
CUBA RANGER DISTRICT
SANTA FE NATIONAL FOREST
T.20N R.1E Sec. 24,25,26, 35, and 36
SANDOVAL COUNTY, NM

Decision & Location: I have decided to approve the Middle Rio de Las Vacas Restoration Project. The purpose of this project is to restore three miles of the Rio de las Vacas to proper functioning conditions based on Forest Service stream surveys and New Mexico Environmental Department (NMED) and Environmental Protection Agency assessments that show the Rio de las Vacas is not meeting its designated use. This project will be implemented by the Forest Service and NMED's Surface Water Quality Bureau in collaboration with local landowners, and the Environmental Protection Agency. New Mexico Trout and the Albuquerque Wildlife Federation would also volunteer time and resources to implement this project. The project is expected to begin in Fall 2007 and project activities such as monitoring will continue for the next three years.

Stream restoration in this area would involve the following activities:

Stream meanders: stream meanders would be induced in areas where the stream has become straightened and narrow and stream flow has began cutting deeper into the soil, losing connection to the adjacent floodplain. This often occurs in stream channels impeded by roads, livestock trails, or other disturbances. In these areas, vanes and baffles or weirs would be used to induce stream meanders by directing stream flows to create functional habitat. Approximately 26 log vanes, 2 cross vanes, and 25 baffles would be created as part of the planned restoration project. Baffles and vanes are expected to restore habitat by re-establishing pools (for fish habitat) and help build-up stream banks that have been lost by trampling or head cutting.

All of these in-stream structures would be built with native materials such as posts, trees, and large rocks. They would all contribute toward more stable banks, which would mean less sedimentation and a chance for riparian vegetation to establish.

Three rock weirs would also be created in the proposed restoration area to raise the water level of the stream at specific locations to re-connect the stream flow to the existing floodplain.

In the area adjacent to School Section, there are several user-created two-track roads extending along the flood plain that are resulting in substantial head-cutting. As part of this project, heavy machinery would be used to remove part of these roads and re-direct the stream flow to re-connect to wetland areas that currently lack sufficient water.

Erosion Control: Erosion control structures would be implemented to slow water flow in areas where it has been cutting into the streambanks or quickly deepening the stream channel. Rock bowls and rock dams (at a height of one rock) would be used to slow the flow of water where heavy erosion has been seen to be occurring to the detriment of stream habitat. It is expected at least 8 rock bowls and one rock dam would be built within the middle Rio de las Vacas restoration area.

Exclosure Fencing: Another main restoration activity would be building and repairing exclosure fencing to exclude trampling of stream banks and soil compaction of streamside habitat as a result of livestock grazing and recreational activities. Although the north two miles of the restoration area already includes exclosure fencing, additional fencing would be installed in this area and around the banks and meanders of the un-fenced area. Exclosure fencing would include the installation of 5 mini-exclosures and 26 hemi-exclosures along the middle Rio de las Vacas in areas to protect woody streamside vegetation and maintain overhanging banks from trampling. Mini-exclosures would be small fenced areas installed in strategic places around vegetation from wood posts, metal t-posts, and smooth wire. Hemi-exclosures would be open drift fences placed along the edges of pools, meanders, and pockets of vegetation to prevent travel pathways through these areas and reduce trampling from cattle.

Upland Water Developments: In addition to exclosure fencing, the restoration project would include the placement of two trick tanks (or other water catchment device) and the drilling of a well or construction of one-and-a-half mile pipeline (if the well drilling does not reach an adequate water source) from an existing well with several wildlife drinkers. These developments would be placed in the adjacent South Ojitos Allotment. The purpose of these developments are to attract wildlife and cattle away from the middle Rio de las Vacas floodplain to the grassy mesa tops where standing water does not naturally occur. These structures would be placed within two miles east of the river.

Willow and Alder Planting: Planting would also be a restoration activity to stabilize banks and promote the development of overhanging banks for fish habitat. Willow and alder plantings would come from nearby sources on private lands. Willow cuttings or alder plants would be placed in small holes staggered in two or more rows. Plantings are also expected to reduce stream temperature by providing shade and stabilizing stream banks for deeper water. This activity would occur at several sections along the two-mile restoration corridor.

Monitoring: To determine the success of restoration efforts monitoring would be a key activity in this restoration project. The proposed project area has already undergone data collection to extensively document the existing condition and existing fish habitat conditions (NMED project data collection and USFS Rio de las Vacas Stream Inventory). Once revegetation activities begin, conditions would be monitored for approximately three years by NMED, followed by a stream inventory by USFS to monitor fish habitat conditions. Measures would include stream morphology changes, elevations, and photo points. Streamside vegetation trends would also be measured as would water quality and temperature.

An independent study would also be included in the monitoring efforts by researching the effect of induced stream meanders on stream bank storage and dissipated flood flows. To do this, a student from the University of New Mexico would place up to 12 shallow monitoring wells in areas where vanes or baffles were placed. These wells would then be monitored for up to one year to measure surface and ground water interactions.

Restoration activities would occur during periods of low flow through the use of heavy machinery and volunteer hand work. A truck and a backhoe would be used to haul and place large rocks and boulders for rock bowl and rock dam structures as well as boulder vanes. A truck and backhoe would also be used to re-shape and re-direct the area at School Section to remove user-created two-track trails and re-direct the flow of water. There would be three areas of access by heavy machinery into the middle Rio de las Vacas floodplain: Telephone canyon from State Road 126 and Forest Road 20, Forest Road 20 at School Section, and from Forest Road 20 between Telephone Canyon and School Section.

Materials for the structures and fencing would be brought from off-site, but some native materials would be used from nearby sources. Rocks and small boulders for rock bowls and other rock structures would be collected from adjacent rock sources, such as a boulder pile on Forest Road (FR) 533 two miles north of

Cuba Ranger District, Santa Fe National Forest

FR 20. Approximately 13 of the 28 planned vanes would be made of 30 to 45-foot trees between 16 and 20 inches in diameter, which would be removed by chainsaw from nearby ponderosa pine forested areas. The remaining vanes would be created from boulders and smaller trees.

This project is categorically excluded from documentation in an Environmental Assessment or Environmental Impact Statement under FSH 1909.15, Chapter 31.2— 7. Modification or maintenance of stream or lake aquatic habitat improvement structures using native materials or normal practices.

My decision includes the following mitigations:

To protect Soil and Water Quality:

- No new roads shall be created by this project.
- Weed-free straw bales shall be used when necessary to temporarily divert stream flow or as erosion control devices
- Army Corps of Engineers 401 and 404 permits will be acquired prior to any relevant in-stream work begins
- Areas of soil disturbance will be reseeded with weed-free seed and mulched with weed-free straw
- All work involving heavy machinery will stop during summer monsoon storms and not proceed until the soil has dried
- An appropriate size spill kit shall be onsite for each piece of heavy machinery present

To protect Wildlife Resources:

- No trees shall be removed from April 15th to August 15th each year
- All fences shall be built to Forest Service specification: fencing should include four horizontal strands, of a height 40-42 inches, with the bottom wire approximately 16 inches from the ground.
- No snags shall be removed as part of this project
- Trees to be cut to create in-stream structures for restoration activities may only be removed from ponderosa pine habitat, outside of mixed conifer habitat

Categorical Exclusion Compliance:

1. Scoping: Agency resource specialists were consulted and public involvement for this project included contacting 26 groups or individuals including local landowners, grazing permittees, environmental groups, state and federal agencies, and other interested parties. Additionally, information on this project was posted on the quarterly Schedule of Proposed Actions (SOPA). Considering the nature and scope of the project, no additional public contact was deemed necessary.

Scoping replies were received from 4 organizations. Three of the organizations fully supported this project. The other organization supported the project but raised several issues. Issues raised during scoping and Forest Service responses are included below:

Comment: "We are concerned about nesting birds… as many of the trees and shrubs in an area will be cut during the restoration activities, we believe that this work should not occur during the nesting season, specifically April 15 to August 15."

> Response: Up to 28 trees will be cut to use as materials in restoration activities. The project includes a mitigation to restrict cutting of trees outside of April 15 to August 15 to protect nesting birds and other wildlife.

Comment: "We are concerned with the low number of snags in the Santa Fe National Forest…"

> Response: This decision does not allow the cutting or removal of snags.

Cuba Ranger District, Santa Fe National Forest

Comment: "We believe that it is essential to set up a long-term plan for the maintenance of restored streams through a continuing program of livestock exclusion, systematic monitoring, and an active prescribed fire program."

> Response: This decision will authorize implementation of management direction in the long-term plan known as the Santa Fe National Forest Plan, which includes standards and guidelines to protect streams, guide prescribed fire activities, and manage other uses such as recreation and livestock grazing. This project will help restore stream conditions through a number of means including livestock exclusion and providing water sources for livestock and elk in upland areas and grassy mesa tops. Systematic monitoring is completed each year through monitoring of livestock use and every five to ten years through extensive stream surveys. In addition, this project will include specific monitoring to determine if project activities are resulting in desired changes to the river over the next several years.

2. The project is located within Forest Plan Management Area ***"D"*** and is consistent with all Forest Plan forest-wide and management area goals, direction, and standards and guidelines.

3. The action does not involve adverse effects to any extraordinary circumstances, i.e., listed/proposed threatened or endangered species or designated critical habitat, or FS sensitive species; floodplains, wetlands or municipal watersheds; congressionally designated areas; inventoried roadless areas; research natural areas; or American Indian religious/cultural sites; or archaeological sites, or historic properties or areas.

4. A biological assessment/evaluation and heritage resource clearance report are in the project file.

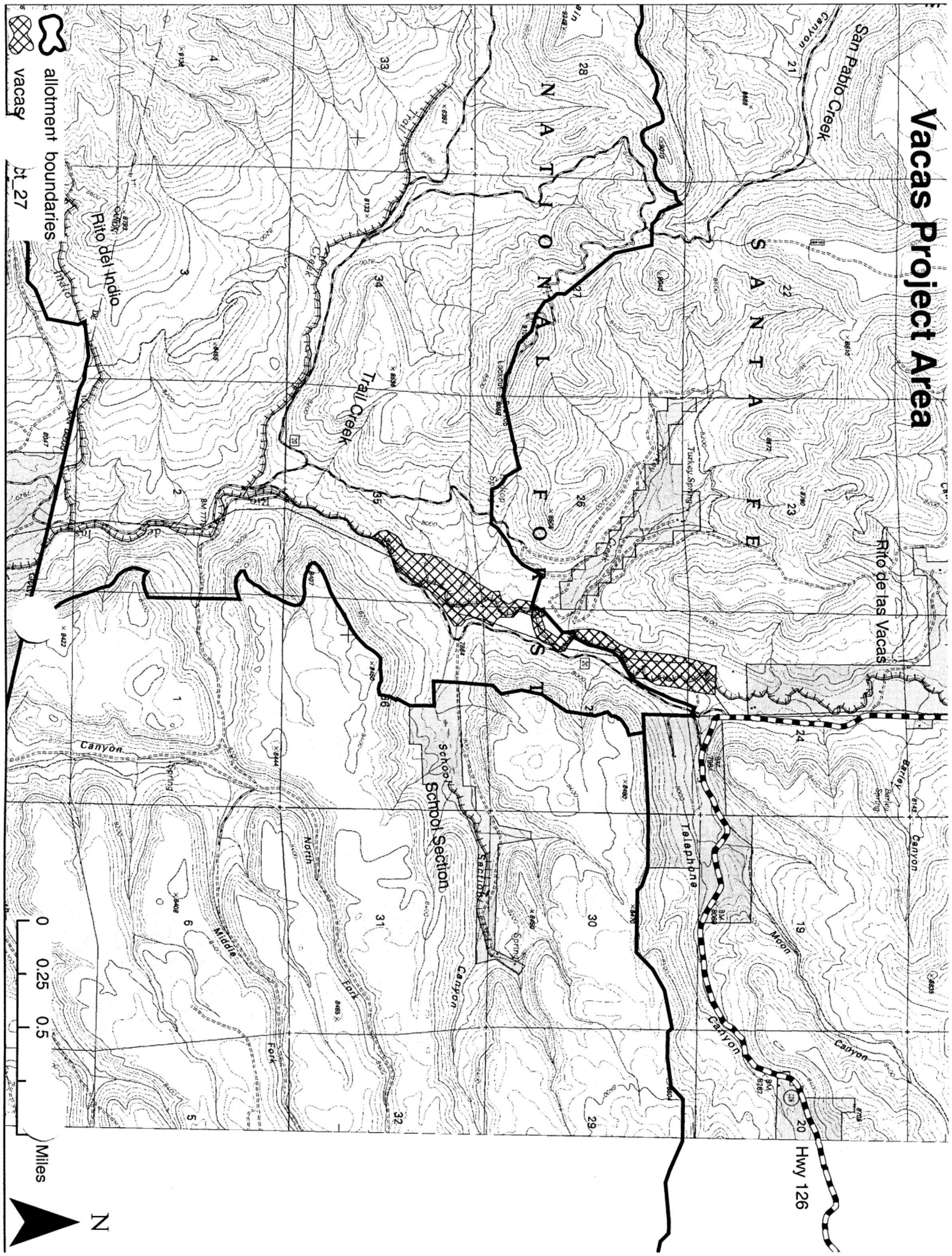
5. This project was developed in consderation of the best available science and is consistent with the Santa Fe National Forest Plan, as amended.

Appeals and Implementation:
This decision is not subject to appeal in accordance with 36 CFR 215.12 (June 4, 2003) and may be implemented immediately.

Contact: For further information, please contact Mike Dechter, Jemez Ranger District Office, P.O. Box 150, Jemez Springs, NM 87025 or e-mail: mdechter@fs.fed.us. Phone: (505) 829-3535.

for [signature] 8/29/07

STEVE F. ROMERO — Date
Cuba District Ranger
Acting


Vacas Project Area
allotment boundaries
vacas_pt_27
San Pablo Creek
Rito del Indio
Trail Creek
Rito de las Vacas
School Section
Hwy 126
0 0.25 0.5
Miles
N

Attachment D

RON CURRY
Secretary

NEW MEXICO
ENVIRONMENT DEPARTMENT

Surface Water Quality Bureau

BILL RICHARDSON
Governor
DIANE DENISH
Lieutenant Governor

May 20, 2010

Chris Grosso
Project Manager
Regulatory Division
Albuquerque District U.S. Army Corps of Engineers
4101 Jefferson Plaza NE
Albuquerque, NM 87109

Dear Mr. Grosso:

I am writing to request that the authorization to conduct the restoration work on the Rio de las Vacas and a tributary, School Section Canyon, on behalf of the Cuba Ranger District located near the village of Cuba, Sandoval County, New Mexico under Section 404 Nationwide Permit No. 27 (Action No. SPA-2007-188-ABQ) be reinstated. The majority of the work authorized by a letter dated April 25, 2007 has not been completed; this is due to the loss of staff and amendments of the workplan. Work that has been completed includes several types of fencing and volunteer hand work. We (NMED Surface Water Quality Bureau and the Cuba Ranger District) would like to complete this grant project by implementing the restoration methods described in the original 404 permit application, using post and boulder vanes and baffles, weirs and native plant materials to stabilize the river channel. Depending on how our funding progresses, we may reduce the boulder vanes by 2, those being listed on our application as sites 3100 and 3200, both the cross vanes, and B 1-4 of the baffles leaving the rest of the Dredge and Fill Inventory as stated in the application. Reinstatement of the authorization will allow us to complete installation of restoration structures that are necessary to stabilize the river channel, improve wetlands habitat, and insure the success and longevity of this project.

Thank-you for your assistance with this project. Please contact me at 505.827.0572 or by email, nina.wells@state.nm.us if you have any questions or concerns, or need additional information.

Sincerely

/signed/
Nina Wells
Project Manager, Watershed Protection Section

cc: Derek Padilla
District Ranger,
Cuba Ranger District

WOOD/jaw/3280
QA CHECK
BORDA

April 25, 2007

Operations Division
Regulatory Branch

SPA-2007-188

Ms. Julie Walker
Environmental Scientist-Specialist
NMED-Surface Water Quality Bureau
P.O. Box 26110
Santa Fe, New Mexico 87502-6110

Dear Ms. Walker:

This is in reference to your April 2, 2007, application, on behalf of the Cuba Ranger District, Santa Fe National Forest (CRD/SFNF) regarding the placement of several rock structures into the Rio De Las Vacas and two tributaries (School Section Canyon and Telephone Canyon) near Cuba, Sandoval County, New Mexico, Action No. SPA-2007-188-ABQ.

By a letter dated April 13, 2006, we notified you that we were evaluating this work under the terms and conditions of Section 404 Nationwide Permit No. 27 for aquatic habitat restoration, establishment, and enhancement activities. A summary of this nationwide permit was enclosed with this previous letter.

After reviewing the project in accordance with the Nationwide Permit pre-construction notification procedures (General Condition No. 27), we have determined that the proposed work will not result in more than minimal individual or cumulative adverse environmental effects. The public interest would best be served by allowing the work to proceed under the nationwide permit with a special condition.

The CRD/SFNF is therefore authorized to proceed under authority of the nationwide permit for aquatic habitat restoration, establishment, and enhancement activities. In addition to the conditions described in the permit summary, the following condition must be met:

The project site must be monitored for three years and a monitoring report will be submitted on an annual basis. The report should be prepared in accordance with Albuquerque District's Mitigation and Monitoring Guidelines. These guidelines can be found on the Corps' website at www.spa.usace.army

The permittee must insure compliance with all conditions of the permit, including submittal of the enclosed Compliance Certification required by General Condition No. 26.

As we stated in our April 13, 2007, letter, the proposed project is located in the Rio De Las Vacas and two tributaries, all of which are intermittent to perennial streams. The CRD/SFNF must receive a Section 401 water quality certification (or a waiver) from the New Mexico Environment Department (NMED) prior to commencing work.

General Condition No. 17 requires that no activity is authorized under any Nationwide Permit which is likely to jeopardize the continued existence of a listed or proposed threatened or endangered species, as identified under the Federal Endangered Species Act, or which is likely to destroy or adversely modify the critical habitat of such species. We have determined that the proposed work, as described, will have no affect on any listed or proposed endangered or threatened species or its critical habitat.

Please note under Further Information in the nationwide permit that this verification does not grant any property rights or privileges. The CRD/SFNF must possess the authority, including property rights or easements, to undertake the work described in their application.

This verification will be valid for 2 years unless the nationwide permit is modified, reissued or revoked. The verification will remain valid if, during that time, the nationwide permit is reissued without modification or the activity complies with any subsequent modification of the nationwide permit authorization. If the nationwide permit authorization expires, is suspended, revoked, or modified such that the activity would no longer comply with the terms and conditions of the nationwide permit, the provisions of 33 CFR 330.6(b) will apply.

If you have any questions regarding this verification or these regulations, please feel free to contact Mr. James Wood of the Regulatory Branch at (505) 342-3280 or by e-mail at james.a.wood@usace.army.mil. Also, at your convenience, please complete and return the attached Customer Service Survey.

Sincerely,

Jean E. Manger

Donald Borda
for Chief, Regulatory Branch

2 Enclosures
1. Compliance Certification form
2. Customer Service Survey

Copies furnished:

Mr. William Eaton
Cuba Ranger District
Santa Fe National Forest
P.O. Box 130
Cuba, NM 87013-0130

Mr. Neal Schaeffer
Environmental Specialist
NMED-Surface Water Quality Bureau
P.O. Box 26110
Santa Fe, NM 87502-6110

Mr. Randy Floyd
NMDGF-Conservation Services
Division
P.O. Box 25112
Santa Fe, NM 87504-5112

Attachment E

Beavers Belong!

Best Western
Kachina Lodge

Taos, New Mexico

September 30, 2006

Animal Protection of New Mexico

Animal Protection of New Mexico
P.O. Box 11395
Albuquerque, New Mexico 87192
www.apnm.org
(505) 265-2322

New Mexico Environment Department
and Animal Protection of New Mexico

Free Workshop:
Coexisting with Beavers by Preventing Damage

May 20–21, 2008, Santa Fe, New Mexico

Beaver dams sometimes cause problems on roads or properties near streams. Landowners often call the NM Dept. of Game and Fish or USDA Wildlife Services for help. Due to small budgets and customary procedures, beavers are often removed lethally. That extreme is not necessary because devices can be built and installed relatively quickly and inexpensively to let water flow in the presence of beavers, allowing them to continue to maintain the beneficial ecological habitat that they provide, without damaging roads or property.

This two-day workshop is co-sponsored by the N.M. Environment Dept. (NMED) and Animal Protection of New Mexico (APNM).

Workshop Purpose: ***Day One*** of the training (**for government-agency participants only**) will include on-site training and construction of devices to mitigate beaver damage (Beaver Deceivers™), as well as live-trapping instruction. ***Day Two*** participants (**open to the public**) will hear from speakers regarding live trapping, Beaver Deceivers™, beaver biology, and habitat restoration related to beavers. These participants will also see the completed device constructed on Day One and observe how to properly live-trap beavers.

Who is Invited: State, federal, city, county, and tribal entities on Day One. On Day Two only, interested public and APNM's volunteer field group, the Beaver Brigade may attend.

When and Where: ***Day One*** — May 20, 9:00 AM - 5:00 PM — Various government agency participants will meet at the NMED south parking lot to carpool to the field site. We will meet in the parking lot of the Harold Runnels Building. ***Day Two*** — May 21, 9:00 AM — Participants are to meet in the NMED Harold Runnels Building Auditorium. Speakers and schedule:

- Bill Zeedyk, Zeedyk Ecological Consulting – riparian and wetland protection and restoration
- Sherrie Tippie, Wildlife 2000 – 22 years' experience live trapping beavers in Colorado
- US Fish and Wildlife Service Representative Denise Smith, Partners for Fish & Wildlife
- NM Department of Game and Fish Depredation Coordinator Barbara Coulter
- Skip Lisle, Beaver Deceivers Int'l – 15 years' experience building Beaver Deceivers™
- Dave Foreman, Rewilding Institute – a think tank dedicated to "the development and promotion of ideas and strategies to advance continental-scale conservation in North America and to combat the extinction crisis."

12:00 PM Lunch on your own (many restaurants are within walking distance)
1:15 PM Meet at NMED south parking lot — carpool to Beaver Deceiver™ site
4:00 PM Adjourn

Important: ***Please RSVP to Debbie Risberg of APNM at debbie@apnm.org, 265-2322 x 25, or 205-5740; call if you need more information.***

Directions to NM Environment Dept., Harold Runnels Building:
Enter Santa Fe from I-25 at St. Francis Drive. Turn west at light on Alta Vista St. The Harold Runnels Building parking lot is the first right.

Attachment F – Monitoring (3)

Rio de Las Vacas Wetlands Restoration Project
Pre-Monitoring Report

Steve Vrooman Restoration Ecology and Rangeland Hands

For the New Mexico Environment Department, SWQB Wetlands Program
October 8, 2008

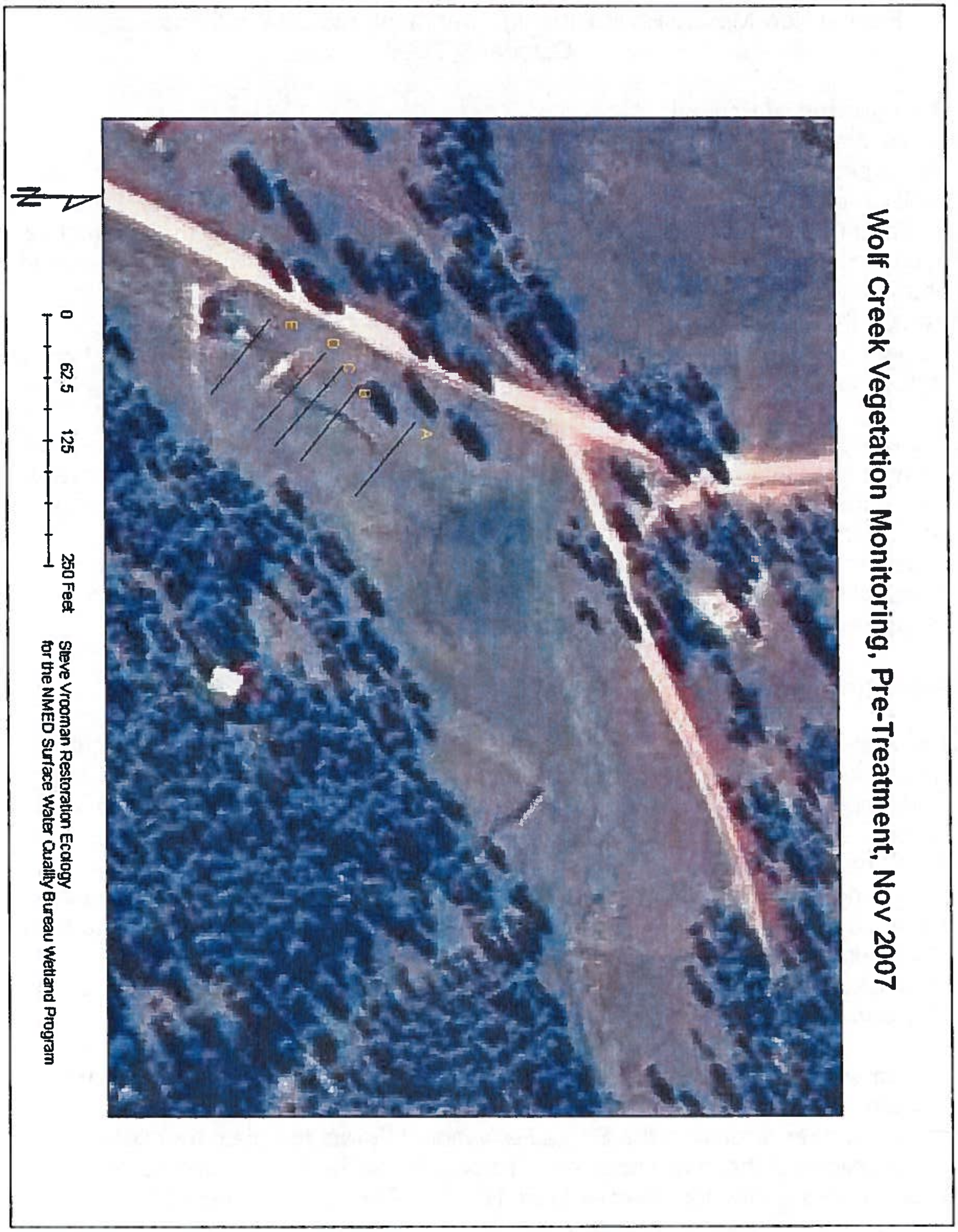
Background of Project:
Steve Vrooman Restoration Ecology was contracted through Rangeland Hands Inc. to perform pre and post vegetation monitoring at the Rio de las Vacas and Wolf Creek Restoration Sites in the Jemez Mountains. The Rio de las Vacas Wetland Restoration Project is a stream restoration project using the techniques of natural channel design and induced meandering to create wetland habitat and promote the growth of wetland vegetation at these two sites. Bill Zeedyk and Van Clothier performed a Rosgen level II survey of the Rio de las Vacas to prepare the restoration design. Steve Carson of Rangeland Hands Inc. is the implementation contractor for the project.

Steve Vrooman Restoration Ecology worked with Dr. Jonathan Coop at the Wolf Canyon site to identify the many species of wetland plants found at this ungrazed site (Appendix A). Dr. Coop took voucher plant collections to correctly identify several rare and obscure species that were found at the site. Five 30m transects were installed and monitored at Wolf Creek. Nineteen line point intercept transects were installed at Rio de las Vacas to monitor vegetation changes due to different wetland restoration techniques.

Experimental Design, Wolf Creek:

The Wolf Creek project involves restoration of a wetland threatened by a gully on private land near the confluence of Wolf Creek and the Rio de las Vacas. The monitoring consists of five 30m cross section transects that run across the valley bottom. Jonathan Coop and Steve Vrooman measured line-point intercept points at 1/2 meter intervals on these transects in October 2007. The Wolf Creek monitoring site was found to have a high number of native wetland plant species due to its being un-grazed by domestic livestock. There is a moderate amount of Elk grazing at the site. A number of collections were taken to confirm their identification; these were checked at the Colorado State University herbarium by Dr. Coop.

Two small pioneer species, *Juncus dudleyi* and *Juncus nodosus*, were found growing in the raw banks of the gully through the wetland at Wolf Creek. Dr. Coop communicated with the Santa Fe National Forest to obtain their information on collections of these two species. These two species were found at 19 different sites throughout the Santa Fe National Forest, in a variety of different habitats and elevations. This suggests that the individuals living at Wolf Creek are part of larger populations found throughout the Jemez and Sangre de Cristo Mountains. Repairing the gully would eliminate their habitat but would also raise the water table in the entire valley.



Results, Wolf Creek Vegetation Pre Monitoring

Forty-one plant species were identified in the five transects at Wolf Creek. A number of these species were wetland species that are less common on grazed sites. A gradient of moisture exists from uphill to downhill, with transect A being the wettest, un-gullied portion of the site, and transect E being the driest. A large wet patch of Carex utriculata (beaked sedge) wetland is located uphill from the gully and should spread down the valley if the water table is restored by gully restoration.

Because each transect is unique in hydrology (wettest to driest), they were not compared directly for this pre-monitoring report.

Line # WCA

Species	Number	% of total abundance
Acmi (Achillea millefolium)	10	8%
Calu (Carex lanuginosa)	8	6%
Caob (Carex obtusata)	5	4%
Capr (Carex praegracilis)	4	3%
Caro (Campanula rotundifolia)	4	3%
Deca (Deschampsia caespitosa)	8	6%
Elpa (Eleocharis palustris)	3	2%
Eltr (Elymus trachycaulus)	1	1%
Erfo (Erigeron formosissimos)	1	1%
Hyne (Hymenopappus newberryi)	1	1%
Juba (Juncus balticus)	2	2%
Maca (Machaeranthera canescens)	3	2%
Mear (Mentha Arvensis)	2	2%
Melu (Medicago lupulina)	10	8%
Mumo (Muhlenbergia montana)	1	1%
Pasm (Pascopyrum smithii)	8	6%
Pohi (Potentilla hippiana)	3	2%
Popr (Poa pratensis)	40	32%
Raca (Ranunculus cardiophyllus)	1	1%
Taof (Taraxacum officinale)	3	2%
Thpo (Thinopyrum ponticum)	1	1%
Trpr (Trifolium pratense)	4	3%
Viam (Vicia americana)	1	1%

Line # WCB

Species	Number	% of total abundance
Acmi (Achillea millefolium)	18	12%
Aggi (Agrostis gigantea)	1	1%
Aran (Argentina anserina)	2	1%
Brte (Bromus tectorum)	1	1%
Cain (Calamagristis inexpansa)	3	2%
Calu (Carex lanuginosa)	17	11%
Caob (Carex obtusata)	7	5%
Capr (Carex praegracilis)	1	1%
Deca (Deschampsia caespitosa)	10	6%
Elel (Elymus elymoides)	1	1%
Elpa (Eleocharis palustris)	2	1%
Eltr (Elymus trachycaulus)	1	1%
Erfo (Erigeron formosissimos)	3	2%
Fear (Festuca arizonica)	2	1%
Geam (Gentianella amarella)	2	1%
Juba (Juncus balticus)	5	3%
Koma (Koeleria macrantha)	2	1%
Maca (Machaeranthera canescens)	1	1%
Melu (Medicago lupulina)	8	5%
Mumo (Muhlenbergia montana)	1	1%
Pasm (Pascopyrum smithii)	9	6%
Pohi (Potentilla hippiana)	4	3%
Popa (Poa palustrus)	1	1%
Popr (Poa pratensis)	44	28%
Taof (Taraxacum officinale)	5	3%
Trpr (Trifolium pratense)	4	3%

Line # WCC

9

Species	Number	% of total abundance
Acmi (Achillea millefolium)	15	9%
Aggi (Agrostis gigantea)	2	1%
Aran (Argentina anserina)	8	5%
Caaq (Carex aquatillis)	2	1%
Calu (Carex lanuginosa)	19	11%
Capr (Carex praegracilis)	1	1%
Deca (Deschampsia caespitosa)	15	9%
Eqar (Equisetum arvense)	1	1%
Getr (Geum triflorum)	8	5%
Juba (Juncus balticus)	6	4%
Maca (Machaeranthera canescens)	8	5%
Melu (Medicago lupulina)	15	9%
Pasm (Pascopyrum smithii)	2	1%
Phpr (Phleum pratense)	5	3%

Popr (Poa pratensis)	50	29%
Prvu (Prunnella vulgaris)	2	1%
Taof (Taraxacum officinale)	7	4%
Trpr (Trifolium pratense)	4	2%

Line # WCD

Species	Number	% of total abundance
Acmi (Achillea millefolium)	6	4%
Aran (Argentina anserina)	11	7%
Calu (Carex lanuginosa)	36	23%
Caut (Carex utriculata)	3	2%
Deca (Deschampsia caespitosa)	12	8%
Epci (Epilobium ciliatum)	1	1%
Hobr (Hordeum brachyantherum)	1	1%
Juba (Juncus balticus)	10	6%
Maca (Machaeranthera canescens)	8	5%
Melu (Medicago lupulina)	8	5%
Phpr (Phleum pratense)	2	1%
Popr (Poa pratensis)	54	34%
Prvu (Prunnella vulgaris)	1	1%
Taof (Taraxacum officinale)	4	3%
Trpr (Trifolium pratense)	1	1%

Line # WCE

Species	Number	% of total abundance
Acmi (Achillea millefolium)	2	1%
Aran (Argentina anserina)	12	7%
Maca (Machaeranthera canescens)	4	2%
Calu (Carex lanuginosa)	46	27%
Caut (Carex utriculata)	4	2%
Deca (Deschampsia caespitosa)	4	2%
Hobr (Hordeum brachyantherum)	9	5%
Irmi (Iris missouriensis)	4	2%
Juba (Juncus balticus)	20	12%
Melu (Medicago lupulina)	4	2%
Phpr (Phleum pratense)	2	1%
Popr (Poa pratensis)	54	31%
Taof (Taraxacum officinale)	7	4%

Most of these transects had a wetland-fringe community of grasses and grasslike sedges such as Carex lanuginosa. The wet-wetland sedge species such as Carex utriculata (beaked sedge) and Carex aquatilis are found on the edge of the gully where the valley is wettest. The uphill fringes of the valley to the North (top of photo) have upland species such as western wheatgrass (Elsm), Kentucky bluegrass (Popr), and yarrow (Acmi).

The most common species found on all transects was Kentucky bluegrass, which is also very dominant at grazed sites. However there was not a large component of red clover (Trpr), redtop (Aggi), timothy (Phpr), or other grazing tolerant species, and there was a large variety of sedges, rushes, and large wetland grasses such as Calamagrostis inexpansa (reedgrass) and Deschampsia caespitosa (tufted hairgrass). The Wolf Creek monitoring site is a rich, highly diverse wetland community of fringe wetland plants, and has great value as habitat even if the gully is not restored.

If the restoration of the wetland gully is implemented, the water table throughout the valley should be raised 2-3 feet and the entire site will become a wetland. This should help the wet-wetland species of sedge spread downhill and protect the gully plug from more erosion. The wet-wetland sedges are larger and have stronger root systems. The water table in the pond should also be raised, as more water will enter it from the raised water table on the uphill side.

Experimental Design, Rio de las Vacas
Nineteen line point intercept transects were installed along the entire length of the restoration site at Rio de las Vacas. The sampling method was designed to monitor as many restoration techniques as possible over the entire site.

Fourteen of the transects are bank section transects that run tangent to the curve of the cut bank. If the bank sloughs off and narrows the channel, the transect will monitor the increase in vegetation on the new bank. If the bank continues to erode, the bank section will show more bare soil and less vegetation overall.

Ten hemicexclosures and four vanes are monitored with a bank section transect. Two transects are cross section transects across channels. The hub at School Section Canyon has three transects across the eastern side of the valley.

Restoration Technique	Transect	# of transects
Hemiexclosure inside	HE3	4
	HE4	
	HE5	
	HE12	
Hemiexclosure outside	HE15	6
	HE17	
	HE18	
	HE21	
	HE25	
	HE26	
Vanes inside	Vane11	2
	Vane13	
Vanes outside	Vane16	2
	Vane18	
Cross Vane inside	Cross Vane 2	1
Zuni bowl inside	ZB 2	1
School Section Canyon	North 0	3
HUB outside	SE 120	
	SW 240	

Hemiexclosures:
The hemiexclosure technique uses an exclosure fence only on one side of the river, the outside eroding bank. These outside banks have been trampled by cattle and are contributing large amounts of sediment to the river. The fencing will block the bankside plants from grazing pressure and allow the bank to rest and revegetate.

An experiment was set up to compare the hemi exclosures inside the large exclosure fence with the hemiexclosures that would be exposed to cattle grazing pressure. Four HE transects were taken inside the large exclosure fence and six HE transects taken outside the fence on the south end of the project site. A comparison between the two types will allow an assessment of the effectiveness of this technique with and without livestock grazing.

Vanes

Four vanes were also monitored with bank section transects. Two vanes were inside the large exclosure, and two were outside the fence on the south end of the site.

The hub at School Section Canyon consists of three spokes across the valley bottom at 0, 120 and 240 degrees. The SSC Hub monitors the increase in wetland vegetation from a restoration of flow across an alluvial fan at the confluence.

Two cross sections were taken, at Cross Vane 2 across the Vacas and Zuni Bowl 2 on the west bank.

Results, Rio de las Vacas Vegetation Pre Monitoring

The entire site has been grazed and has suffered a reduction in the number and variety of plant species found. A greater number of species are upland and non-native species than were found at Wolf Creek.

Hemiexclosures inside the large exclosure

Line # HE 3 North

Species	Number	% of total abundance
Pasm (Pascopyrum smithii)	4	50%
Popr (Poa pratensis)	2	25%
Stro (Stipa robusta)	2	25%

Line # HE 4

Species	Number	% of total abundance
Caaq (Carex aquatillis)	5	56%
Caut (Carex utriculata)	2	22%
Popr (Poa pratensis)	1	11%
Thpo (Thinopyrum ponticum)	1	11%

Line # HE 5

Species	Number	% of total abundance
Pasm (Pascopyrum smithii)	9	60%
Popr (Poa pratensis)	2	13%
Rowo (Rosa woodsii)	2	13%
Taof (Taraxacum officinale)	1	7%
Lyph (Lycurus phleoides)	1	7%

Line # HE 12

Species	Number	% of total abundance
Poco (Poa compressa)	1	33%
Popr (Poa pratensis)	1	33%
Stro (Stipa robusta)	1	33%

Hemiexclosures outside of the large exclosure

Line # HE 15

Species	Number	% of total abundance
Aggi (Agrostis gigantea)	14	41%
Alnus (Alnus Mill.)	2	6%
Caut (Carex utriculata)	1	3%
Eltr (Elymus trachycaulus)	1	3%
Pohi (Potentilla hippiana)	1	3%
Popr (Poa pratensis)	9	26%
Taof (Taraxacum officinale)	3	9%
Trre (Trifolium repens)	3	9%

Line # HE 17

Species	Number	% of total abundance
Aggi (Agrostis gigantea)	7	32%
Alnus (Alnus Mill.)	4	18%
Caut (Carex utriculata)	5	23%
Popr (Poa pratensis)	4	18%
Taof (Taraxacum officinale)	2	9%

Line # HE 18

Species	Number	% of total abundance
Aggi (Agrostis gigantea)	6	40%
Alnus (Alnus Mill.)	2	13%
Caut (Carex utriculata)	1	7%
Phpr (Phleum pratense)	3	20%
Popr (Poa pratensis)	1	7%
Trre (Trifolium repens)	2	13%

Line # HE 21

Species	Number	% of total abundance
Agde (Agropyron desertorum)	1	8%
Aggi (Agrostis gigantea)	4	31%
Bogr (Bouteloua gracilis)	1	8%
Phpr (Phleum pratense)	1	8%
Popr (Poa pratensis)	1	8%
Trre (Trifolium repens)	5	38%

Line # HE 26 (Vane 20)

Species	Number	% of total abundance
Acmi (Achillea millefolium)	1	4%
Aggi (Agrostis gigantea)	7	27%
Arfr (Artemesia frigida)	1	4%
Brin (Bromus inermis)	1	4%
Caaq (Carex aquatillis)	4	15%
Caut (Carex utriculata)	3	12%
Cirx (Circium sp.)	1	4%
Phpr (Phleum pratense)	3	12%
Popr (Poa pratensis)	1	4%
Rowo (Rosa woodsii)	1	4%
Taof (Taraxacum officinale)	2	8%
Thpo (Thinopyrum ponticum)	1	4%

Line # HE 25

Species	Number	% of total abundance
Aggi (Agrostis gigantea)	5	56%
Alnus (Alnus Mill.)	1	11%
Pohi (Potentilla hippiana)	2	22%
Trre (Trifolium repens)	1	11%

Vanes inside:

Line # Vane 11

Species	Number	% of total abundance
Bogr (Bouteloua gracilis)	1	10%
Erdi (Erigeron divergens)	1	10%
Poax (Poa species)	1	10%
Poco (Poa compressa)	2	20%
Popr (Poa pratensis)	4	40%
Trre (Trifolium repens)	1	10%

Line # Vane 13

Species	Number	% of total abundance
Agde (Agropyron desertorum)	2	18%
Aggi (Agrostis gigantea)	5	45%
Mear (Mentha arvensis)	2	18%
Pohi (Potentilla hippiana)	1	9%
Trre (Trifolium repens)	1	9%

Vanes outside:

Line # Vane 16

Species	Number	% of total abundance
Agde (Agropyron desertorum)	1	16%
Aggi (Agrostis gigantea)	2	33%
Bogr (Bouteloua gracilis)	1	16%
Taof (Taraxacum officinale)	1	16%
Trre (Trifolium repens)	1	16%

Line # Vane 18

Species	Number	% of total abundance
Agde (Agropyron desertorum)	1	6%
Aggi (Agrostis gigantea)	7	41%
Arfr (Artemesia frigida)	1	6%
Bogr (Bouteloua gracilis)	1	6%
Popr (Poa pratensis)	1	6%
Rhus (Rhus L.)	2	12%
Trre (Trifolium repens)	4	24%

Cross Sections:

Line # CV2

Species	Number	% of total abundance
Aggi (Agrostis gigantea)	10	36%
Caut (Carex utriculata)	6	21%
Pasm (Pascopyrum smithii)	8	29%
Rile (Ribes leptanthum)	2	7%
Stro (Stipa robusta)	2	7%

Line # ZB 1, 2 @ old crossing

Species	Number	% of total abundance
Acmi (Achillea millefolium)	2	6%
Brin (Bromus inermis)	4	13%
Cale (Caltha leptosepala)	3	9%
Caut (Carex utriculata)	1	3%
Juba (Juncus balticus)	4	13%
Poco (Poa compressa)	6	19%
Popr (Poa pratensis)	7	22%
Taof (Taraxacum officinale)	2	6%
Trre (Trifolium repens)	3	9%

School Section Canyon Hub:

Line # 0 (N) hub

Species	Number	% of total abundance
Acmi (Achillea millefolium)	2	9%
Agde (Agropyron desertorum)	5	22%
Aggi (Agrostis gigantea)	9	39%
Aster sp.	2	9%
Dapa (Danthonia parryi)	3	13%
Irmi (Iris missouriensis)	2	9%

Line # 120 (SE) hub

Species	Number	% of total abundance
Acmi (Achillea millefolium)	1	4%
Aggi (Agrostis gigantea)	8	31%
Dapa (Danthonia parryi)	10	38%
Juba (Juncus balticus)	3	12%
Trre (Trifolium repens)	4	15%

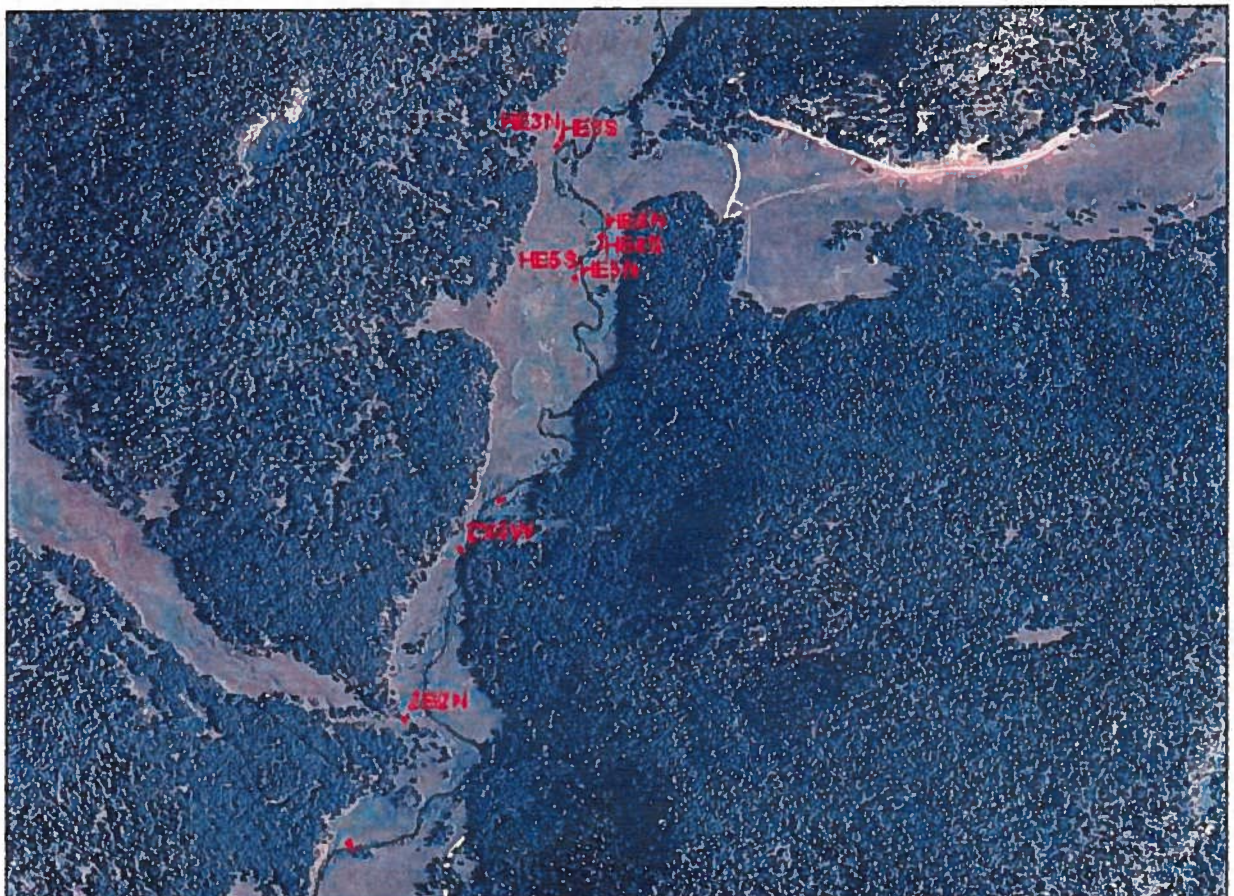
Line 0240 (SW) hub

Species	Number	% of total abundance
Aggi (Agrostis gigantea)	16	57%
Desx (Descurainia ssp.)	9	32%
Irmi (Iris missouriensis)	1	4%
Trre (Trifolium repens)	2	7%

Vegetation Pre Monitoring Results at Rio De las Vacas

There were 29 plant species found on the line-point transects at the Rio de las Vacas. The project area at Rio de las Vacas has been grazed by domestic livestock for many years, both inside and outside the large exclosure. This has facilitated a shift in community composition from a species-rich native community, to one dominated by more grazing tolerant non-natives. Non native grass species such as Redtop (Agrostis gigantea), crested wheatgrass (Agropyron desertorum), and smooth brome (Bromus inermis) share dominance with tolerant native grass species such as Kentucky bluegrass (Poa pratensis) and Poa compressa. The remainder of these transects consist of grazing tolerant forbs such as rocky mountain iris (Iris missouriensis), red clover (Trifolium repens) and yarrow (Achillea millefolium).

Rio de las Vacas Vegetation Monitoring, North Half, Nov 2007

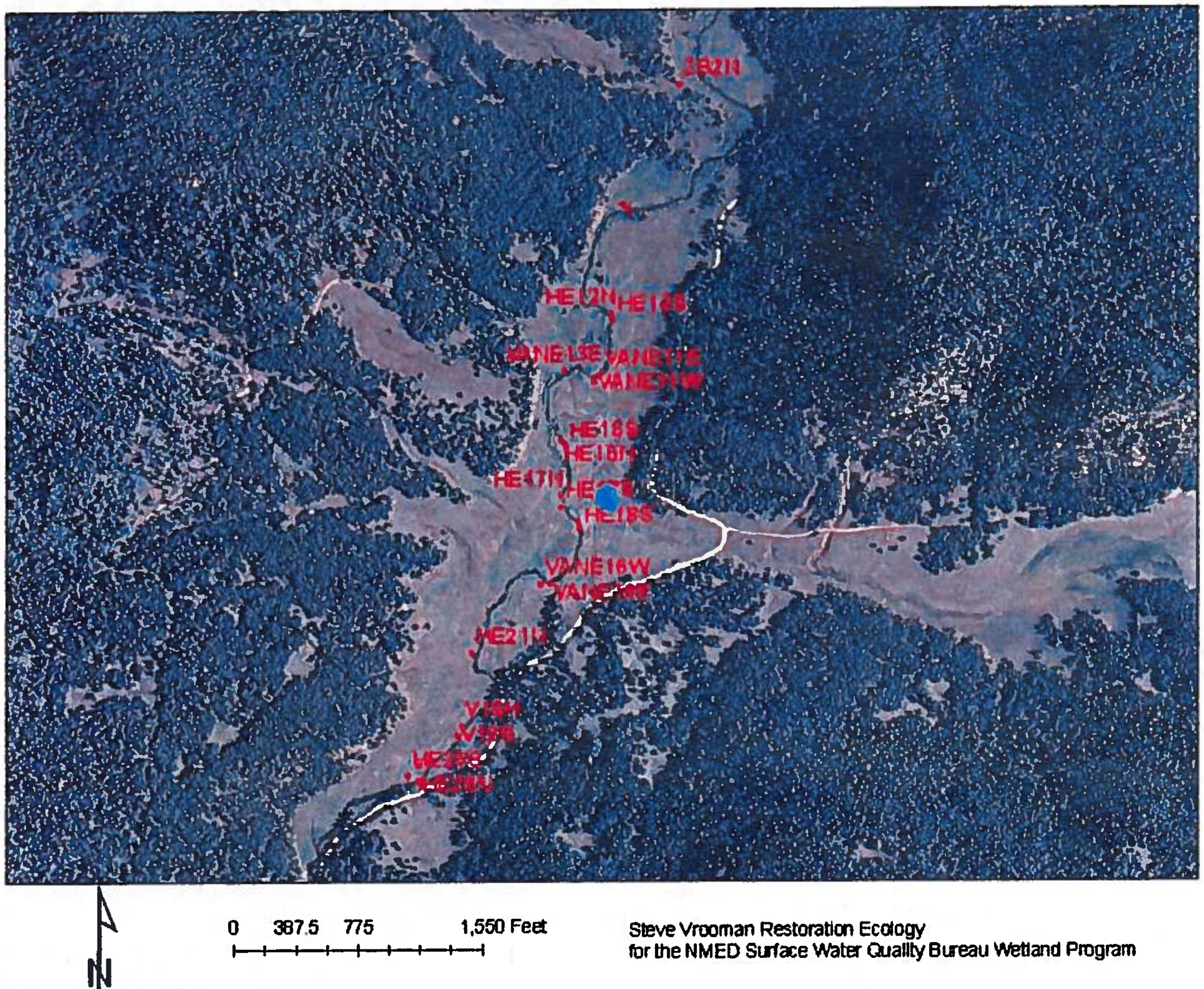


N

0 400 800 1,600 Feet

Steve Vrooman Restoration Ecology
for the NMED Surface Water Quality Bureau Wetland Program

Rio de las Vacas Vegetation Monitoring, South Half, Nov 2007



Steve Vrooman Restoration Ecology
for the NMED Surface Water Quality Bureau Wetland Program

Species List for Wolf Creek Monitoring Site

Acmi (Achillea millefolium)	yarrow
Aggi (Agrostis gigantea)	redtop
Aran (Argentina anserina)	silver cinquefoil
Brte (Bromus tectorum)	cheatgrass
Caaq (Carex aquatillis)	water sedge
Cain (Calamagrostis inexpansa)	bluejoint reedgrass
Calu (Carex lanuginosa)	sedge
Caob (Carex obtusata)	sedge
Capr (Carex praegracilis)	sedge
Caro (Campanula rotundifolia)	bluebell
Caut (Carex utriculata)	beaked sedge
Deca (Deschampsia caespitosa)	tufted hairgrass
Elel (Elymus elymoides)	squirreltail
Elpa (Eleocharis palustris)	spikerush
Eltr (Elymus trachycaulus)	slender wheatgrass
Epci (Epilobium ciliatum)	fringed willowherb
Eqar (Equisetum arvense)	horsetail
Erfo (Erigeron formosissimos)	fleabane
Fear (Festuca arizonica)	arizona fescue
Geam (Gentianella amarella)	gentian
Getr (Geum triflorum)	geum
Hobr (Hordeum brachyantherum)	barley
Hyne (Hymenopappus newberryi)	
Irmi (Iris missouriensis)	rocky mountain iris
Juba (Juncus balticus)	baltic rush
Koma (Koeleria macrantha)	junegrass
Maca (Machaeranthera canescens)	hoary tansyaster
Mear (Mentha arvensis)	field mint, poleo
Melu (Medicago lupulina)	black medic
Mumo (Muhlenbergia montana)	mountain muhlyi
Pasm (Pascopyrum smithii)	western wheatgrass
Phpr (Phleum pratense)	timothy
Pohi (Potentilla hippiana)	potentilla
Popa (Poa palustris)	fowl bluegrass
Popr (Poa pratensis)	Kentucky bluegrass
Prvu (Prunnella vulgaris)	selfheal
Raca (Ranunculus cardiophyllus)	buttercup
Taof (Taraxacum officinale)	dandelion
Thpo (Thinopyrum ponticum)	tall wheatgrass
Trpr (Trifolium pratense)	red clover
Viam (Vicia americana)	vetch

Species List for Rio de las Vacas

Acmi (Achillea millefolium)	yarrow
Agde (Agropyron desertorum)	crested wheatgrass
Aggi (Agrostis gigantea)	redtop
Alnus (Alnus Mill.)	alder
Arfr (Artemesia frigida)	fringed sagebrush
Aster sp.	aster
Bogr (Bouteloua gracilis)	blue grama
Brin (Bromus inermis)	smooth brome
Caaq (Carex aquatillis)	water sedge
Cale (Caltha leptosepala)	marsh marigold
Caut (Carex utriculata)	beaked sedge
Cirx (Circium sp.)	thistle
Danthonia parryi	parry's oatgrass
Desx (Descurainia ssp.)	tansymustard
Eltr (Elymus trachycaulus)	slender wheatgrass
Erdi (Erigeron divergens)	creeping fleabane
Irmi (Iris missouriensis)	rocky mountain iris
Juba (Juncus balticus)	baltic rush
Lyph (Lycurus phleoides)	wolftail
Mear (Mentha arvensis)	field mint
Pasm (Pascopyrum smithii)	western wheatgrass
Phpr (Phleum pratense)	timothy
Poax (Poa species)	bluegrass
Poco (Poa compressa)	bluegrass
Pohi (Potentilla hippiana)	potentilla
Popr (Poa pratensis)	Kentucky bluegras
Rhus (Rhus L.)	sumac
Rile (Ribes leptanthum)	gooseberry
Rowo (Rosa woodsii)	woods rose
Stro (Stipa robusta)	sleepygrass
Taof (Taraxacum officinale)	dandelion
Thpo (Thinopyrum ponticum)	tall wheatgrass
Trre (Trifolium repens)	red clover

Appendix A:
Voucher Plant Collections - Wolf Canyon Wetland
Collections by J. Coop & S.Vrooman October 2007
Determinations by J.Coop & R.Massatti November 2007

Morphospecies name (field collection)	Species
Agrostis	*Agrostis gigantea* Roth
Calamagrostis inexpansa	*Calamagrostis stricta* (Timm) Koel. ssp. *inexpansa* (Gray) C.W. Greene
CAOB	*Carex obtusata* Lilj.
CALA (Carex lanuginose)	*Carex pellita* Muhl. ex Willd.
CAPR	*Carex praegracilis* W. Boott
CAUT	*Carex utriculata* Boott
DECA	*Deschampsia caespitosa* (L.) Beauv.
Epilobium	*Epilobium ciliatum* Raf.
Geum sp.	*Geum aleppicum* Jacq.
Junsp2	*Juncus dudleyi* Wieg.
Junsp1	*Juncus nodosus* L.
Aster sp. 1	*Machaeranthera canescens* (Pursh) Gray ssp. *canescens* var. *ambigua* B.L. Turner (=*Dieteria canescens* Nutt.)
Aster sp. 2	*Machaeranthera canescens* (Pursh) Gray ssp. *canescens* var. *ambigua* B.L. Turner (=*Dieteria canescens* Nutt.)
PHPR	*Phleum pretense* L.

Rio de Las Vacas Wetlands Restoration Project Monitoring Report

Keystone Restoration Ecology and Rangeland Hands

For the New Mexico Environment Department, SWQB Wetlands Program
November 2010

Background of Project:

Steve Vrooman of Keystone Restoration Ecology was contracted through Rangeland Hands Inc. to perform pre and post vegetation monitoring at the Rio de las Vacas and Wolf Creek Restoration Sites in the Jemez Mountains. The Rio de las Vacas Wetland Restoration Project is a stream restoration project using the techniques of natural channel design and induced meandering to create wetland habitat and promote the growth of wetland vegetation at these two sites. Bill Zeedyk and Van Clothier performed a Rosgen level II survey of the Rio de las Vacas to prepare the restoration design. Steve Carson of Rangeland Hands Inc. was the implementation contractor for the project.

Steve Vrooman of Keystone Restoration Ecology performed monitoring at nineteen line point intercept transects at Rio de las Vacas to monitor vegetation changes due to different wetland restoration techniques.

Experimental Design, Rio de las Vacas

Nineteen line point intercept transects were installed along the entire length of the restoration site at Rio de las Vacas. The line-point intercept technique is sampled by dropping a rod or stick at a point every 2.5 feet. The species of every plant that touches the rod is recorded as well as the soil, water or vegetation where the rod touches the ground. This technique was used for bank transects, transects between 50 and 60 feet long that were located tangent to the curve of the bank.

Restoration Technique	Transect	# of transects
Hemiexclosure inside	HE3	4
large exclosures	HE4	
	HE5	
	HE12	
Hemiexclosure outside	HE15	6
large exclosures	HE17	
	HE18	
	HE21	
	HE25	
	HE26	

Vanes inside	Vane11	2
	Vane13	
Vanes outside	Vane16	2
	Vane18	
Cross Vane inside	Cross Vane 2	1
Zuni bowl inside	ZB 2	1
School Section Canyon	North 0	3
HUB outside	SE 120	
	SW 240	

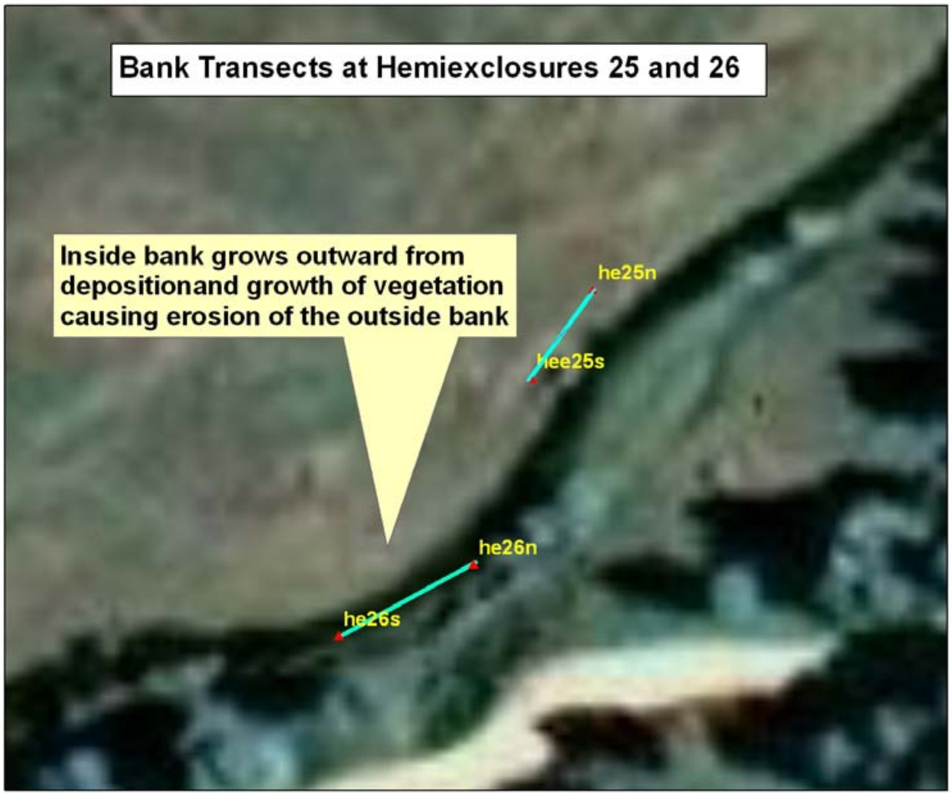
Bank Section Transect for Monitoring Bank Erosion:
This monitoring technique was created for the project at Rio de las Vacas to monitor bank erosion over time. Each transect was located with the two ends of the transect on healthy banks, with the transect running tangent to the curve of the bank. In most situations, the middle of the transect runs through the creek at the outside corner of a curve.

These outside banks were suffering from a great amount of erosion from several interacting processes. Many of the banks of the Rio de las Vacas suffer directly from trampling by cattle as they try to get to the water to drink. This causes sediment to fall into the creek along along its entire length. As this sediment is dissolved and carried downstream, it is deposited on inside meander bends and allows for the growth of more Carex Utriculata, a large, vigorous wetland sedge. This vegetation is very tough and narrows the channel, forcing water against with outside meander bend with excessive force.

The force of floodwaters against the outside bank causes erosion by undercutting the bank and causing the bank to slough into the creek. This new soil is mostly washed away in the next flood cycle and ends up being deposited on the inside of the next meander bend, causing more bank erosion downstream. Even in the absence of trampling by cattle, excess sedimentation of the creek can continue, as the soil from the outside banks continues to be a source of excess sediment in the system.

If the vanes or hemiexclosures are effective, the outside banks should reach an angle of repose and grow wetland vegetation, armoring the bank against erosion. In addition, the management of cattle grazing through the system of large exclosures should reduce the overall amount of bank erosion along the Rio de las Vacas and the excess amount of fine sediment in the system.

The bank erosion transects will monitor if these outside banks are continuing to erode or healing. If the bank is healing, the band transects should show less percentage water or soil and more vegetation. In addition, the vegetation should change from upland to wetland vegetation as the bank sloughs in and grows plants closer to the water. If the bank continues to erode, the bank section will show more bare soil or water and less vegetation overall.



Hemiexclosures:
A new and innovative technique for bank restoration was created by Bill Zeedyk, the restoration designer of the project. Bill noticed that the large exclosures were hard to maintain over time, due to flooding, damage by cattle and elk, and vandalism by the public to gain access for fishing and camping.

The hemiexclosure technique uses an exclosure fence only on one side of the river, the outside eroding bank. This doesn't limit access by people or cattle to most of the creek, only the areas that have excessive erosion and sedimentation. The fencing will block the bankside plants from grazing pressure and allow the bank to reach an angle of repose and revegetate.

An experiment was set up to compare the hemi exclosures inside the large exclosure fence with the hemiexclosures that would be exposed to cattle grazing pressure. Four HE transects were taken inside the large exclosure fence and six HE transects taken outside the fence on the south end of the project site. A comparison between the two types will allow an assessment of the effectiveness of this technique with and without livestock grazing.

The **Vanes** were not built until summer 2010, so they will be used as a control for the hemiexclosures, showing the results for un-treated banks.

Hub
The hub at School Section Canyon consists of three spokes across the valley bottom at 0, 120 and 240 degrees. The SSC Hub monitors the increase in wetland vegetation from a restoration of flow across an alluvial fan at the confluence of School Section Canyon and the Rio De las Vacas. This work was not completed, however, until fall 2010, so no results due to the treatment can be observed.

Cross sections
Two cross sections were taken, at Cross Vane 2 across the Vacas and Zuni Bowl 2 on the west bank.

Results, Rio de las Vacas Vegetation Monitoring
The pre-monitoring data was taken during November 2007. The follow-up monitoring was taken in October 2010. The project suffered from several set-backs and an irregular schedule due to staff changes and other unavoidable delays. The machine-built work was only competed during summer 2010. This includes all the vanes, and the earth work at the hub at School Section Canyon.

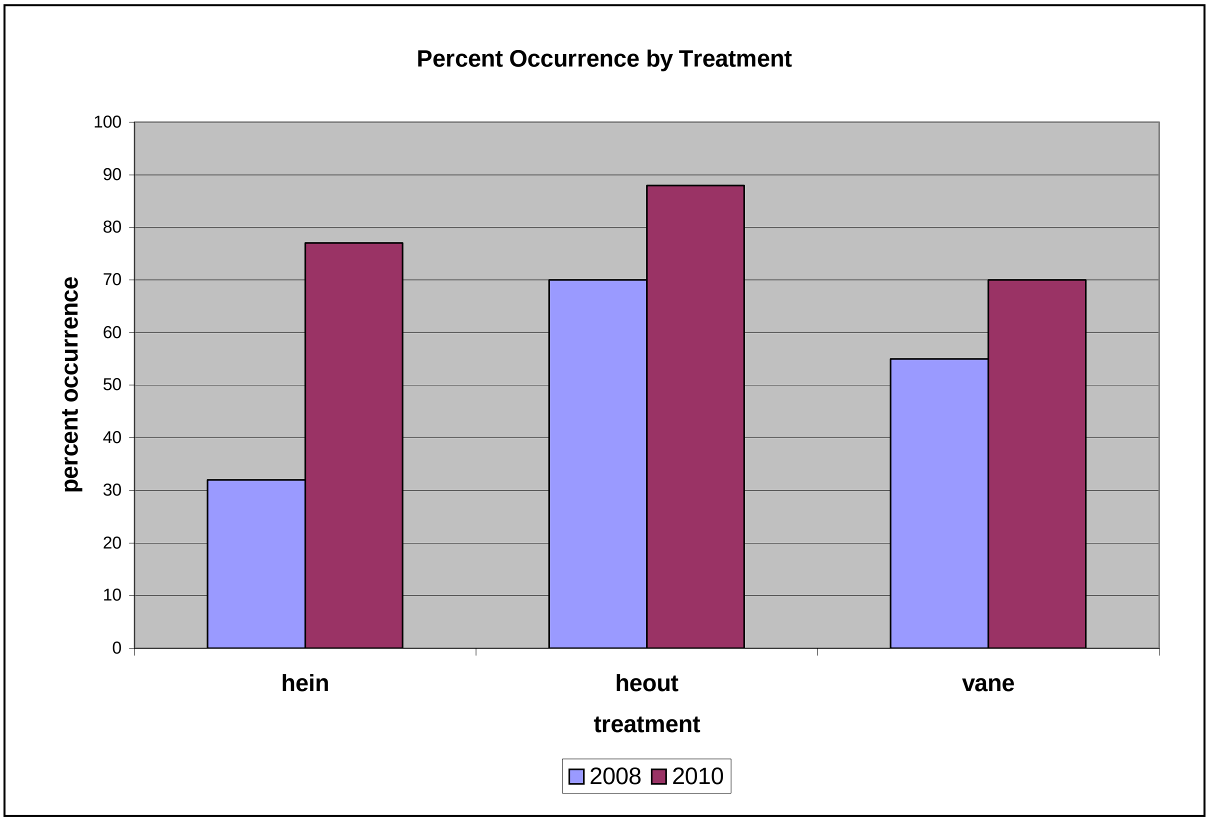
The hub at School Section Canyon should show only the natural changes in vegetation over time, and the largest effects should be due to the large amount of cattle at the site.

The vane transects will show the amounts of bank erosion on untreated banks. The bank transects at vanes inside the large exclosure were very close to a 'water gap' which gave access to cattle quite easily. All the vanes were considered a 'control' for the purpose of this experiment.

The hemi-exclosures were completed during summer 2008, and they should provide a good evaluation of the effectiveness of this new technique over a winter and summer runoff season.

There were cattle in the large exclosure during re-monitoring in October 2010. The most obvious point of access was due to damage by flooding during the summer of 2010, which washed out the 'watergap' fence across the creek. Cattle were free to walk up the shallow creek and get into the exclosure. However, many positive changes were seen, especially a major increase in the amount of willows, young cottonwoods, and alders. Before the repair of the large exclosure in 2008, willows were almost un-seen at the site. After the repair, there were patches of dense willows hundreds of feet across and beaver dams at the site. Despite the moderate grazing in the exclosure, there was a remarkable change in the amount and vigor of all plant species.

The data is presented as percent occurrence, which can sum to over 100%, as two or more species can occur at one sampling point. This is very similar to percent cover. Occurrence is a more accurate representation of the results from a line-point transect, as it does not assume that the points taken on the line represent the entire line, and could give us % cover for the bank transect overall.



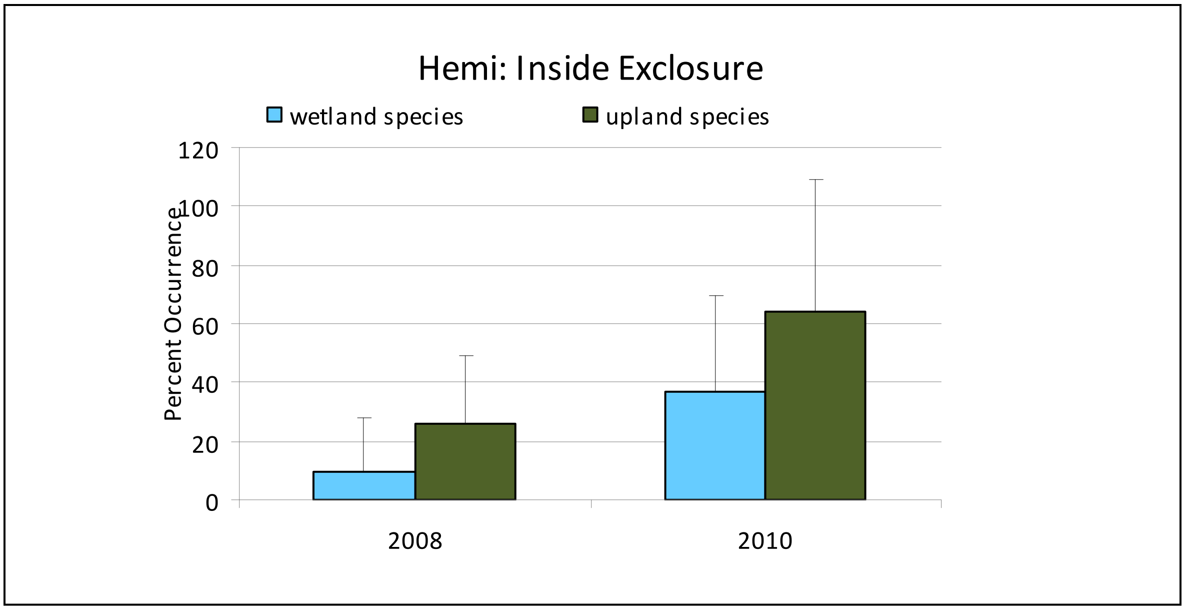
This chart compares percent occurrence by treatment between 2008 and 2010. Percent occurrence compares bare soil with any vegetation, and is very similar to percent cover for each bank transect. Overall, the hemiexclosures inside the large exclosure showed the largest increase in percent occurrence, from 31% to 77%, a significant increase, with a ($P<0.0001$). The hemiexclosures outside the large exclosure also had a significant increase, from 70% to 88%, with a ($P=0.0012$). The vanes (control) showed an increase in percent occurrence from 55% to 70%, but this increase was not significant ($P=0.13$).

The proportional increase in hemiexclosures inside the large exclosure was significantly greater than proportional increase for hemiexclosures outside. ($P = 0.01$). The difference between hemiexclosures outside and vanes (control) was not significant.

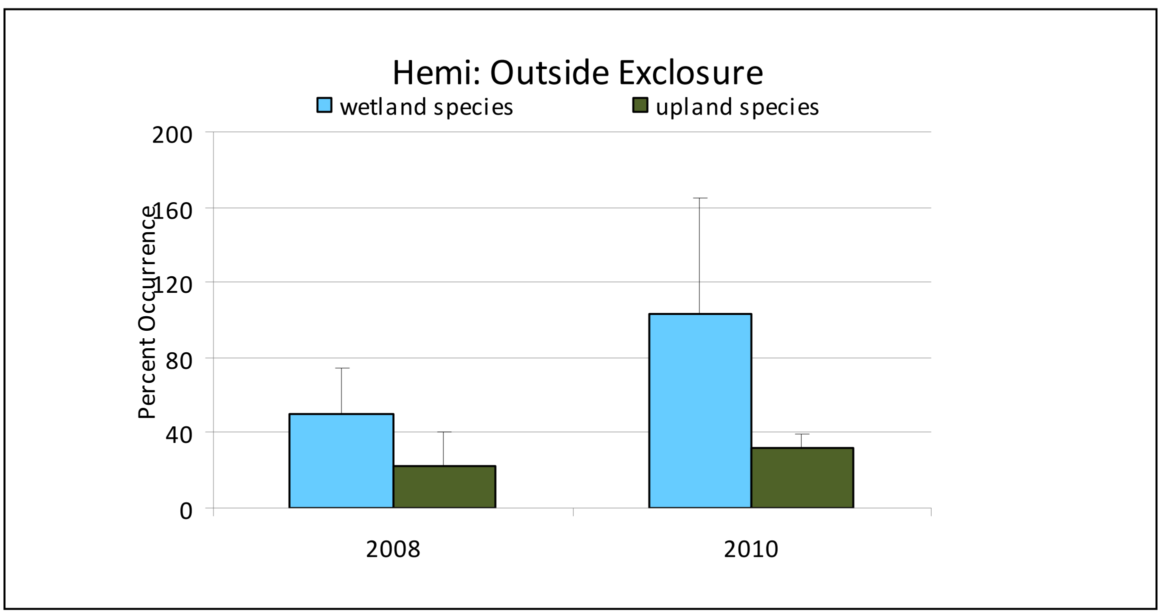
Overall, these results show that the hemiexclosures inside the large exclosure were the most effective, followed by the hemiexclosures outside, then the vane controls. This would be expected, as the large exclosures were relatively effective at excluding grazing, and the hemiexclosures inside were provided an additional layer of grazing protection. Overall, the percent occurrence of species increased for every treatment and the control, indicating that the vegetation at the site improved and grew over the two years of the study.

Comparison within Treaments

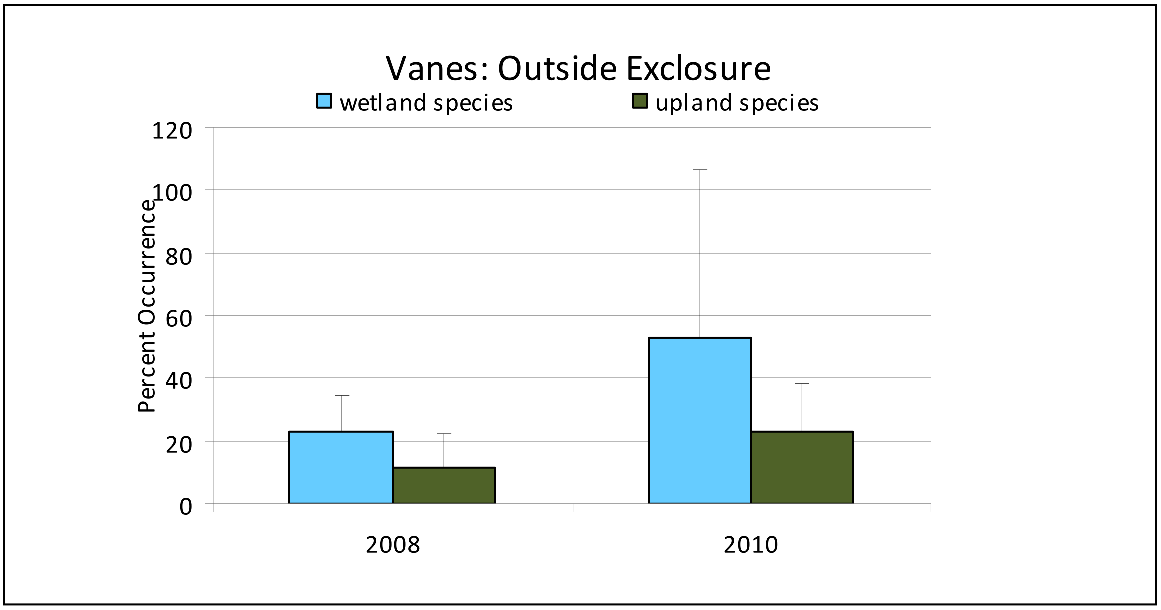
The following charts show the percent increase in occurrence from 2008 to 2010 for wetland versus upland species for each treatment.



This chart shows that percent occurrence for both wetland and upland species increased from 2008 to 2010. The proportion of wetland to upland species was not significantly different from 2008 to 2010 (Chi-sq p>0.05). The error bars represent one significant deviation from the mean. There were more wetland species inside the exclosure, and this proportion increased in the two years of the study. The presence of the large exclosures at the site for many years, may be the reason for the larger proportion of wetland species in this treatment, than hemis outside the large exclosures, as seen below.



This chart shows that percent occurrence for both wetland and upland species increased from 2008 to 2010 in the hemiexclosures outside. The proportion of wetland to upland species was not significantly different from 2008 to 2010 (Chi-sq p>0.05). The error bars represent one significant deviation from the mean.



The vanes were used as a 'control' for the hemiexclosures, as they were not built until summer 2010. This is an imperfect control, but shows bank erosion over two winter and summer runoff seasons without any hemiexclosures. The percent occurrence for both wetland and upland species increased from 2008 to 2010. The proportion of wetland to upland species was not significantly different from 2008 to 2010 (Chi-sq $p>0.05$). The error bars represent one significant deviation from the mean.

Results by treatment

Each treatment showed an increase in percent occurrence overall, proportionate to the type (wetland versus upland) and the percent occurrence for each treatment in late 2007. There was not a difference for any treatment in the response of wetland versus upland species. This could be expected, as a three year study is a short amount of time to see an increase in a plant species from one point to another by tillering or recruitment by seed. A grass species such as Western Wheatgrass would have to spread a maximum distance of 2.5 feet (the distance between points) to show an increase in occurrence, this is a large increase over three years.

The most likely reason for the overall increase in all treatments was some large scale factor affecting the entire site. Two of the most important factors for plant growth are grazing and precipitation. It could be assumed that this difference was due to precipitation, but wetland plants would have not shown a large increase due to precipitation if they had their roots in the water table anyways. If upland species had a much greater proportion increase than wetland species, we could assume that they benefited from extra rain or snowfall. Because both types of species increased, with their different moisture regimes, some other factor, probably grazing, was most likely responsible for the large overall increase in occurrence for all plant species.

Grazing in the Hemiexclosures

In addition, each hemiexclosure had differing success in excluding grazing, some were grazed by cattle crossing the creek at a riffle, sometimes the fences were broken down by cattle or elk and were open to grazing, for at least several months before the second sampling period. The results for each individual transect show that some transects inside the large exclosure, such as HE4, and HE5, and outside the large exclosure (HE15, HE21, and HE25) had absolutely no grazing and had the largest increases in both wetland and upland cover. See results for individual transects.

t-Test: Paired Two Sample for Means	**All Wetland Species by year**	
	2008	*2010*
Mean	6.692307692	15.23077
Variance	34.8974359	163.5256
Observations	13	13
Pearson Correlation	0.710334739	
Hypothesized Mean Difference	0	
df	12	
t Stat	-3.225417979	
P(T<=t) one-tail	0.003640465	
t Critical one-tail	1.782287548	
P(T<=t) two-tail	**0.007280929**	
t Critical two-tail	2.178812827	

t-Test: Paired Two Sample for Means	**All Upland Species by year**	
	2008	*2010*
Mean	4.615384615	8.615385
Variance	16.92307692	46.58974
Observations	13	13
Pearson Correlation	0.706563552	
Hypothesized Mean Difference	0	
df	12	
t Stat	-2.954195784	
P(T<=t) one-tail	0.006024956	
t Critical one-tail	1.782287548	
P(T<=t) two-tail	**0.012049912**	
t Critical two-tail	2.178812827	

t-Test: Paired Two Sample for Means	**All Species by year**	
	2008	*2010*
Mean	11.30769231	23.84615
Variance	54.23076923	153.4744
Observations	13	13
Pearson Correlation	0.802558615	
Hypothesized Mean Difference	0	
df	12	
t Stat	-5.775568171	
P(T<=t) one-tail	4.40169E-05	
t Critical one-tail	1.782287548	
P(T<=t) two-tail	**8.80337E-05**	
t Critical two-tail	2.178812827	

These paired t-tests prove that the overall occurrence of wetland, upland and all species increased from 2008 to 2010 significantly. Wetland species occurrence went from 6% occurrence to 15% with a P value of 0.007. Upland species occurrence went from 4.6% to 8.6% with a P value of 0.012. Overall species occurrence went from 11 to 23 % with a P value of 0.00008. As discussed in the treatment section, this appears to be due to a difference in grazing management, versus precipitation.

This was a three year monitoring study. There may be a greater response over time by wetland species versus upland species, but two years is not long enough for new plants to get established by seed. Some plants that spread by runners did increase, but it appears that wetland species did not colonize new habitats by showing a greater proportion increase than upland species. Over a longer period of study, with the hemiexclosures working and maintained, wetland species should colonize the entire bank transect.

Conclusions

The effectiveness of the hemiexclosures was tested by statistical analysis over the three years of the study. The hemiexclosures inside the large exclosure showed a large increase in % occurrence of vegetation on each bank transect, followed by the hemiexclosures outside the large exclosures and the vane controls. The overall amount of vegetation increased at every transect, showing a response to some large factor affecting the entire site. Due to a similar response from wetland and upland species, precipitation was probably not this factor, and grazing appears to have been managed better over time, leading to this large improvement in bank vegetation from 2008 to 2010.

The large exclosures and the hemiexclosures need continual, probably yearly, repair from damage due to grazing, vandalism, and flooding. In addition, Canada thistle (Ciar) is increasing all over the site, and has covered many acres outside the study area. This noxious weed can spread easily by seed and roots and is difficult to control.

Hemiexclosures inside the large exclosure

Line # HE 3 2008			Line # HE 3 2010		
Species	Number	% occurrence	Species	Number	% occurrence
Pasm (Pascopyrum smithii)	4	20	Pasm (Pascopyrum smithii)	5	24
Popr (Poa pratensis)	2	10	Popr (Poa pratensis)	0	0
Stro (Stipa robusta)	2	10	Stro	1	5
			Amar (Ambrosia artemisiifolia)	15	71
			Eqar (Equisetum arvense)	3	14
			Trre (Trifolium repens)	1	5
Percent cover 2008		23	Percent cover 2010		80

Hemiexclosure 3 is at a very tall bank, about 6 feet tall with a lot of eroding earth. The bank of the stream is about 5 feet west of the transect, so this transect is monitoring the revegetation of an eroding slope. The stream bank did not erode, and this bare slope is revegetating with several species such as common ragweed (Ambrosia artemisiifolia) and field horsetail (Eqeisetum arvense). Due to this, the overall percent occurrence by vegetation went from 23% to 80%.

Line # HE 4 2008			Line # HE 4 2010		
Species	Number	% occurrence		Number	% occurrence
Caaq (Carex aquatillis)	5	25	Caaq (Carex aquatillis)	3	16
Caut (Carex utriculata)	2	10	Caut (Carex utriculata)	2	10
Popr (Poa pratensis)	1	5	Popr (Poa pratensis)	5	25
Thpo (Thinopyrum ponticum)	1	5	Thpo (Thinopyrum ponticum)	0	0
			Popr (Poa pratensis)	5	25
			Aggi (Agrostis gigantea)	4	21
			Phpr (Phleum pretense)	2	10
			Elps (Eleocharis palustris)	3	16
			Trre (Trifolium repens)	2	10
			Ciar (Cirsium arvense)	2	10
% occurrence		37	% occurrence		68

This hemiexclosure has a thick stand of wetland vegetation such as Carex utriculata and Redtop along the bank. Other wetland species such as Carex aquatilis and Eleocharis palustris were found on the transect as well. In general, the percent occurrence increased from 37% to 68%. There was also an increase in a noxious weed, Cirsium arvense (Canada thistle), which spreads from both seeds and creeping rhizomes and has an enormous abundance at the site.

Line # HE 5 2008			Line # HE 5 2008		
Species	Number	% occurrence	Species	Number	% occurrence
Pasm (Pascopyrum smithii)	9	36	Pasm (Pascopyrum smithii)	10	40
Popr (Poa pratensis)	2	8	Popr (Poa pratensis)	1	4
Rowo (Rosa woodsii)	2	8	Rowo (Rosa woodsii)	8	32
Taof (Taraxacum officinale)	1	4	Taof (Taraxacum officinale)	0	0
Lyph (Lycurus phleoides)	1	4	Lyph (Lycurus phleoides)	0	0
			Amar (Ambrosia artemisiifolia)	5	20
			Muas (Muhlenbergia asperifolia)	3	12
			Sair (Salix irrorata)	3	12
			Ruhi (Rudbeckia hirta)	2	8
			Aggi (Agrostis gigantea)	1	4
% occurrence	13	52	% occurrence	25	100

This hemiexclosure needs the south end fixed, otherwise it was a complete success. The small amount of grazing was not such as problem due to the thick growth of thorny Woods' rose that protected the bank from grazing. About 90% of the bluestem willow cuttings (Sair) that were planted in the exclosure took. The majority of the cover was Western Wheatgrass (Pascopyrum smithii), and Woods' Rose. A number of native bank species such as Muas (Scratchgrass), Ruhi (Black-eyed Susan), and Aggi (redtop), were found in 2010 and were not present, or easily seen in 2008.

Line # HE 12 2008			Line # HE 12 2010		
Species	Number	% occurrence	Species	Number	% occurrence
Poco (Poa compressa)	1	5	Poco (Poa compressa)	1	5
Popr (Poa pratensis)	1	5	Popr (Poa pratensis)	0	0
Stro (Stipa robusta)	1	5	Stro (Stipa robusta)	1	5
			Eqar (Equisetum arvense)	7	33
			Aggi (Agrostis gigantea)	5	24
			Taof (Taraxacum officinale)	2	10
			Elpa (Eleocharis palustris)	2	10
			Pohi (Potentilla hippiana)	1	5
			Trre (trifolium repens)	1	5
% occurrence		14	% occurrence		62

Hemi-exclosure 12 now has good vegetative cover on the bank, the percent occurrence went from 14 to 62%. A positive sign is seen in the presence of Eqar (horsetail), Aggi (redtop) and Elpa (spikerush), which are all wetland/facultative wetland species.

Hemiexclosures outside of the large exclosure

Line # HE 15 2008			Line # HE 15 2010		
Species	Number	% occurrence	Species	Number	% occurrence
Aggi (Agrostis gigantea)	14	64	Aggi (Agrostis gigantea)	22	100
Popr (Poa pratensis)	9	41	Popr (Poa pratensis)	3	14
Taof (Taraxacum officinale)	3	14	Taof (Taraxacum officinale)	0	0
Trre (Trifolium repens)	3	14	Trre (Trifolium repens)	3	14
Alnus (Alnus Mill.)	2	10	Alnus (Alnus Mill.)	5	23
Caut (Carex utriculata)	1	5	Caut (Carex utriculata)	2	10
Eltr (Elymus trachycaulus)	1	5	Eltr (Elymus trachycaulus)	0	0
Pohi (Potentilla hippiana)	1	5	Pohi (Potentilla hippiana)	0	0
			Caaq (Carex aquatilis)	15	68
			Ruhi (Rudbeckia hirta)	3	14
			Ciar (Cirsium arvense)	3	14
			Juba (Juncus balticus)	2	10
			Eqar (Equisetum arvense)	2	10
			Elpa (Eleocharis palustris)	1	5
% occurrence		100	% occurrence		100

This hemiexclosure is working very well, with no grazing impact and the fences in perfect repair. There is also some overhung bank fish habitat forming under the vigorous bank vegetation. Native vegetation appears to be growing more vigorously than the non-natives such as Kentucky bluegrass (Popr), Dandelion (Taof), and Eltr (Slender Wheatgrass). The most noticeable change is the increase in Alders (Alnus) and the large increase in wetland obligate species such as Carex aquatilis, Elpa (spikerush), and Ruhi (Black-eyed Susan). However, even though the native vegetation is vigorous, there is still an infestation of Ciar (Canada thistle), which is found in the entire project area.

Line # HE 17 2008			Line # HE 17 2010		
Species	Number	% occurrence	Species	Number	% occurrence
Aggi (Agrostis gigantea)	7	32	Aggi (Agrostis gigantea)	0	
Alnus (Alnus Mill.)	4	18	Alnus (Alnus Mill.)	6	27
Caut (Carex utriculata)	5	23	Caut (Carex utriculata)	5	23
Popr (Poa pratensis)	4	18	Popr (Poa pratensis)	5	23
Taof (Taraxacum officinale)	2	9	Taof (Taraxacum officinale)	0	
			Caaq (Carex aquatilis)	2	9
			Ruhi (Rudbeckia hirta	1	5
			Acmi (Achillea millefolium)	1	5
% occurrence	13	59	% occurrence	13	59

This hemiexclosure is working well but cattle are crossing the stream and grazing this bank. The bank is still migrating outward, and many of the alders are overhanging the water. There is a small increase in Alder cover, probably due to the lack of grazing. There is a complete lack of redtop (Aggi), but a small increase in Carex aquatilis. About 10 feet of bank has slumped into the creek, and this sod is now irrigated and is permanently wet, leading to this change in vegetation cover.

Line # HE 18 2008			**Line # HE 18 2010**		
Species	Number	% occurrence	Species	Number	% occurrence
Aggi (Agrostis gigantea)	6		Aggi (Agrostis gigantea)	8	
Alnus (Alnus Mill.)	2		Alnus (Alnus Mill.)	2	
Caut (Carex utriculata)	1		Caut (Carex utriculata)	2	
Phpr (Phleum pratense)	3		Phpr (Phleum pratense)	0	
Popr (Poa pratensis)	1		Popr (Poa pratensis)	2	
Trre (Trifolium repens)	2		Trre (Trifolium repens)	1	
			Eqar (Equisetum arvense)	6	
			Amar (Ambrosia artemisiifolia)	2	
			Epci (Epilobium ciliatum)	1	
% occurrence	12	60	% occurrence	18	90

This hemiexclosure has access to cattle on both sides, but has worked for some time to prevent excess grazing. There is significantly more vegetative cover, areas that were once soil now have some vegetation. The increase in species of vegetation (Eqar, Amar, Epci) is most likely due to the lesser grazing pressure within the exclosure than outside, but there has not been a qualitative change towards more wetland vegetation.

Line # HE 21 2008			**Line # HE 21 2010**		
Species	Number	% occurrence	Species	Number	% occurrence
Agde (Agropyron desertorum)	1	5	Agde (Agropyron desertorum)	0	0
Aggi (Agrostis gigantea)	4	20	Aggi (Agrostis gigantea)	5	25
Bogr (Bouteloua gracilis)	1	5	Bogr (Bouteloua gracilis)	0	0
Phpr (Phleum pratense)	1	5	Phpr (Phleum pratense)	0	0
Popr (Poa pratensis)	1	5	Popr (Poa pratensis)	3	15
Trre (Trifolium repens)	5	25	Trre (Trifolium repens)	0	0
			Ciar (Cirsium arvense)	5	25
			Caaq (Carex aquatilis)	3	15
			Caut (Carex utriculata)	2	10
			Eqar (Equisetum arvense)	2	10
			Sair (Salix irrorata)	1	5
			Juba (Juncus balticus)	1	5
% occurrence	15	75	% occurrence	19	95

This transect has seen a large decrease in non-native, grazing-tolerant species such as Crested Wheatgrass (Agde), Timothy (Phpr), and white clover (Trre). There has been a moderate increase in wetland species such as Carex aquatilis, Carex utriculata, and Juncus balticus, probably due to limited grazing pressure. There have been a number of bluestem willows (Salix irrorata) pole-planted and about 60% are still living. One concern is a large increase in Canada thistle (Ciar), growing on a bare, eroding bank. Overall, the percent occurrence has increased from 75 to 95 % due to less grazing.

Line # HE 25 2008			**Line # HE 25 2010**		
Species	Number	% occurrence	Species	Number	% occurrence
Aggi (Agrostis gigantea)	5	25	Aggi (Agrostis gigantea)	5	25
Alnus (Alnus Mill.)	1	5	Alnus (Alnus Mill.)	7	35
Pohi (Potentilla hippiana)	2	10	Pohi (Potentilla hippiana)	2	10
Trre (Trifolium repens)	1	5	Trre (Trifolium repens)	0	0
			Rowo (Rosa woodsii)	5	25
			Juba (Juncus balticus)	5	25
			Caaq (Carex aquatilis)	3	15
			Elpa (Eleocharis palustris)	1	5
			Epci (Epilobium ciliatum)	1	5
% occurrence	10	50	% occurrence	18	86

This hemiexclosure has remained un-harmed and has no grazing inside the exclosure. There has been a large increase in two woody species, Woods' Rose and Alder. These two species were present on the site, but were able to expand by suckering due to the removal of grazing pressure. There has also been a large increase in wetland vegetation such as Carex aquatilis, Juncus balticus, Elpa (spikerush) and Willow-herb (Epci). There has also been a large increase in percent occurrence in general, from 50 to 86%.

Line # HE 26 2008			**Line # HE 26 2010**		
Species	Number	% occurrence	Species	Number	% occurrence
Acmi (Achillea millefolium)	1	4	Acmi (Achillea millefolium)	1	4
Aggi (Agrostis gigantea)	7	28	Aggi (Agrostis gigantea)	19	76
Arfr (Artemesia frigida)	1	4	Arfr (Artemesia frigida)	0	0
Brin (Bromus inermis)	1	4	Brin (Bromus inermis)	0	0
Caaq (Carex aquatillis)	4	16	Caaq (Carex aquatillis)	10	40
Caut (Carex utriculata)	3	12	Caut (Carex utriculata)	0	0
Ciar (Cirsium arvense)	1	4	Ciar (Cirsium arvense)	0	0
Phpr (Phleum pratense)	3	12	Phpr (Phleum pratense)	2	8
Popr (Poa pratensis)	1	4	Popr (Poa pratensis)	3	12
Rowo (Rosa woodsii)	1	4	Rowo (Rosa woodsii)	0	0
Taof (Taraxacum officinale)	2	8	Taof (Taraxacum officinale)	1	4
Thpo (Thinopyrum ponticum)	1	4	Thpo (Thinopyrum ponticum)	0	0

			Eqar (Equisetum arvense)	5	20
			Pohi (Potentilla hippiana)	2	8
			Ruhi (Rudbeckia hirta)	5	20
% occurrence	19	76	% occurrence	24	96

This hemiexclosure was constructed under a tall bank, near the bottom of the project and very close to the road. The narrow strip between the creek and the steep bank was heavily trampled by cattle. The old cattle trails have filled in with Redtop (Aggi). There has been a large increase in wetland species such as Carex aquatilis, Field horsetail (Eqar), and Black-eyed Susan (Ruhi). The hillside above the bank is slumping in and changing from Smooth brome (Brin) to Redtop and other wetter, native species.

Vanes inside:

Line # Vane 11 2008			**Line # Vane 11 2010**		
Species	Number	% of total abundance	Bank eroded, data lost		
Bogr (Bouteloua gracilis)	1	10%			
Erdi (Erigeron divergens)	1	10%			
Poax (Poa species)	1	10%			
Poco (Poa compressa)	2	20%			
Popr (Poa pratensis)	4	40%			
Trre (Trifolium repens)	1	10%			

This vane was not installed on this bank, and the cattle were inside this large exclosure. This bank suffered a large amount of erosion, at least 4 feet of bank was lost. Both rebar pins on either end of the transect were lost, one was found nearby in the water. This transect and bank were trampled heavily due to the location of the large exclosure fence running along the top of the bank. This forced cattle, once they entered the exclosure, to walk very close to the top of the bank and cause damage.

Line # Vane 13 2008			**Line # Vane 13 2010**		
Species	Number	% occurrence	Species	Number	% occurrence
Agde (Agropyron desertorum)	2	10	Agde (Agropyron desertorum)	0	0
Aggi (Agrostis gigantea)	5	25	Aggi (Agrostis gigantea)	2	10
Mear (Mentha arvensis)	2	10	Mear (Mentha arvensis)	0	0
Pohi (Potentilla hippiana)	1	5	Pohi (Potentilla hippiana)	0	0
Trre (Trifolium repens)	1	5	Trre (Trifolium repens)	0	0
			Pasm (Pascopyrum smithii)	6	30
			Caaq (Carex aquatilis)	3	15
			Ciar (Cirsium arvense)	2	10
			Eqar (Equisetum arvense)	1	5
% occurrence	14	70	% occurrence	16	80

This transect was within a large exclosure, but the vane has not been installed. This exclosure had a large amount of grazing pressure, but this began this summer after a large flood. The entire site has improved conditions with a huge increase in the amount of willows and wetland vegetation after grazing exclusion. This site had moderate improvement and a large increase in Western Wheatgrass (Pasm) cover. There was no fencing issue in this location , unlike Vane 11 above, that focused the cattle on this site, so it remained relatively untouched.

Vanes outside large exclosures:

Line # Vane 16 2008			**Line # Vane 16 2010**		
Species	Number	% occurrence	Species	Number	% occurrence
Agde (Agropyron desertorum)	1	5	Agde (Agropyron desertorum)	0	0
Aggi (Agrostis gigantea)	2	10	Aggi (Agrostis gigantea)	1	5
Bogr (Bouteloua gracilis)	1	5	Bogr (Bouteloua gracilis)	2	10
Taof (Taraxacum officinale)	1	5	Taof (Taraxacum officinale)	1	5
Trre (Trifolium repens)	1	5	Trre (Trifolium repens)	0	0
			Popr (Poa pratensis)	2	10
			Elpa (Eleocharis palustris)	1	5
			Juba (Juncus balticus)	1	5
% occurrence	8	40	% occurrence	8	40

This vane was installed in the summer of 2010, and has had little flooding to deposit sediment behind the vanes, which would provide a rich seedbed for wetland vegetation. However, the soil placed between the vanes had a thick growth of spikerush (Elpa), and small pools of water between the vanes were acting as a fish nursery. There was no change in overall percent occurrence by vegetation, but some small increase in wetland plants, Juncus balticus and spikerush (Elpa).

Line # Vane 18 2008			**Line # Vane 18 2010**		
Species	Number	% occurrence	Species	Number	% occurrence
Agde (Agropyron desertorum)	1	5	Agde (Agropyron desertorum)	0	0
Aggi (Agrostis gigantea)	7	32	Aggi (Agrostis gigantea)	13	60
Arfr (Artemesia frigida)	1	5	Arfr (Artemesia frigida)	0	0
Bogr (Bouteloua gracilis)	1	5	Bogr (Bouteloua gracilis)	0	0
Popr (Poa pratensis)	1	5	Popr (Poa pratensis)	2	9
Rhus (Rhus L.)	2	9	Rhus (Rhus L.)	0	0
Trre (Trifolium repens)	4	18	Trre (Trifolium repens)	1	5
			Juba (Juncus balticus)	7	32
			Caut (Carex utriculata)	5	23
			Caaq (Carex aquatilis)	2	9

			Mear (Mentha arvense)	2	9
			Elpa (Eleocharis palustris)	3	14
			Eqar (Equisetum arvense)	1	5
			Rowo (Rosa woodsii)	1	5
% occurrence	12	55	% occurrence	20	91

This transect was placed across a corner with a large radius of curvature, not a sharp bend. Two vanes were installed in the summer of 2010. There has been a large increase in percent occurrence (55 to 91%) and many of the new plants are wetland species such as Carex utriculata, Carex aquatilis, Spikerush (Elpa), and stream mint (Mear). There is no hemi-exclosure at this site, so the increase in vegetation may be due to the vanes, or to this bank being generally free from grazing or trampling.

Cross Sections:

Line # CV2 2008			**Line # CV2 2010**		
Species	Number	% occurrence	Species	Number	% occurrence
Aggi (Agrostis gigantea)	10	42	Aggi (Agrostis gigantea)	10	42
Caut (Carex utriculata)	6	25	Caut (Carex utriculata)	5	21
Pasm (Pascopyrum smithii)	8	33	Pasm (Pascopyrum smithii)	4	17
Rile (Ribes leptanthum)	2	8	Rile (Ribes leptanthum)	2	8
Stro (Stipa robusta)	2	8	Stro (Stipa robusta)	2	8
			Ruhi (Rudbeckia hirta)	4	17
			Popr (Poa pratensis)	4	17
			Soca (Solidago Canadensis)	2	8
			Caaq (Carex aquatilis)	3	13
% occurrence	15	63	% occurrence	18	75

This transect runs perpendicular to the creek, downstream from the proposed location of cross vane 2. Due to the large expense in the rock and installation of this structure, it has not yet been built. However, this transect acts as a test of the effectiveness of the large exclosure. There has been a noticeable narrowing of the creek, % occurrence went from 63 to 75 %, which involved narrowing of the channel by vegetation. The entire transect on dry ground has plant cover. There was an increase in two wetland species, Black-eyed Susan (Ruhi), and Carex aquatilis. Goldenrod (Soca) was also found in this survey, which is a nitrogen fixing forb and a preferred grazing plant by cattle. This survey shows that the conditions at this site are improving due to the effectiveness of the large exclosure.

Line # ZB 1,2 2008			**Line # ZB 1,2 2008**		
Species	Number	% occurrence	Species	Number	% occurrence
Acmi (Achillea millefolium)	2		Acmi (Achillea millefolium)	1	
Brin (Bromus inermis)	4		Brin (Bromus inermis)	2	
Cale (Caltha leptosepala)	3		Cale (Caltha leptosepala)	0	
Caut (Carex utriculata)	1		Caut (Carex utriculata)	0	
Juba (Juncus balticus)	4		Juba (Juncus balticus)	4	
Poco (Poa compressa)	6		Poco (Poa compressa)	0	
Popr (Poa pratensis)	7		Popr (Poa pratensis)	4	
Taof (Taraxacum officinale)	2		Taof (Taraxacum officinale)	4	
Trre (Trifolium repens)	3		Trre (Trifolium repens)	6	
			Aggi (Agrostis gigantea)	7	
			Caaq (Carex aquatilis)	1	
			Pasm (Pascopyrum smithii)	3	
			Elpa (Eleocharis palustris)		
% occurrence		82	% occurrence		100

This cross section runs across an old road-bed that was recently closed off to acess and a hillside seep that flows into the creek. The rock zuni bowls are capturing water from the road bed and seep and are preventing erosion. However, there is a portion of the large exclosure fence that the private landowner nearby may be cutting to allow cattle into the large exclosure. This landowner has a conflict with the forest service over the closed road and this appears to be leading to this vandalism.

The cattle trail created by this fence cutting crosses the transect at the zuni bowl. The overall results show a large increase in plant occurrence in the transect, and no bare soil, however, there is are a large amount of weedy species that tolerate grazing, rather than wetland species growing in the water from the hillside seep. Species such as white clover (trre), Redtop (Aggi), and dandelion (Taof), represent these grazing tolerant weeds. Overall, the erosion has stopped, but this area will not reach its full potential until the fence cutting stops and grazing in the large exclosure stops.

School Section Canyon Hub:

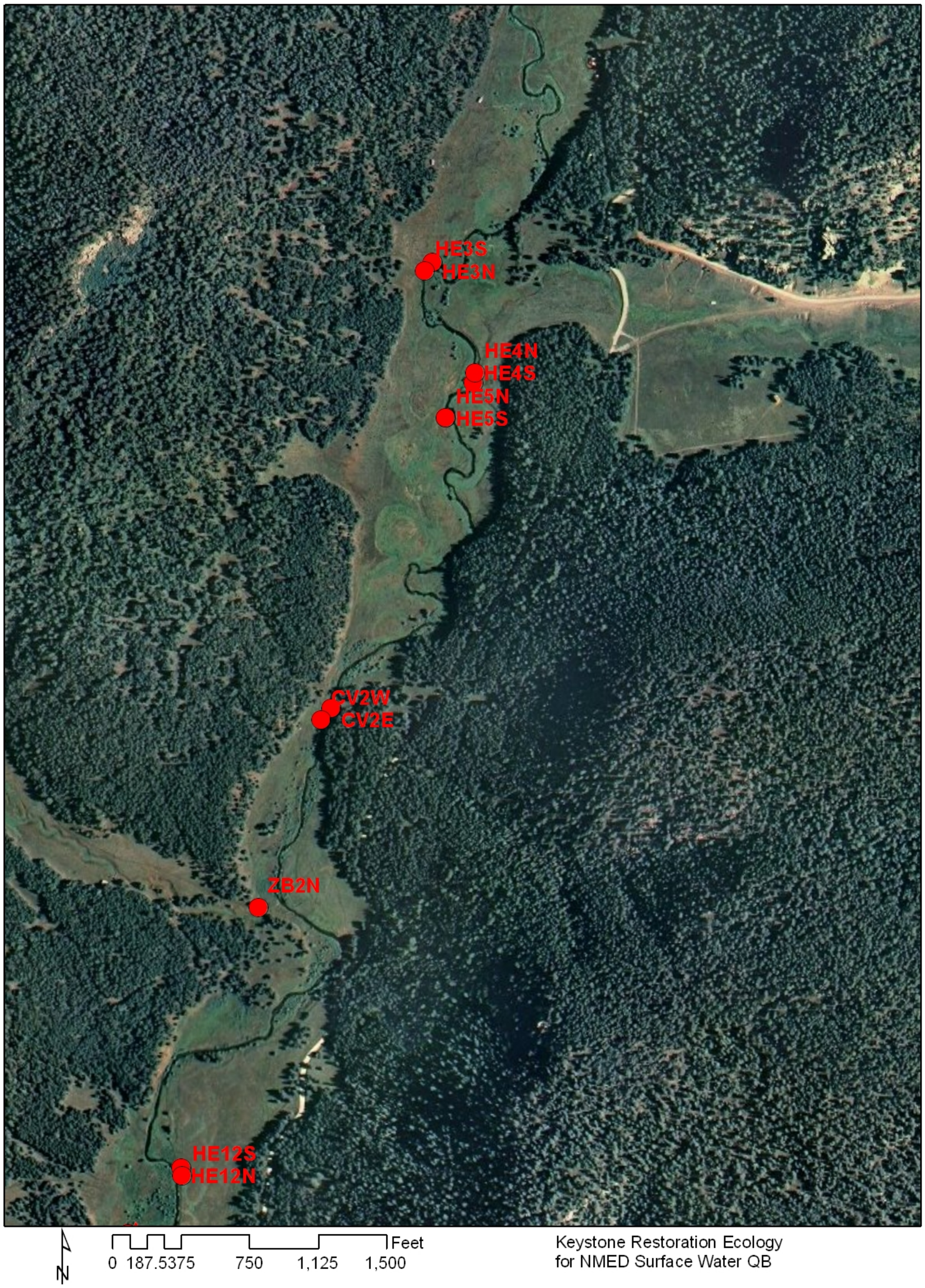
Line # 0 North hub 2008			**Line # 0 North hub 2010**		
Species	Number	% occurrence	Species	Number	% occurrence
Acmi (Achillea millefolium)	2	10	Acmi (Achillea millefolium)	0	0
Agde (Agropyron desertorum)	5	25	Agde (Agropyron desertorum)	0	0
Aggi (Agrostis gigantea)	9	45	Aggi (Agrostis gigantea)	0	0
Aster sp.	2	10	Aster sp.	0	0
Popr (Poa pratensis)	3	15	Popr (Poa pratensis)	13	65
Irmi (Iris missouriensis)	2	10	Irmi (Iris missouriensis)	3	15
			Pasm (Pascopyrum smithii)	5	25
			Stro (Stipa robusta)	1	5
			Taof (Taraxacum officinale)	2	10
			Juba (Juncus balticus)	1	5
% occurrence	15	75	% occurrence	19	95

Line # 120 SE hub 2008			**Line # 120 SE hub 2010**		
Species	Number	% occurrence	Species	Number	% occurrence
Acmi (Achillea millefolium)	1	5	Acmi (Achillea millefolium)	0	0
Aggi (Agrostis gigantea)	8	40	Aggi (Agrostis gigantea)	4	20
Popr (Poa pratensis)	10	50	Popr (Poa pratensis)	13	65
Juba (Juncus balticus)	3	15	Juba (Juncus balticus)	6	30
Trre (Trifolium repens)	4	20	Trre (Trifolium repens)	1	5
			Cage (Carex geophila)	10	50
% occurrence		100	% occurrence		100

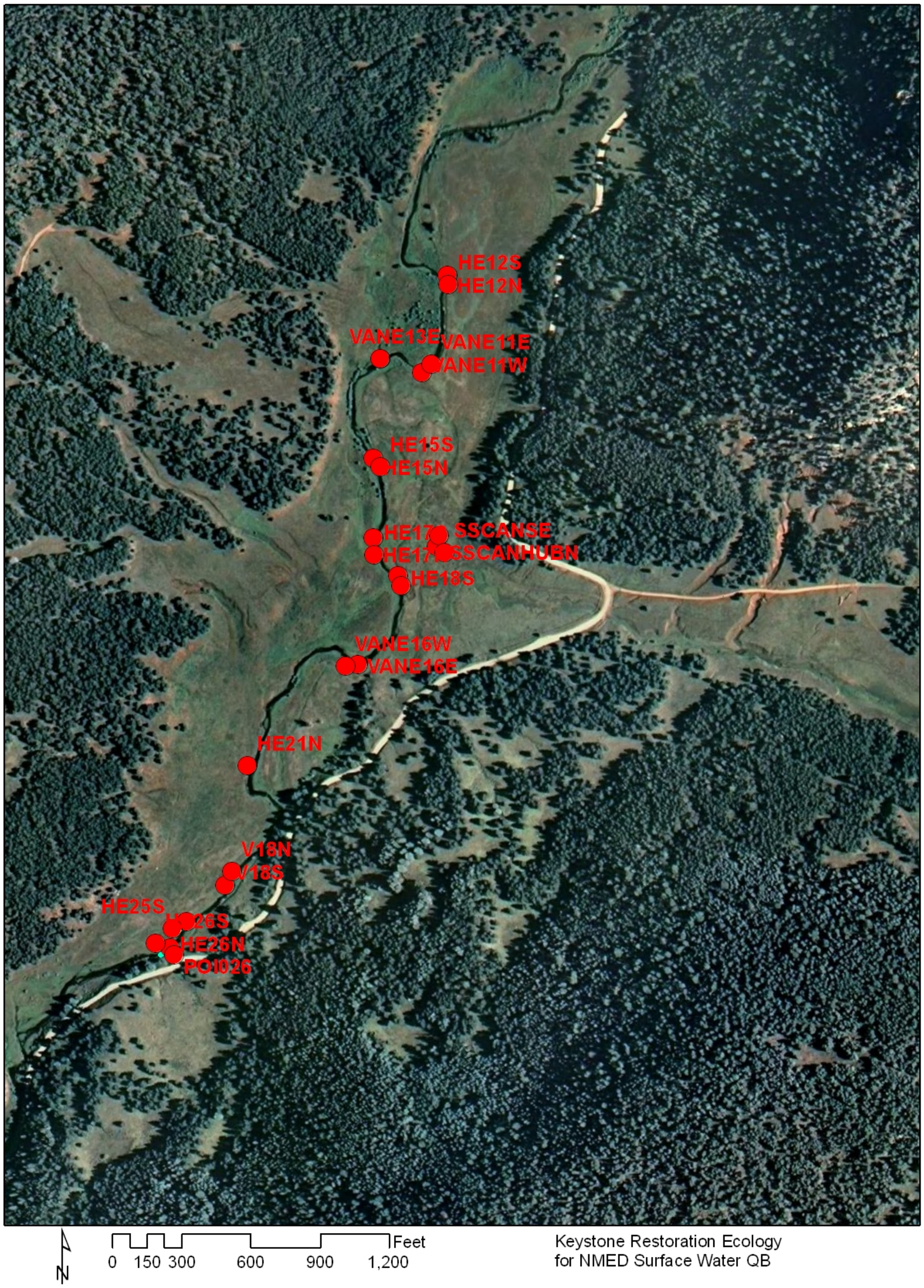
Line # SW hub 2008			**Line # SW hub 2010**		
Species	Number	% occurrence	Species	Number	% occurrence
Aggi (Agrostis gigantea)	16	80	Aggi (Agrostis gigantea)	0	0
Irmi (Iris missouriensis)	1	5	Irmi (Iris missouriensis)	6	30
Trre (Trifolium repens)	2	10	Trre (Trifolium repens)	0	0
Popr (Poa pratensis)	9	45	Popr (Poa pratensis)	18	90
			Cage (Carex geophila)	4	20
			Pasm (Pascopyrum smithii)	3	15
			Juba (Juncus balticus)	6	30
% occurrence		100	% occurrence		100

The results from these transects are rather difficult to tease out. The treatment, which involved cutting a flow splitter to spread floodwaters across the hub, was completed in fall 2010, so there are no results from the study from 2007 to 2010. The changes in vegetation over time can only be due to rainfall or grazing regime. There is no clear pattern towards a particular type of species. Redtop (Aggi) appeared to decrease, while Kentucky bluegrass increased. During both sampling times, this area was very heavily grazed, these two species are hard to tell apart at 2 inches tall with no seedheads. This transects should show a large increase in wetland species already found on-site such as Juba and Cage now that the flow from School Section Canyon preferentially flows across the hub during winter snowmelt or summer flooding.

Rio de las Vacas Vegetation Monitoring, 2007-2010



Rio de las Vacas Vegetation Monitoring, 2007-2010 Downstream



Species List for Rio de las Vacas

Acmi (Achillea millefolium)	yarrow
Agde (Agropyron desertorum)	crested wheatgrass
Aggi (Agrostis gigantea)	redtop
Alnus (Alnus Mill.)	alder
Arfr (Artemesia frigida)	fringed sagebrush
Aster sp.	aster
Bogr (Bouteloua gracilis)	blue grama
Brin (Bromus inermis)	smooth brome
Caaq (Carex aquatillis)	water sedge
Cage (Carex geophila)	dryland sedge
Cale (Caltha leptosepala)	marsh marigold
Caut (Carex utriculata)	beaked sedge
Ciar (Circium arvense)	Canada thistle
Danthonia parryi	parry's oatgrass
Desx (Descurainia ssp.)	tansymustard
Eltr (Elymus trachycaulus)	slender wheatgrass
Elpa (Eliocharis palustris)	spikerush
Erdi (Erigeron divergens)	creeping fleabane
Irmi (Iris missouriensis)	rocky mountain iris
Juba (Juncus balticus)	baltic rush
Lyph (Lycurus phleoides)	wolftail
Mear (Mentha arvensis)	field mint
Pasm (Pascopyrum smithii)	western wheatgrass
Phpr (Phleum pratense)	timothy
Poco (Poa compressa)	bluegrass
Pohi (Potentilla hippiana)	potentilla
Popr (Poa pratensis)	Kentucky bluegrass
Rhus (Rhus L.)	sumac
Rile (Ribes leptanthum)	gooseberry
Rowo (Rosa woodsii)	woods rose
Stro (Stipa robusta)	sleepygrass
Taof (Taraxacum officinale)	dandelion
Thpo (Thinopyrum ponticum)	tall wheatgrass
Trre (Trifolium repens)	white clover

Surface Water and Ground Water Interactions of the Rio de las Vacas, NM; Characterizing Exchange and Predicting Response Using Thermal Data

A Professional Project Report Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Water Resources: Hydroscience Concentration

Andrew Robertson

Water Resources Program
The University of New Mexico
Albuquerque, New Mexico
December 2008

Contents

Figures

Tables

Acknowledgements

I would like to thank the Graduate and Professional Student Association (GPSA), the Student Research Allocations Committee (SRAC), and the Office of Graduate Studies (OGS) for funding this work. I would also like to thank Global Water Instrumentation, Inc. and Rodgers & Company, Inc., especially Jeff Watson and Mike Lucero, for discounted products and expert advice. I would like to acknowledge Julie Watson and Nina Wells at the New Mexico Environment Department and Mike Dechter of the U.S. Forest Service for supporting this project, and my colleagues at the New Mexico USGS Water Science Center for their advice and encouragement. I would also like to acknowledge those individuals who were directly involved in the field work, analysis and editing including James Robertson, Monique Robertson, Keith Laffler and Kurt McCoy. Finally, thanks to my committee members Dr. Julie Coonrod, Dr. Cliff Dahm, and Dr. Bruce Thomson and to Annamarie Cordova for seeing this project through and acting in a timely manner to ensure my success.

I. Abstract

Temperature signatures in the hyporheic zone of a perennial, northern New Mexico stream suggest a complex and dynamic system of interactions on a diurnal time scale. Fourteen shallow wells were instrumented with temperature data loggers and installed along four transects across a 40 ft reach of a proposed, channel-modifying restoration structure on the Rio de las Vacas. Temperature signatures in the banks and the floodplain of the reach suggest a parallel flow system while the instream wells suggest a losing reach within 15 to 30 in. of the stream bed. The thermal signatures of a losing reach that appear at the shallow depths dissipate at greater depths below the stream. Hydraulic head measurements alone, do not adequately describe the subsurface dynamics. This study suggests that the subsurface flow regime includes discrete flow paths that have minimal interaction and their discharge characteristics are temperature dependant. As a result of the temperature data, the overall estimated ground water exchange currently decreases from 0.43 cubic feet per second (cfs) to 0.40 cfs at bankfull and 0.21 cfs to 0.20 cfs at baseflow. The estimated increase in exchange from adding 7 feet of stream length with the proposed structure decreases from 0.49 cfs to 0.45 cfs at bankfull and 0.24 cfs to 0.23 cfs at baseflow conditions. The restricted loss of stream water to the subsurface reduces the residence time in the subsurface. Therefore gains in thermal stability by adding surface area over which the exchange could occur, would likely not counter the increase in stream temperatures from increased exposure to solar radiation.

II. Introduction

Objectives

Data were collected from June 2007 to July 2008 to characterize the surface water and ground water exchange characteristics in a 40 foot reach of the Rio de las Vacas. The objectives of this study were to: (1) characterize the surface water and ground water exchange prior to the installation of channel-modifying structures, (2) compare the predicted response of hydraulic data to thermal data, (3) predict the impacts on this exchange with a change in channel morphology and (4) make reasonable assumptions of the flow regime controls.

Significance

Society benefits from the ecological services provided by functionally intact and biologically complex freshwater ecosystems. Such services include: provisions (e.g. products, drinking water and food), supports (e.g. waste processing and nutrient cycling), and enriching or cultural services (e.g. aesthetics and recreation) (Giller, 2005). These services are increasingly compromised as freshwater habitats and organisms have become threatened (Palmer et al., 2005). Indeed, species loss is greater in freshwater habitats than in any other ecosystem (compared to terrestrial and marine habitats) (Jenkins, 2003). In New Mexico, the state environment department in compliance with Section 303(d)(1) of the Clean Water Act, reports that "[f]rom a total of over 6,561 primarily perennial stream miles, almost 2,612 assessed miles, or 40%, have identified impaired designated or attainable uses...” (NMWQC, 2006).[1]

Thus, there is a recognized need to restore and maintain rivers and streams for the current and future services they provide. “River restoration projects aim to increase ecosystem goods and services, and ideally convert damaged freshwater systems into sustainable ones whilst protecting downstream and coastal ecosystems.” (Giller, 2005).

One important component of freshwater ecosystems is the benthos and hyporheic zones. “…understanding how water within the fluvially derived sediments and the stream channel interacts is critical to efforts attempting to protect both ground water and surface water resources, and the stream and riparian ecology” (Woessner, 2000). Of late, interactions and functions of the near channel sediments have received considerable attention from the research community. However, there has been little attempt to incorporate this research into restoration models or in post-assessment of completed projects.

This study was originally begun as an effort to employ additional hyporheic monitoring to a specific, channel-modifying structure as part of a federally funded restoration project[2], thus enhancing the success of the project by providing added benefits, including

[1] The document also reports the total size of impairment due to thermal effects is 1,054 miles (16.1%) and sedimentation/siltation as 1,015 miles (15.5%) (out of 6,561 stream miles).
[2] “Rio de Las Vacas Wetlands Restoration Project” funded under the FY05 EPA Wetlands Program Development Grant Program, Region 6 CWA Section 104(b)(3).

scientific contribution and improved methods without any lasting harm, included as attributes of a successful restoration project outlined by Palmer et al. (2005).

The scientific contribution this project may have on the overall Rio de las Vacas Restoration Project is to predict the hyporheic response to induced morphological changes in the stream channel. As noted above, little work has been done, to link the groundwater response to restoration projects and to channel meanders. The value of thermal monitoring methods may benefit research on stream/groundwater interactions that are becoming increasingly inseparable to freshwater ecological research and thus restoration work.

As noted in several studies, it is critical to the understanding of the shallow alluvial flow paths for near continuous data collection to determine small temporal variations. "Understanding of the stream-groundwater system interactions requires knowledge of subsurface flow pathways and their linkage with streams, rates of flow within and between these two domains, and variation in these processes both spatially (transect, reach, watershed) and temporally (diel, seasonal, and annual)." (Wroblicky et al., 1992).

Exchange between the surface and ground water provides an indication of the value of stream bank storage, flood attenuation, nutrient exchange, temperature stability and added hyporheic biota. These factors are instrumental in determining the immediate system's ecology including cold water species habitat, water quality and species diversity, as well as downstream implications.

Previous Work

Near Channel Ground Water Exchange

Previous work has determined that there are many elements involved in producing surface and shallow ground water exchanges. Spatial and temporal elements combine in a series of variables to produce a dynamic system that provides stability and resilience to the stream/river system. Potential differences can result from geologic elements, including variation in sediment features (e.g. porosity) (Vaux, 1962), positive relief features (Jobson and Carey 1989, Savant et al., 1987) and overall topography (Harvey and Bencala, 1993). The direction and magnitude of vertical hydrologic exchange within headwater streams has been shown to be dependant upon not only the geologic setting but also the stream discharge (Henry et al., 1994).

Stream discharge is the manifestation of climatic elements, and watershed characteristics (especially size), that along with flooding and drought, influence interactions on an annual, seasonal, and diurnal time scale (Harvey and Bencala, 1993, Lee and Hynes, 1977, Triska et al., 1990, Valett, 1993). Henry et al. (1994) also reported that diurnal fluctuations in the hydraulic head corresponded to evapotranspiration rates suggesting a strong connection between the hyporheic and riparian zones.

Research on the hyporheic zone has offered insight into the functional significance and enormous ecological importance of stream and shallow aquifer exchange. Studies have been performed on nutrient cycling (Dahm et al., 1998, Grimm and Fisher, 1984) of carbon (Dahm et al,. 1991, Hemond, 1990), nitrogen (Duff and Triska ,1990, Hill, 1990, Lowrance et al., 1984, Peterjohn and Correll, 1984, Triska et al., 1989, Triska et al., 1990) and dissolved oxygen (Woods, 1980) and solute transport (Harvey and Bencala 1993), and have identified benthos specific flora and fauna (Boulton et al., 1992, Coleman and Hynes, 1970, Danielopol, 1989) and the impacts on microbial dynamics (Hendricks, 1993) and overall stream metabolism (Dahm et al., 1991, Grimm and Fisher, 1984)

Research has suggested that groundwater interaction plays a role in algal and macrophyte abundance (Coleman and Dahm, 1990, Fortner and White, 1988, Hendricks and White, 1988), which directly determine the streams ability for primary production. Numerous investigators have demonstrated the importance of the stream channel exchange on fish habitat (Baxter and Hauer, 2000, Benson, 1953, Cunjak and Power, 1986, Curry and Noakes, 1995, Ebersole et al., 2001, Garrett et al., 1998, Hansen, 1975, Nielson et al., 1994, Sowden and Power, 1985, Vaux, 1962) and there is growing evidence that the hyporheic zone may play a significant role in riparian vegetation (Kondolf et al., 1987, Triska et al., 1993, Henry et al., 1994, Valett, 1993)

Most studies to date on near-channel, ground and surface water interactions have been done using piezometers to measure the hydraulic potential differences in near-channel sediments and the surface water (Baxter and Hauer, 2003, Henry et al., 1994, Dahm and Valett, 1996, Geist, et al., 1998, Stanford et al., 1994, Wroblicky et al., 1992). Other techniques include winter ice observations (Baxter and Hauer, 2000, Benson, 1953), dye and tracer experiments (Dahm and Valett, 1996, Harvey and Bencala, 1993, Triska et al., 1989) and accretion studies of stream flow (Kondolf et al., 1987, Riggs, 1985, Stanford et al., 1994).

Temperature Studies

Using temperature in groundwater studies began with Keys and Brown (1978) using temperature as a tracer to map groundwater movement. Silliman and Booth (1993) used temperature to identify gaining, neutral or losing reaches in streams and two years later performed and presented a qualitative method for estimating water flux through stream sediments based upon temperature time series (Silliman et al., 1995). Ebersole et al., 2001 mapped the stream bed temperatures of streams and suggested that cool upwelling ground water may allow some refugia for rainbow trout in warm stream reaches. More recently Torgersen et al., (2001) used airborne thermal remote sensing to determine groundwater inflows. For a review of the use of temperature in ground water studies see Anderson (2005).

Conceptual Description

Three flow regimes are possible when considering ground water / surface water interactions:

- Gaining reach – temperature driven by advection in ground water; little variation in time
- Zero Flux – temperature driven by conduction with no mass exchange.

- Losing reach – sediment temperatures should reflect surface temperatures with a lag in phase resulting from travel time and reduced amplitude, advective driven process

Background

Study Location

The Rio de las Vacas (HUC code 130202020201) is located in north-central New Mexico (Figure 1). The head waters are in Rio Arriba County and flow through Sandoval County. The Rio de las Vacas watershed is approximately 101,343 acres and is 25.1 miles long. It is a part of the Jemez River watershed and the larger Rio Grande Basin. The Rio de las Vacas is a perennial, 5th order stream with headwaters originating from springs in the San Pedro Parks Wilderness (Ferrell et al. 2003).

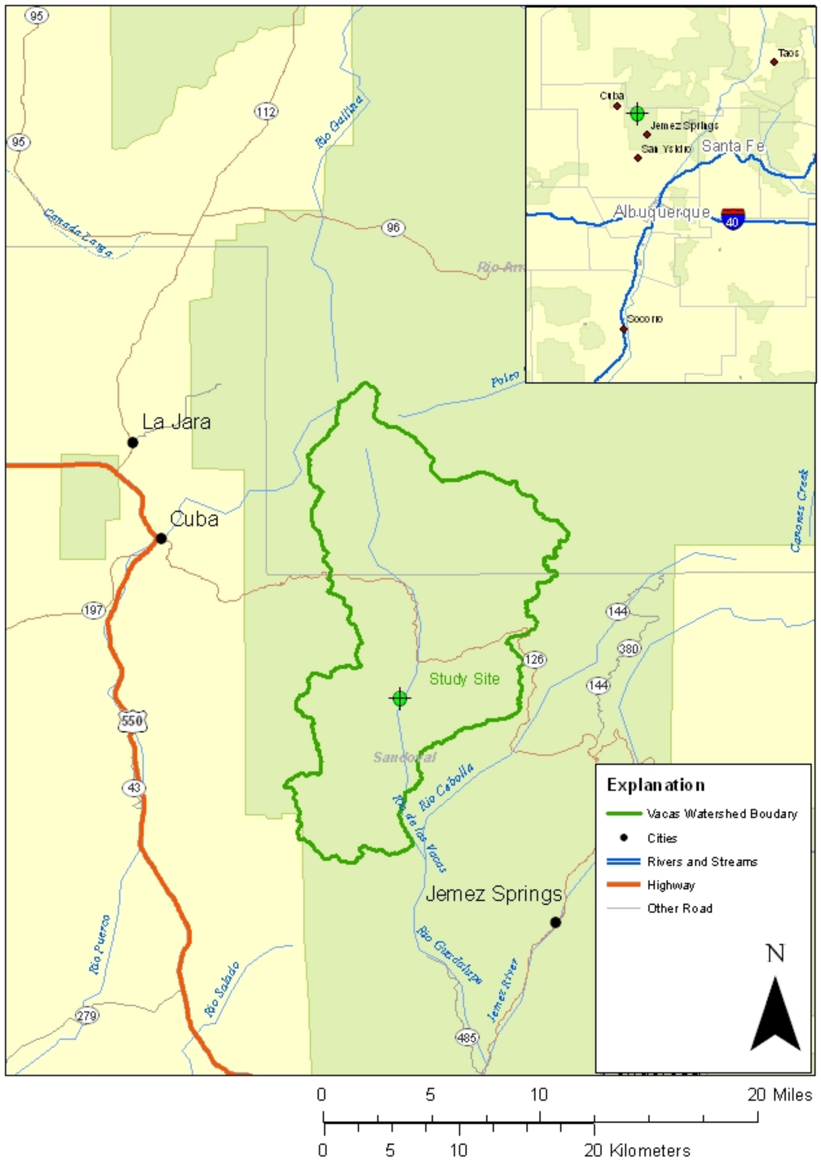


Figure 1. Map of study site location.

The valley is composed of Bandelier Tuff to the east and Precambrian Granite to the west. The alluvial valley fill overlays Abo and Madera limestones.

Vegetation

The site is located at approximately 7,900 feet above mean sea level and surrounding hillslopes host mixed conifers. The valley bottom is mostly open and covered with grasses and wetland species such as cattails and sedges in low lying areas. Alders and dogwoods are sparse but present upstream and downstream of the site (Figure 2).


Figure 2. Photo viewing upstream (north) from transect 3 prior to well emplacement.

Channel Description

The study reach drains approximately 63,389 acres (99 sq. mi.) The reach is characterized by a long straight run, terminating in a pool. The left bank includes a 4 foot cutbank

(Figure 2) into a small terrace and steeply rising hill slope interrupted by the road cut. The right bank slopes gradually out of the stream (Figure 3).

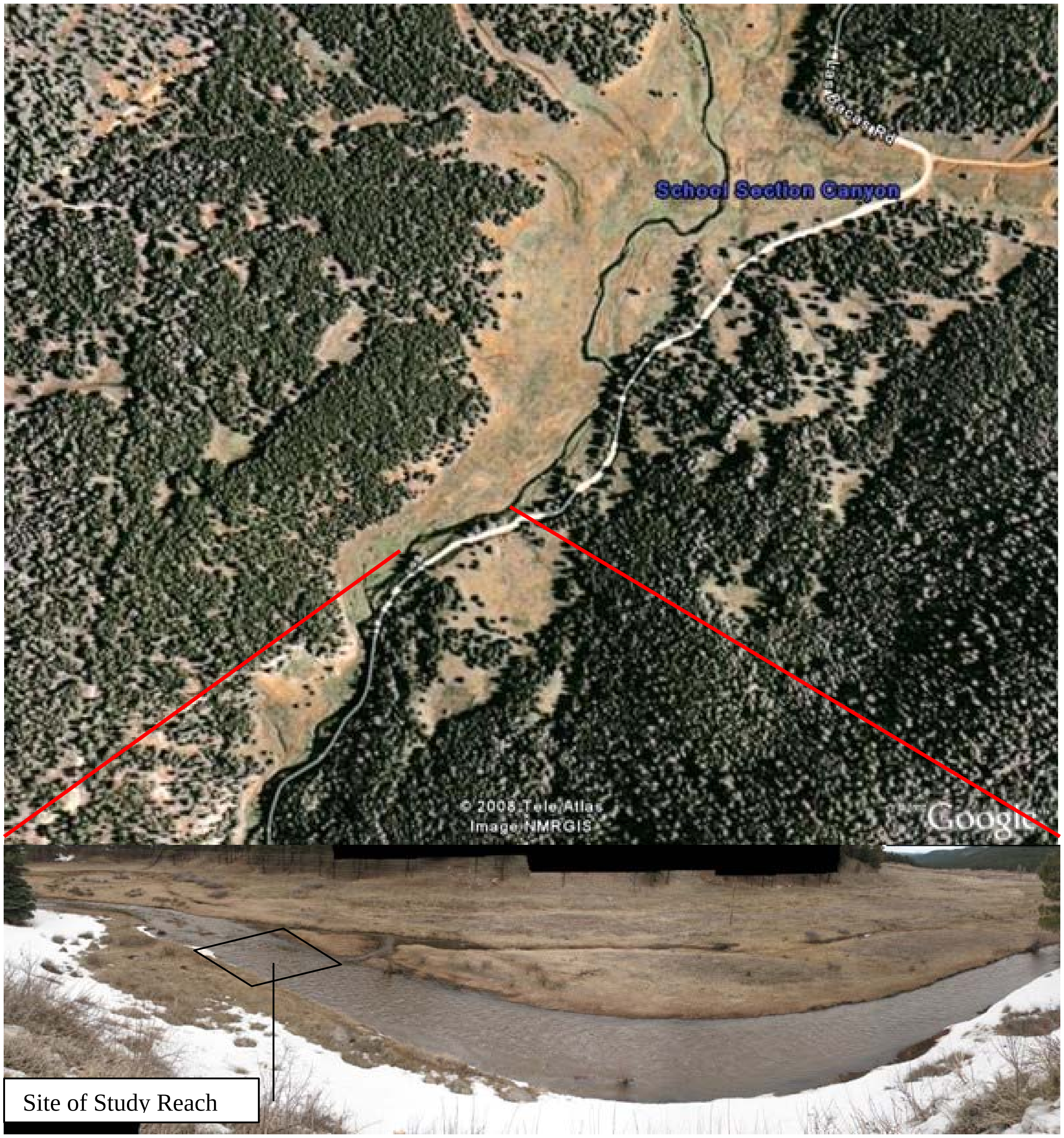


Figure 3. Aerial photo of study site and photo looking over stream from hill to river left.

An abandoned channel is located almost midway through the floodplain (Figures 3 and 4) and is perennially wet and flows in large runoff events. Surveyed flood debris in the summer of 2007 shows a stream stage that would have submerged the high ground between the main channel and the abandoned channel.

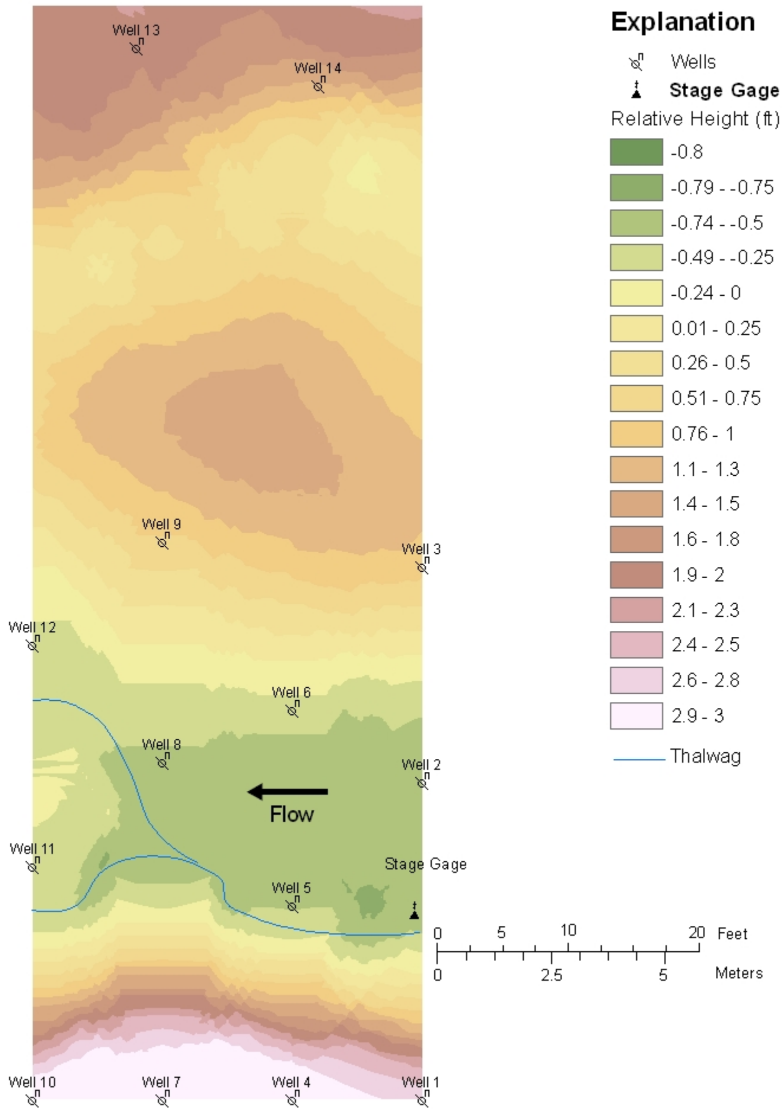


Figure 4. Plan view of study site, bottom of figure is the left bank and stream flow is right to left. Relative land surface elevations are Kriged data from cross-sectional surveys.

Above bankfull, water is capable of accessing the abandoned channel 50 feet from the cut bank (Figure 5). The average bankfull dimensions calculated for each transect are given in Table 1. The bankfull dimensions were calculated using a roughness coefficient (Manning's *n*) of 0.040.

	Average	Standard Deviation
Bankfull Dimensions		
Cross-sectional area (ft.sq.)	55	11
Width (ft)	52	12
Mean depth (ft)	1.1	0.1
Maximum depth (ft)	2.0	0.1
Hydraulic radius (ft)	1.1	0.1
Width-depth ratio	49	14
Bankfull Flow		
Velocity (ft/s)	2.1	0.1
Discharge rate (cfs)	116	22
Froude number	0.36	0.01
Flood Dimensions		
Width of flood prone area (ft)	91	8
Entrenchment ratio	1.9	0.5

Table 1. Bankfull stream dimensions; (ft. sq. = square feet, ft = feet, ft/s = feet per second, cfs = cubic feet per second)

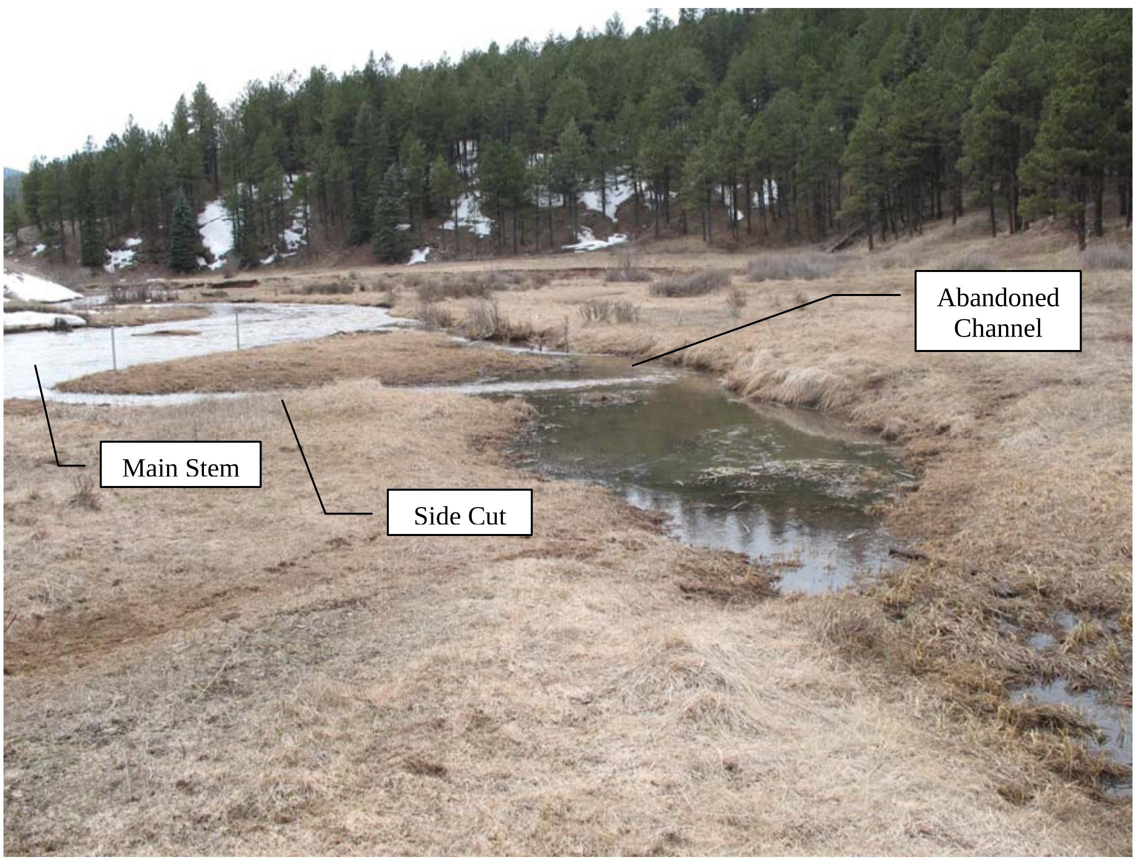


Figure 5: Photo looking downstream from right bank. The side cut entering from the main stem to the left is flowing water. Water upstream of the side cut is still from back water and ground water.

The thalwag within the reach becomes less well defined as the stream flows from the top to the bottom of the reach. The longitudinal profile (Figure 6) shows a slight increase in the bed depth from the top of the reach to just before entering the downstream pool.

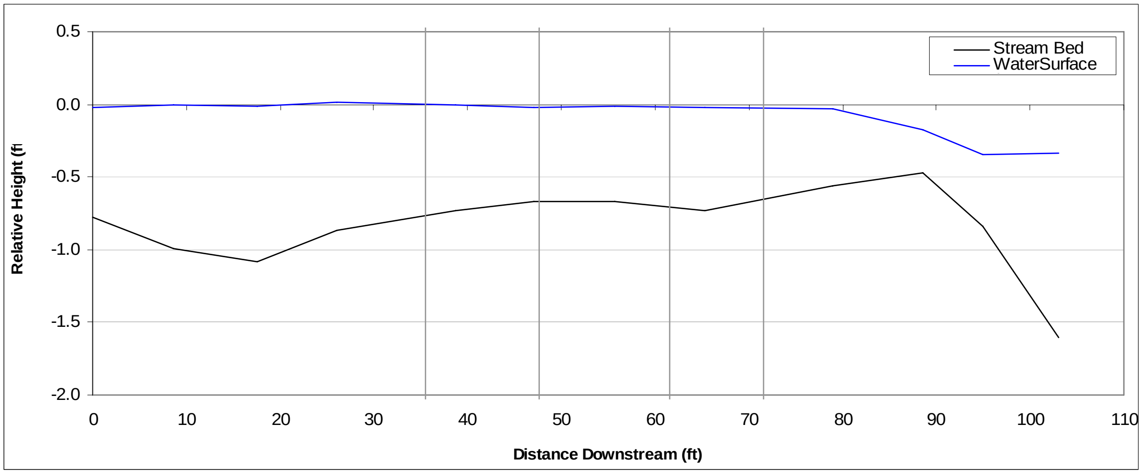


Figure 6. Longitudinal profile of reach. Stream flow is left to right. Vertical lines represent transect positions 1 to 4, from left to right.

The Wolman pebble count (Wolman, 1954) technique was performed to determine the size of clasts within the reach. From the 93 samples taken the bed material was determined to be 20% sand, 52% gravel, 26% cobble and 2% boulder. There was also a noticeable film of silt/clay on the bedding when surveyed in June 2007. The D50 grain size is 1.46 in (37 mm). The exposed surface of the cut bank appears to be composed of mainly clays and fines, while the flood plain shows mainly larger clasts both sorted and unsorted and clear examples of imbrication suggesting a continually moving channel.

Climate

The climate for the study site is typical of a high elevation, semi-arid zone. Average summer temperatures are around 60° F and teens for the winter. There were significant monsoon events in August and September and snow accumulations in December through

February or March. Figure 7 displays the daily maximum, minimum and average temperatures collected at the site.

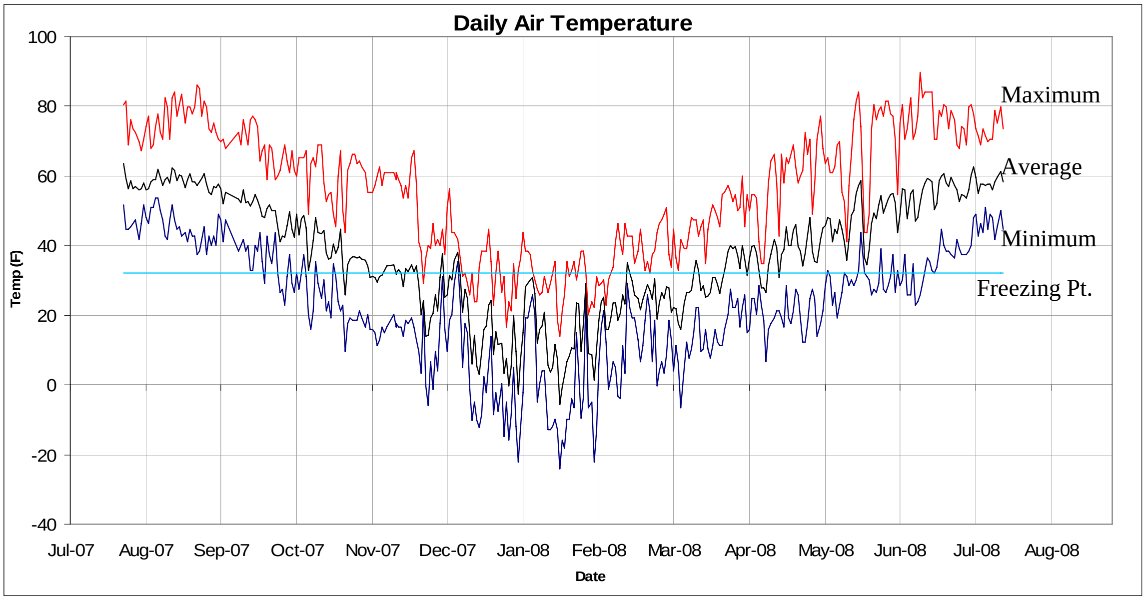


Figure 7. Daily temperature statistics measured at the study site.

III. Methodology

Site Selection

As described above, the water body was chosen to accompany a federally-funded restoration project. The specific reach was chosen for access, limited traffic, downstream location, planned structure type and topography.

Well Construction

Wells were constructed using 5 and 3 foot sections of 1 ½ inch galvanized steel pipe and installed on June 24 and 25, 2007. The length of the well was adjusted by using various sections and fastened together with steel couplings. Each well included a wire-wrapped steel drive point, and end cap.

To place the wells in the ground, a hole was started by pounding a steel “rock-breaking” rod into the ground. After the hole was started the drive point and risers of appropriate length were driven in using a slide hammer and/or sledge hammer. The screened sections were completed at various depths targeting the top of the screen ½ to 1 foot below the water table in the wells on banks and floodplain and ½ to 1 foot below the streambed for instream wells. Figure 8 shows a comparison of the well constructions including top of casing (TOC) and screened sections.

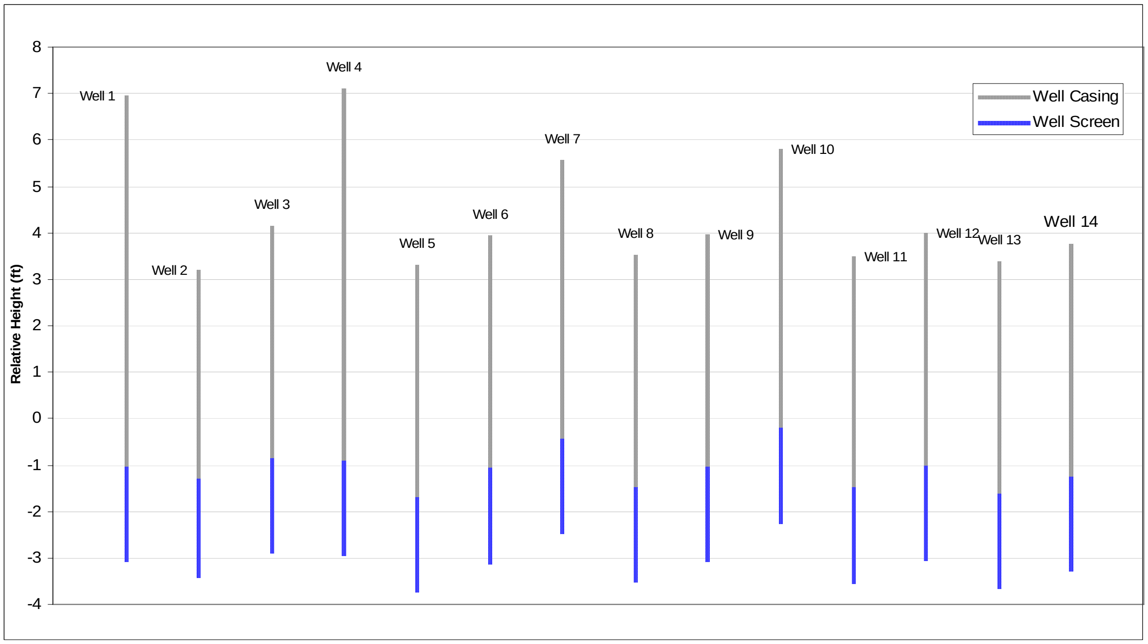


Figure 8. All wells and their relative TOC and screened interval heights. (0 feet is an arbitrary stream base flow height on June 24, 2007.)

The wells were installed along four transects that crossed the stream from the left to the right bank. The transects were established by creating the upstream transect 10 feet above the top of the planned structure and then at 10 foot intervals downstream. Each transect includes 3 wells, one well on the left bank and the remaining two staggered as to capture a smaller horizontal gap (Figure 9). Finally 2 wells were installed in the flood plain far to the right and across from an abandoned channel.

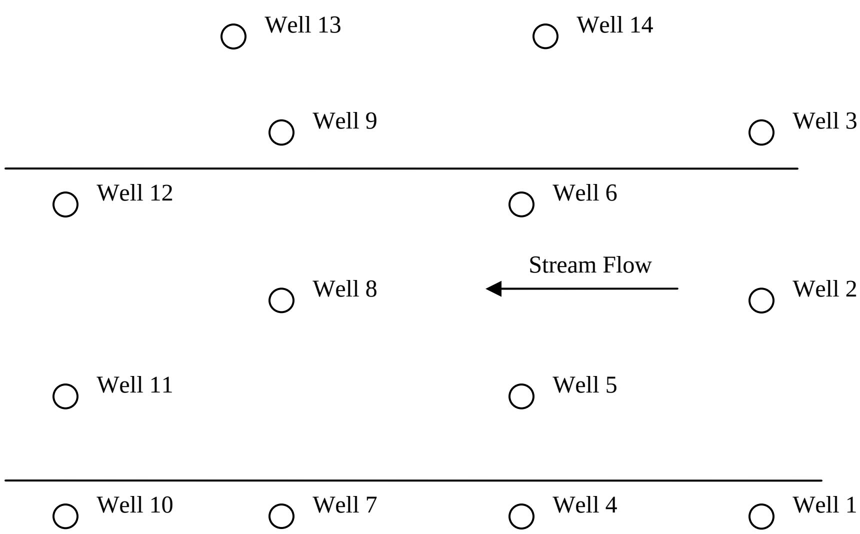


Figure 9. Conceptual plan view of well placement in reach.

Figure 10, 11, 12 and 13 represent transects 1, 2, 3 and 4 respectively. Transect 1 is the upstream transect and transect 4 is the downstream transect.

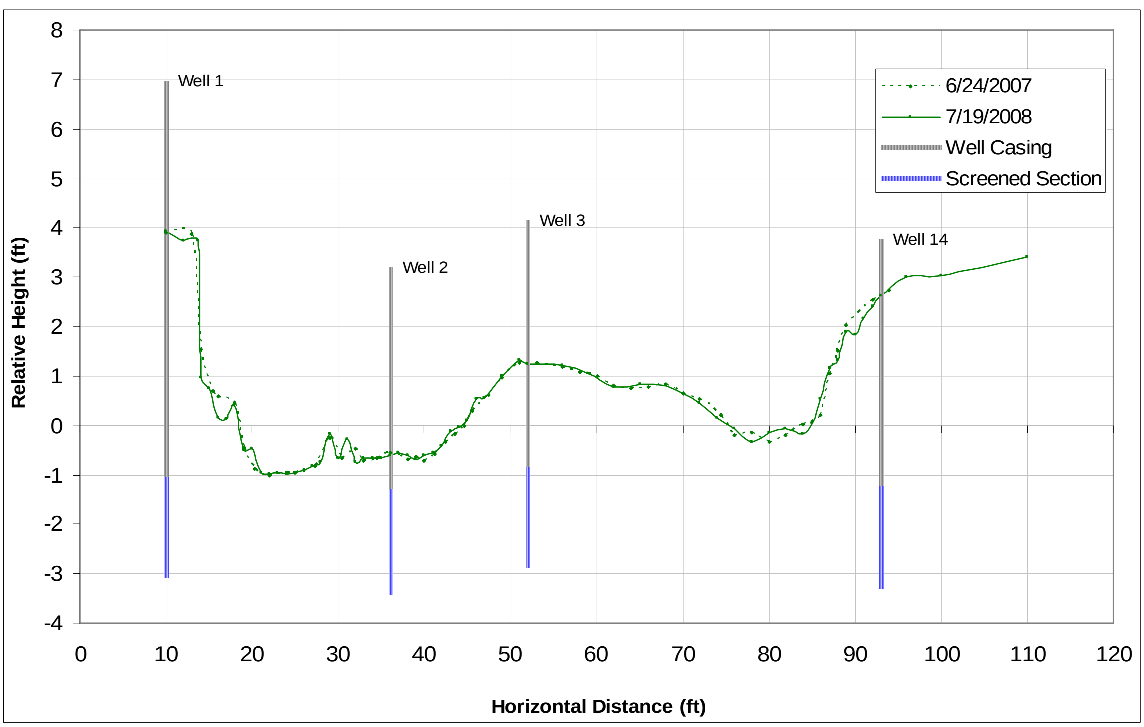


Figure 10. Well locations on transect 1, the most upstream transect. Green lines are surveyed cross-section dimensions at post-run off flows for 2007 and 2008. Base flow on 6/24/07 is 0 ft reference.

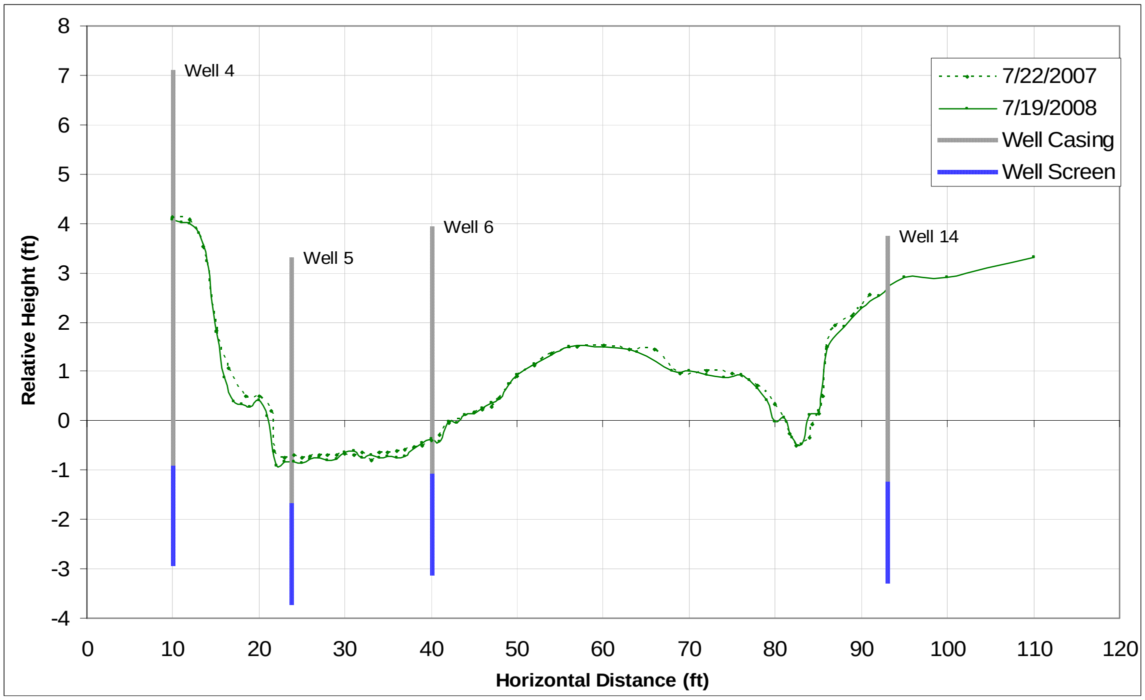


Figure 11. Well locations on transect 2; 10 feet downstream of transect 1. Green lines are surveyed cross-section dimensions at post-run off flows for 2007 and 2008. Base flow on 6/24/07 is 0 ft reference.

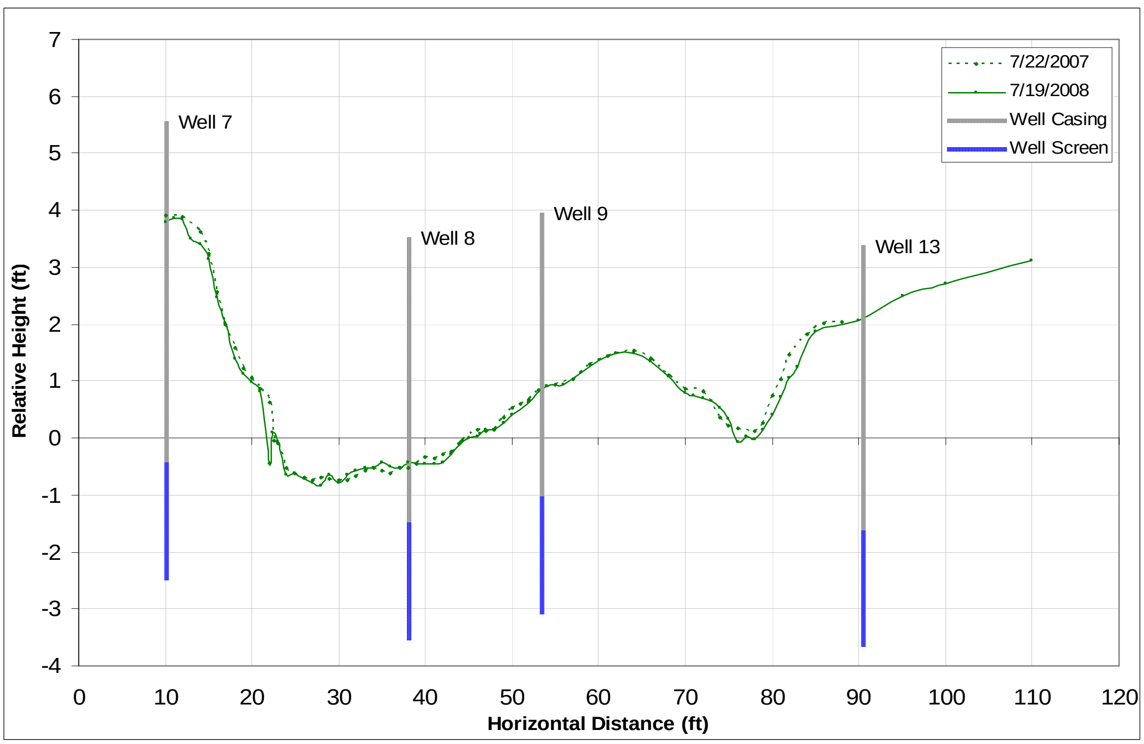


Figure 12. Well locations on transect 3; 20 feet downstream of transect 1. Green lines are surveyed cross-section dimensions at post-run off flows for 2007 and 2008. Base flow on 6/24/07 is 0 ft reference.

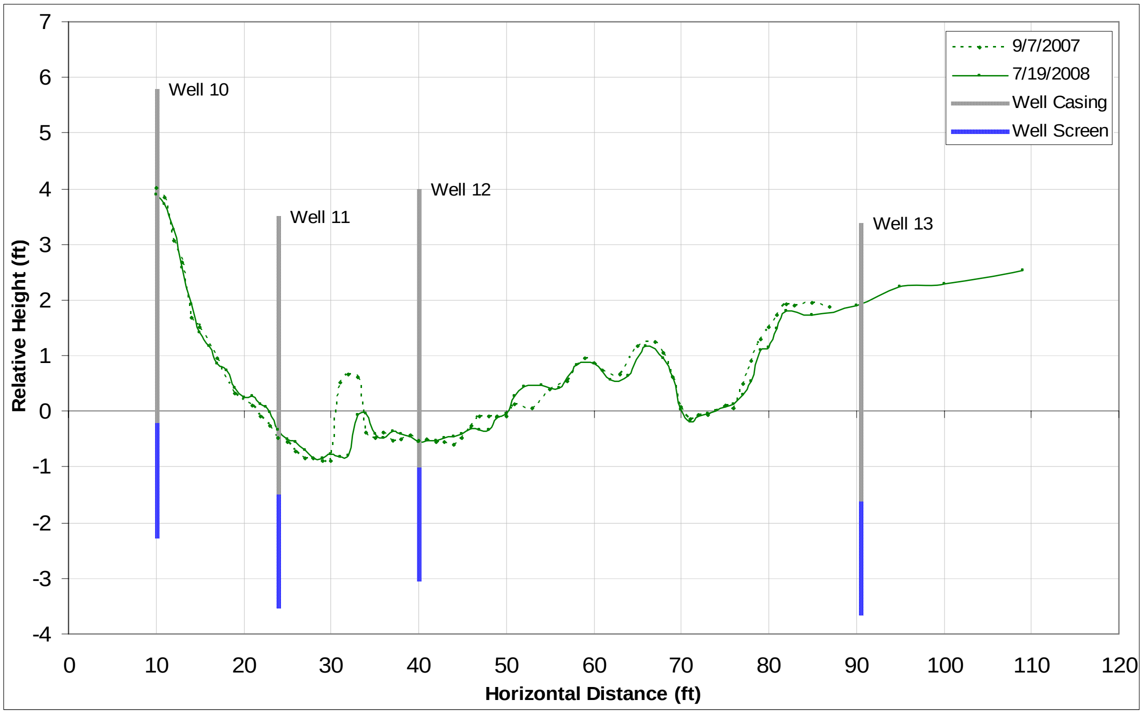


Figure 13. Well locations on transect 4; 30 feet downstream of transect 1 and the farthest downstream transect. Green lines are surveyed cross-section dimensions at post-run off flows for 2007 and 2008. Base flow on 6/24/07 is 0 ft reference.

A large event on December 1, 2007, according to the recovered equipment, destroyed all instream wells (Wells 2, 5, 6, 8, 11 and 12) and the stream gage. In May of 2008 one instream well was replaced. Well 5b was constructed as close as possible to the previous specifications and resulting data support a minimal change in the two wells.

Stream Stage Gauge

A stream stage gauge was established on transect 1 in the thalwag approximately 14 feet from well 1. The gauge was constructed of the same galvanized material with the exception of the screened interval. A T-coupling was added at the base of the riser to allow stream water to enter and act as a stilling well. A pressure transducer (Global Water

Instrumentation, Inc., WL16S Water Level Logger, accuracy – 0.01 ft / 0.2° F)[3] was added for real time stage and temperature measurements.

Water Levels

Water levels were determined using an electronic depth tape from the top of the casing. The relative water level below the surveyed top of casing could then be calculated to the site reference. Relative heights within the reach were determined using a construction survey scope (Dewalt Builders Level - DW090K) and staff gauge (accuracy - 0.25 in) with a large boulder on the left bank used as the ultimate reference. Water levels were collected during site visits on 6/24/07, 7/22/07, 9/7/07, 11/9/07, 1/4/08, 3/28/08, 5/9/08, 6/14/08, and 7/19/08.

One pressure transducer was dedicated as the stream stage monitor and one additional pressure transducer was moved from well to well to get higher time-based resolution.

Temperature Data

Each well was instrumented with a temperature data logger (Alpha Mach, iBCod Type 22L, accuracy - 0.9° F)[4] suspended to the top of the casing by twine. The data logger was set a few inches from the bottom of the screen (Figure 14).

[3] This is the product referenced when the term "pressure transducer" is used.
[4] This is the product referenced when the term "temperature data logger" is used.


Figure 14. Instrumenting an instream well.

The temperature data loggers were set to record between ½ hour and 2 hours depending on projected times between site visits. Additionally, two wells were instrumented with a pressure transducer for a limited period of time.

Recovered data loggers from the destroyed wells were later employed at different depths in wells 1, 3, 5b, and 14 to determine a temperature vertical profile.

Slug Tests

Slug tests were performed in the summer of 2008 using stream water. One gallon amber, glass containers were filled with stream water and allowed to set in the sun for 1 to 4 hours. A pressure transducer, programmed to record every second, was placed in the well and temperature and water level were allowed to equilibrate. At equilibrium the well was filled as quickly as possible with the preheated stream water in the top of the casing. The instrumentation was removed when the water level retuned to within +/- 5% the original displacement.

Hydraulic-conductivity estimates were determined by the Bouwer and Rice (1976) method for slug test analysis in unconfined aquifers. The data was analyzed using spreadsheets, available from the USGS website (Halford and Kuniansky, 2002).

Analytical Modeling

The numerical model for a one-dimensional heat flow equation was adapted to predict the temperature at a given depth. The heat flow equation is given in Equation 1.

$$\frac{\partial T}{\partial t} = \frac{\lambda_x}{\rho_s C_s}\left[\frac{\partial^2 T}{\partial x^2}\right] - \frac{q_x n \rho C}{\rho_s C_s}\left[\frac{\partial T}{\partial x}\right] \qquad \text{Equation 1}$$

Where T is temperature, t is time, λ_x is the thermal conductivity, ρ_s is the porous medium density, C_s is the specific heat capacity of the porous medium, x is the depth, n is the porosity, q_x is the fluid Darcy velocity, ρ is the fluid density, and C is the fluid heat capacity. The heat flow equation given in Equation 1 assumes a flux over a constant volume.

Equation 1 is derived from the conservation of energy, where “the rate at which the total internal energy of the control volume changes is equal to the sum of the individual rates of change due to conduction, [and] convection…” (Deming, 2002).

The conductivity term refers to the conductive heat transfer to or from the control volume. The magnitude of this term for a given volume, i.e. constant λ_x, ρ_s, and C_s, is determined by the thermal gradient and direction is determined by the sign.

The advective term represents a heat transfer due to fluid flow which is a function of the Darcy velocity. The sign of the term depends on the direction of mass flux, i.e. mass leaving a given volume yields a negative term, mass entering a volume yields a positive term. For the analytical temperature predictions used in this study the advective term becomes positive for a losing reach and negative for a gaining reach.

Integrating the heat flow equation over time and space and selecting the thermal gradient as the surface water temperature and the residual ground water temperature from the previous time step, a semi-empirical equation is constructed. The semi-empirical equation (Equation 2) for the predicted groundwater temperatures used in this study becomes

$$T_{gw} = T_{gw(t-1)} + \frac{\lambda_x t}{\rho_s C_s x^2}\left[T_{sw} - T_{gw(t-1)}\right] + \frac{q_x n \rho C t}{\rho_s C_s x}\left[T_{sw} - T_{gw(t-1)}\right] \qquad \text{Equation 2}$$

Where T_{gw} is the ground water temperature at time $(t) = t$, λ_x is the thermal conductivity, ρ_s is the density and C_s specific heat capacity of the porous medium, x is the depth of the temperature probe, T_{sw} is the measured surface water temperature, n is the porosity, q_x is the fluid Darcy velocity, ρ is the fluid density, and C is the fluid heat capacity.

The constants used in the calculation were the values for liquid water and saturated Tottori sand (Table 2) reported by Stonestrom and Constantz (2003).

	Density	Porosity	Specific Heat Capacity	Thermal Conductivity
	kg/m^3	V_{pores}/V_{bulk}	J/kg °C	W/m °C
Liquid water	1000	n/a	4200	0.60
Porous Medium	1830	0.31	2600	2.2

Table 2. Constants used in analytical temperature estimation

The fluid Darcy velocity (q_x) was selected to create the best fit to the observed ground water temperatures by adjusting the hydraulic gradient (*dh/dl*). The hydraulic conductivity (*K*) was determined from the temperature-dependant Muskat equation (Equation 3) and using the experimentally measured intrinsic permeability from the slug tests.

$$K = kg\frac{\rho}{\eta} \qquad \text{Equation 3}$$

Where *k* is the intrinsic permeability, *g* is the acceleration due to gravity, ρ is the fluid density at the surface water temperature, and η is the dynamic viscosity at the surface water temperature. Both the density and dynamic viscosity are temperature sensitive.

Table 3 lists the *K* values calculated using the Muskat equation at different temperatures and at the given intrinsic permeability (*k*) = $1.88 * 10^{-10}$ ft^2.

T (°C)	T (°F)	K (ft/s)	% Change
0	32	3.16E-04	
5	41	3.27E-04	17.7%
10	50	4.32E-04	16.2%
15	59	4.95E-04	14.7%
20	68	5.62E-04	13.6%
25	77	6.32E-04	12.4%
30	86	7.05E-04	11.5%

Table 3. Calculated hydraulic conductivities (K) at different temperatures and at a given intrinsic permeability (k) = $1.88 * 10^{-10}$ ft^2.

The boundary conditions for $T_{gw}(x,t)$ are:

$T_{gw}(0,t) = T_{sw}(t)$

$T_{gw}(x,0)$ = first measured ground water measurement

The very low sensitivity to errors in the estimated thermal properties is the result of the large volumetric heat capacity (the product of the density and specific heat capacity of the porous medium) in the denominator of both the advective and conductive term. This relationship yields such small values that an error of +/- 300% in the estimations would translate into a +/- 1° F error in the predicted temperature only for temperature gradients of hundreds of degrees or time steps of weeks.

IV. Results and Discussion

Stream Stage and Subsurface Water Levels

The water levels measured during site visits were found to be nearly equal and fluctuated congruently with the stream stage. The largest head difference was 0.25 feet between wells and between the wells and the stream stage suggesting an extremely responsive system (Figure 15). The average hydraulic gradient from the top of the reach to the bottom of the reach was found to be 0.003 ft/ft. Multiplying this value by the hydraulic conductivity measured in the slug tests, the Darcy velocity in the horizontal direction is calculated to be 5.1 x 10^{-7} ft/s. All stage and head values are measured relative to the stream stage (0.0 ft) on 6/24/07.

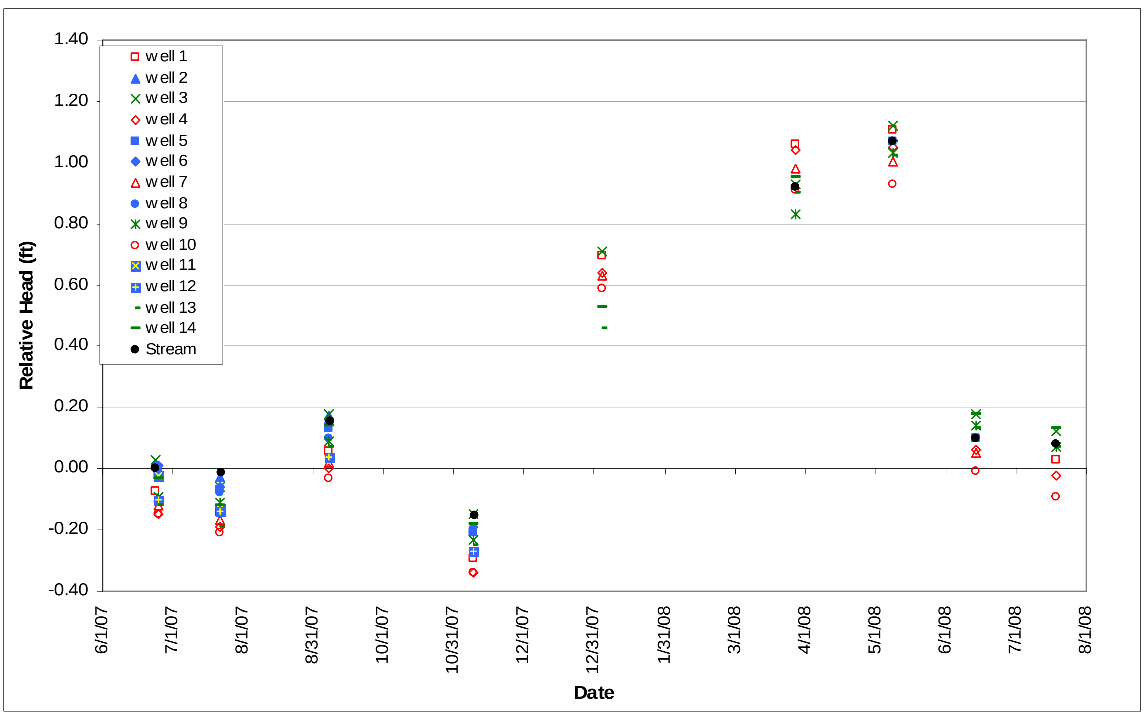


Figure 15. Measured water levels from each site visit. Left bank wells are open, red marks, right bank and floodplain wells are green ticks, instream wells are closed, blue marks and the stream stage is a closed, black circle.

The water levels indicate a strong snow-melt driven system. The annual flow regime can be classified into 3 categories. The first is monsoonal appearing in late July and receding in early October. The second is snowmelt runoff beginning in March and running into June. The final regime is the base flow period occurring between snow-melt and monsoons. The characterizations that lead the following discussions are depicted graphically in Figure 16.

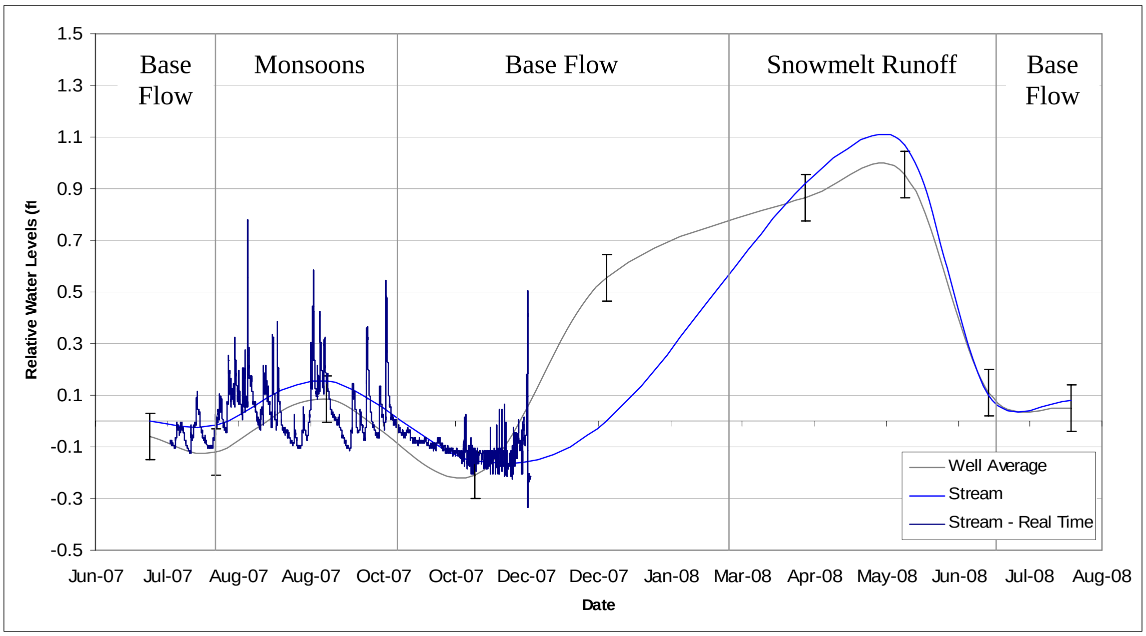


Figure 16. Average well water levels and stream stage data. Note the January 4, 2008 stream stage value is estimated as ice prevented an accurate measurement.

Water levels collected during site visits indicate that ground water generally flows down-valley and from the right bank to left bank between snowmelt runoff events and left to right during snowmelt runoff. Figure 17 is a collection of ground water level contour maps showing gaining and loss potentials. Contours were constructed from Kriged water level data collected during site visits. It is presumed that the left bank receives some groundwater from the catchment to the south and west (Figure 3), which at lower elevations, would gain melt water earlier and dissipate sooner than stream water derived from the higher elevation source.

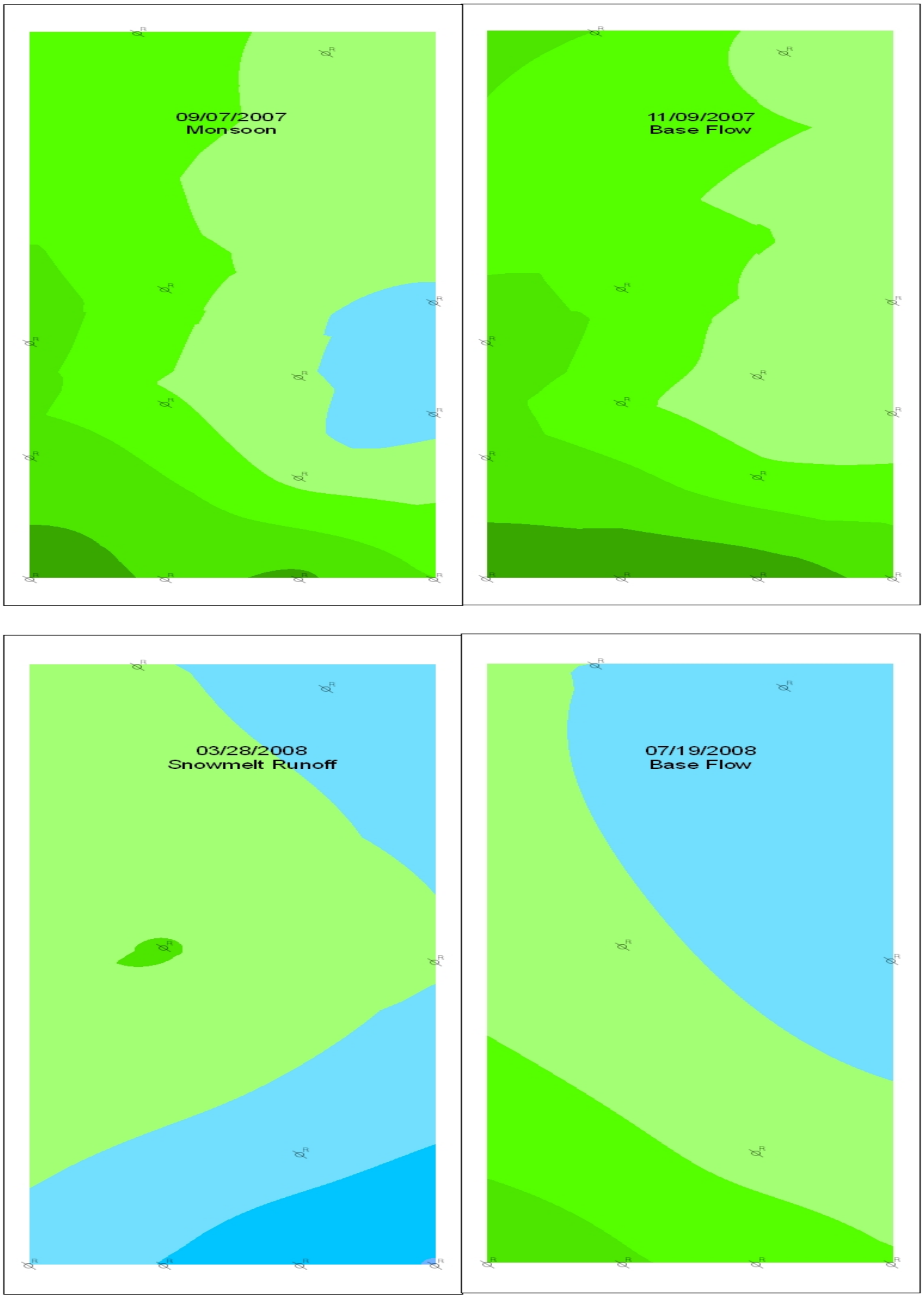


Figure 17. Ground water level contour map relative to stream stage. Contours are 0.05 ft (approximately 1.5 cm) with green indicating potential loss from stream and blue indicating potential gain to stream. Bottom of map represents river left with stream flow from right to left. Note that data are missing from instream wells for the 2008 water levels.

The idea that the subsurface is extremely responsive to changes in the stream stage was demonstrated by placing a pressure transducer in two instream wells. The pressure transducer was first placed in an instream well on the first transect, well 2 (Figure 18). This period was characterized by the tail end of the monsoon season and the start of a low flow period. The second time period included the low flow period in an instream well (well 11) at the downstream end of the reach (Figure 19). The period ended with a large event that destroyed all the instream wells.

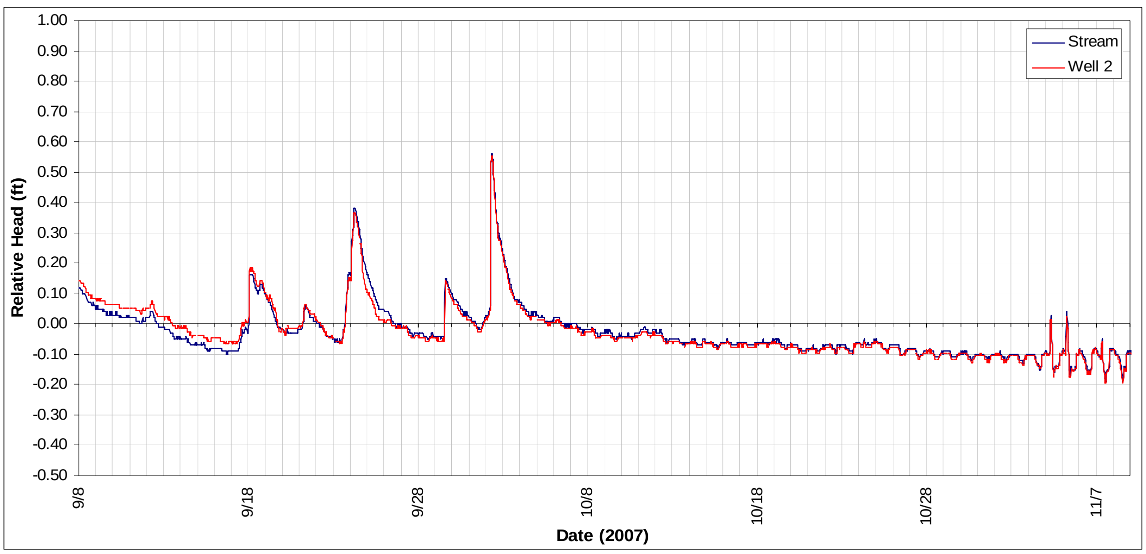


Figure 18. The relative head difference between the stream stage and instream well water level. Note the response to precipitation events in September and the diurnal fluctuations in October.

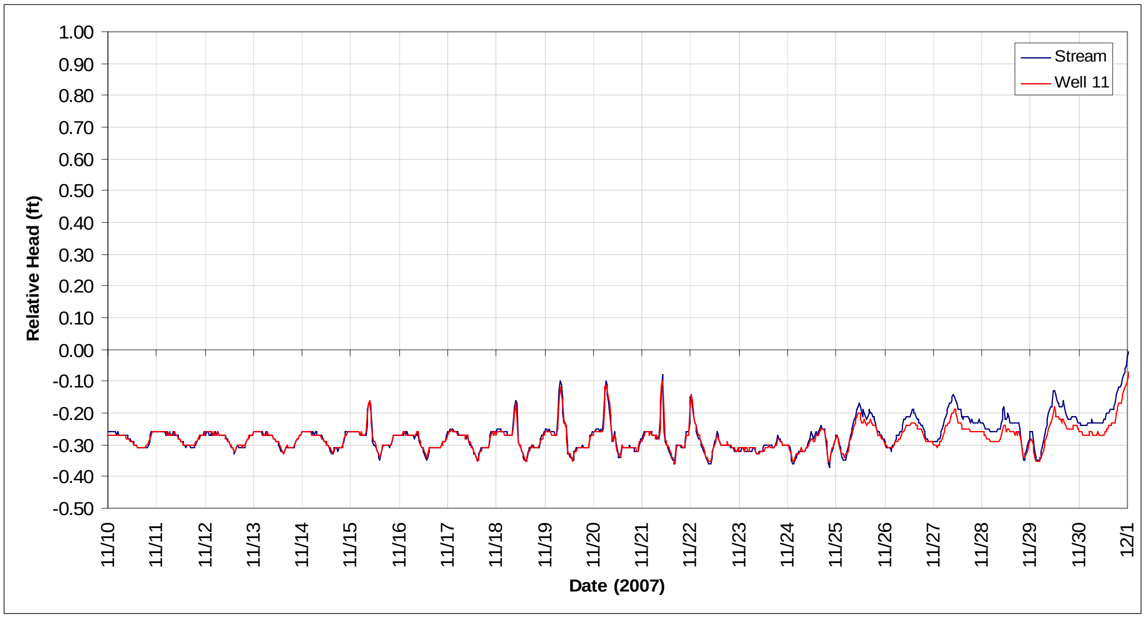


Figure 19. The relative head difference between the stream stage and instream well water level.

Hydraulic Conductivity

An experiment was performed to measure the hydraulic conductivity of the porous medium using a slug test. Figure 20 shows the return to static water level after the positive displacement slug test.

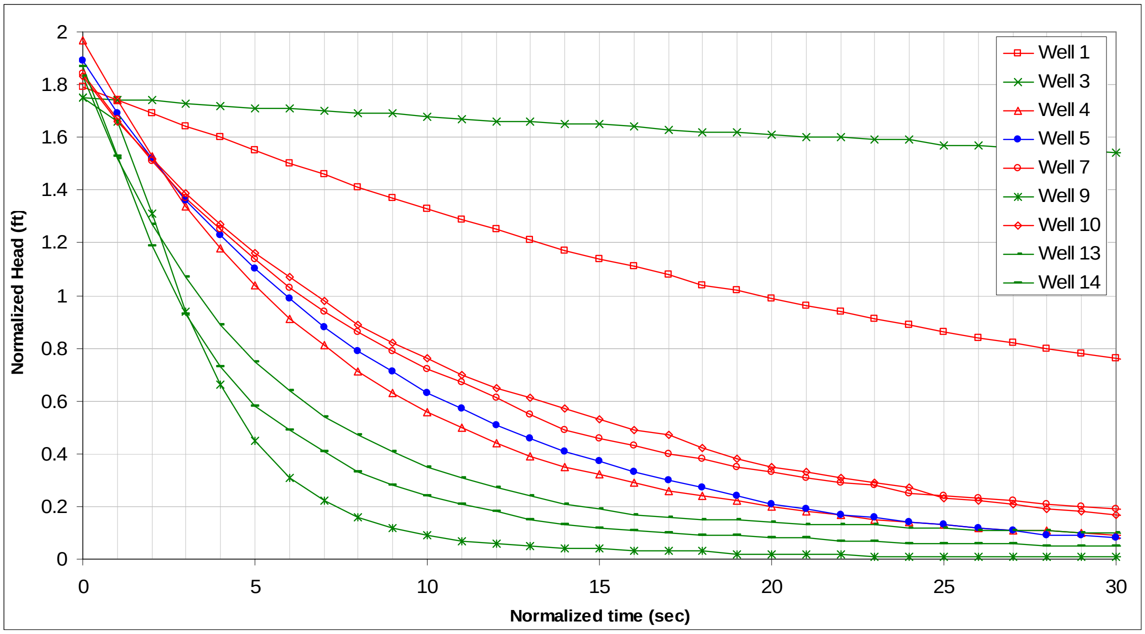


Figure 20. The head change over time of wells that were slug tested. Green lines with ticks represent right bank and floodplain wells, red lines with open marks represent left bank wells and the blue line with closed marks represent a reconstructed instream well. Zero head is the starting water level.

The right bank as a whole had higher hydraulic conductivities than did the left bank. It is worth noting that the two slowest responding wells were located in the first transect suggesting an additional control on the groundwater regime through the reach. The slower response of the left bank wells is thought to be the result of a smaller grain size as noted in the exposed surface of the cut bank. Smaller gain sizes, in alluvial deposits, indicate slow moving water. The results of the slug test along with clasts placement and size observations (see Channel Description section in the Introduction) suggest that the current channel has only recently occupied its current position. With this in mind it appears very likely that the larger clasts surveyed in the stream channel do not go very deep, and therefore the instream well displays a similar hydraulic conductivity as the left bank wells. The lower conductivity values in transect 1 may be the result of a slower stream current dropping out fines at the top of the reach.

The Bouwer and Rice (1976) estimated hydraulic conductivity values for the reach are reported in Table 4.

Well	ft/sec	m/sec
Well 9	5.5E-04	1.7E-04
Well 14	2.9E-04	8.8E-05
Well 13	2.5E-04	7.6E-05
Well 4	1.8E-04	5.5E-05
Well 5b	1.7E-04	5.2E-05
Well 7	1.6E-04	4.9E-05
Well 10	1.6E-04	4.9E-05
Well 1	4.6E-05	1.4E-05
Well 3	7.7E-06	2.3E-06

Table 4: List of measured hydraulic conductivities in descending order.

The estimated values agree with reported values (Schwartz and Zhang, 2003) for a sand/gravel alluvial aquifer. Average values are reported in Table 5.

Aquifer Material	ft/sec		m/sec	
	high	*low*	*high*	*low*
Gravel	9.8E-02	9.8E-04	3.0E-02	3.0E-04
Coarse Sand	2.0E-02	3.0E-06	6.0E-03	9.0E-07
Medium Sand	1.6E-03	3.0E-06	5.0E-04	9.0E-07
Fine Sand	6.6E-04	6.6E-07	2.0E-04	2.0E-07
Slit, Loess	6.6E-05	3.3E-09	2.0E-05	1.0E-09
Till	6.6E-06	3.3E-12	2.0E-06	1.0E-12
Clay	1.5E-08	3.3E-11	4.7E-09	1.0E-11

Table 5: Average reported values for unconsolidated sedimentary material.

Ground Water Temperatures

Groundwater temperatures were collected by a temperature data logger at 0.5 to 2.0 hour intervals for all wells within the reach. The data retrieved suggest a more complicated system than that which might be deduced from the relative heads reported above.

The left bank temperature profile appears to be nearly independent of other ground water in the reach. The temperature shows a strong annual signature with only a few short term trends appearing. The signature is characteristic of either a very deep and thus buffered temperature regime or a gaining reach. The lack of a strong hydraulic gradient (dh/dl) from the stream averaging 0.02, 0.02, 0.01, and 0.01 ft/ft for well 1, 4, 7 and 10 respectively suggests little flux that would be thermally buffered as with depth. Figure 21 shows the left bank temperature profiles along with the stream daily average temperature.

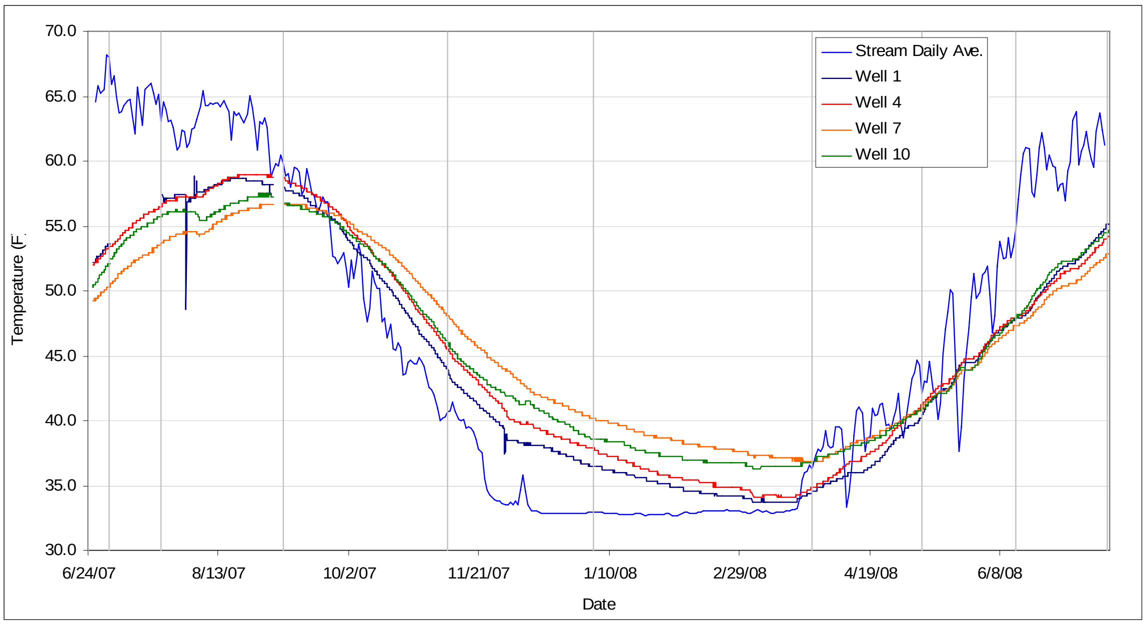


Figure 21. Left bank temperature profiles over time. Vertical grid lines denote site visits.

The right bank appears to have much more connectivity. There are no diurnal signatures in the right bank but large multi-day temperature shifts appear with varying degrees of amplitude and delay in the temperature profiles. The difference in the temperature signals in the left bank and right bank and floodplain is most likely due to a conductive heat transfer. The wells on the left bank are buried to a depth of approximately 4 feet, while those on the right bank are buried between 1 to 2.5 feet (Figures 10 to 13). The wells on river right are also closer to open water (wells 3 and 9 to the stream and wells 13 and 14 to the abandoned channel). Figure 22 shows the right bank temperature profiles along with the stream daily average temperature.

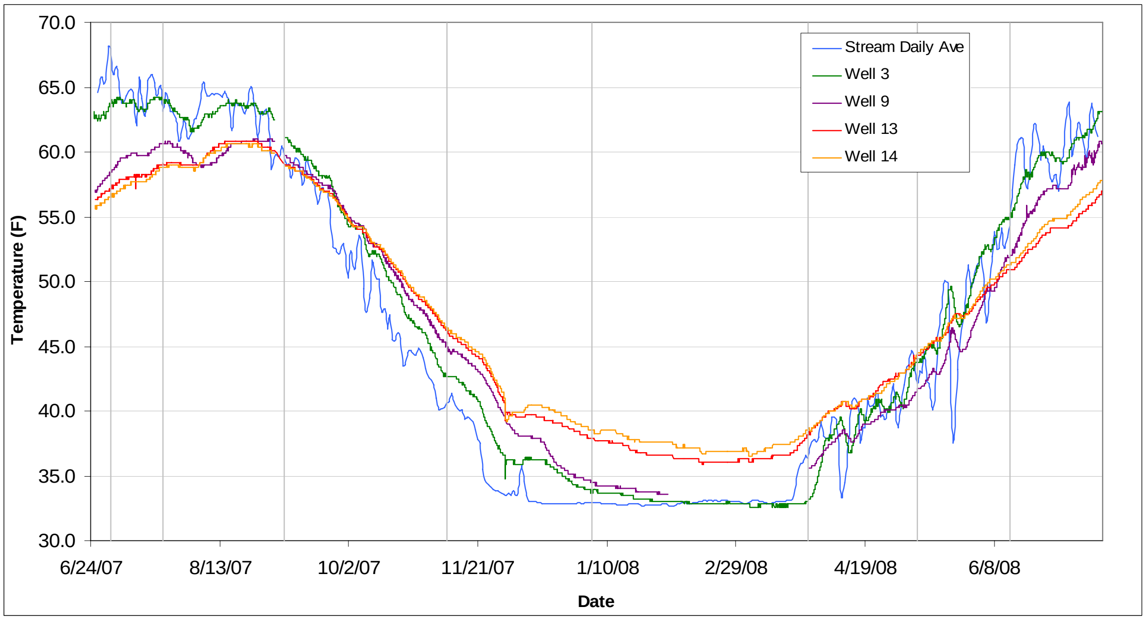


Figure 22. Temperature profile of right bank and floodplain wells. Vertical grid lines denote site visits.

The instream wells show varied temperature signals depending on seasonal flow, the well's location in the stream course and depth of the instrument. Only two wells (well 5 and well 12) of the six are presented in order to minimize congestion. Well 2, well 6, and well 8 displayed responses that were similar to wells 5 and 12. The well 11 thermograph was very similar to the stream thermograph indicating a strong loss from the stream.

The following figures, 21, 22, 23, 24, and 25, show representative thermographs of the 2007 post-runoff base flow condition, 2007 monsoons, 2007 post-monsoon conditions, 2008 runoff and 2008 post-runoff flow conditions, respectively.

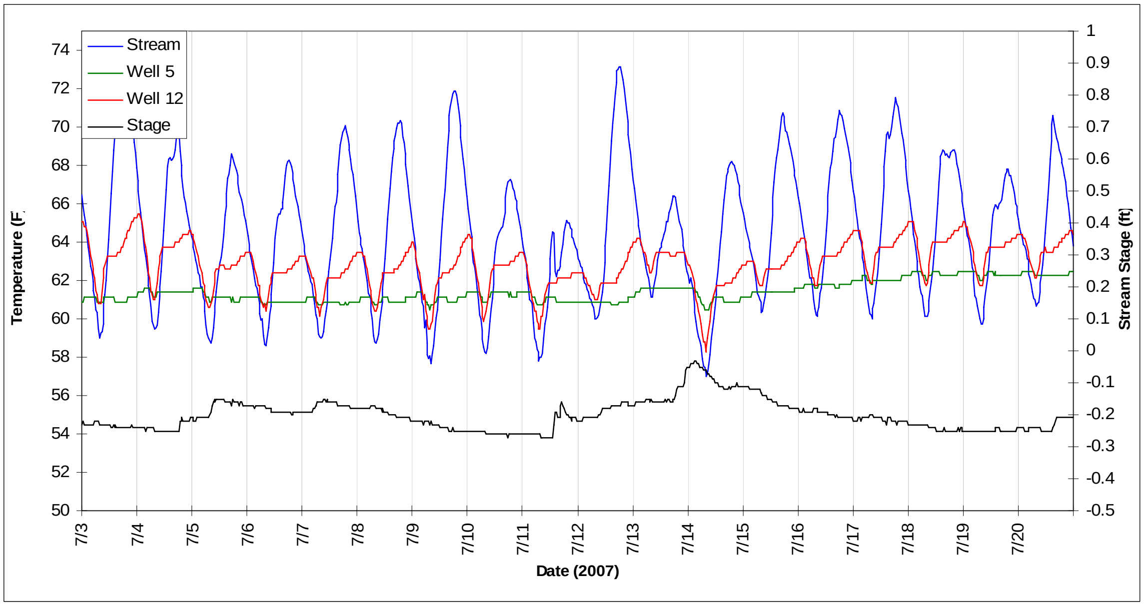


Figure 23. Snapshot instream wells' temperature signature during 2007 post-runoff base flows.

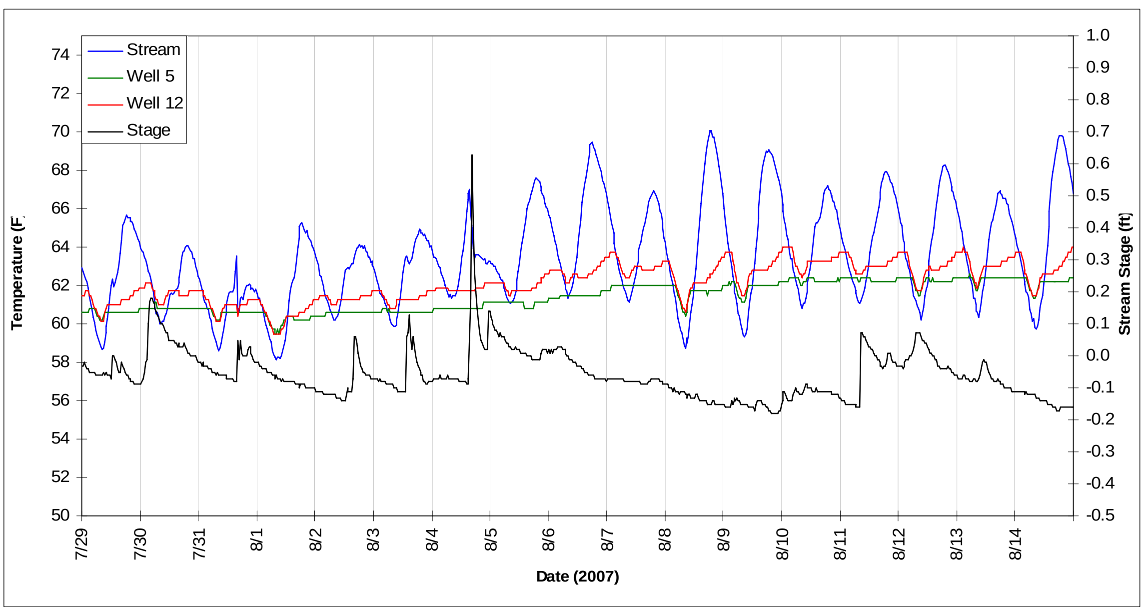


Figure 24. Snapshot of instream wells' temperature signature during 2007 monsoon events and higher base flow.

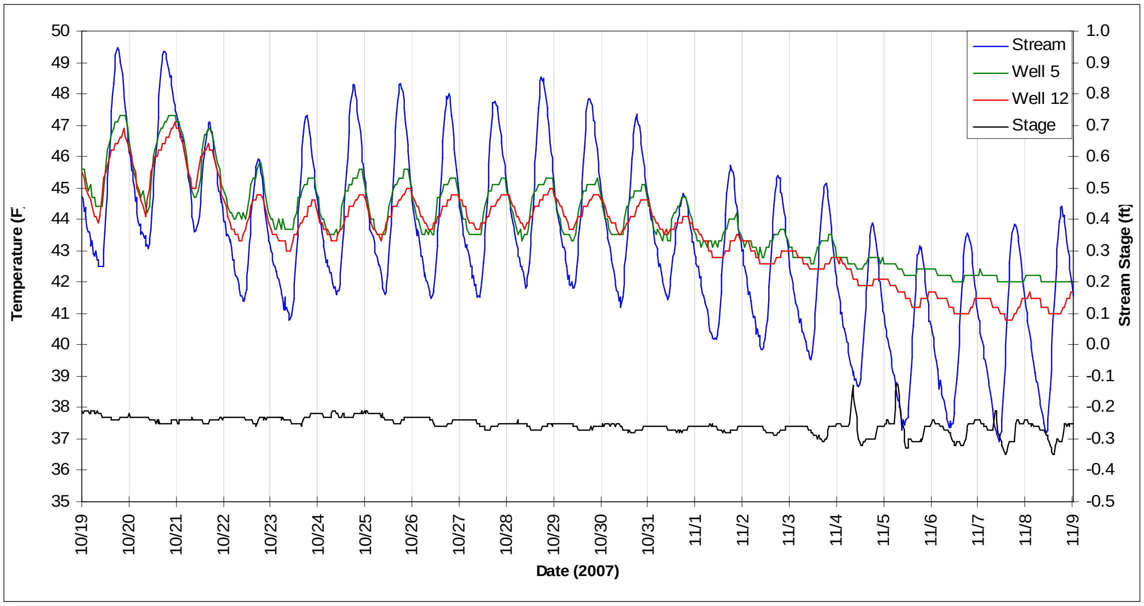


Figure 25. Snapshot of instream wells' temperature signature during 2007 post monsoon base flows.

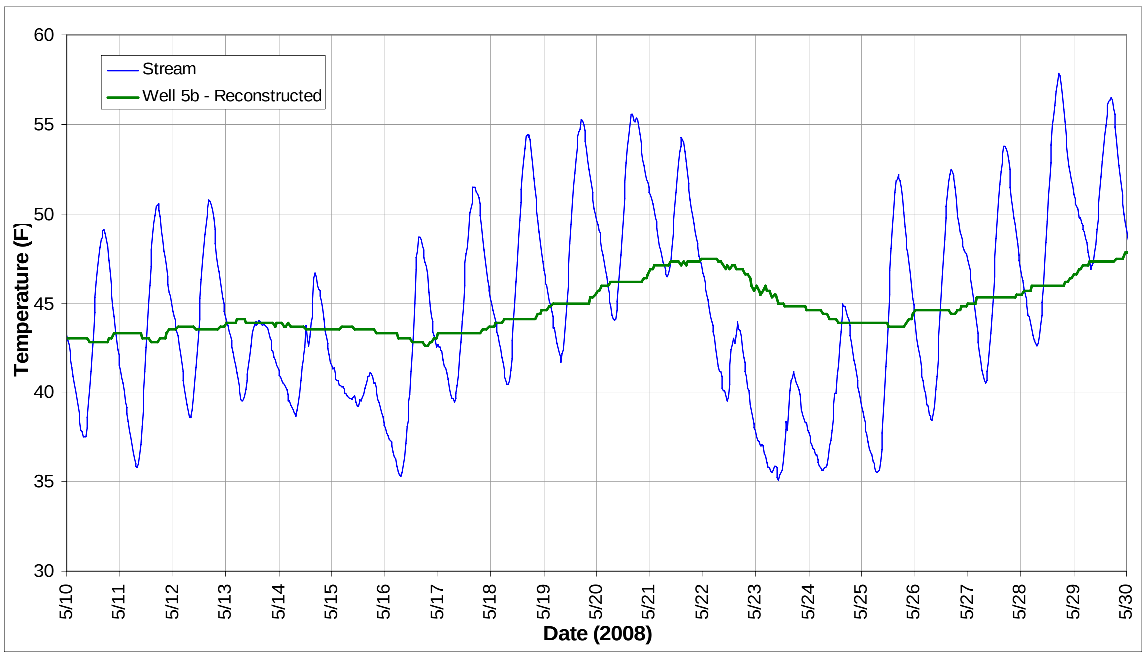


Figure 26. Snapshot of instream well's temperature signature during 2008 runoff. Well 12 was lost in the December 1, 2007 event as were all other instream wells.

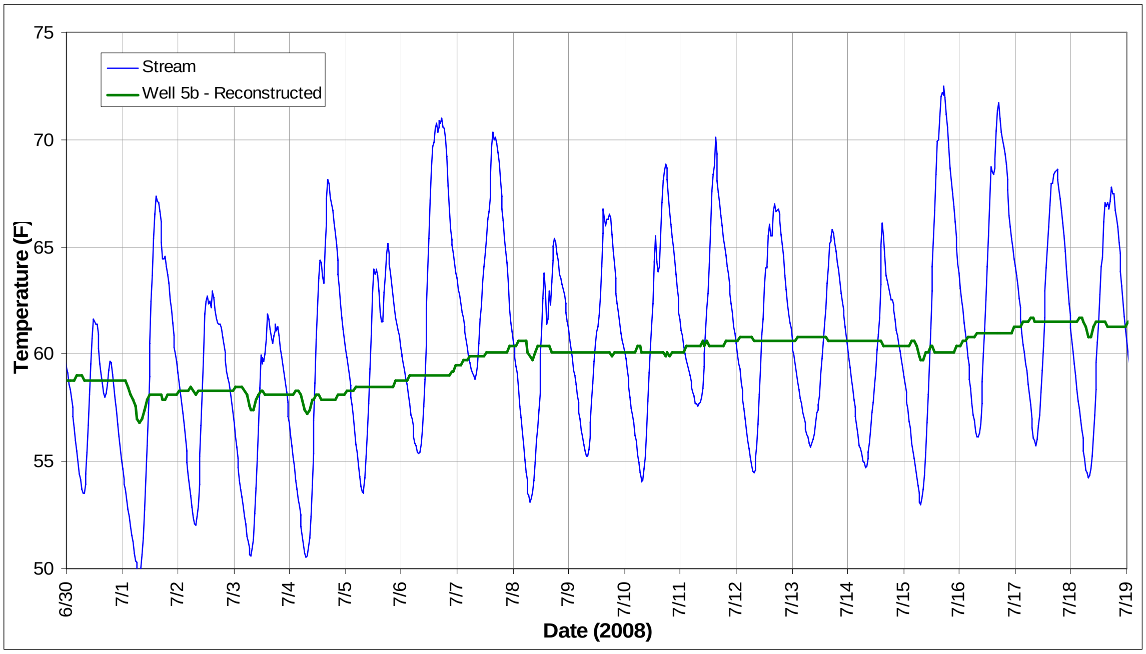


Figure 27. Snapshot of instream well's temperature signature during 2008 post runoff base flows.

With the exception of runoff, the temperature signals at depth display characteristics of a losing reach and a gaining reach. This combination not only appears from well to well and at depth, but also appears to have some diurnal control. In well 5/5b this generally appears as a small, quick temperature drop and recovery in the early morning where stream temperatures are coolest. In well 12 the profile may be described as a flat line within a quasi - sin wave. In all cases this occurs on the rising limb of the temperature curve.

In a losing reach, it is presumed that at greater depths one finds a reduced amplitude and increased lag times in the diurnal temperature signal. Conversely, in a gaining reach the temperature at any depth would be more or less constant and uniform on a daily time scale. The instream wells within this particular reach appear to have components of both and to varying degrees depending on specific location.

Diurnal stream discharge patterns, that reduce discharge during the afternoon, have been widely observed as a response to evapotranspiration (ET) (Henry et al. 1994). Constanz et al. (1994) demonstrated that these discharge patterns may also be a function of the stream temperature itself. According to the Muskat equation (Equation 3), the hydraulic conductivity of bed material is dependant upon the temperature of the fluid, thus as the stream temperature cools one expects to see less loss in a losing stream reach. This would, of course, not be the case in a gaining reach due to the relative uniform temperature of the ground water.

The expected results from a decrease in the stream temperature on a losing reach may include: 1. decreased subsurface flux at the monitoring site, resulting in less thermal response to cooler stream temperatures, 2. decreased subsurface flux upstream of station resulting in an increase in discharge, with a change in the cross-sectional profile between upstream and downstream enhancing or negating the reduced flux on the monitoring station, 3. a decreased subsurface flux upstream may reduce a deeper ground water flux at the monitoring station, effectively increasing hydraulic gradient between it and the stream stage, or 4. some combination of the three.

Vertical Gradient

To resolve the cause of these thermal responses, a temperature profile with depth was determined by placing temperature data loggers at several depths within several wells. Figure 26 is the resulting thermograph of the reconstructed instream well 5b.

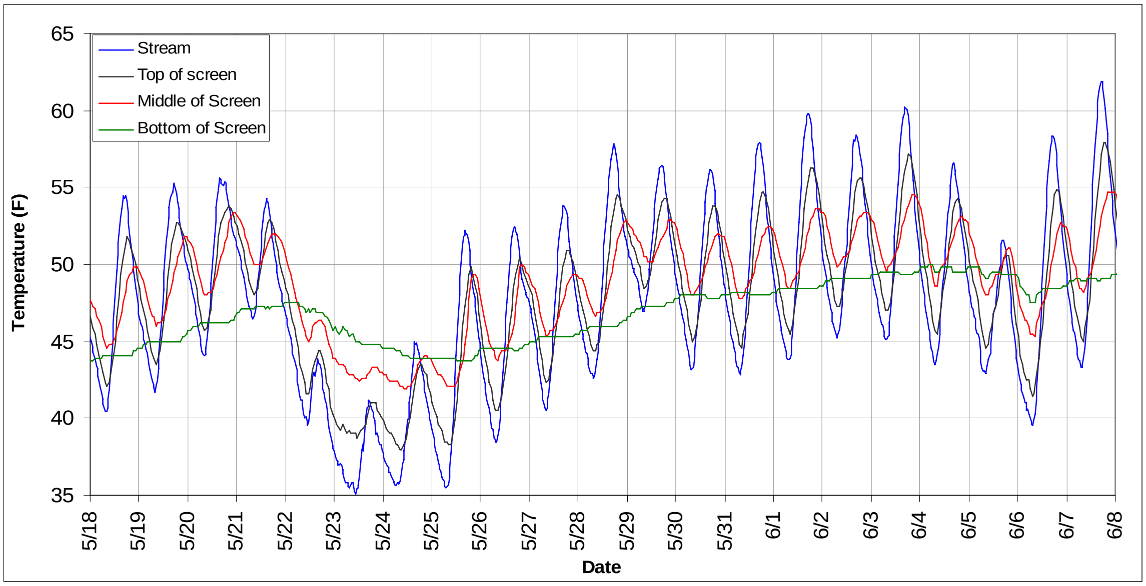


Figure 28. Temperature profiles of the top of the screen, the middle of the screen and the bottom of the screen in well 5b during runoff in 2008.

In the temperature profile displayed above, we see what is presumed to be a strong losing stream at the upper sections of the screened interval and a departure from that classic profile at the bottom of the screen. This would suggest that there may be a strong resistance to vertical flow, a defined layer of low conductivity or that the deepest temperature probe intersects an independent ground water flow path.

One key point to note in the above thermograph is subsurface temperature response during the sharp decline in surface water temperatures of 5/22/08 to 5/25/98. The deeper groundwater temperatures were able to maintain temperatures higher than the shallower temperature probes suggesting an inversion or well water mixing is unlikely, at least under certain flow conditions. This is not to say that there is no thermal influence within the well, as reported earlier the slow Darcy velocity in the horizontal direction would allow for conductive thermal exchange in the well water.

Analytical Solution

In order to compare the vertical gradient results with the expected responses, the analytical heat equation was adapted, as described in the methods section. The predicted responses offer insight into the thermal and hydrologic system controls. Figures 29, 30, and 31 show the analytical results for three depths in well 5b during runoff conditions. Figures 32, 33 and 34 show the analytical results for post runoff, baseflow conditions.

The amplitude of the subsurface response is dictated primarily by the flux and the time of response is primarily dictated by depth.

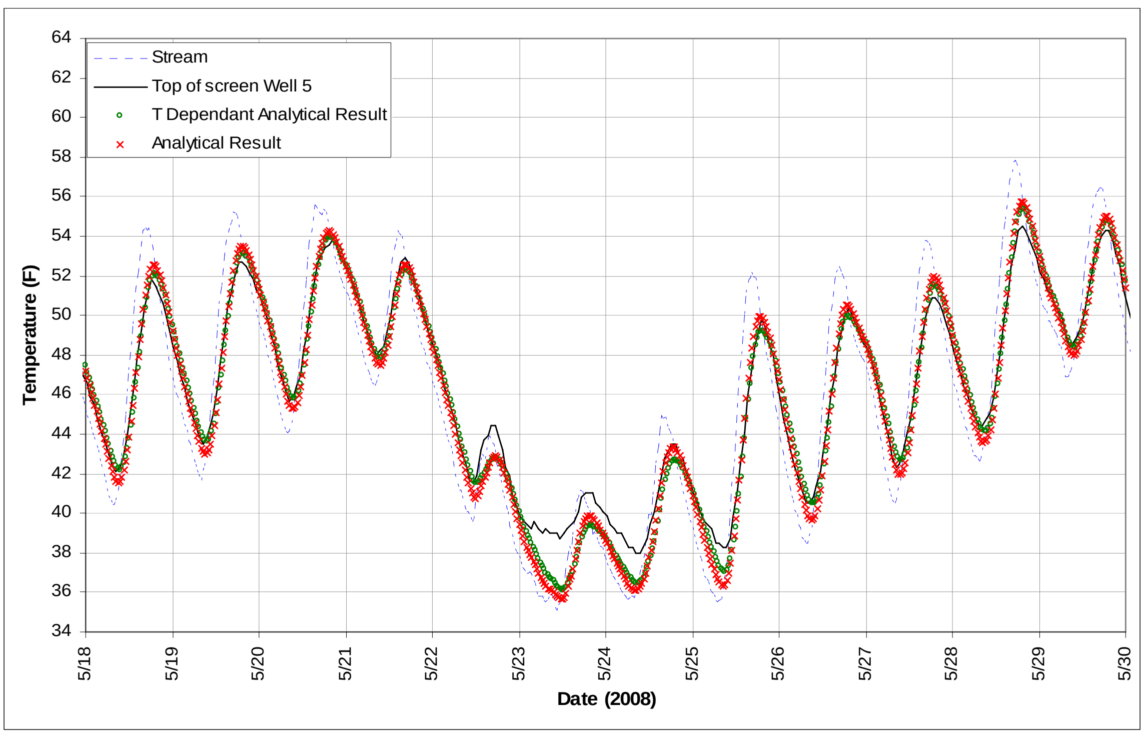


Figure 29. Graph depicting stream and well temperatures with the corresponding analytical predictions with and without temperature compensation. Depth = 1.0 ft, q = 1.60 x 10^{-4} ft/s. This graph represents runoff conditions.

The temperature-dependent results include a temperature-dependent hydraulic conductivity derived from the intrinsic permeability measured in the slug tests and the temperature-based density and viscosity functions. The temperature-based results should yield a more accurate depiction, and will be the only results reported below.

The departures from the predicted temperature at the top of the screen (Figure 29) are minimal and may be characterized as just missing the minimum and/or maximum predicted ground water temperature.

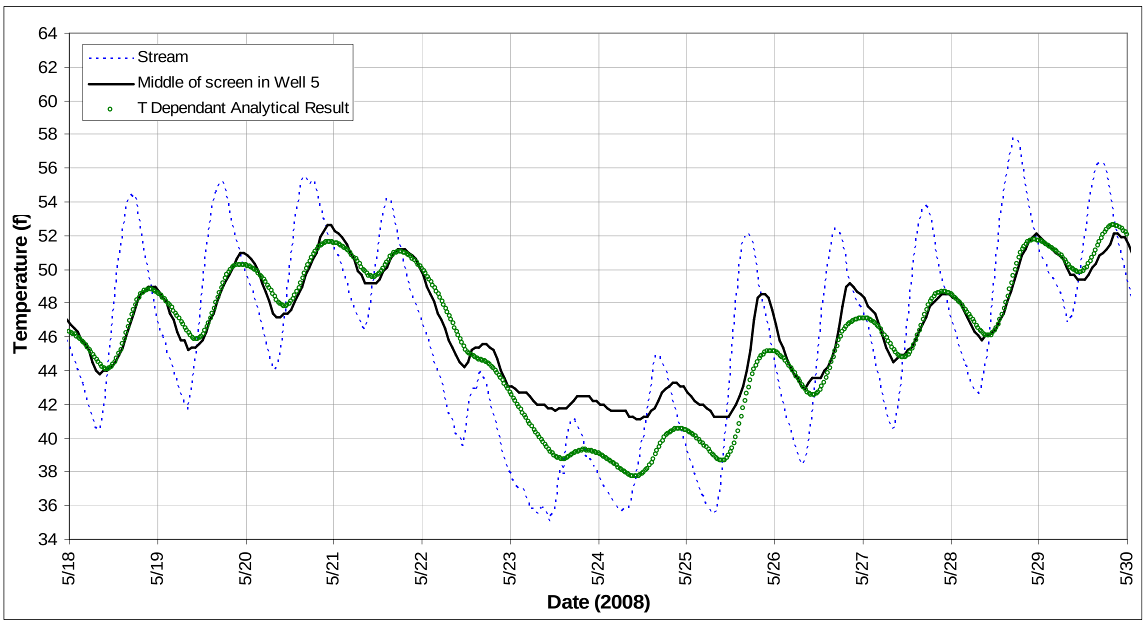


Figure 30. Graph depicting stream and well temperatures with the corresponding analytical predictions with temperature compensation. Depth = 2.0 ft, q = 1.07 x 10^{-4} ft/s. This graph represents runoff conditions.

The departures from the predicted values in the middle of the screened interval (Figure 30) are more pronounced as the depth increases and the best fit mass flux value was slightly lowered, but lag times are similar. The larger departures in the predicted temperature from the observed temperature, especially on May 23, 24 and 25, are likely due to the application of equation 2. In equation 2 the temperature difference at a given depth (x) is the difference in stream temperature and the predicted ground water temperature at time (*t*) = *t* – *1*. It is likely that as the temperature falls, in this case, the ground water temperatures at lower depths are warmer (Figure 28) and would yield a change in the thermal gradient (*dT/dx*) in both the conductive and advective term.

At the bottom of the screen the lag times become consistently later and the flux had to be significantly lowered to achieve a reasonable relationship with predicted temperature fluctuations.

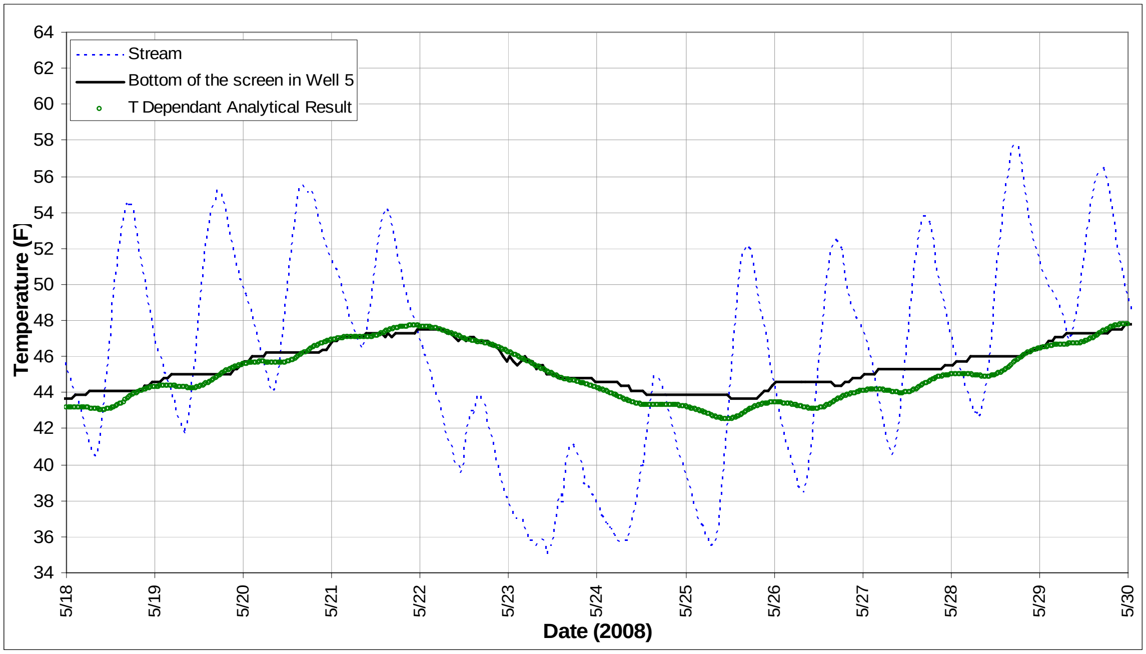


Figure 31. Graph depicting stream and well temperatures with the corresponding analytical predictions with temperature compensation. Depth = 3.0 ft, q = 1.89 x 10^{-5} ft/s. This graph represents runoff conditions.

The departures at the bottom of the screen in well 5b to the predicted values suggest a source from outside the stream water in the study reach.

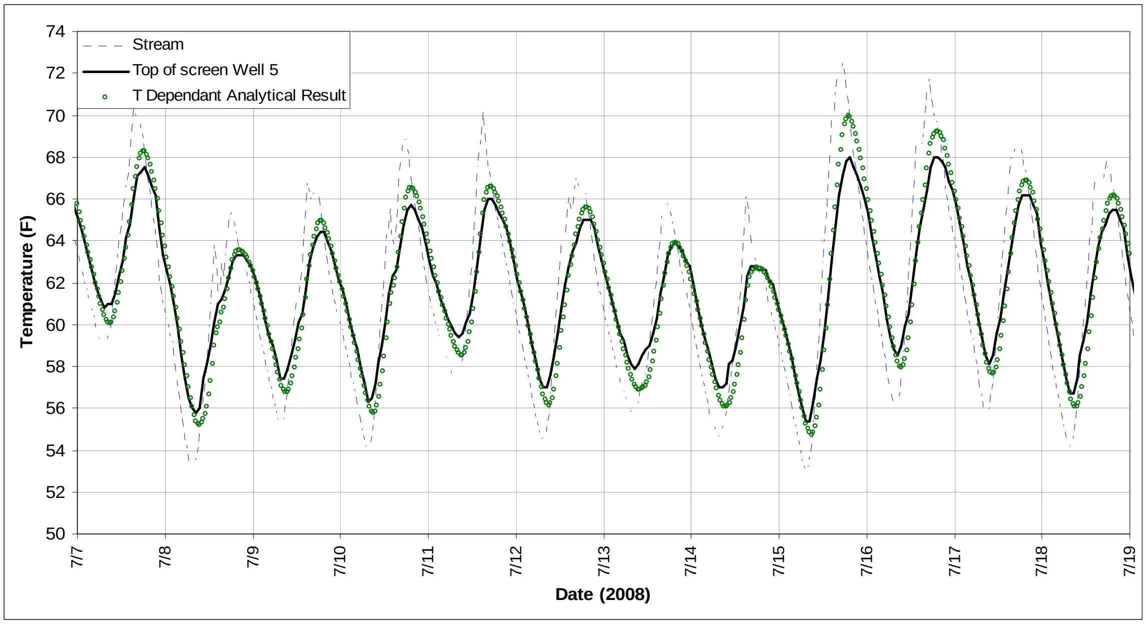


Figure 32. Graph depicting stream and well temperatures with the corresponding analytical predictions with temperature compensation. Depth = 1.0 ft, q = 1.60 x 10^{-4} ft/s. This graph represents baseflow.

Again the measured temperature values in the top of the screen (Figure 32) agree reasonably well with the predicted values at the same flux rate.

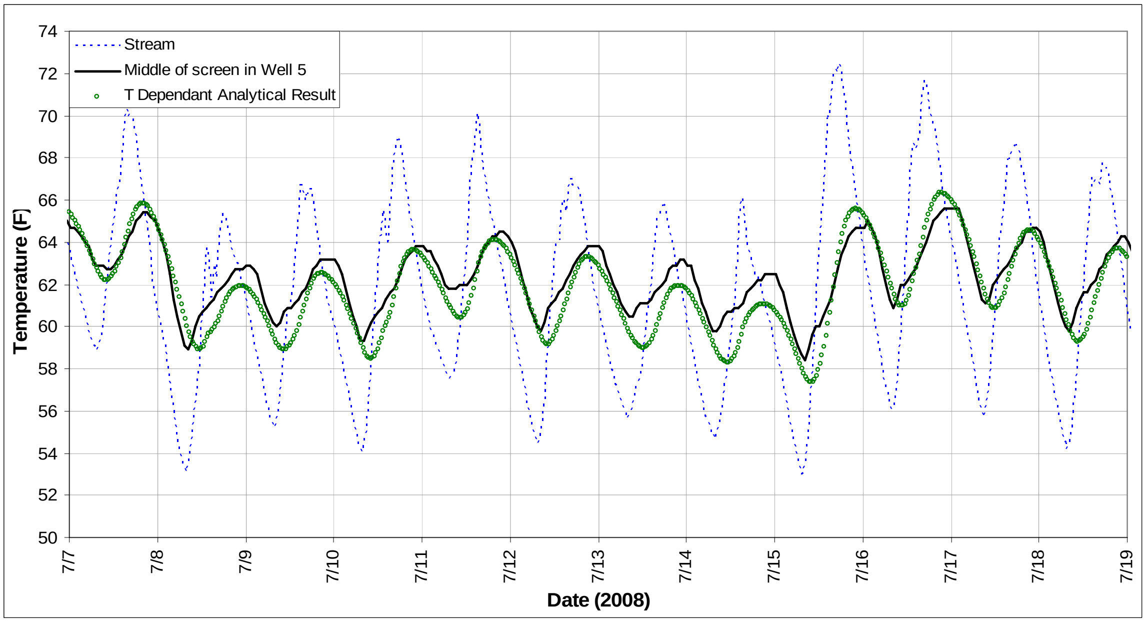


Figure 33. Graph depicting stream and well temperatures with the corresponding analytical prediction with temperature compensation. Depth = 2.0 ft, q = 1.07 x 10^{-4} ft/s. This graph represents baseflow.

The departures for the middle of the screen temperature values are still not high, but the departures become consistent each day. The measured temperatures display lag times and rates of change that are predicted with the simple 1-D system, but these temperatures appear to be "pushed" by an external source at relatively regular intervals. We also begin to see the unconventional rebound from low temperatures that appear in well 12 (Figures 23 and 24).

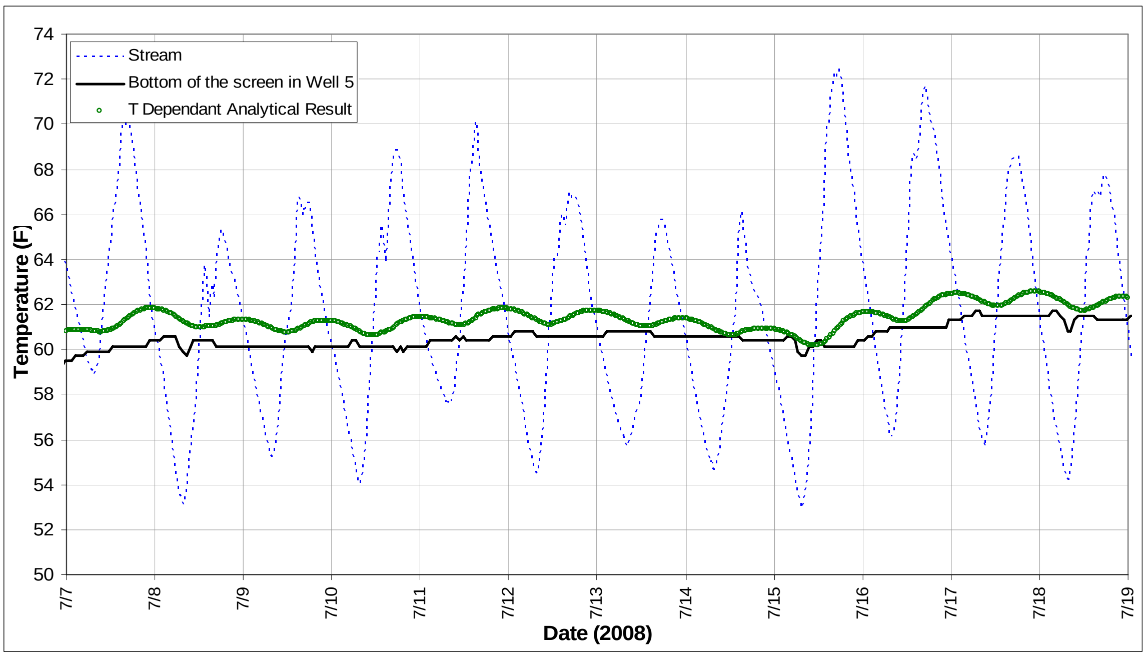


Figure 34. Graph depicting stream and well temperatures with the corresponding analytical predictions with temperature compensation. Depth = 3.0 ft, q = 1.89 x 10^{-5} ft/s. This graph represents baseflow conditions.

The bottom of the well appears to become completely isolated from the diurnal stream temperature fluctuations as is estimated in the calculated values. The clear departures in the theoretical ground water temperature represent a discrete flow path that would be capable of enhancing or reducing the thermal gradient.

Again we find a fairly uniform flux into the subsurface at shallow depths, and thus stream stage playing a minor role in the subsurface response characteristics. As noted earlier the analytical predictions take into account the temperature dependant flux. Together these suggest that for the observation period the stream water characteristics within the reach impact the ground water dynamics only at a shallow depth.

The adaptation of the heat flow equation (Equation 2) to this study proved very useful and helped to confirm some suggested interactions. The strengths of the model are its ease of use, flexibility and the self-correcting nature regarding the initial boundary conditions. As pointed out earlier, it fails to account for additional heat sources and/or sinks, such as a deeper ground water flow path. The results of the predicted ground water temperatures also require, if values are not measured, an estimation of the thermal conductivity, density, specific heat capacity and porosity of the porous medium. This adaptation would likely be useful for unsaturated sediments, but care should be given to use of a well versus a buried temperature probe.

Conceptual Flow Net

From the thermal data, it is possible to derive this conceptual flow net (Figure 35) of the subsurface, adding a 3^{rd} dimension, depth, to the overall ground water exchange. The vertical Darcy velocity is over 300 times greater than the horizontal velocity and thus the flux appears almost vertical in the shallower depths.

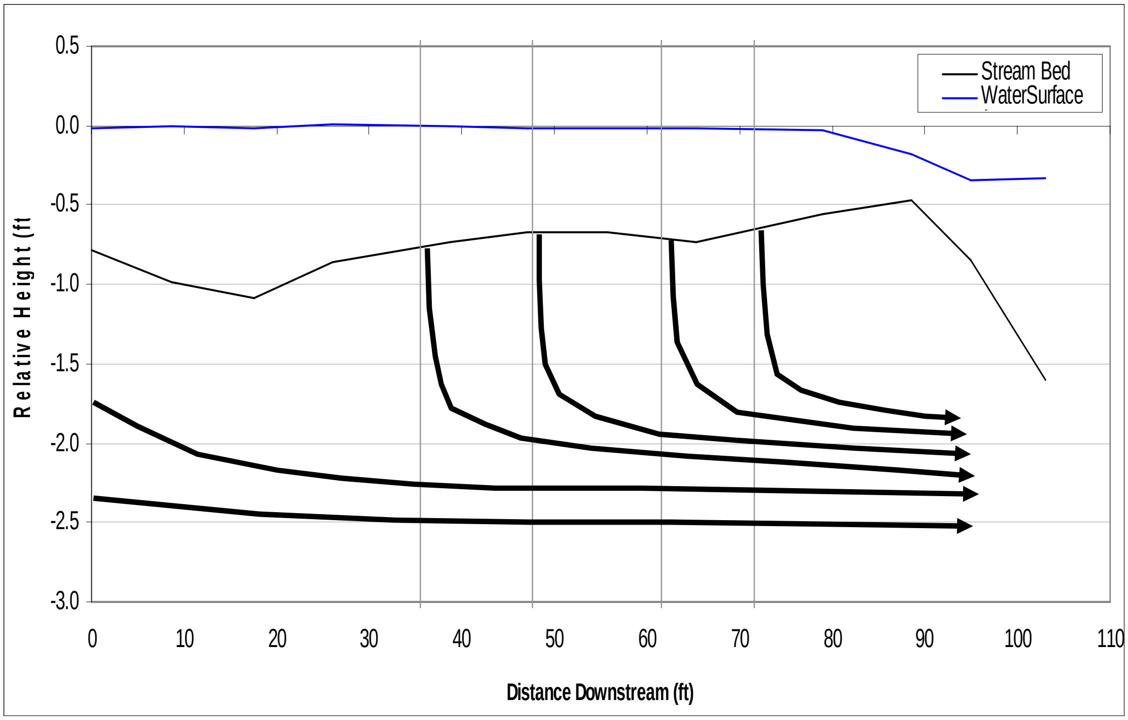


Figure 35. Conceptual Flow Net from Thermal Data (note that vertical scale is exaggerated.)

It is unclear how much contribution variances in depth of the flow paths produce advective response in the ground water temperature.

Hydraulic and Thermal Exchange Rates

From the thermal results and the hydraulic results we obtain a difference in the estimated loss from the stream to the ground water. The loss over the surface of the stream bed is calculated using Equation 4

$$Q = w*l*q \qquad \text{Equation 4}$$

Where Q is the discharge as a volume of water over a discrete time step from the stream to the subsurface, w is the width of the stream at bankfull and average base flow, and l is the length of the reach. The Darcy velocity (q) in the hydraulic-based estimation is calculated from the average hydraulic gradient between the stream and the instream wells and the hydraulic conductivity measured in the slug tests. The thermal-based flux was the best fit value from the analytical solution at a shallow depth. The results of the two estimations are presented in Table 6.

Hydraulic gradient-based flux		Temperature-based Flux	
Q_{bkf}	Q_{base}	Q_{bkf}	Q_{base}
0.43	0.21	0.40	0.20

Table 6. Estimated discharge (cfs) in the reach using hydraulic gradient-based flux and temperature-based flux. Q_{bkf} is the discharge at bankfull flow and Q_{base} is the discharge at the average baseflow.

The difference represents approximately a 28% reduction in the Darcy velocity from the hydraulic gradient data to the temperature data. The consistency of the estimated ground water temperature to the measured data represents a better estimate over time than the hydraulic-based data and at a large cost savings to hydraulic-based continuous data. To highlight this, a researcher or restoration practitioner could instrument 7 wells with 3 temperature data loggers for about the same price of 1 pressure transducer.

Predicted Change in Exchange

The structure proposed at the study site is a “baffle” constructed of native materials. The structure is a right triangle running 24 ft along the left bank and at the downstream side it sticks out 13 ft into the stream channel (Figure 35).

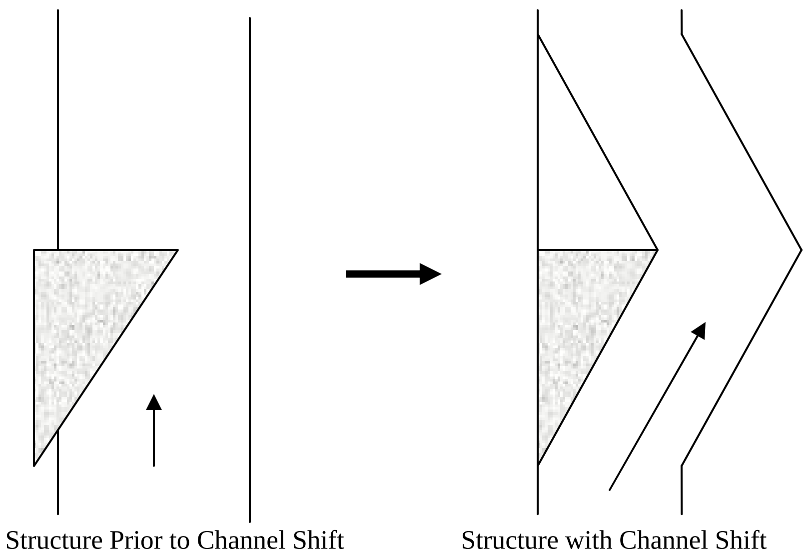


Figure 36. Conceptual drawing of proposed channel-modifying structure.

The purpose of the structure is to slow the water velocity through the structure allowing entrained sediments to deposit and create a point bar while redirecting swifter water around the structure forming a new thalwag. The downstream side of the structure will also exhibit slow velocities and thus the point bar grows by twice the structure size. The length of the channel is expected to grow by at least the hypotenuse of the structure plus an equal length on the downstream side. The overall length of the reach increases from 48 ft to 55 ft.

Adding stream length with the proposed structure increases the total estimated exchange to 0.49 cfs at bankfull and 0.24 cfs at baseflow based on the hydraulic gradient based estimation and approximately 0.45 cfs at bankfull and 0.23 cfs at baseflow using thermal-based estimation. This flow is not expected to produce a net loss for the stream. Instead this refers to an increase in residence time of water in the subsurface.

V. Conclusions

The data presented here were collected from the Rio de las Vacas study site over 13 months in 2007 and 2008. The description of the reach and its ground water / surface water interactions present a complex system where temperature plays an important role. It was determined that the reach is a losing stream at shallow depths, with parallel ground water flow at depth and in the stream banks. The laminar ground water flow is considerably more stable in temperature and is generally cooler with depth in spring, summer and fall months (warmer in the winter months). The contribution to the subsurface flow at depth in the study reach is determined by upstream dynamics and the contribution of stream flow within the reach to the subsurface is found to be limited. As ground water temperature dynamics are not correlated with the stream stage in time, the disruption in classic subsurface temperature profiles may be dictated by upstream infiltration that on a diurnal time step is temperature dependant or the result of a conductive heat transfer with deeper ground water. The temperature-based exchange estimations provide a slightly different discharge value of stream water to the subsurface than the hydraulic-based exchange estimation. This study has confirmed the use of temperature data loggers as a low cost, robust alternative for monitoring directional changes and magnitude of this exchange over small time steps. The predicted gains in stream loss to the subsurface are between 0.05 to 0.06 cfs for an estimated 7 feet of added stream length from the proposed structure. The minimal gains in the exchange, would likely not counter the increase in stream temperatures from increased exposure to solar radiation. Therefore additional measures, such as planting woody vegetation for shade, are required to offset overall increases in stream temperatures.

References

Anderson, M. P. 2005. Heat as a Ground Water Tracer. *Ground Water*, Vol. 43, No. 6, pp. 951-968.

Baxter, C. V. and F. R. Hauer. 2000. Geomorphology, hyporheic exchange and selection of spawning habitat by bull trout (*Salvelinus confluentus*). *Canadian Journal of Fisheries and Aquatic Sciences* 57: 1470-1481.

Baxter, C., and R. F. Hauer. 2003. Measuring groundwater-stream water exchange: New techniques for installing minipiezometers and estimating hydraulic conductivity. *Transactions of the American Fisheries Society* 132: 493-502.

Benson, N. G. 1953. The importance of groundwater to trout populations in the Pigeon River, Michigan. Proceedings of the North American Wildlife Conference 18: 269-281.

Boulton, A. J., H. M. Valett, and S. G. Fisher. 1992. Spatial distribution and taxonomic composition of the hyporheos of several Sonoran desert streams. *Archiv für Hydrobiologie* 125, no.1: 37-61.

Bouwer, H. and R. C. Rice. 1976. A Slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. *Water Resouces Research* 12: 423-428.

Coleman, R. J. and C. N. Dahm. 1990. Stream geomorphology: effects on periphyton standing crop and primary production. *Journal of the North American Benthological Society* 9: 293-302.

Coleman, M. J. and H. B. N. Hynes. 1970. The vertical distribution of invertebrate fauna in the bed of a stream. *Limnology and Oceanography* 15: 31-40.

Constantz, J., Thomas, C. L., and Zellweger, G. 1994. Influence of diurnal variations in stream temperature on streamflow loss and groundwater recharge. *Water Resources Research*. 30: 3253-3264.

Cunjak, R. A. and G. Power. 1986. Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). *Canadian Journal of Fisheries and Aquatic Sciences* 43: 1970-1981.

Curry, R. A. and D. L. G. Noakes. 1995. Groundwater and the selection of spawning sites by brook trout, *Salvelinus fontinalis*. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 1733-1740.

Dahm, C. N., D. L. Carr, and R. L. Coleman. 1991. Anaerobic carbon cycling in stream ecosystems. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 24: 1600-1604.

Dahm, C. N., N. B. Grimm, P. Marmonier, H. M. Valett, and P. Vervier. 1998. Nutrient dynamics at the interface between surface waters and groundwaters. *Freshwater Biology* 40: 427-451.

Dahm, C. N. and H. M. Valett. 1996. Hyporheic zones. Pages 107-119 in F. R. Hauer and F. A. Lamberti editors. Methods I Stream Ecology. Academic Press, San Diego, California.

Danielopol, D. L. 1989. Groundwater fauna associated with riverine aquifers. *Journal of the North American Benthological Society*. 8: 18-35.

Deming, David. 2002. Introduction to Hydrogeology. McGraw-Hill Higher Education. New York, NY.

Duff, J. H. and F. J. Triska. 1990. Denitrification in sediments from the hyporheic zone adjacent to a small forested stream. *Canadian Journal of Fisheries and Aquatic Sciences*. 47: 1140-1147.

Ebersole, J. L., W. J. Liss, and C. A. Frissell. 2001. Relationship between stream temperature, thermal refugia and rainbow trout *Oncorhynchus mykiss* abundance in arid-land streams in the northwestern United States. *Ecology of Freshwater Fish.* 10: 1-10.

Ferrell, S., S. Eddy, D. Goodman, K. Lund, and J Simino. 2003. Rio de Las Vacas: Stream inventory report, Santa Fe National Forest, http://www.fs.fed.us/r3/sfe/fish/reports/stream_inventory_reports/index.html

Fortner, S. L. and D. S. White. 1988. Interstitial water patterns: a factor influencing the distribution of lotic aquatic vascular macrophytes. *Aquatic Botany* 31: 1-12.

Garrett, J. W., D. H. Bennett, F. O. Frost, and R. F. Thurow. 1998. Enhanced incubation success for Kokanee spawning in groundwater upwelling sites in a small Idaho stream. *North American Journal of Fisheries Management* 18: 925-930.

Geist, D. R., M. C. Joy, D. R. Lee, and T. Gonser. 1998. A method for installing piezometers in large cobble beddrivers. *Ground Water Monitoring and Remediation*. 18: 78-82.

Giller, P. S. 2005. River restoration: Seeking ecological standards. Editor's introduction. *Journal of Applied Ecology* 42: 201-207.

Grimm, N. B., and S. G. Fisher. 1984. Exchange between interstitial and surface water: implications for stream metabolism and nutrient cycling. *Hydrobiologia* 111: 219-228.

Halford, K. J. and Kuniansky, E. L. 2002. Spreadsheets for the Analysis of Aquifer-Test and Slug-Test Data, Version 1.2, Open File Report 02-197.

Hansen, E. A. 1975. Some effects of groundwater on brown trout. *Transactions of American Fisheries Societ*y 104, no. 1: 100-110.

Harvey, J. W., and K. E. Bencala. 1993. The effect of streambed topography on surface-subsurface water exchange in mountain catchments. *Water Resource Research* 29, no. 1: 89-98.

Hill, A. R. 1990. Groundwater flow paths in relation to nitrogen chemistry in the near-stream zone. *Hydrobiologia* 206: 39-52.

Hemond, H. F. 1990. Wetlands as the source of dissolved organic carbon to surface waters. Pages 301-313 in E. M. Perdue and E. T. Gjessing, eds., Organic Acids in Aquatic Ecosystems, John Wiley and Sons, Ltd.

Hendricks, S. P. 1993 Microbial ecology of the hyporheic zone: A perspective integrating hydrology and biology. *Journal of the North American Benthological Society* 12: no. 1: 70-78.

Hendricks, S. P. and D. S. White. 1988. Hummocking in lotic *Chara*: Observations on alterations of hyporheic temperature patterns. *Aquatic Botany* 31: 13-22.

Henry, K.S., H. M. Valett, J.A. Morrice, C. N. Dahm, G. J. Wroblicky, M.A. Santistevan, and M. E. Campana. 1994. Ground water – surface water exchange in two headwater streams. *Proceedings of the Second International Conference on Ground Water Ecology* (eds J. A. Stanford & H. M. Valett), pp. 319-328. American Water Resources Association, Herndon.

Jenkins, M. 2003. Prospects for biodiversity. *Science* 302:1175-1177.

Jobson, H. E., and W. P. Carey. 1989. Interaction of fine sediment with alluvial streambeds. *Water Resources Research*. 25, no. 1: 135-140.

Keys, W. S. and R. F. Brown. 1978. The use of temperature logs to trace the movement of injected water. Ground Water 16, no. 1: 32-48.

Kondolf, G. M., J. W. Webb, M. J. Sale and T. Felando. 1987. Basic hydrologic studies for assessing impacts of flow diversions on riparian vegetation: examples from streams of the eastern Sierra Nevada, California, USA. *Environmental Management*.11: 757-769.

Lee, D. R. and H. B. N. Hynes. 1977. Identification of groundwater discharge zones in a reach of Hillman Creek in southern Ontario. *Water Pollution Research in Canada* 13: 121-133.

Lowrance, R., R. Todd, J. Fail, O. Hendrickson, R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural wetlands. *BioScience* 34: 374-377.

New Mexico Water Quality Commission (NMWQC), "2004-2006 State of New Mexico Integrated Clean Water Act §303(d) §305(b) Report", http://www.nmenv.state.nm.us/wqcc/303d-305b/2004/index.html

New Mexico Water Quality Commission (NMWQC), "Water Quality and Water Pollution Control in New Mexico ~ 1998", http://www.nmenv.state.nm.us/swqb/305b/1998/305b_98.html

Nielsen, J. L., T. E. Lisle, and V. Ozaki. 1994. Thermally stratified pools and their use by steelhead in northern California streams. *Transactions of the American Fisheries Society*. 123: 613-626.

Palmer, M. A., E. S. Bernhardt, J. D. Allan, P. S. Lake, G. Alexander, S. Brooks, J. Carr, S. Clayton, C. N. Dahm, J. Follstad Shah, D. L. Galat, S. G. Loss, P. Goodwin, D. D. Hart, B. Hassett, R. Jenkinson, G. M. Kondolf, R. Lave, J. L. Meyer, T. K. O'Donnell, L. Pagano, and E. Sudduth. 2005. Standards for ecologically successful river restoration. *Journal of Applied Ecology* 42: 208-217.

Peterjohn, W. T. and D. L. Correll. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. *Ecology* 65: 1466-1475.

Riggs, H. C. 1985, Streamflow characteristics. Elsevier, New York.

Savant, S. A., D. D. Reible, and L. J. Thibodeaux. 1987. Convective transport within stable river sediments. *Water Resources Researc*h 23, no. 9:1763-1768.

Schwartz, F. W. and H. Zhang. 2003. Fundamentals of Ground Water. John Wiley and Sons, Inc. New York, NY.

Silliman, S. E., and D. F. Booth. 1993. Analysis of time-series measurements of sediment temperature for identification of gaining vs. losing portions of Juday Creek, Indiana. *Journal of Hydrology* 146: 131-148.

Silliman, S. E., J. Ramirez, and R. L. McCabe. 1995. Quantifying downflow through creek sediments using temperature time series: One-dimensional solution incorporating measured surface temperatures. *Journal of Hydrology* 167: 99-119.

Sowden, T. K. and F. Power. 1985. Prediction of rainbow trout embryo survival in relation to groundwater seepage and particle size of spawning substrates. *Transactions of the American Fisheries Society* 114: 804-812.

Stanford, J. A., J. V. Ward and B. K. Ellis. 1994. Ecology of the alluvial aquifers of the Flathead River Montana. Pages 367-389 in J. Gilbert, D. L. Danielopol and J. A. Sanford, editors. Groundwater ecology. Academic Press, San Diego, California.

Stonestrom, D. A. and J. Constantz. 2003. Heat as a Tool for Studying the Movement of Ground Water Near Streams. United States Geological Survey Circular 1260.

Torgersen, C. E., R. N. Faux, B. A. McIntosh, N. J. Poage and D. J. Norton. 2001. Airborne thermal remote sensing for water temperature assessment in rivers and streams. *Remote Sensing of Environment*. 76: 386-398.

Triska, F. J., V. C. Kennedy, R. J. Avanzino, G. W. Zellweger, and K. E. Bencala. 1989. Retention and transport of nutrients in a third-order stream in northwestern California: hyporheic processes. *Ecology* 70: 1893-1905.

Triska, F. J., V. C. Kennedy, R. J. Avanzino, G. W. Zellweger, and K. E. Bencala. 1990. In situ retention-transport response to nitrate loading and storm discharge in a third-order stream. *Journal of the North American Benthological Society* 9: 229-239.

Triska, F. J., J. H. Duff, and R. J. Avanzino. 1993. Patterns of hydrologic exchange and nutrient transformation in the hyporheic zone of a gravel-bottom stream: Examining terrestrial-aquatic linkages. *Freshwater Biology* 29: 259-274.

Valett, H. M. 1993. Surface-hyporheic interactions in a Sonoran desert stream: Hydrologic exchange and diel periodicity. *Hydrobiologia* 259:133-144.

Valett, H. M., C. C. Hakenkamp, and A. J. Boulton. 1993. Perspectives on the hyporheic zone: integrating hydrology and biology. Introduction. *Journal of the North American Benthological Society* 12: 40-43.

Vaux, W. G. 1962. Interchange of stream and intergravel water in a salmon spawning riffle. United States Fish and Wildlife Service Scientific Report, Fisheries 405:1-10.

Winter, Thomas C., et al., "Ground Water and Surface Water: A Single Resource, U.S. Geological Survey Circular 1139", 1998.

Woessner, William H. 2000. Stream and fluvial plain ground water interactions: rescaling hydrogeologic thought. *Ground Water* 38, no. 3: 423-429.

Wolman, M. G. 1954. A method of sampling coarse river-bed material. Transactions, American Geophysical Union. 35. pp. 951-956.

Woods, P.F. 1980. Dissolved oxygen in intergravel water of three tributaries to Redwood Creek, Humboldt County, California. *Water Resources Bulletin,* AWRA 16, no.1. 105-111.

Wroblicky, G. J., M. E. Campana, H. M. Valett, J. A. Morrice, K. S. Henry, C. N. Dahm, J. V. Hurley and J. M. Noe. 1992. Remote monitoring of stream hyporheic zones with inexpensive pressure transducer-data acquisition systems, proceedings of the first international conference on ground water ecology (eds. J. A. Stanford and J. J. Simons), pp 267-277, American Water Resources Association, Bethesda.