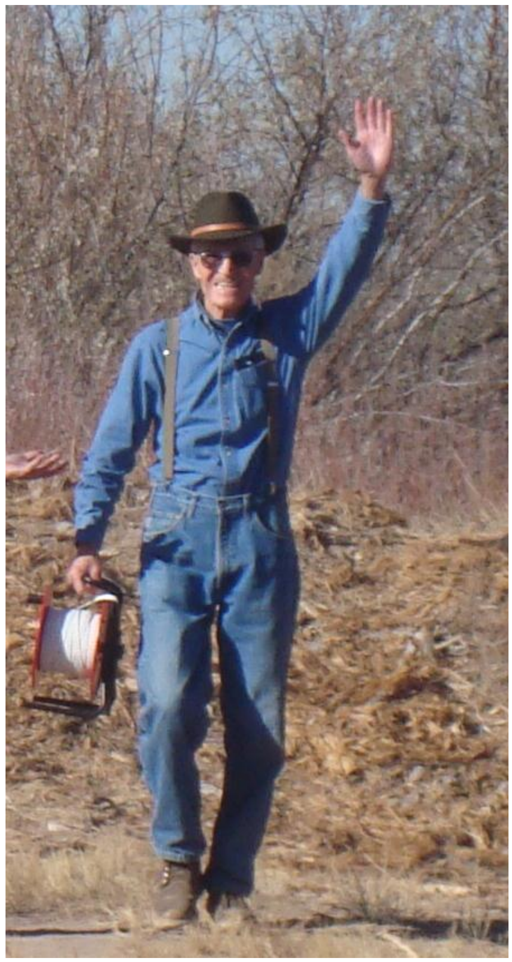
Bosque Ecosystem Monitoring Program (BEMP) Comprehensive Report: 1997-2009



Kim D. Eichhorst, Daniel C. Shaw, Jennifer F. Schuetz, Kimi Scheerer, Melanie Keithley, and Clifford S. Crawford

Bosque Ecosystem Monitoring Program

Bosque Ecosystem Monitoring Program (BEMP) Comprehensive Report: 1997-2009

By Kim D. Eichhorst[1], Daniel C. Shaw[2], Jennifer F. Schuetz[3], Kimi Scheerer[4], Melanie Keithley, and Clifford S. Crawford

---

University of New Mexico

Open-File Report 12-5

Prepared in cooperation with

Bosque School

With support for the printing and preparation of this report from:

Albuquerque, New Mexico
June 2012

[1] Co-director, MSC 03 2020, Department of Biology, University of New Mexico, Albuquerque, NM 87131; kimde@unm.edu

[2] Co-director, Bosque School, 4000 Learning Rd. NW, Albuquerque, NM 87120; dan.shaw@bosqueschool.org

[3] Field coordinator, MSC 03 2020, Department of Biology, University of New Mexico, Albuquerque, NM, 87131; schuetz@unm.edu

[4] Education coordinator, Bosque School, 4000 Learning Rd. NW, Albuquerque, NM 87120; kimi.scheerer@bosqueschool.org

This report is dedicated to Dr. Cliff Crawford, BEMP founder, mentor, and friend.

Cover photo by Kim Eichhorst

Additional information about BEMP and copies of the previous reports can be accessed and downloaded at: http://www.bosqueschool.org

Copies of this report can be obtained by emailing
Rebecca Belletto, BEMP Operations Manager
rebecca.belletto@bosqueschool.org
Bosque School, 4000 Learning Rd. NW
Albuquerque, NM 87120

Table of Contents

Executive Summary

The Bosque Ecosystem Monitoring Program (BEMP) is a long-term ecological monitoring program focusing on the Rio Grande riparian forest, or bosque. The majority of data collections are done by K-12 students and their teachers with associated BEMP staff or University of New Mexico (UNM) interns (undergraduate seniors and graduates).

BEMP is mainly a partnership between UNM and Bosque School, but is also involved in a number of important collaborations and partnerships with other entities: Long Term Ecological Research Schoolyard/Sevilleta National Wildlife Refuge; Bernalillo County Open Space; US Army Corps of Engineers; US Bureau of Reclamation; New Mexcio Watershed Watch; Bosque Education Guide; Pueblos of Santa Ana, Ohkay Owingeh, and Santo Domingo (formerly Kewa); National Hispanic Cultural Center & Rio Grande Nature Center State Parks; City of Albuquerque Open Space and BioPark; Middle Rio Grande Conservancy District; and, most recently, New Mexico Natural Heritage Program, Hawks Aloft, and New Mexico Interstate Stream Commission.

As of 2009, BEMP has a total of 25 sites spanning 140 miles of the Rio Grande, and has grown from almost 200 participants in 1997 to just over 5000. Each site has a history of hosting different student scientists and providing a wealth of data. Groundwater wells, ditch culverts, rain gauges, leaf litter tubs, temperature data loggers, pitfall traps, and marked transect points are all part of the (usually) inexpensive equipment used to monitor these bosque sites year-round.

BEMP now has data on post-fire, post-clearing, and landscape lowering effects on plant establishment and groundwater recovery, including response of native and exotic trees and understory vegetation.

Mission Statement: The mission of the Bosque Ecosystem Monitoring Program is collaborative long-term ecological monitoring of key abiotic and biotic processes and characteristics to promote continued education, understanding, and stewardship of the Middle Rio Grande riparian ecosystem for scientists, teachers, students, policy makers and the public.

Introduction

As BEMP moves into its second decade of data collection and education outreach, we find that we have met some of our initial goals and surpassed others. A unique collaborative program that relies on school children working with scientists, BEMP has demonstrated that it is truly a sustainable monitoring program collecting valid and useable data. The goal of eight sites, set forth in the original National Science Foundation (NSF) Informal Science Education Program proposal, was met in 1999, and has since been met an additional three times. Initial ideals of involving up to ten schools are now met almost weekly during the busiest parts of the school year. Using low-tech, low-cost field equipment to see us through times of lean funding has proven helpful, and it is a method that is easily replicated in schoolyards or backyards for comparisons; however, high-tech equipment (such as pressure transducers that log water table depth every half-hour) now graces roughly half of our sites. University interns learning U.S. Fish and Wildlife Service protocols for monitoring water chemistry interact as mentors to kindergarten through 12th grade students, and are using their various experiences with BEMP to enrich their resumes. Completing the outreach cycle, today's university interns include some of our "first generation" BEMP students. It is cause for celebration to have university seniors excited to be mentors in the same program they remember participating in as children.

How much do BEMP students benefit from being in the field each month, or from doing follow-up lab work in the classroom? Certain elements of science and math are made more tangible and understandable in practice than through reading about them or listening to a lecture. How better to understand the water cycle than to monitor monthly rainfall levels (and learning to pour oil in the emptied gauges to prevent new rainfall from evaporating); or seeing low, baseline river flows spike into high, fast flows after rainstorms; or by melting snow in rain gauges to record accurate precipitation throughout the winter, and then recording the high water table levels and river flows after snowmelt in the spring? Certainly the students who put on waders and walk through flooded sites have a memorable grasp of the impact of high river flows on the water table. So, too, do the students left on the shores of the flood, not allowed to go traipsing through the muck to collect data.

Many of these experiences are further branded into memory when the students make presentations and perform skits at the BEMP spring Student Congress events. The students who were disappointed by the drying of all of their wells during the construction of the Albuquerque Drinking Water Project (DWP) diversion dam later translated that into a fun skit, and their obvious delight in presenting this in front of others was well-tempered with their ending conclusions on why they saw certain changes at their sites. These events will stay with them, and in addition, they will be remembered by others who watched their presentations.

Likewise, put yourself in the shoes of the 4th graders who monitored a thickly-forested site in Belen for half a year only to show up the seventh month to find a blackened landscape. Thick fine ash covered the ground where they had once hidden under saltcedar to write in their journals. Yes, they knew the saltcedars were exotic, but they also recognized that they make superb fortresses, perfect for feeling safe and secluded. Others in the class preferred climbing on an old fallen cottonwood trunk for their journal writing. The stunned silence at seeing that favored perch blackened and ruined by the hot-burning fire quickly gave way to delight, as one student (followed inevitably by all) learned to use the oldest of drawing mediums: charcoal. The canvas of choice, naturally, was their own faces. The students commented on how the black soil made the burned site feel hot compared to the adjacent site which was still covered with grasses and yerba mansa. Even areas of bare dirt and wood chips were cooler than the blackened soil, so, they brought out their thermometers and compared ground temperatures to confirm what they had discovered. By the time of their last monthly monitoring, there were already lush green swales in the black ash as grasses, yerba mansa, and rushes reclaimed their territory. Many trees, too, were resprouting, leaving students knowing that their site would soon be back.

If you ask, you will find that these sites do indeed "belong" to the students. Before participating in BEMP, many of these youngsters (and even some university interns) had never been to the bosque. By the end of the year, those same newcomers can show you around their site, pointing to a spot where they once found porcupine tracks; where they saw a lizard eating bugs out of a pitfall trap; which litterfall tubs have ant nests beneath them; and where the best spots are for sitting and drawing. This sense of ownership/stewardship/belonging to the land that many of us take for granted is sadly lacking for many youngsters of today. Fostering this sense of stewardship in people is one of the key goals of BEMP. Students are quite willing to link themselves to their site if given the opportunity. If enough of a positive impression is made that their sense of stewardship for the ecosystems continues through adulthood, then these same students will nurture this caretaking desire in others, and keep the needs of ecosystems in mind as they make decisions as legislators, scientists, teachers, parents, workers, recreationists, or whatever their chosen role in society may be. Who knows? Perhaps BEMP's biggest impact is yet to come!

Picture 1. Students use field guides to identify tracks in the dirt at a BEMP site.

Time has shown the data collected by these 2,000 young scientists who monthly monitor BEMP sites every year to be robust, valid, and useful. They are requested and used by other scientists, federal and state agencies, students and BEMP staff, and prove just as useful as the data collected by staff or hired botanists. Agencies and scientists interested in clearing exotic vegetation and restoring areas of the bosque are learning from the data what BEMP second graders can easily tell you: mechanically clearing an area often leads to five foot diameter tumbleweeds and six foot tall *Kochia*.

We are learning a lot from our student-collected datasets. Many BEMP sites have had restoration work, which allows us to track abiotic and biotic responses to various methods of clearing and restoration and gauge their success. After three years at some cleared sites, cover from exotic *Kochia* plants was still increasing, though the native plants were sometimes a dominant component of the understory. By year five, many of the trees chopped down and initially chemically treated had three to five times the number of growing stems, and provided substantial cover at the sites. While this scenario has been the most common one at cleared BEMP sites, there is always the exception. The Rio Grande Nature Center (RGNC) has remained clear of exotics (having no exotic tree regrowth even in the first year after clearing), and the only exotic understory plants are white sweetclover, tumbleweed, and exotic grasses, all of which were present at the site to begin with, if not as prevalent as after clearing.

Groundwater is, of course, of particular interest to most of us in this semi-arid region. The commonly held belief is that removal of exotic trees, particularly phreatophytes like saltcedar, will result in an increase in the level of the water table, that is, remove saltcedar with its roots in the groundwater, and there will be a measurable increase in available water. We can see the diel signal, or the impact of trees on the water table, so surely we would be able to see the recovery of a water table if those same trees are removed. We can also see changes in the water table over the seasons, and yet with more than ten years of data, BEMP shows the gradual decline of the Albuquerque water table at some sites, in spite of variations in precipitation and river flow (with the exception of high river flows in 2005). However, many of our cleared sites have yet to show a recovery of the water table after exotic (and some native) trees are removed. Pumping in Albuquerque and the marked drawdown of the deep aquifer (Falk et al. 2011) are likely influencing/mitigating factors on water table recovery. Trees cannot compete with nor compensate for such a large demand on groundwater. But, even at the BEMP sites well south of Albuquerque, and possibly outside the sphere of influence of the most significant drawdown, we do not see a difference between cleared and forested sites attributable to the removal of exotics.

Are there any water savings from exotic removal? Most likely so, especially at sites where the removed trees are chipped, creating a barrier to soil evaporation losses. When removed trees are allowed to stump and root-sprout, however, they come back more densely than before they were removed. Any initial savings in water consumption (through reduced evapotranspiration or ET) is then countered by higher ET losses from the new, denser growth (Cleverly et al. 2008). Where the trees do not resprout (usually through multiple chemical treatments), any savings in ET is not yet evident as an impact to the groundwater.

Effects from clearing vegetation can best be seen in the vegetation transect data, although tree regrowth can also be tracked through the litterfall data. As early as our first report (2001), we compared these two datasets and maintained that they are a great example of cross validation; this is still the case. At each of our 25 sites along the Rio Grande, over 500 students collect fallen plant materials (litterfall) from ten tubs per site each month. The collected leaves, buds, seeds, flowers, twigs, stems and bark are dried, sorted, and weighed. This measure of primary production is collected and processed by students, and is supported by the ten 30 m vegetation transects measured by hired botanists each August (who monitor plant cover and species lists for each site).

The vegetation transect data give an almost comprehensive list of species found at each site and are used to calculate species diversity, exotic and native cover, and to track changes in vegetation over time, especially following disturbance.

The litterfall data are used to track only the dominant tree species, but are still useful in showing differences between sites or tracking changes within a site over time. For example, Belen started off as a young site, with young cottonwoods and willows cropping up amidst recently flooded and scoured grounds and groves of mature Russian olive stands. The data show a gradual increase in native leaf production and reproductive parts as cottonwoods and willows became sexually mature. There is little wood biomass dropped at this site (as seen in both the litterfall dataset and the woody debris dataset). Although Russian olive cover has increased slightly over the years, likely due to a slow dieback occurring at the innermost parts of each Russian olive, Russian olive leaf fall is slowly declining.

Education and Stewardship

It started with a pair of sixth grade boys. One held the spool of a 100-meter tape measure, the other the running end. Guided quite firmly by a sixth grade girl with a compass, the boys stretched the tape measure along the northern boundary of what would come to be the very first Bosque Ecosystem Monitoring Program (BEMP) site. The boy with the tape in his hand crawled on hands and knees through the thick New Mexico olive understory as the girl with the compass shouted to him to stay more to the left and keep the line straight and on course. Today, that sixth grade girl does a whole different type of directing, now that she has a B.S. in Theater and performs off-Broadway in New York City. And for over ten years now, ‘her’ BEMP site has been monitored by more than 750 different sixth grade students, along the very lines stretched out by that trio of students.

Since that first class of Bosque School sixth graders set up the Alameda BEMP site in the late winter and early spring of 1997 just south of the Alameda Bridge in Albuquerque, over 25,000 students, teachers, and other community members have been involved in BEMP (Figure 1a). Annual participation is now around 5,000, with people from rural, tribal, and urban communities. Our students come from public, charter, parochial, private, and home schools. Some monitor BEMP sites all year long; some participate in BEMP community education events; and others experience BEMP in summer camp or one day field trips to the bosque (Figure 1a). Like New Mexico itself, the program is diverse, with the majority of participants from Hispanic or Native American backgrounds (Figure 1b).

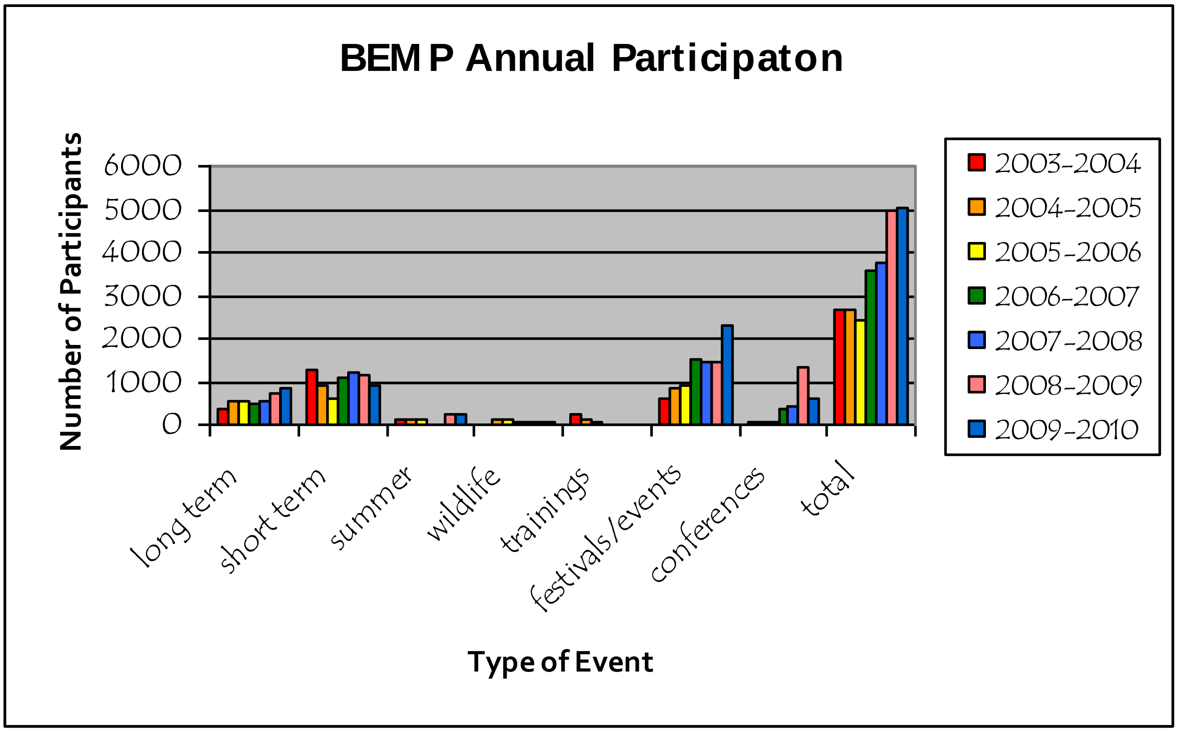


Figure 1a. BEMP annual participation since 2003.

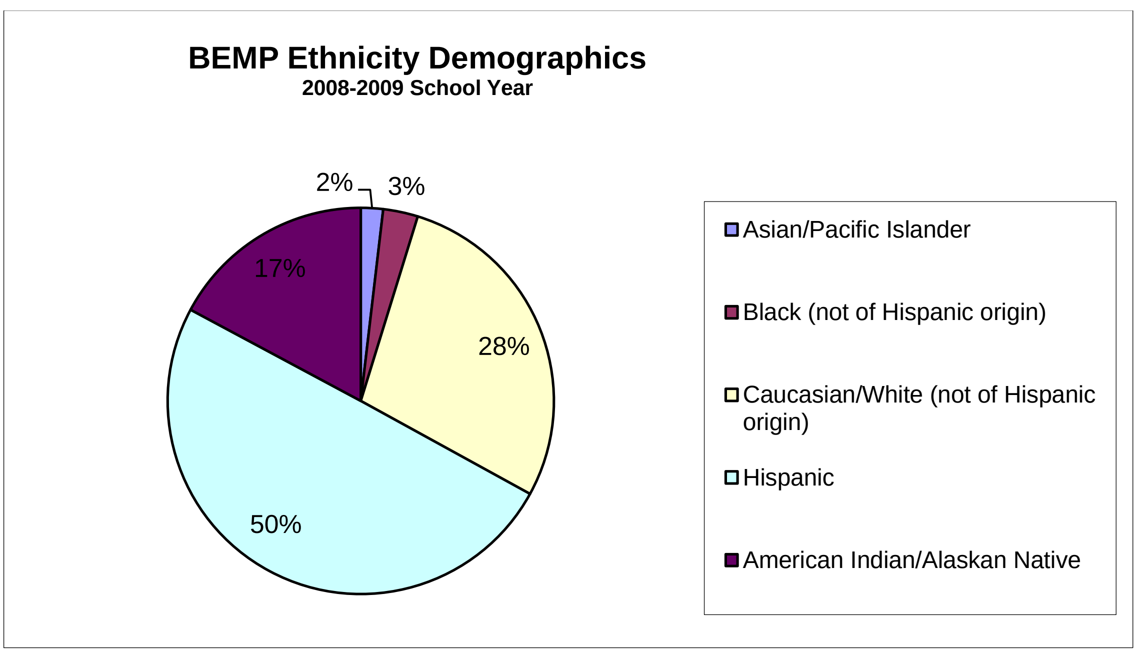


Figure 1b. BEMP ethnicity demographics from 2008-2009.

“Bosque Internship – Bosque Ecosystem Monitoring Program,” is a UNM Biology undergraduate class (408L) and graduate class (508L) connecting UNM students with BEMP classrooms. In addition to learning about the structure, functioning, and biological diversity of the Rio Grande and its riverside forest, students in these UNM classes also serve as mentors to younger students, provide quality control oversight at BEMP monitoring locations, and otherwise support BEMP within the community.

No matter what sort of background they have, where they live, or even how old they are, all BEMP participants share several key elements. First and foremost, they are citizen scientists. They gather data about key ecosystem variables in the Rio Grande’s riverside forest. All BEMP participants are part of a larger ecosystem study where their findings and results have meaning beyond the classroom because they are being used by natural resource managers to inform multi-million dollar decisions. Second, BEMP participants all play a role in being stewards of their home watershed, thereby gaining a sense of place within the landscape in which they dwell.

Most BEMP students participate in the field work that is part of routine monitoring efforts. They “beep” groundwater wells, scoop leaves out of litterfall tubs, go eyelevel with rainfall gauges, dig into soil and set pitfall traps, and accumulate knowledge about bosque flora, fauna, hydrology, and ecosystem interaction. They also spend time in the out-of-doors. There they get cold, swat off mosquitoes, get mud on their shoes, and brush their hands along prickly and irritating tumbleweeds. Yet too, they have watched a bald eagle lift off from feeding on a mallard carcass just to be replaced by a red-tailed hawk. Others have laughed and splashed about in big chest waders as they gathered macroinvertebrates from the river. Still others, while canoeing through the heart of Albuquerque, have seen great blue herons perched in cottonwoods looking more like dinosaurs than birds. Coyotes, beaver, deer, sandhill cranes, Rio Grande silvery minnows, and Woodhouse’s toads have all captured their imaginations. They know the fresh smell of the woodland after a heavy rain and have discovered the pungent odor of yerba mansa growing in low lying ground. In short they have come to know the bosque, not as a name, but as an experienced place. They build visceral connections with their home landscape.

There are other students who have used BEMP as a launching pad for creating better connections within their communities. Native American students from Sandoval County have explored community traditions with their elders as they monitored the bosque on their tribal lands. One Albuquerque middle school BEMP student coordinated dozens of his peers to protect mature cottonwoods from being fed upon by beaver, painstakingly wrapping the trees in chicken-wire mesh. He was recognized for his actions with a national community service award and prize money. He donated the money to BEMP to create a bus fund to pay for BEMP field trips. He wanted to make sure that students who would not otherwise have the opportunity to monitor the Rio Grande and its riverside forest would get to participate in BEMP.

BEMP also supports a variety of in-depth science research projects. A Valencia County high school student used BEMP arthropod data to compare burned and unburned forest sections for a research effort that would win him a state science fair competition. A pair of home school students won a national science competition sponsored by the Discovery Channel with their BEMP research on germination of exotic saltcedar plants. A pair of BEMP high school students took their porcupine research project to a southwest professional wildlife meeting and won the student prize by beating out graduate students. Other research projects supported student science learning in a wide variety of settings, even if they did not receive outside recognition. Although the awards and accolades for individual BEMP students are exciting, the day to day, month in, month out, year-to-year science for thousands of kids is also remarkable.

Every BEMP site – from Alameda, our first, to Crawford, our 25th – has been installed in cooperation with a local K-12 school, but there is no “one type of BEMP classroom.” For example, one site involves elementary public school kids while a short distance away, an Advanced Placement Biology class from La Cueva High School monitors another site. Both groups collect the same core data, but each involves different classroom lessons and age-appropriate ancillary lessons and experiences. It falls to the BEMP staff to make sure that each classroom is supported in the best way for a particular group of students. Our goal is to have BEMP serve the needs of student learning that is consistent with state and national science education reform efforts, benchmarks, and standards. Our program is content rich, directly connects university faculty and natural resource scientists with students, and demonstrates practical applications of theoretical scientific concepts.

BEMP staff routinely survey participating teachers and consider how they use the program with their students. This information was published in the 2005 Bosque School report, “Participating Teachers’ Perceptions and Use of the New Mexico Watershed Watch and Bosque Ecosystem Monitoring Programs.” Through seven replicated surveys conducted across ten years, all teachers whose K-12 students participated in one of two long-term environmental monitoring programs were asked about their use of those programs, their reasons for program participation, how they used it within their curricula, how well it fit their students, and the obstacles they faced. All participating teachers in BEMP’s sibling program, New Mexico Watershed Watch (NM-WW) stream monitoring program (sponsored by the New Mexico Department of Game and Fish) were surveyed in 1996, 2001, 2003, and 2005. A nearly identical survey instrument was used in 2001, 2003, and 2005 with teachers whose students participated in BEMP. Although reasons for program participation varied widely, dominant themes included a desire for teachers to provide their students with opportunities to participate in “real science;” to do work that had meaning beyond their own classroom; that took place in field settings with “hands on” activities; and that provided for community-based, service learning. Obstacles for continued participation tended to be logistical. It appears that strong administrative support for each teacher’s participation in the studied monitoring programs is an important element. Overall, participating teachers believe that the BEMP and NM-WW programs put their students into the field with a reasonable level of challenge and solid support. (The full report is available at BEMP’s web-site).

Across BEMP’s first decade, over ten state and national teaching awards have been presented to BEMP classroom teaches for their accomplishments with their students and their involvement in BEMP. This includes the North American Association of Environmental Education Classroom Teacher of the Year award presented to Belen Public School’s Rio Grande Elementary teacher Molly Madden. Mary Erwin received the Environmental Education Association of New Mexico Outstanding Educator of the Year award for 2008. All grantees and award recipients have often remarked on the power and success of the partnerships BEMP creates between students, natural resource managers, and scientists.

Out of BEMP classrooms emerge thousands of stories, some simple and sweet, such as a University of New Mexico Professor who had a group of middle school students sniffing dangling pupae of cottonwood beetles attached to an overhead branch. Others are groundbreaking, like the BEMP students who discovered ten years after a forest fire that stump sprouted cottonwood trees can indeed achieve sexual maturity, flower, and reproduce. Still other stories are milestones, like the

Hispanic girl who participated in BEMP as a sixth grade student and later, as a University of New Mexico biology major and BEMP intern, returned to her South Valley neighborhood to serve as a mentor to a new generation of BEMP students, helping them set goals of going to college, and perhaps even becoming biology majors. BEMP has reached a level of maturity where its stories are now circling back, connecting science, education, forest, river, and students into one experience for the good of the community and the bosque.


Picture 2. BEMP students work together to read and record precipitation data.

Site Report/New Sites

What follows are brief reports on the history of each BEMP site, in the order in which they were established.

Alameda – With a dense understory of New Mexico olive and a mature overstory of Rio Grande cottonwood, Alameda represents one of the most native sections of the bosque. Unlike many BEMP sites where exotic species represent half or more of the vegetation, over 90% of the vegetation at Alameda is native, telling an older story, of how parts of the bosque might have been before European contact. It is fitting then, that Alameda is the oldest BEMP site.

In the late winter and early spring of 1997, Bosque School sixth grade students and their teachers marked out transects, dug wells, and installed litterfall tubs and pitfalls. Since that time, every successive Bosque School sixth grade class has helped to monitor the Alameda BEMP site. It is BEMP's longest school partnership and has involved six different teachers and over 750 students.

The site is dominated by mature and senescing cottonwoods. During the first ten years of monitoring, we have not documented any new cottonwood sprouts within the site itself, though there have been a few at river's edge just beyond the site's boundaries. Over that same span of years, a number of large cottonwood branches have sloughed off, and several mature cottonwoods have died.

Mechanical clearing of exotics has taken place along this stretch of bosque, though interference within the site itself was minimal, since the vegetation is mostly native. Of particular concern in regard to management of the area was the installation of the San Juan Chama Drinking Water Diversion Project's dam, just upstream of the site. As part of understanding that project's impacts, the City of Albuquerque's water utility, precursor to what is now the Albuquerque Bernalillo County Water Utility, approached BEMP and requested assistance in monitoring the area. Using the Alameda BEMP site as its cornerstone, BEMP bracketed the proposed dam with three additional sites. As engineering plans changed, two additional BEMP sites were added to the area. Across time, the Alameda BEMP site provided us with a perspective of pre and post dam construction conditions, and then of the impacts of the Diversion Project in this stretch of the bosque.

The Alameda site remains of fundamental importance to BEMP. Its longevity, connection with the area's largest river diversion project, and its high native composition make it essential to a long-term understanding of the bosque. With its adjacent sandbars and islands, it affords excellent wildlife viewing and has provided countless opportunities for students to connect with nature in the bosque.

Rio Grande Nature Center – The approximate location of the Rio Grande Nature Center (RGNC) BEMP site was decided in late November 1996 at a meeting between Rebecca Tydings of the Center and Dan Shaw and Cliff Crawford of BEMP. The site's perimeter, established that following December, surrounded a dominant stand of slender but mature cottonwoods, and clusters of Russian olives and saltcedars. The understory was dominated by white sweetclover, snakeweed and a variety of arid-adapted shrubs, forbs and grasses. Throughout the following spring, the site evolved into a working reality made possible by the help of friends and volunteers: groundwater wells were inserted, vegetation plots mapped out, cottonwood diameters measured, and litterfall tubs, pitfall traps and ground/air temperature dataloggers installed. However, it was not until November 1997 that 8-foot treated posts were installed and hung with rain gauges. Meanwhile, data collection, mainly by adult volunteers and BEMP staff, commenced as the site developed. Since then, monitoring has been augmented by students in the Nature Center's summer camp program, as well as by teachers and students from various schools. BEMP interns and staff were also involved from the beginning, and during the first few years, a small and dedicated group of home school families was a vital addition to the program at the RGNC. They were succeeded over time by classes from a number of schools, most recently by teacher Mary Erwin's enthusiastic classes at Bandelier Elementary. In 2004, understory clearing prompted by a nearby bosque fire completely changed the appearance of the Nature Center site, but monitoring continued without missing a beat, as did the decade-long support of BEMP by the RGNC.

Los Lunas – The Los Lunas site was installed in March 1997 through the work of Los Lunas biology teacher Debbie Loftin and her students, and beginning in October 1998, Century High School, an alternative high school in Los Lunas, monitored the site, with the help of teacher Rick Cole. BEMP staff and interns took over monitoring when Century High School could not monitor any longer. In August 2004 Los Lunas Middle School teacher Brian Crawford and Ron Becker, a teacher of gifted students at three elementary schools in Los Lunas, co-monitored the site. In 2006, Ron took over all monitoring with his elementary-aged students. Then in fall 2007, Rick Cole again joined BEMP, and his environmental science class at Los Lunas High School continues to monitor the site. A natural trough in the middle of the site floods via seepage each May, when the river is at high stage. The trees are aging here, and large cottonwood limbs are steadily falling.

Belen – Rebecca Tydings of the RGNC chaired a meeting of teachers at the Senator Willie M. Chavez State Park at Belen on June 7, 1997 to provide instruction about the Bosque Educational Guide. She asked Cliff Crawford to discuss BEMP and the bosque monitoring effort. One of the teachers present was Molly Madden, from nearby Rio Grande Elementary, who was already spearheading a drive to develop a relationship between the Belen Public Schools and the state, and was also interested in establishing a BEMP site at the park. Clarence Valdez, who managed Willie Chavez State Park, gave Dr. Crawford a tour that revealed one grassy stretch between the old mixed bosque to the west and the Rio Grande, where stands of young cottonwoods, coyote willows and Russian olives (but no saltcedars) stood partly covered with overbank flood water. Apparently, the site had been mowed regularly by the Bureau of Land Management until two or three years before. No convincing was necessary, and on July 27, Dan Shaw and Cliff Crawford set up a provisional BEMP site perimeter. After adjustments to that original perimeter, the rest of the site was carefully set up and trails were cut through the thick willows. Many volunteers were involved, and the first monthly collection was made on February 27, 1998 by Molly Madden, several other teachers from Rio Grande Elementary, and a great set of eager young students. Ten years later, the perhaps 15-year old cottonwoods are tall, capable of flowering, and crowded, as are the willows. Russian olives remain a prickly presence. The site experienced a low ground fire in February 2007 which killed only a small number of younger trees. Earlier in the decade, the site was studied for nutrient cycling under a 4-year Conservation and Restoration Biology grant to UNM. Molly Madden, now retired, still comes out with Delphine Baca and her second grade class for monthly monitoring.

Santa Ana – The Santa Ana site, located adjacent to a fitness trail that winds through the bosque just east of the Hyatt Regency Tamaya Resort and Spa, was BEMP's fifth site. It was installed in partnership with the Pueblo of Santa Ana in July of 1999, and is monitored by Bernalillo High School's Environmental class and Santa Ana's Department of Natural Resources site representative, Laura Peña.

Out of respect for Santa Ana's tribal government, this site maintains ten leaf litter bins and two rain gauges, but no groundwater wells. The site is a great example of a managed native-dominated bosque, as it has undergone strict invasive/exotic control under the guiding hand of the Pueblo's Department of Natural Resources. More information about the Pueblo of Santa Ana's Department of Natural Resources can be found at http://65.100.28.11.

Savannah – On New Year's Day, 2000, Bosque School moved into its permanent campus near the corner of Montaño and Coors Boulevards in Albuquerque, directly abutting roughly 113 acres of riverfront bosque on the river's west side. At that time, the bosque acreage was owned by local philanthropists Ray and Barbara Graham. Over time, the Grahams had maintained a portion of the bosque by mowing large swaths of it on a nearly annual basis. In so doing, they created an area of grasses and forbs, with island pockets of overstory cottonwood stretching above a thick understory of Russian olive, saltcedar, and other woody stemmed plants. The overall condition of the meadows surrounding small copses of trees created the impression of African savannahs.

Bosque School sought to establish a local BEMP site and the mowed area represented a management strategy not currently contained within any other BEMP site. Because of its unique characteristics, this BEMP site was named the Savannah site and it has become the most visited of all BEMP's sites. BEMP established a BEMP Educator position, along with a program that supports visiting students for one-day study trips to the bosque. Funds secured from the National Science Foundation, Albuquerque Community Foundation, PNM Foundation, and other foundations support study sessions with bus money and where necessary, money for substitute teachers. BEMP now annually hosts about 2,000 students and other visitors for study trips to Savannah, helping them participate in bosque ecosystem monitoring. Core monthly monitoring is done by either visiting students, or Bosque School 6th grade students.

In early 2003, the 113 acres owned by the Grahams, which included the Savannah BEMP site, was sold to the City of Albuquerque and preserved by incorporating it into the City's Open Space program. A covenant requires the City to allow Bosque School to continue its environmental science, education and related activities on the 113 acres in perpetuity, guaranteeing the continuation of BEMP at this location.

In June of 2003, human-caused wildfires burned through the bosque on both sides of the river and on both sides of Montaño Boulevard, directly impacting the bosque south of Montaño Bridge on the northernmost lands previously owned by the Grahams. Because of their reduction of wildland fuels, the mowed areas served as firebreaks, allowing firefighters the opportunity to stop the fire's spread before it moved further south and into the Savannah site.

Since the fire, the City has periodically mowed the Savannah site, but not as frequently as when the Grahams owned it. There are periodic flushes of woody stemmed plants, including both natives such as the Rio Grande cottonwood, and exotics like Russian olive and tree-of-heaven.

Lemitar – Lemitar, our southern-most site, is located just north of Socorro. Installed at the Socorro Nature Area in 2002 with the support of the Socorro Save our Bosque Task Force, and in particular, with the help of Wes Anderson of the US Bureau of Land Management and Doug Boykin of New Mexico State Forestry, it is our only site outside the levee (and in this case also outside of the concrete-lined Low Flow Conveyance Channel). It is also our most xeric site. Much of the landscape is open, with a sparse cover of grasses, forbs, broom dalea, sand sage, and four-wing saltbush. A handful of stunted cottowoods can be found scattered across the site along with interspersed clumps of saltcedar. Cottonwood Valley Charter School students have routinely assisted in monthly collections at the BEMP site since it was set up.

National Hispanic Cultural Center – The National Hispanic Cultural Center (NHCC) BEMP site was made possible in 2001 when Cyndie Abeyta, the Middle Rio Grande Bosque Coordinator at Ecological Services, U.S. Fish and Wildlife Service, made arrangements for its establishment with NHCC officials. The site was setup mainly by School on Wheels teacher Vince Case and his hardworking students. In 2009, Vince continued as site representative; he and his students exemplify the value of careful long-term monitoring of environmental change in the bosque. This is especially true at a site which has been impacted by the clearing of woody litter and invasive tree species by City of Albuquerque Open Space, and by the extensive removal of jetty jack lines that were constructed in the mid-1900s to counter the effects of river flooding. Partial repositioning of some of the site's original vegetation plot locations is one consequence of these actions. Currently, the site is quite open, with a log-lined dirt road running south along the river from the bike path near the Avenida Caesar Chavez Bridge. Its big old cottonwoods are an attractive backdrop for the large NHCC parking lot just beyond the levee and riverside drain to the east. The Center and its Jardines del Bosque project has been a strong supporter of the BEMP site monitoring, and also of education, research, ecology and restoration on the 12 acres that includes the BEMP site.

Ohkay Owingeh (formerly the San Juan site) – Located beside an extensive constructed wetland at the Pueblo of Ohkay Owingeh (formerly called San Juan Pueblo) just north of Española, is a BEMP site that is periodically flooded by rising wetland water and a correspondingly rising adjacent water table. It has experienced wildfire twice in the past decade (once before the site was installed, and again in June 2003), and it was cleared of invasive vegetation in 2001, the year of its installation. Its relatively few cottonwoods are very large and prone to losing limbs. The largest has a diameter of over 9 feet. Resprouting Russian olives are kept trimmed; the site is otherwise heavily vegetated by mostly native shrubs, vines, forbs and grasses. From the now unused farm fields to the east, the view of the site is striking. David Morgan, the environmental consultant who built the wetland, originally received permission from Charles Lujan, the pueblo's environmental director, to ask BEMP to set up a monitoring site as part of the wetland restoration project. Giselle Piburn, a Santa Fe resident who works for Morgan, was responsible for getting Ohkay Owingeh Community School students to participate in the site's monthly monitoring. As the representative for this most northern of BEMP sites, she has gone to great lengths to interest students and teachers in the program; their regular presence at BEMP's annual student congresses is but one example of that dedication.

Diversion – The Diversion site was completed in November 2002 and has been monitored by Bosque School 6th graders from the inception. The Drinking Water Diversion (DWD) fish passage is located at the northern end of this site. This site is one of four that have automated groundwater recording devices on all of the wells as part of an on-going collaboration between the US Army Corps of Engineers' (USACE) Urban Flood Demonstration Program and the University of New Mexico.

Calabacillas – The Calabacillas site was installed in early 2003, and was monitored by the River Rangers after-school group through the spring of 2005. Since the fall of 2005, monitoring has been undertaken by elementary school students from Dolores Gonzales Elementary School and their teacher, Jodi Colchamiro. Calabacillas is on the west bank of the river across from the Alameda site and is the southwest bracketing site of the DWD.

Minnow – The Minnow site was installed during late 2002, with a cluster of five groundwater wells. Precipitation gauges were installed in early 2003. This site was initially set up to monitor only those two functions, but with the decision to construct the DWD dam upstream, Minnow turned into a full BEMP site, monitored by a home-schooled group of children coordinated by educator Lee Crowder. The Minnow site was profiled during a spring 2008 visit by Nepalese officials who are interested in transferring the BEMP model to a stretch of the Bagmati River, which runs through Khatmandu, Nepal. Minnow is one of four sites which have automated groundwater recording devices as part of the collaboration between the (USACE) Urban Flood Demonstration Program and the University of New Mexico.

Harrison – Harrison was installed in spring of 2003. As part of the site is located in the floodplain, about 70 % of the site has flooded each May for 2-4 weeks, depending on the flow each year. The willows have doubled their height, making the site quite a maze. Harrison Middle School teachers Jane Nedom, Christine Penfold and Laura DeSmet have monitored the site with their students throughout the years. Currently, teacher Josh LaClair is in his second year of participating in BEMP.

Sevilleta – The Sevilleta site is located on the southern boundary of the Sevilleta National Wildlife Refuge just upstream of San Acacia Diversion Dam. It was installed in 1993. Woody vegetation at this site is extremely dense and consists primarily of Russian olive and saltcedar mixed with cottonwoods and a patchy understory of coyote willow. Most of the cottonwoods are saplings but some are relatively large trees which, judging from old Bureau of Reclamation river maps, are probably not much older than 30 years. In the last few years many of the young cottonwoods have begun rotting at the stem base and dying. It is possible that the mortality is linked to the site's high groundwater salinity and/or to a fungal/bacterial infection of root systems. The soils contain heavy clay, which retains occasional overbank floodwater and water from strong rains for some time. Occasional swards (grassy surface areas) and small meadows dominated by saltgrass occur among the trees, and small stands of red bladderpod provide patches of color in the summer. In the fall of 2007 the Refuge completed a sheltered education center and an education pond adjacent to this BEMP site. For the past five years the site was monitored diligently by Beth Crowder and her family, as well as by other families in the High Desert Home School group.

Valencia Cleared – In early 2003, the Valencia Soil and Water Conservation District cleared fifteen acres near the Willie Chavez State Park in Belen. In the summer of 2003, the Valencia Cleared site was established in an area that had been dominated by cottonwood, Russian olive and saltcedar but was now an open area of wood chips, with a few cottonwoods and Goodding's willows and some quickly reestablishing patches of yerba mansa. Although the site was rapidly taken over by regrowth of the cut trees and native and exotic understory, it remained clear enough to provide a perfect staging ground for firefighters to create a firebreak and stop the 2007 Belen fire (see Valencia Forest section below). Monitoring of the site was taken on by Rio Grande Elementary, starting with Chris Montgomery and her class of 5th graders for the first two years and currently monitored by Monica MacEachen and her 2nd graders.

Valencia Forest – Directly adjacent to the Valencia Cleared site is the Valencia Forest site (the two sites share a border). Also established in the summer of 2003, this site remained uncleared and dominated by cottonwood, Russian olive and saltcedar, with a lush saltgrass meadow at the south end of the site. Janet Tabet's 4th grade class from Rio Grande Elementary monitored this site for the first several years. In February 2007, the site burned, along with many acres to the south. Due to the potential hazards of monitoring a burned site where dead cottonwoods were left standing, BEMP staff took over the monitoring. The Middle Rio Grande Conservancy District subsequently cleared the site of some of the dead standing cottonwoods and much of the saltcedar and Russian olive regrowth that occurred after the fire.

Montaño – The bosque fire of 2003 permitted BEMP an excellent opportunity to consider the response of the riparian forest to fire. Bosque School had some limited pre-fire information from the area that had burned, and even though it was not as comprehensive as a BEMP site would have offered, there was still enough information to start evaluating the shift in environmental conditions. A decision was made to install a BEMP site inside the recently burned area a few weeks after the fire. Located between the Savannah BEMP site and Montaño Bridge, it would serve as one half of the paired combination of a burned and an unburned site located within 100 meters of each other. The site took the name of both the 2003 fire and the road that essentially created its northern boundary: Montaño.

The Montaño BEMP site received considerable post-fire restoration work performed under contract to the Ciudad Soil and Water Conservation District. This included downing and chipping standing dead snags; removal and chemical herbicide treatment of emerging exotics; and planting new cottonwoods and other native trees. A portion of the Montaño BEMP site received no post-fire treatment and has served as a control.

All of these efforts have been studied and documented through the Montaño BEMP site. Like Savannah, Montaño is routinely monitored by both Bosque School sixth graders and area students who visit the location as a part of study trips. The close proximity of the sites allows students to examine unburned portions of the bosque at Savannah, and burned forest at Montaño.

Reynolds Cleared – After mechanically clearing the bosque near the Willie Chavez State Park in 2003, the Valencia Soil and Water Conservation District (SWCD) continued to clear exotic trees and shrubs from different bosque areas in Belen. In order to get a more in-depth picture of forest response to clearing, two new BEMP sites were set up following the same design as the Valencia Cleared and Forest sites, where a mechanically cleared site was directly adjacent to an untreated site. These new sites were named for Marcel Reynolds, Valencia SWCD treasurer. The two Reynolds sites are north of the NM 64 Bridge, on the east side of the Rio Grande (roughly one mile north of the Valencia Cleared and Forest sites).

Wells at Reynolds Cleared were installed in spring 2004; vegetation plots, tubs and pitfalls were installed August 2004. Brian Martinez and his environmental science class at Belen High School monitored the site for two years, but the class was cut from the high school curriculum, and Brian could not continue monitoring. Subsequently, BEMP staff and interns have monitored the site. The cleared site is covered in *Kochia* and tumbleweed, with a few cottonwood pole plants, and natives such as New Mexico olive interspersed.

Reynolds Forest – Wells at Reynolds Forest were installed in spring 2004; vegetation plots, tubs and pitfalls were installed August 2004. As with Reynolds Cleared, Brian Martinez and his environmental science class at Belen High School monitored the site for two years, until the class was cut from the curriculum. Subsequently, BEMP staff and interns have monitored the site. Reynolds Forest is dominated by a cottonwood overstory with a saltcedar and Russian olive understory. Yerba mansa patches are located in the northern section of the site, and wild currant is interspersed throughout. The site continues to experience cottonwood dieback, which continues to increase the high woody debris or fuel load.

Rt. 66 – Rt. 66 was installed in December 2004 by Brian Martinez and students from his Belen High School environmental science class. A natural seep, or trough, is located in the center of the site, taking up about a third of the area. East and west sides of the depression have been cleared by Albuquerque Open Space each summer since the site installation. In spring 2008, the northern half of the site, including willows in the trough, was also cleared by Open Space crews. Tess Sanchez and her high school class at APS School on Wheels (SOW) monitored the site for about two years, after which, John Glaser and his SOW students took over the site.

Badger – Just before construction started on Albuquerque's Drinking Water Project (DWP) Diversion Dam in January 2005, wells were installed to the north of the DWD on the east bank. Only groundwater wells were monitored until 2006, when Badger came online as a full BEMP site. Badger has been monitored by Bosque School 6th graders from the start, and is one of the four sites with automated groundwater recording devices in all of its wells, as part of a collaboration between the USACE's Urban Flood Demonstration Program and the University of New Mexico.

Bobcat – The Bobcat site lies to the north of the DWD on the west bank and was installed in anticipation of DWD construction. La Cueva high school students monitored only groundwater wells until 2006, when the site came online as a full BEMP site. This site is the fourth and last of the sites that have automated groundwater recording devices as part of the collaboration between the USACE's Urban Flood Demonstration Program and the University of New Mexico.

BioPark – Discussions about a possible BEMP site at the Albuquerque BioPark reached fruition in late 2006 with an agreement involving Ondrea Hummel of the Army Corps of Engineers, Matt Schmader of the City of Albuquerque Open Space Division, Amy Henderson and other officials at the BioPark, and BEMP staff. The site was to be located in the bosque between the BioPark's Tingley fishing ponds and a proposed wetland area draining a large constructed pond to the north, roughly paralleling the nearby river bank to the west. The site would be part of the BioPark Wetland Restoration Plan, to be monitored by volunteers, schools and students in the community under the direction of BioPark education coordinators. Representatives of all parties toured the site and the general location was approved. The perimeter was measured out on January 11, 2007, installation took place between February 16 and February 22, and the first monthly monitoring began on March 20. Dave Karrmann, BioPark Aquarium Educator, is the site representative. Washington Middle School students and teachers were the main participants in monthly monitoring through May 2009. The site, which is dominated by medium sized cottonwoods over a potentially dense and rapidly resprouting Russian olive sub-canopy, is not unattractive, judging by the numbers of BioPark visitors using the north-south dirt road that bisects it. Of ecological significance is the site's proximity to the wetland and pond – its southwest corner is actually in the wetland's cattail/bulrush marsh. An extension of a Corps of Engineers Urban Flood Demonstration Project grant to UNM applied to the pond, the marsh, the BEMP site and the densely populated young willow/cottonwood/Russian olive on a nearby riverside sandbar. Christian LeJeune, BEMP's educator hydrologist monitored groundwater flows in relation to river flows during the first few years.

Santo Domingo/Kewa – The Pueblo of Santo Domingo BEMP site (known as Kewa during the time frame of this report) was created in partnership with the Santo Domingo Tribe Natural Resources Department in January of 2008. This site, located south of the pueblo and just east of the river, is monitored in a joint effort by 7th grade science students at Santo Domingo School, teacher Elaine Smith and site representative Jeff Morton of the Natural Resources Department. The Kewa site was initially funded with assistance from the Collaborative Forest Restoration Program (CFRP) grant.

The Kewa site is unique not only because of its pueblo history, but also because horses can often be found browsing the understory of the BEMP site. As at most BEMP sites, there are ten leaf litter bins and two rain gauges; however, in respect of tribal government, no BEMP groundwater wells have been installed. More information about Santo Domingo's Natural Resource Department can be found at http://sdutilities.com.

Crawford – The Crawford site is our twenty-fifth site; its boundaries and vegetation plots were set up on September 5, 2008. This site is BEMP's CFRP site (Collaborative Forest Restoration Program) and is named for the founder and program director of BEMP, Dr. Cliff Crawford. The Crawford site is approximately one mile south of the Valencia Forest site and was completely burned in the February 2007 fire that also affected the V. Forest and Belen sites. Four months after the fire, the MRGCD chopped and cleared resprouting exotic trees, as well as some of the larger (and more dangerous) dead cottonwoods. The agency cleared once more before February 2009, when the Interstate Stream Commission lowered the terrace and adjacent banks (Picture 3), creating a backwater area when river flows reach 2500 cubic feet per second (cfs) (Picture 4). With flows of 3000 cfs or more, the newly lowered area containing the Crawford site will experience overbank flooding, which has likely not been the case here for several decades. This site is nevertheless a strongly hydrologically connected area, with seep floods occurring at higher flows, creating a habitat for water-indicative plants like yerba mansa, rushes, and sedges. The vegetation at this site seems almost equally divided between natives and exotics. Along the east 200 meters of the site there is a newly established Hawks Aloft bird transect that will double as a vegetation transect, mimicking the lines of the Hink-Ohmart (1984) transects.

Picture 3. March 2009: Marsh buggies were used to lower the backwater area by 2 to 4 feet.

Picture 4. May 7, 2009: As Rio Grande flows reach 2,500 cfs they start to flow into the new backwater area. North well was left on an island of unlowered land to protect the well.

Picture 5. September 2010: Newly established vegetation covers the backwater area. Lower areas are dominated by cottonwoods, where higher areas have more saltcedar.

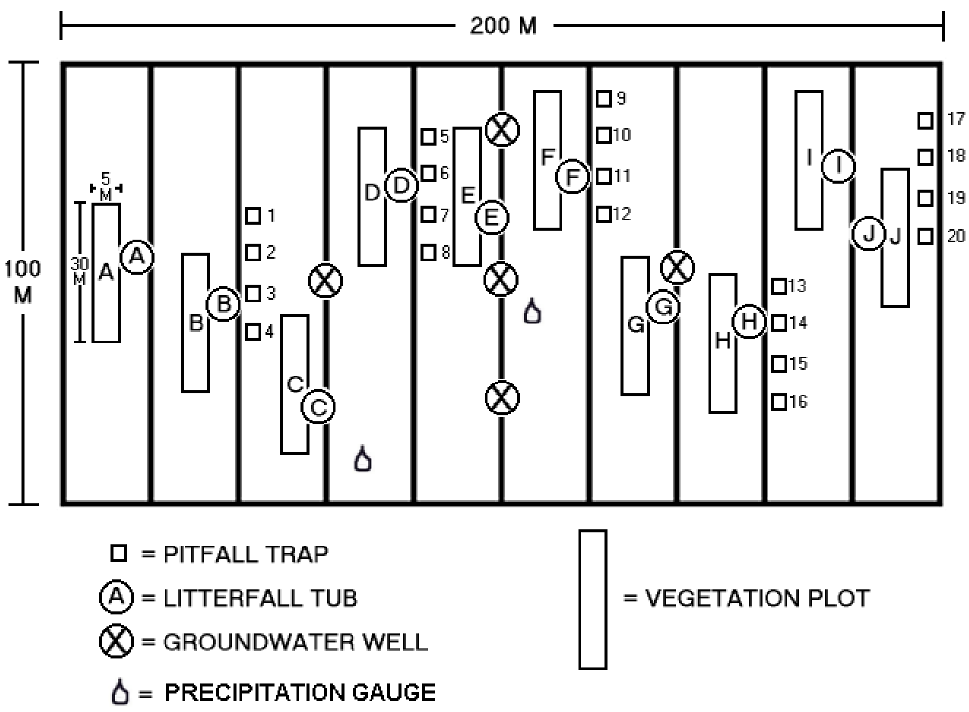


Figure 2. Typical BEMP site layout.

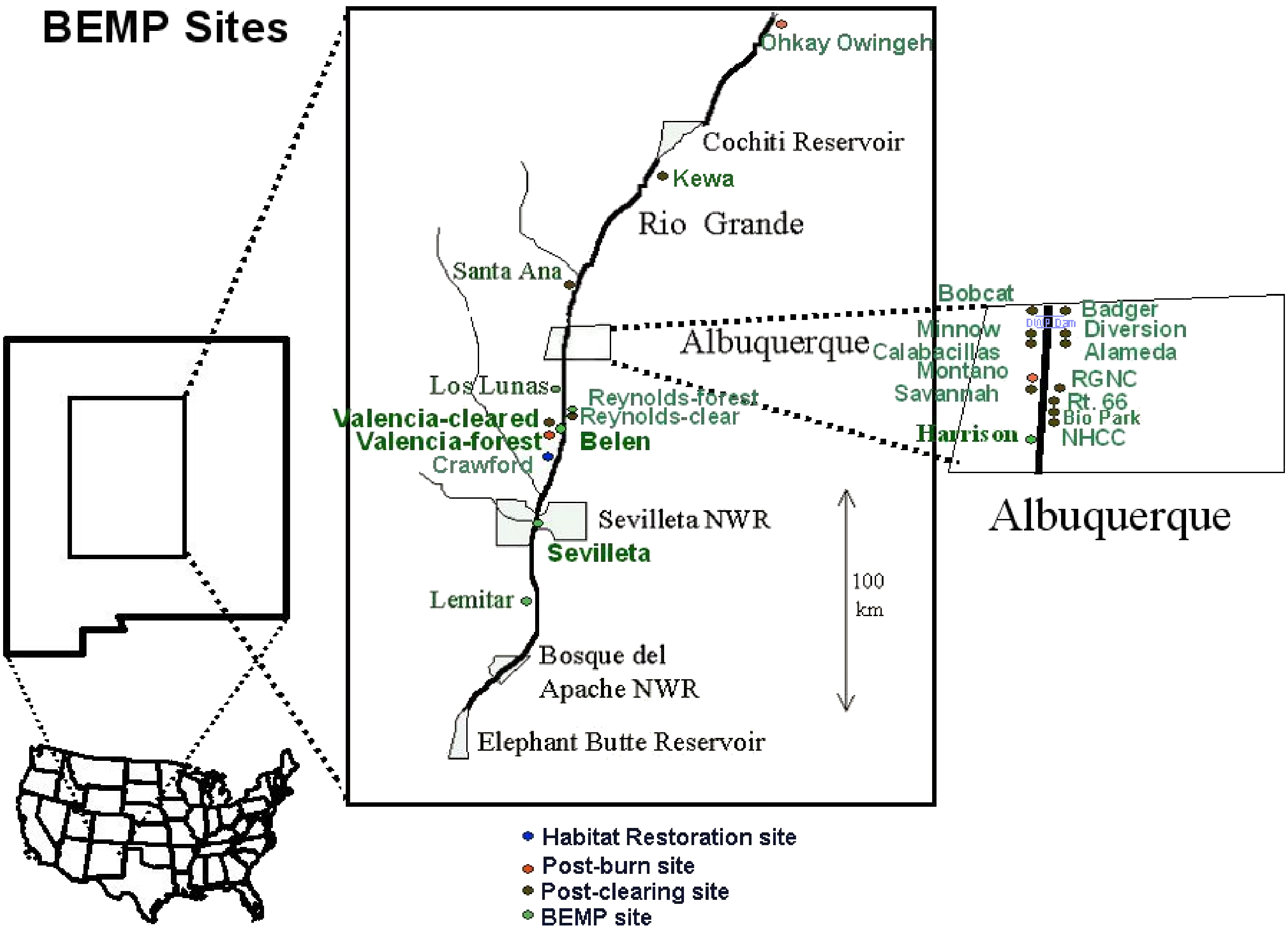


Figure 3. Map of BEMP sites.

Methods

As this is to be a complete, self-contained report, basic monthly monitoring methods are recapped and included. All methods are available online at www.bosqueschool.org.

Sites are monitored on a consistent basis, and while we still use the phrase "third Tuesday of the month" to determine when to monitor, this is now a marker for which week of the month we monitor our 25 BEMP sites. The increase in sites and number of schools involved meant a certain amount of leeway was needed in the monitoring schedule. This has also been beneficial in our UNM intern class, allowing more students the flexibility to get to more sites.

During the week of the third Tuesday of each month, basic monitoring is conducted at each site by various classes (kindergartners through high school seniors), teachers, associated site representatives, University interns, and/or BEMP staff – a combination which includes at least one trained person, if not several. Monthly monitoring consists of recording groundwater depth in the five wells at each site and the level of water in the nearby ditch or drain. These levels are then compared with the average river flow (as taken from the USGS river gages) on the day each individual site was monitored. For Ohkay Owingeh, the Otowi gage is used; for all Albuquerque sites the Central Bridge gage is used; the Isleta gage is used for sites in Los Lunas and Belen (where previously the Bernardo gage was used); and the San Acacia gage used for the southernmost sites.

With a couple of exceptions, groundwater wells are set up in the center of each BEMP site; two inch PVC pipe is pounded into the ground during a time of low river flow (and presumably deep water table). The bottom two meters of the PVC are slotted and the base is set in sand, allowing groundwater to flow into the well. The total length of each well is recorded (important for those with permanent pressure transducers, recording groundwater depth every 30 minutes). The casing height above ground is recorded and subtracted from the recorded total depth-to-groundwater each month to give a depth to groundwater from the ground surface (important when considering root length of phreatophytes). The water sensor of a Solinst water level meter or "beeper" is lowered into the well until it beeps, and the exact measurement is recorded from an exact location on each well, marked by a blackened notch in the lip of the PVC. Likewise, the depth to water in the adjacent ditch/drain is recorded from a predetermined and consistent spot at each site (e.g., the middle of a culvert, bridge).

There are two precipitation gauges at each site, one located in the open and one under canopy. As sites shift and mature, these rain gauges must occasionally be moved to maintain this dichotomy. Every month the amount of water in each gauge is recorded in both millimeters and inches; there are two separate scales on each gauge, helping to ensure accurate readings. The water level is read below an existing layer of oil. Then the contents are dumped and fresh oil is poured in the gauge to prevent evaporation (about 10 mm). Precipitation data are presented in millimeters on the website.

Finally, there are ten litterfall tubs per site; each tub is placed mid-way on a randomly located vegetation plot, found every 20 meters (Figure 2). The tubs are 40 cm in diameter and have holes drilled in the bottom to allow water to drain. The tubs are staked down, and at sites that are known to flood, the tubs are raised on a PVC stand. All fallen leaves, reproductive parts, and wood are collected from the ten tubs at each site and placed in paper bags, which are then dried for 48 hours at 60 degrees Celsius. The contents of each bag are then weighed and sorted into leaves, wood and reproductive parts. Ten dominant tree species (six natives and four exotics) are further separated out by their leaves. Data on the web are calculated in grams per meter squared for site annual sums or monthly means.

In addition to monthly monitoring, BEMP hires botanists to survey the ten 30 m vegetation transects at each site (Figure 2) once each year in August/September. Along the transects, each species is measured and recorded. If individual plants of the same species overlap, then the cover is recorded as continuous (so for any one species, there can be up to 100% cover, but no more). If there is a gap of three cm between herbaceous plants, then the cover is recorded as continuous. If there is a gap of five cm between shrubs, or a gap of 1 m between upper canopy trees, then the cover is recorded as continuous. Because there is overlap between species and between the canopy layer and understory layer, there can be more than 100% vegetation cover at a site.

As with any large program or research project, there are always a few exceptions to the established norms, and a few dates with missing data. For example, a few sites (e.g., Badger, Bobcat, Minnow) are less than 100 meters wide due to the narrowness of the bosque between the levee and river at that site. After clearing and work on the fish passage, the 'A' litterfall tub at Diversion was removed (the 'A' line was bulldozed) and only nine tubs were monitored for almost two years. Vandalism, clearing, fire, flood, falling trees, windstorms, incorrect or questionable data, and missing datasheets all lead to gaps in the data, representing less than five percent of the total data collected.

BEMP Collection Data

Pages 24 – 58 contain the graphs of BEMP abiotic and biotic data. Interpretations of these graphs begin on page 59.

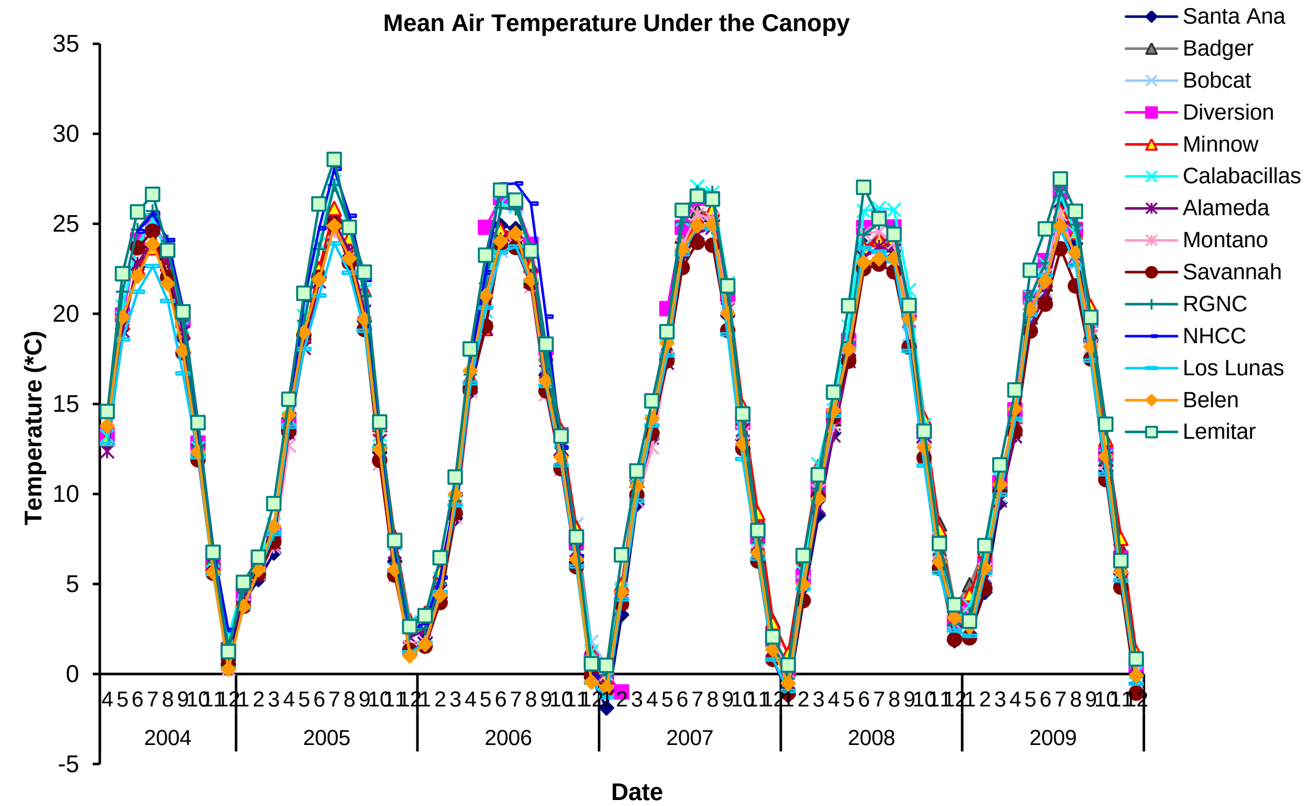


Figure 4. Mean air temperature (at 2 m) under the canopy (sites listed north to south).

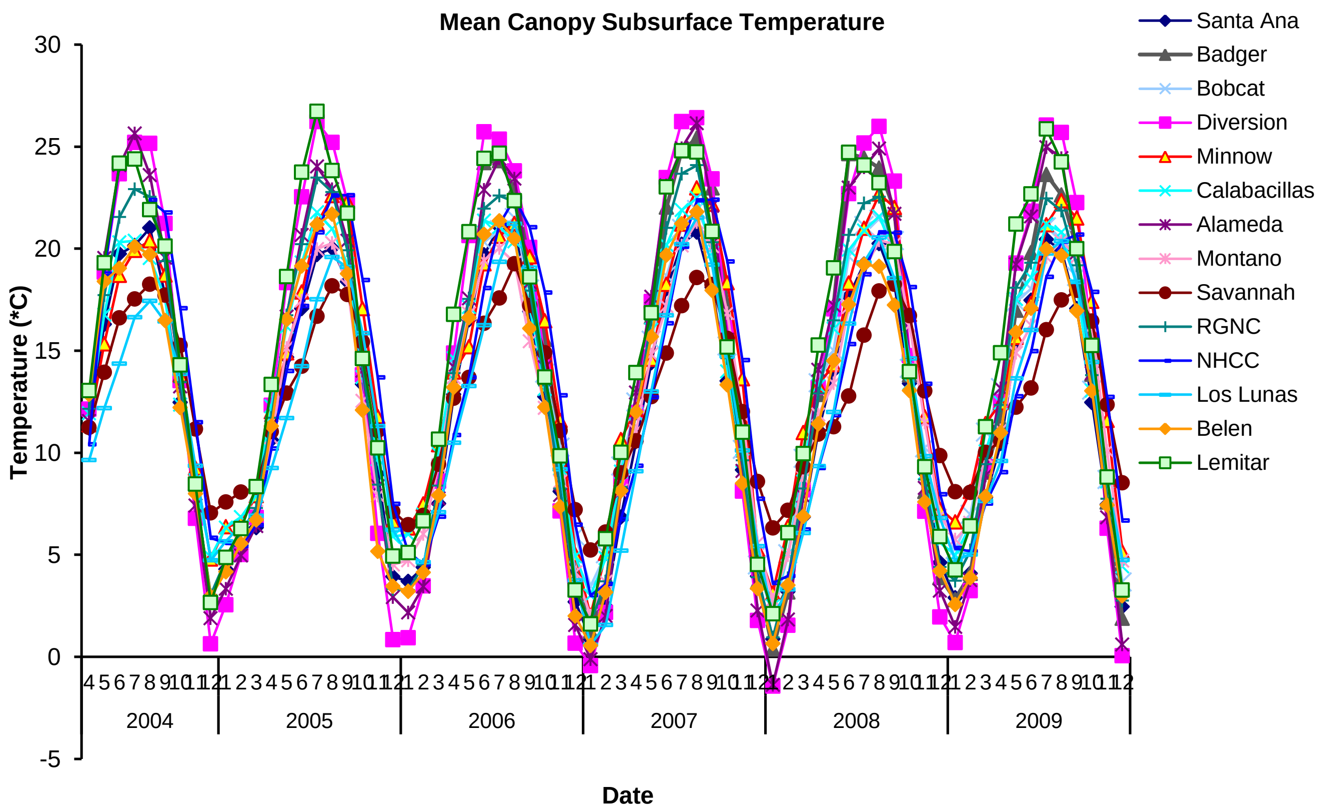


Figure 5. Mean subsurface temperature (2 cm below ground) under the canopy (sites listed north to south).

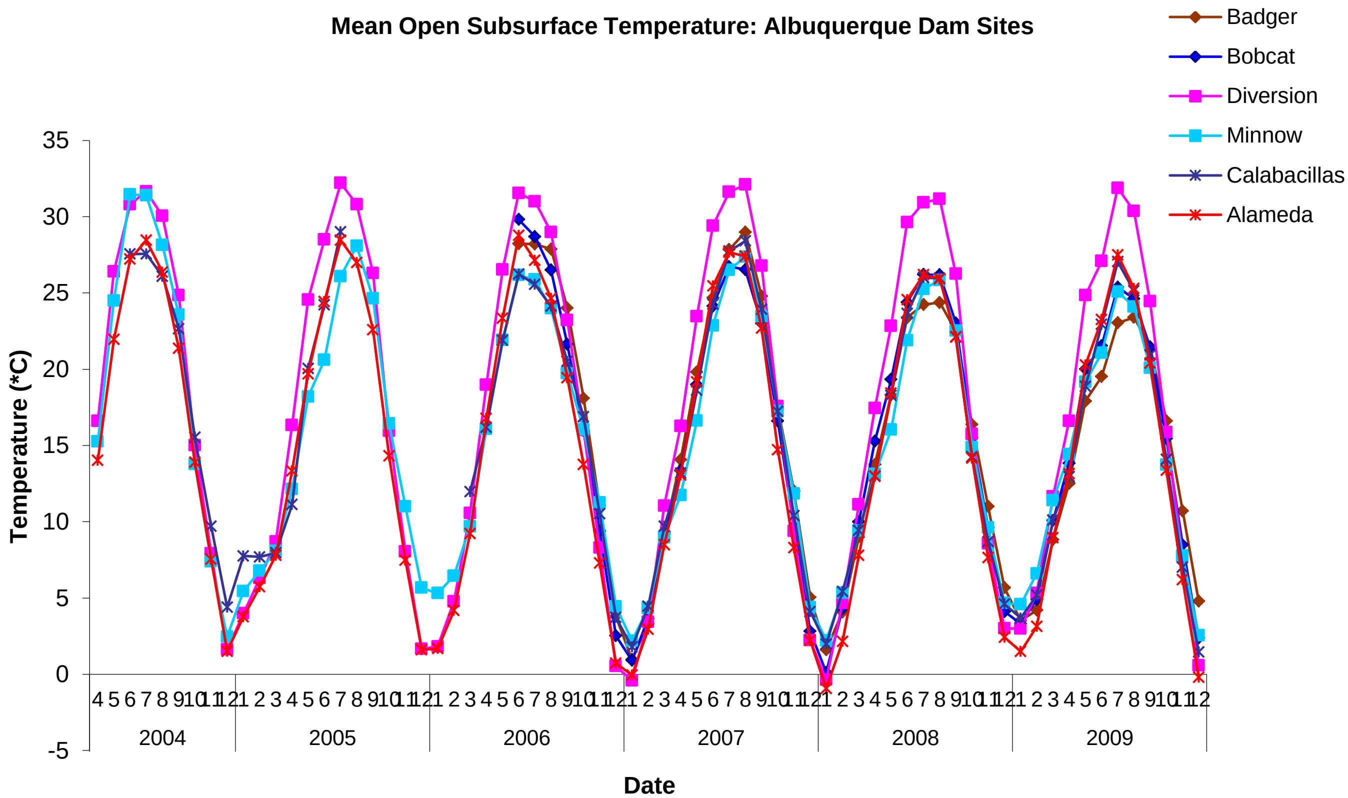


Figure 6. Mean subsurface temperature (2 cm below ground) in the open at the Albuquerque sites surrounding the DWP diversion dam. Sites directly across the river from each other have the same symbols; east sites are in reds, west sites are in blues.

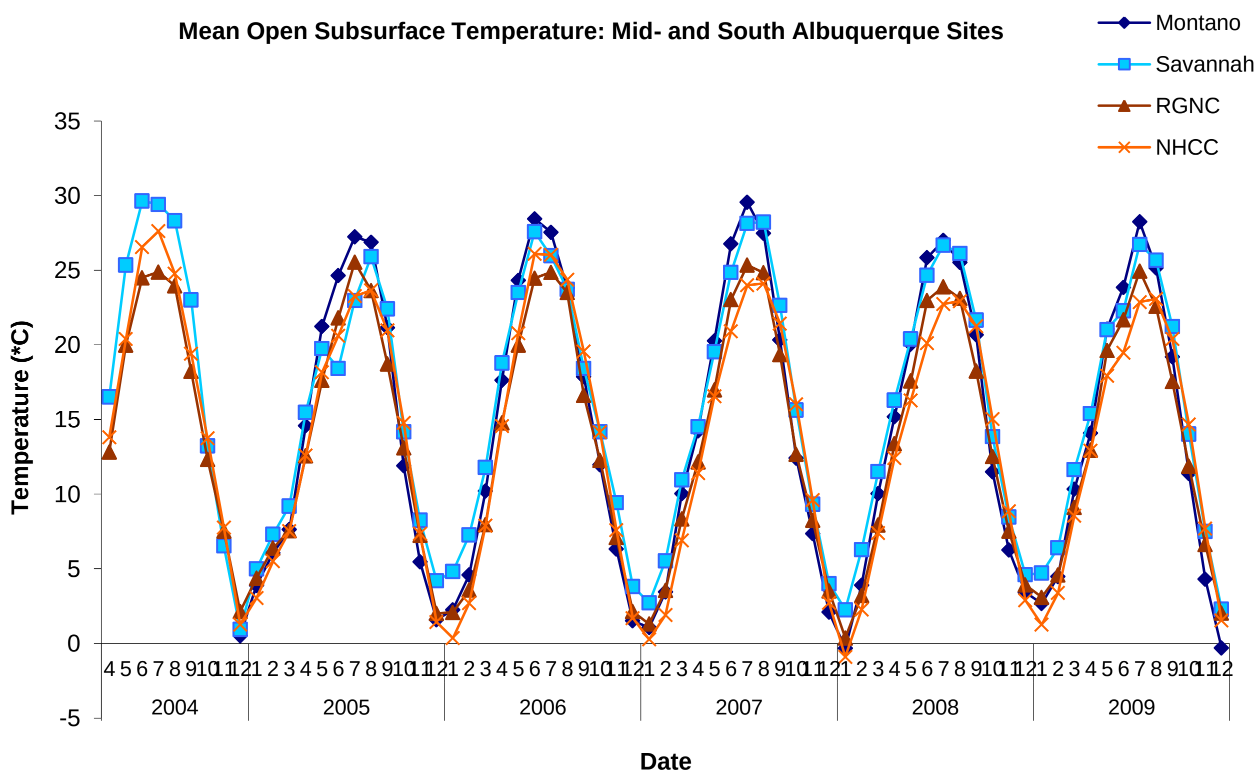


Figure 7. Mean subsurface temperature (2 cm below ground) in the open at mid-to-south Albuquerque sites. East sites are in reds, west sites are in blues.

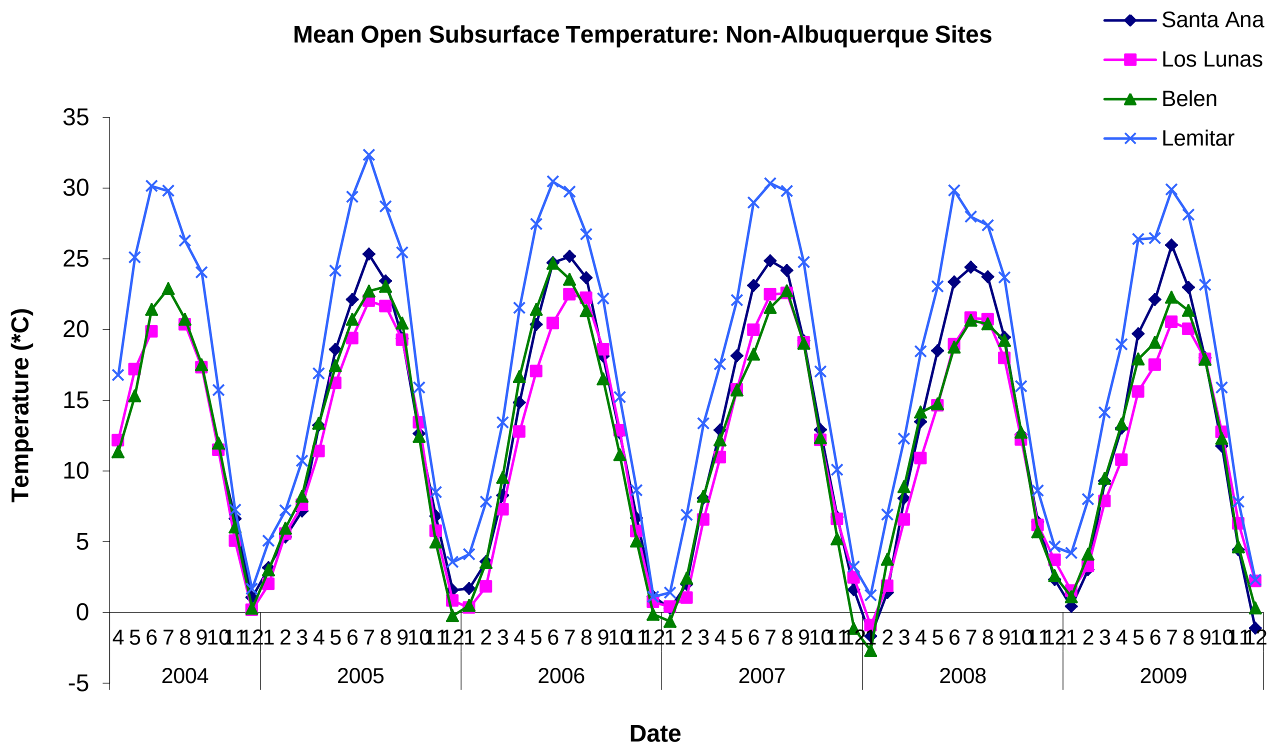


Figure 8. Mean subsurface temperature (2 cm below ground) in the open at sites to the north and south of Albuquerque.

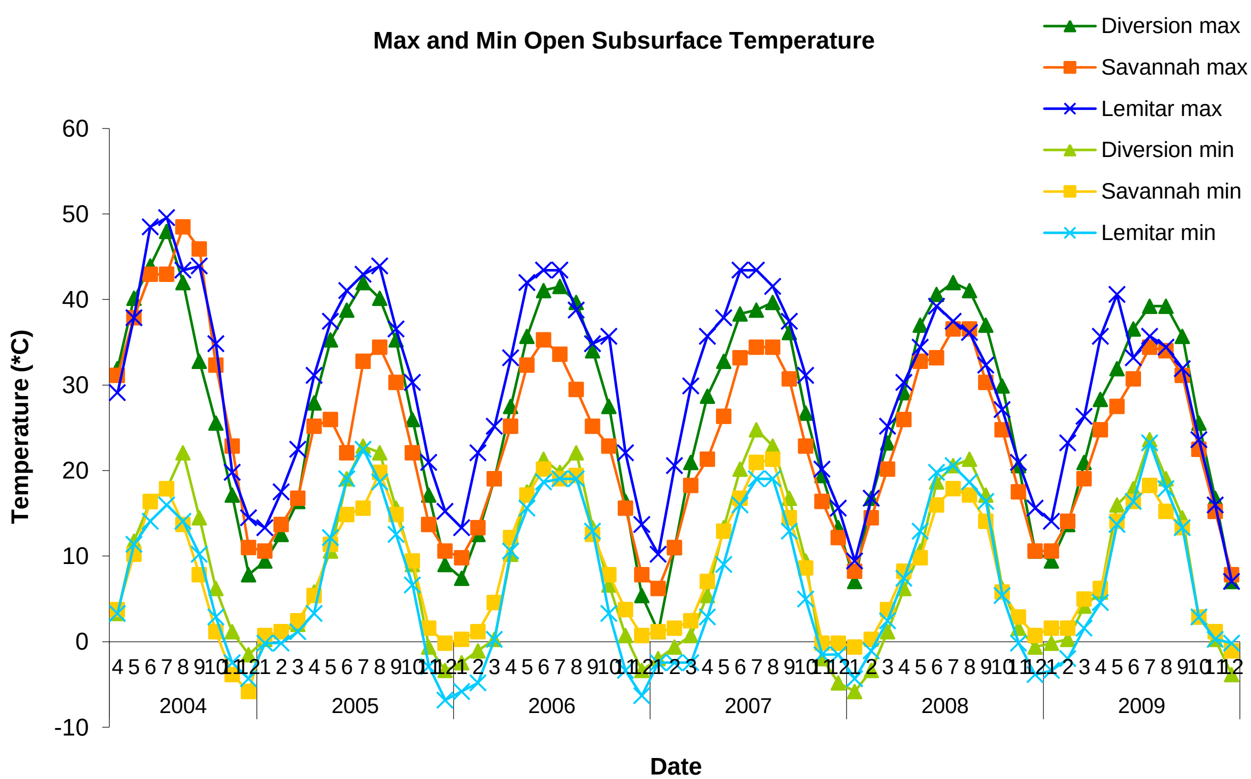


Figure 9. Maximum and minimum subsurface temperatures (2 cm below ground) in the open at three of the warmest sites: Diversion and Savannah (in Albuquerque), and Lemitar (to the south).

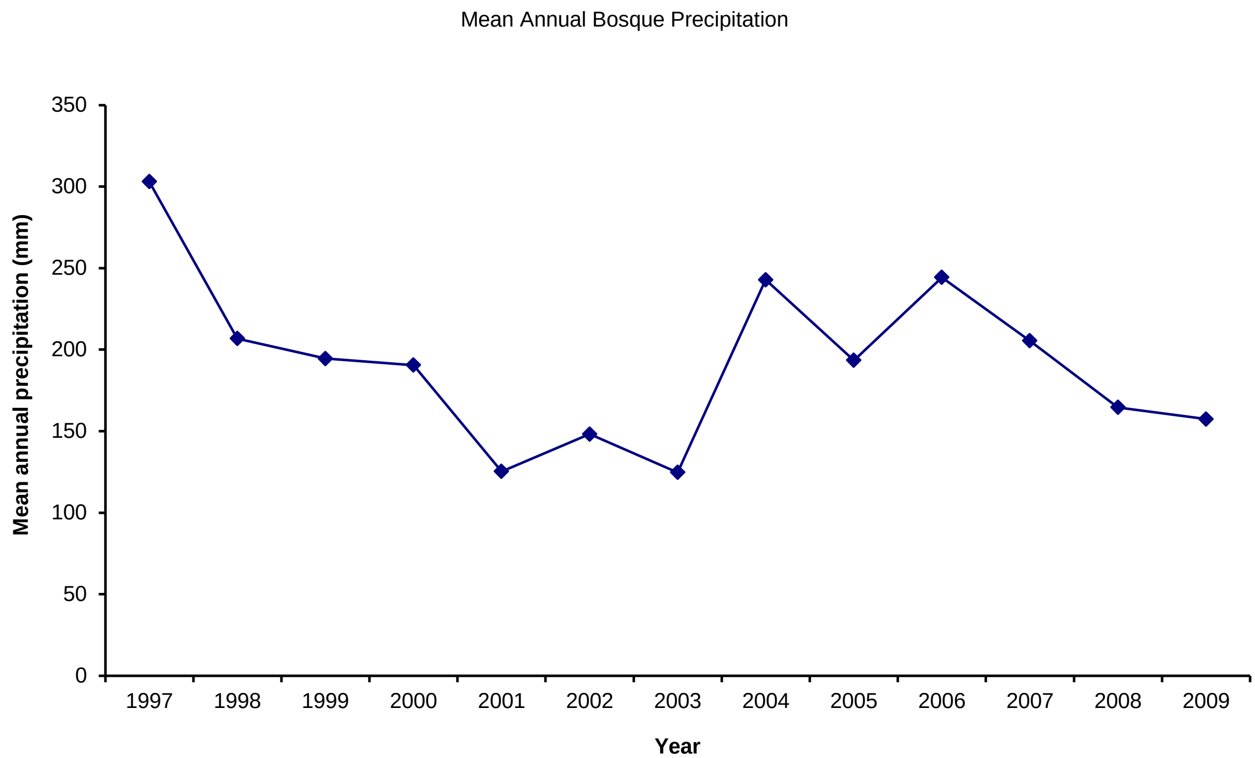


Figure 10. Average annual bosque precipitation, averaged across all BEMP site averages from April 1997 though December 2007.

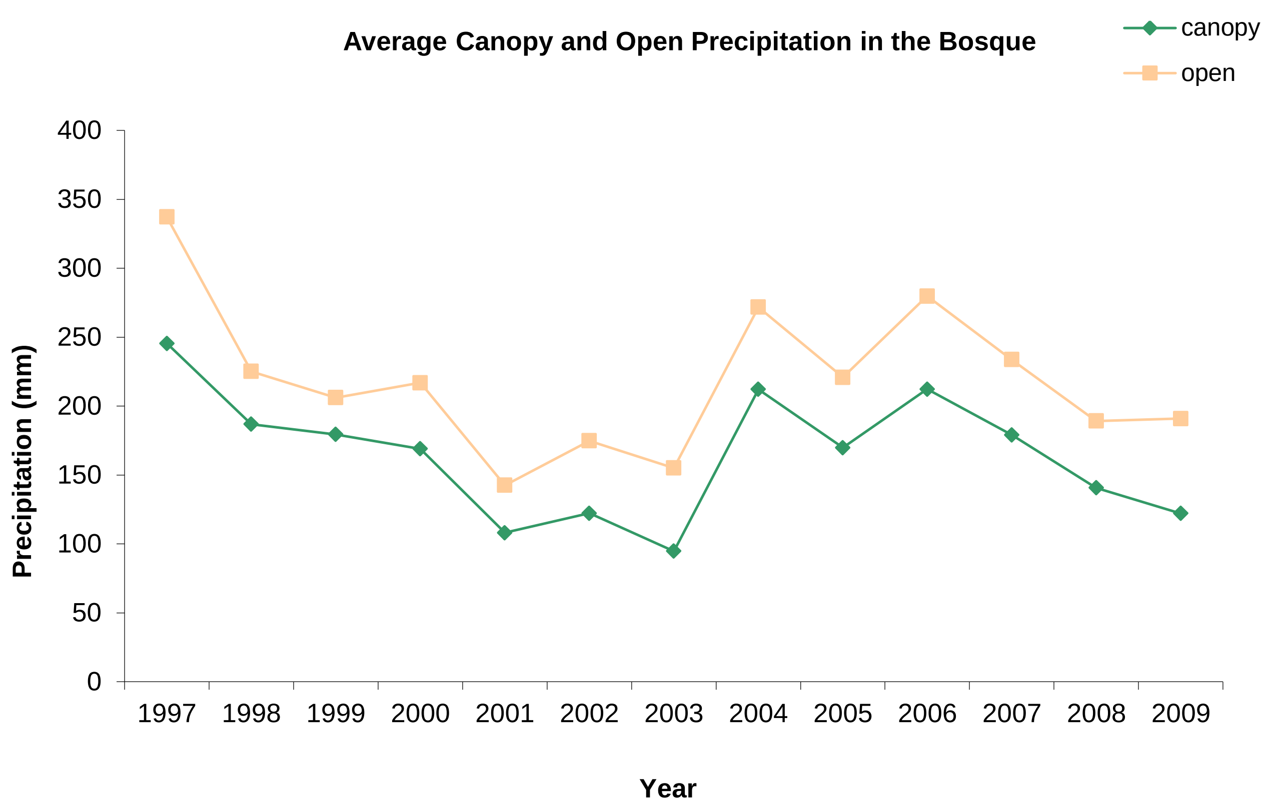


Figure 11. Average annual bosque precipitation in open gauges and canopy gauges.

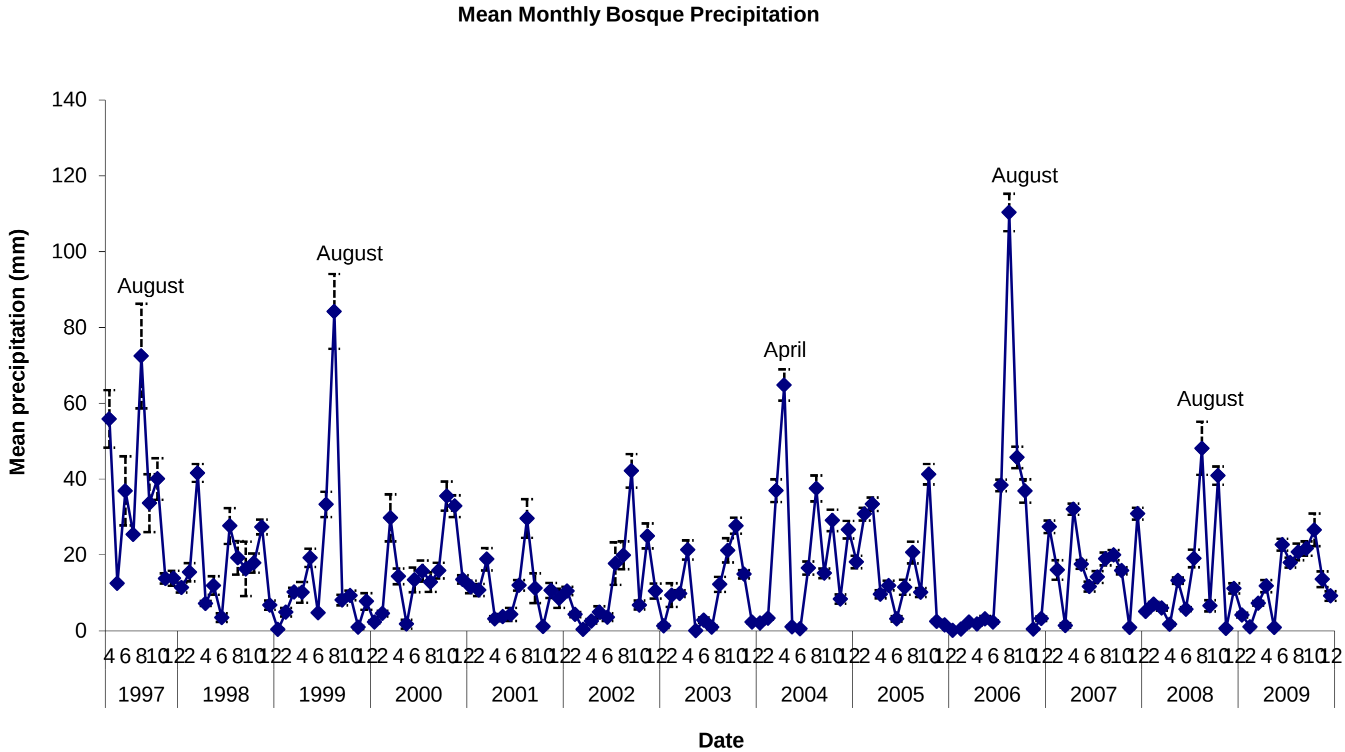


Figure 12. Total monthly bosque precipitation averaged across all BEMP sites. Standard error bars represent variation between sites.

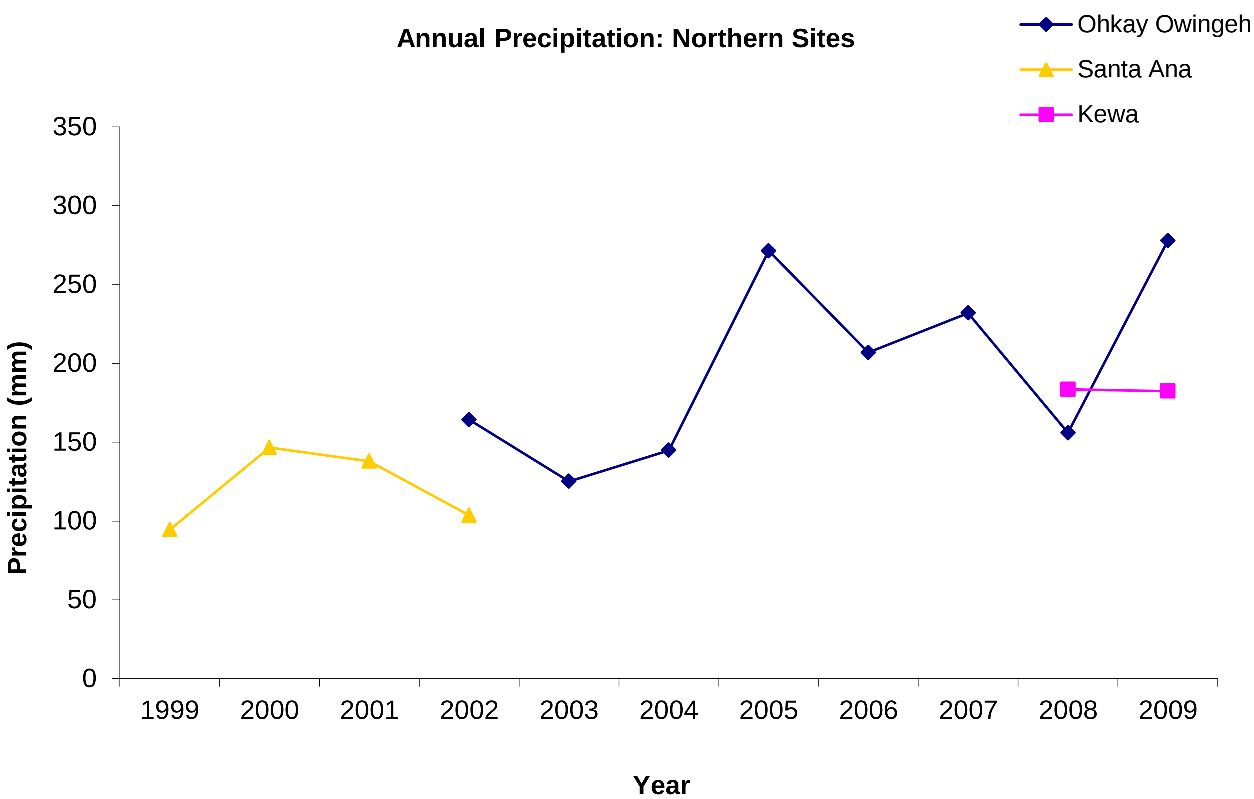


Figure 13. Total annual precipitation (averaged across the two rain gauges within each site) for the northern-most BEMP sites: Ohkay Owingeh, Kewa, and Santa Ana.

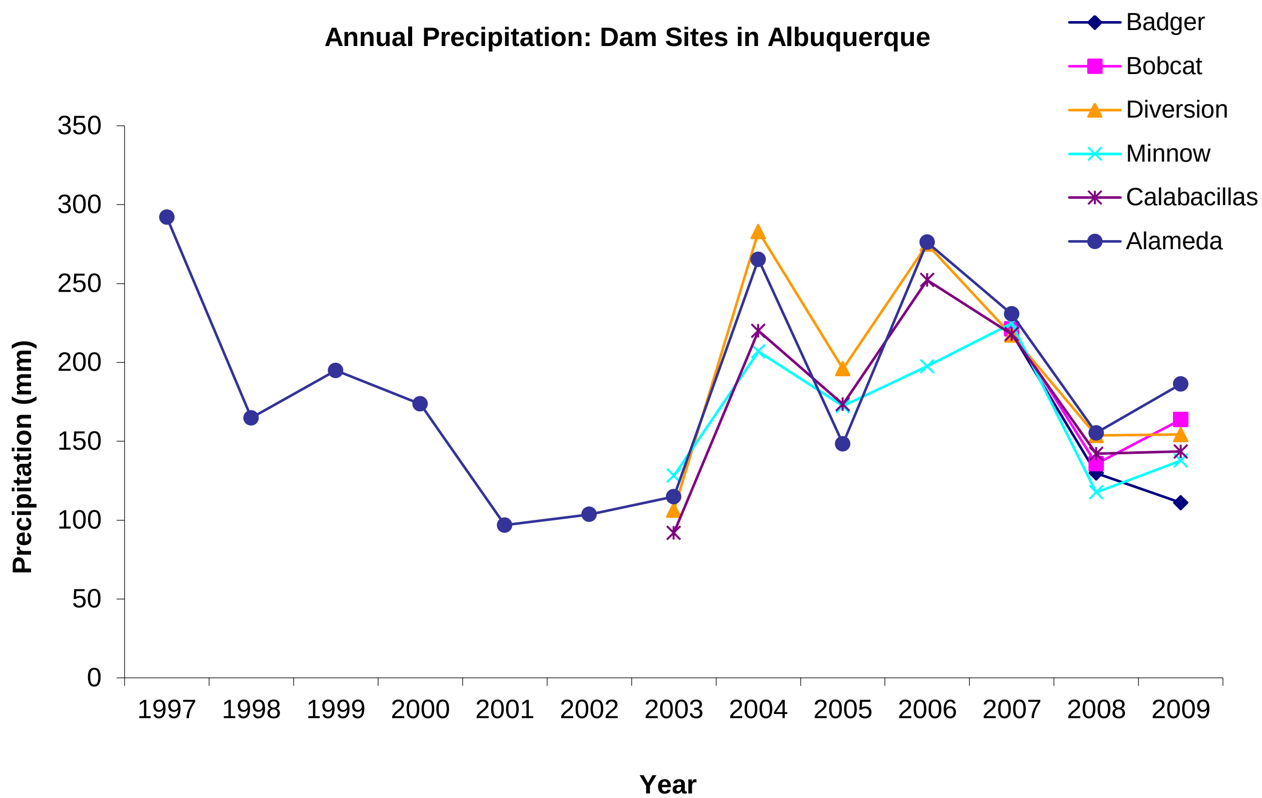


Figure 14. Total annual precipitation (averaged across the two rain gauges within each site) for the northern BEMP sites in Albuquerque (those bracketing the DWP dam): Badger, Bobcat, Diversion, Minnow, Calabacillas and Alameda.

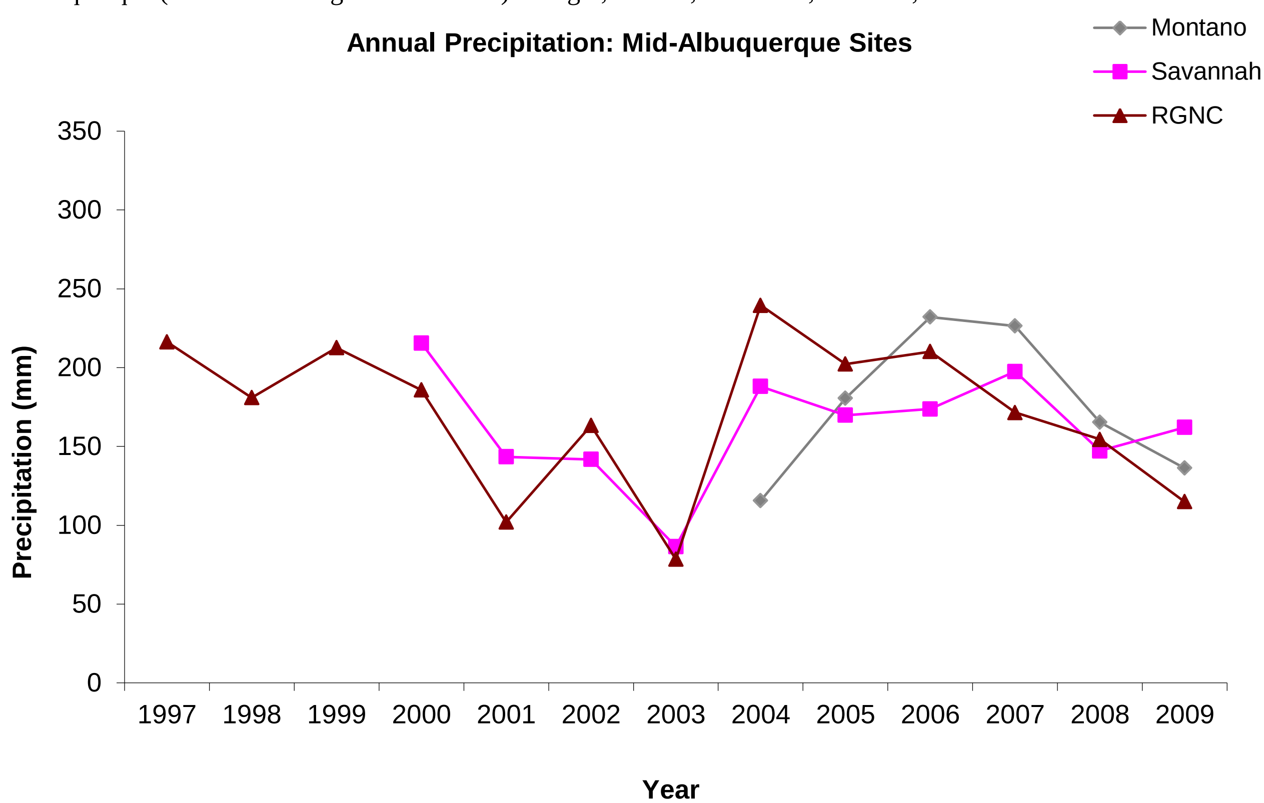


Figure 15. Total annual precipitation (averaged across the two rain gauges within each site) for the mid-Albuquerque sites: Moñtano, Savannah, and the Rio Grande Nature Center (RGNC).

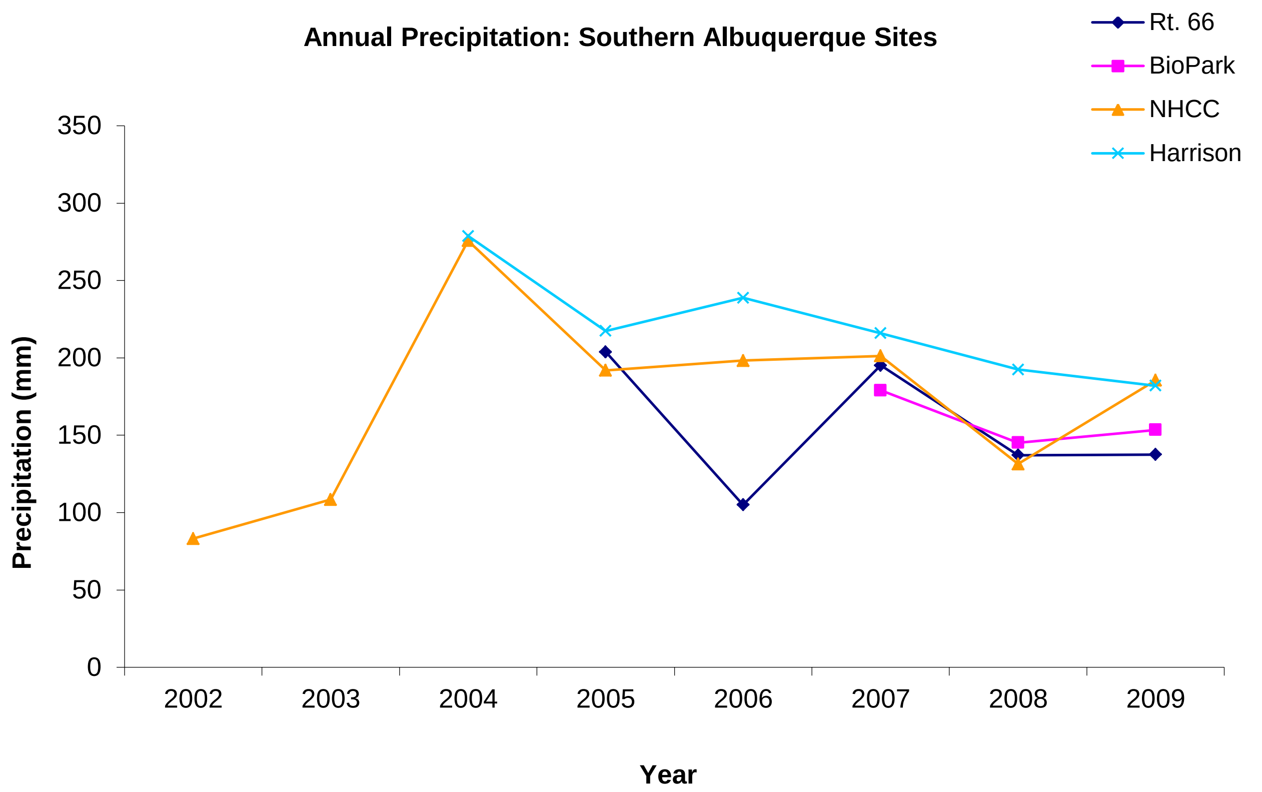


Figure 16. Total annual precipitation (averaged across the two rain gauges within each site) for the south Albuquerque sites: Rt. 66, BioPark, the National Hispanic Cultural Center (NHCC), and Harrison.

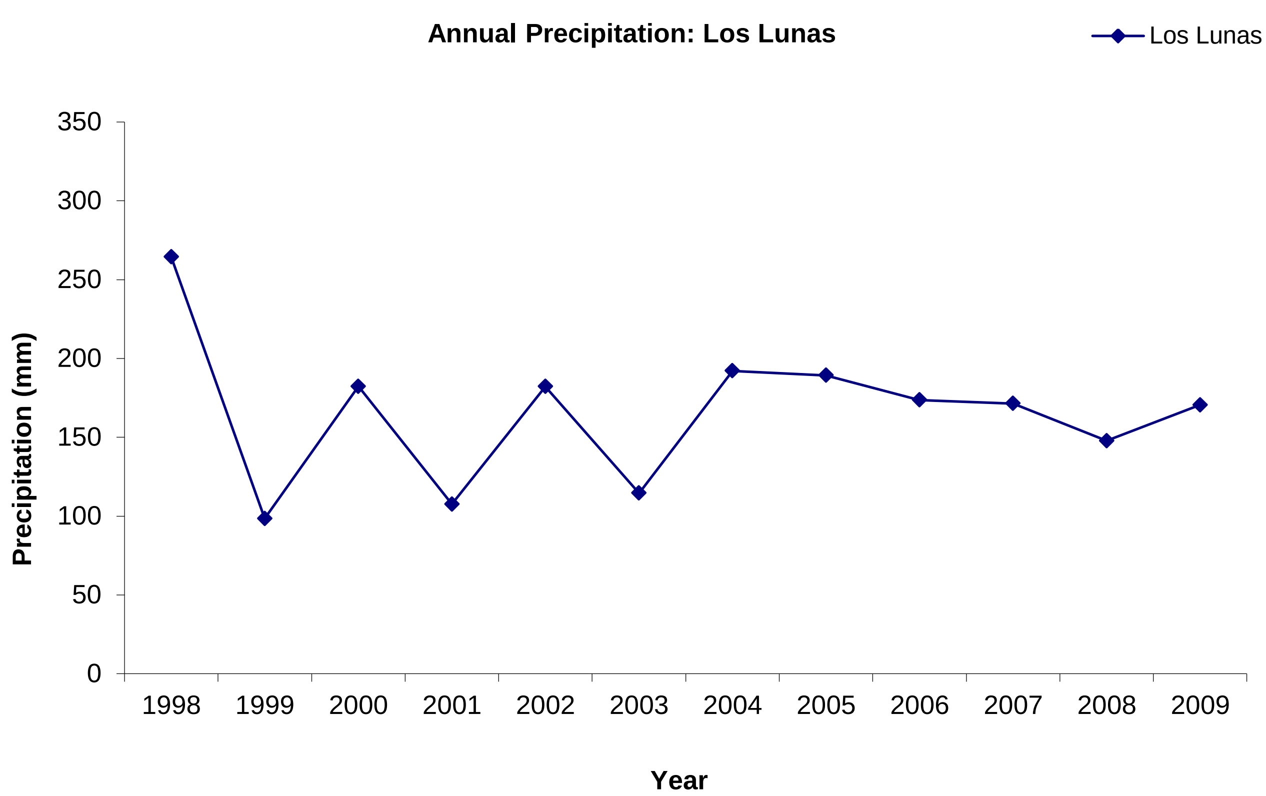


Figure 17. Total annual precipitation (averaged across the open and canopy rain gauges) at Los Lunas, just south of Albuquerque.

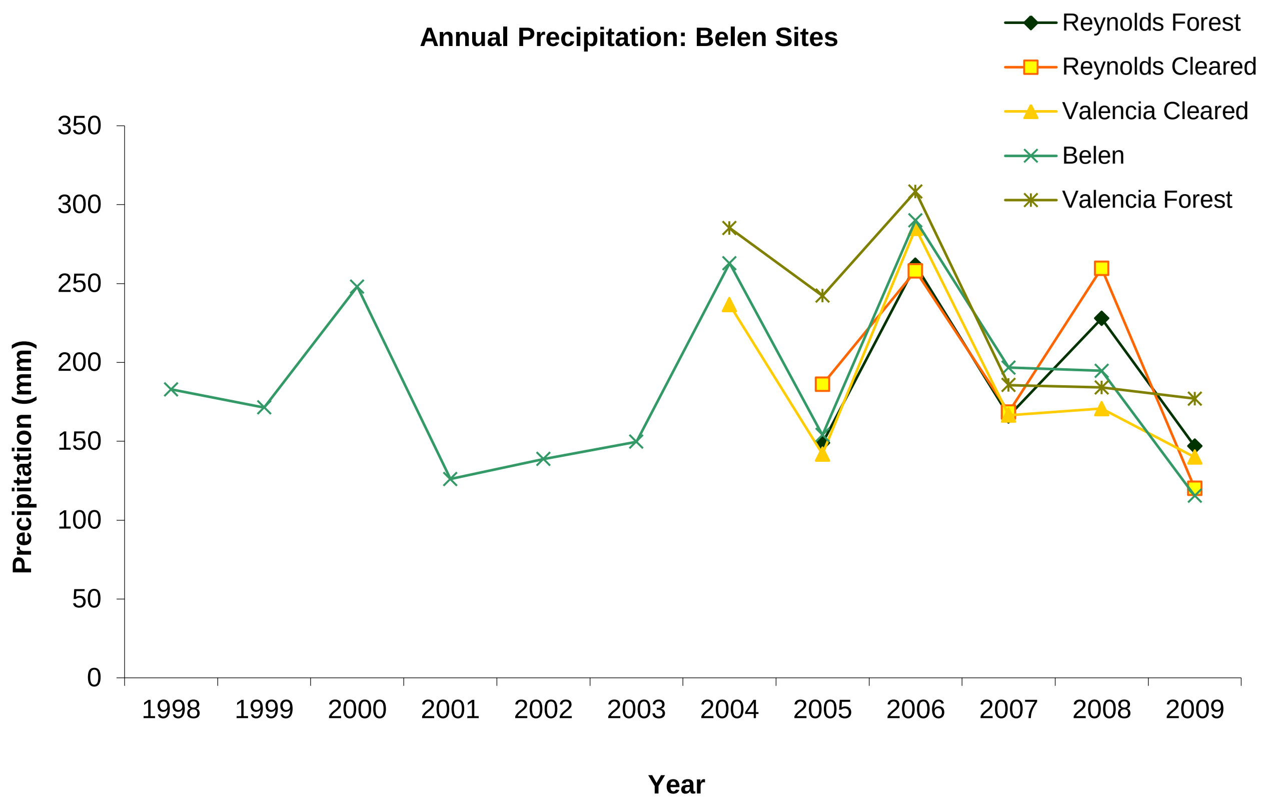


Figure 18. Total annual precipitation (averaged across the two rain gauges for each site) in Belen: Reynolds Forest, Reynolds Cleared, Valencia Cleared, Belen, and Valencia Forest.

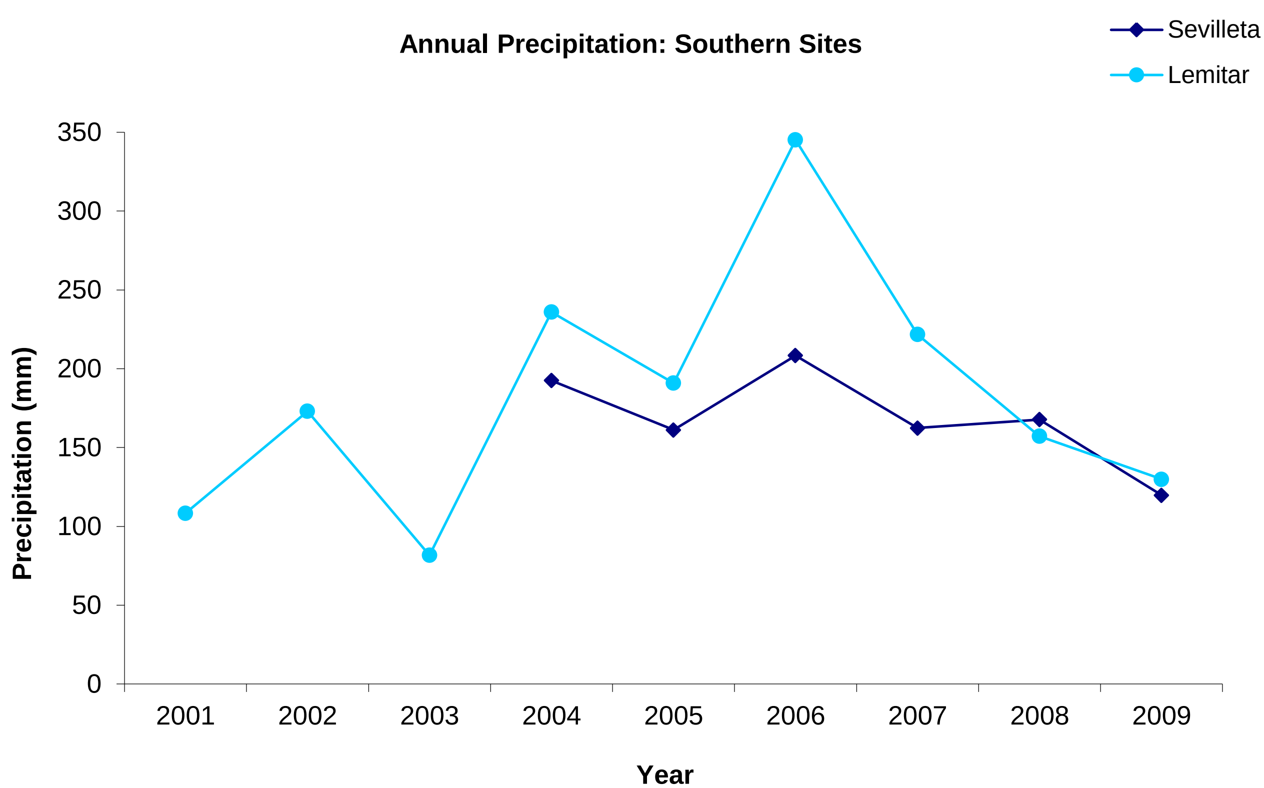


Figure 19. Total annual precipitation (averaged across the two rain gauges for each site) for the southern-most BEMP sites: Sevilleta and Lemitar.

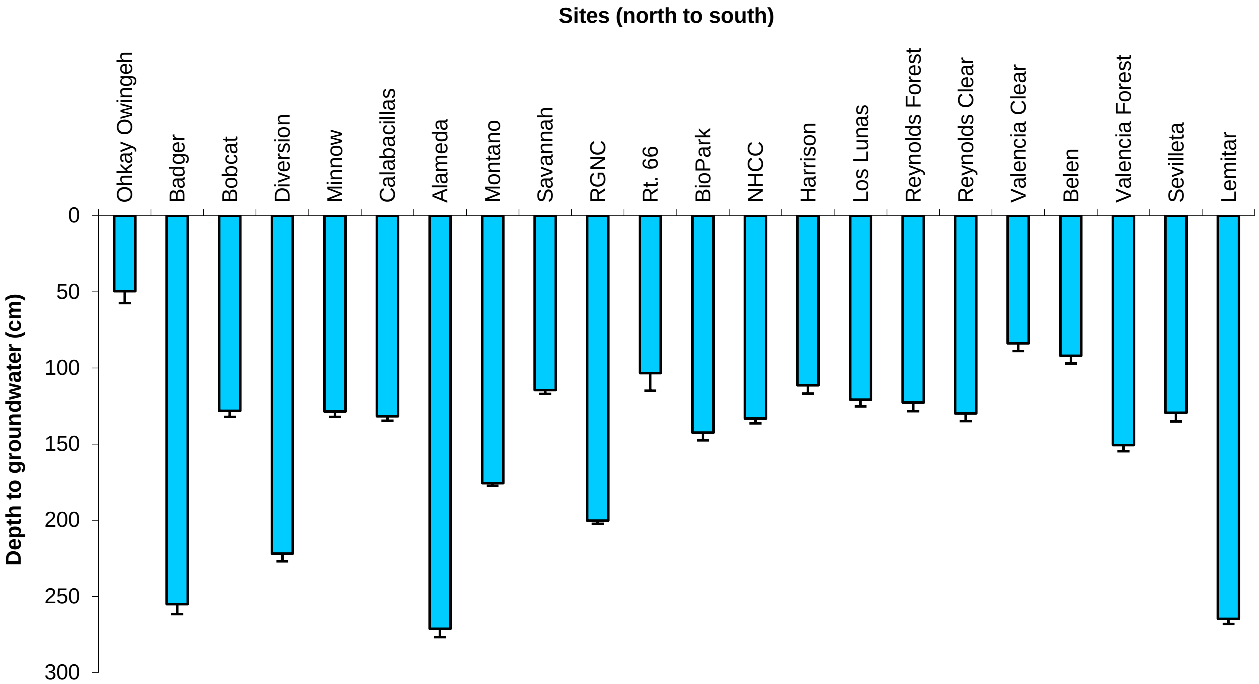


Figure 20. 2007 mean annual depth to groundwater at sites from north to south. Standard error bars represent the variation between months.

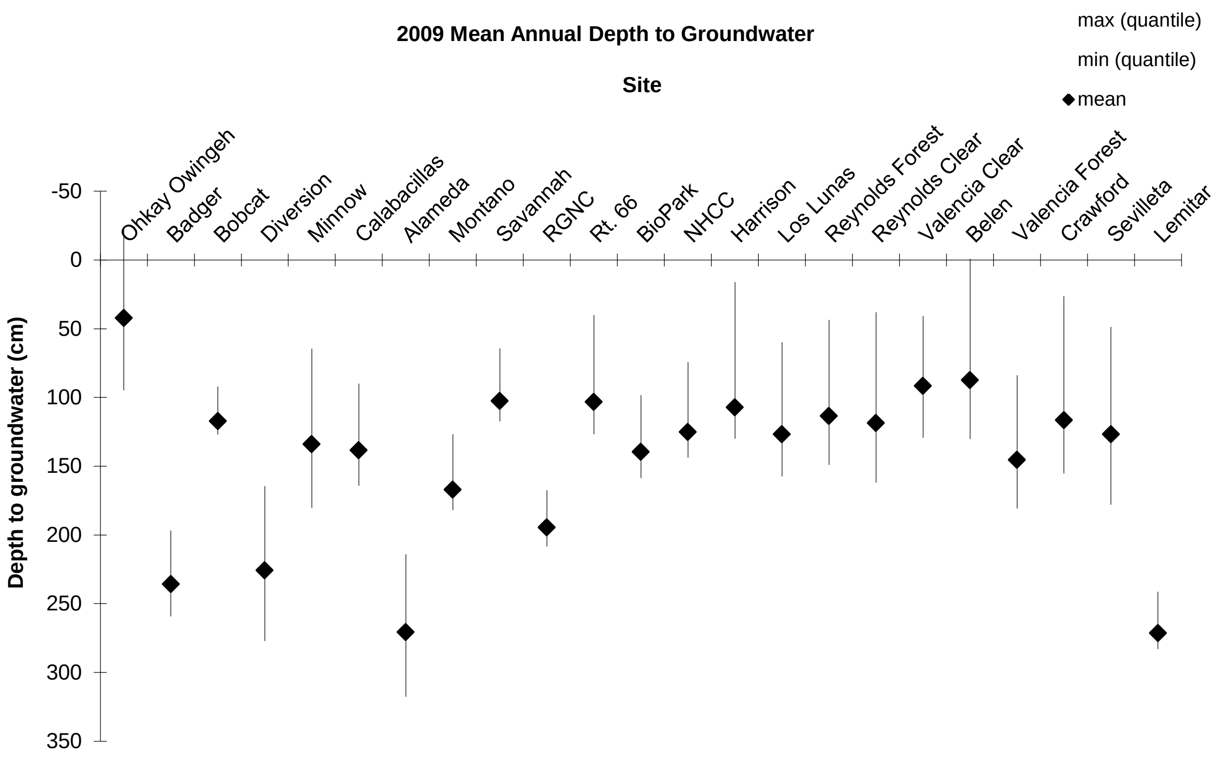


Figure 21. 2009 mean annual depth to groundwater; bars show annual highest and lowest water table levels measured (estimated quantiles).

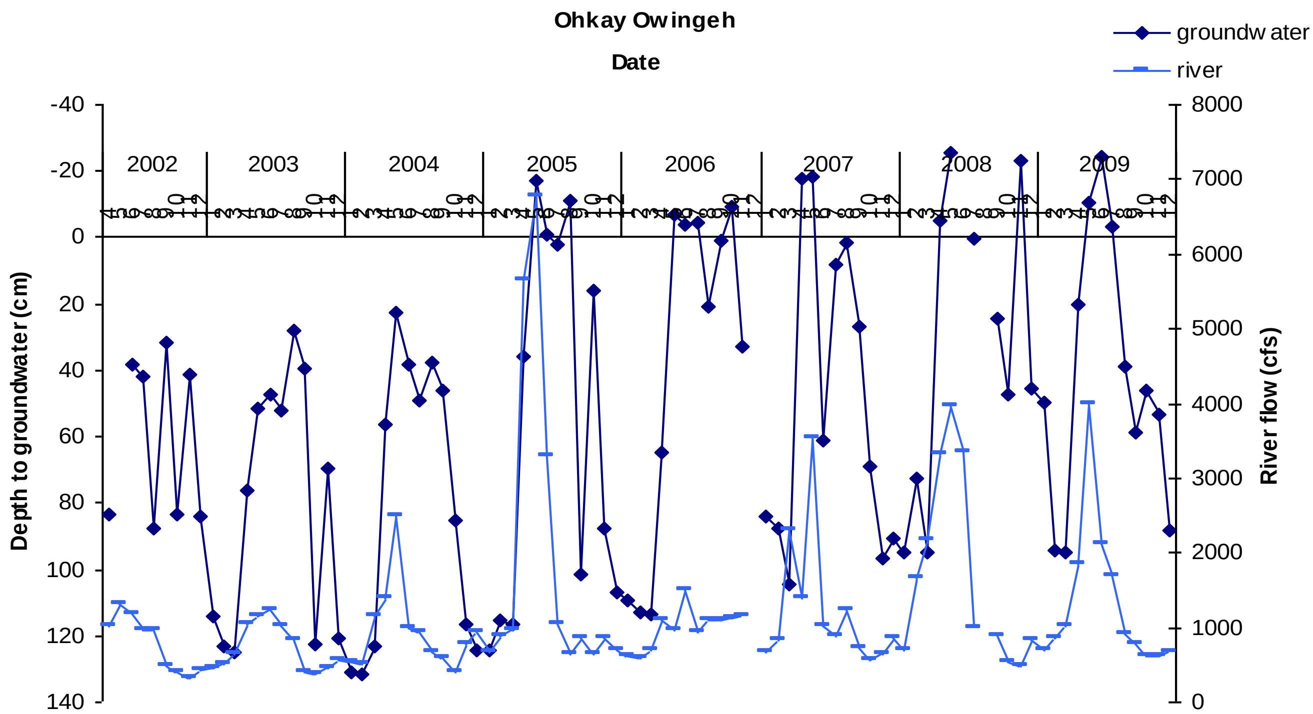


Figure 22. Mean depth to groundwater from ground surface (primary y-axis) at Ohkay Owingeh, compared with Rio Grande flow (from the USGS Otowi river gage) in cubic feet per second (secondary y-axis).

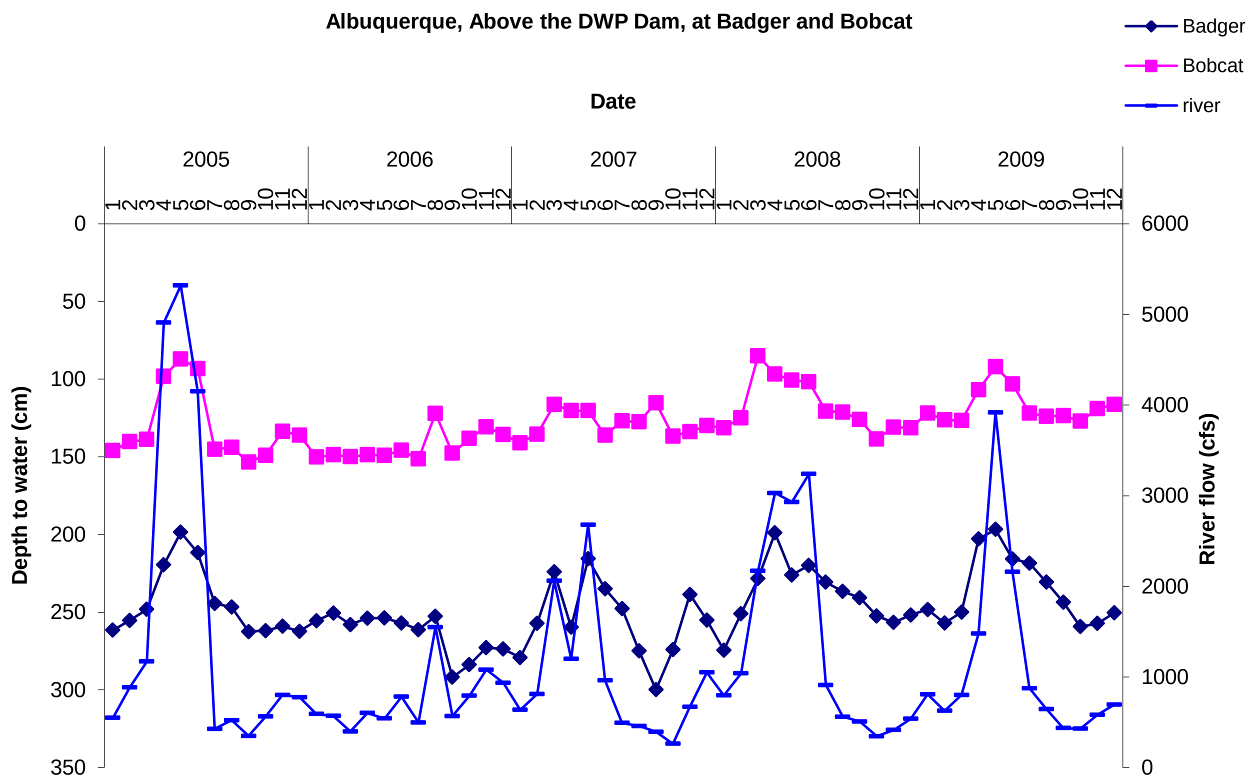


Figure 23. Mean depth to groundwater from ground surface (primary y-axis) above the DWP Diversion Dam in Albuquerque (Badger, on the east side of the river, and Bobcat on the west) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

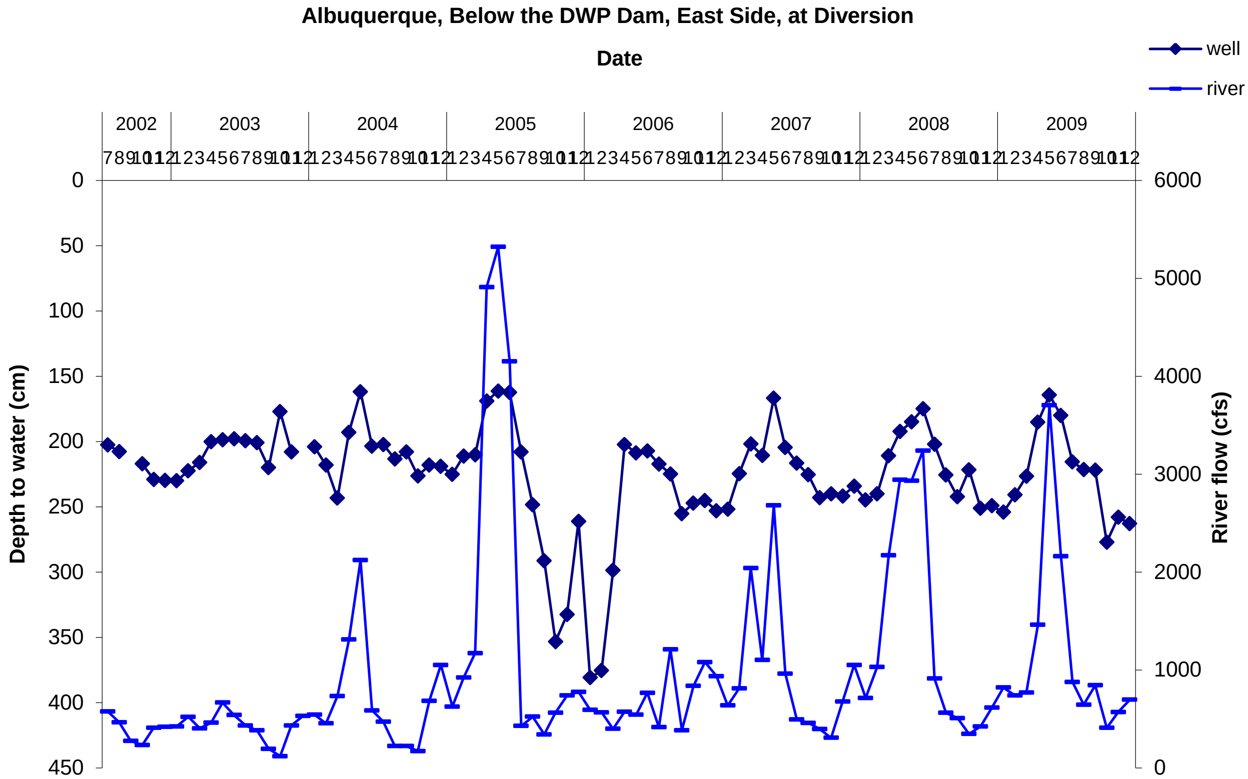


Figure 24. Mean depth to groundwater from ground surface (primary y-axis) below the DWP Diversion Dam in Albuquerque on the east side of the river (Diversion site) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

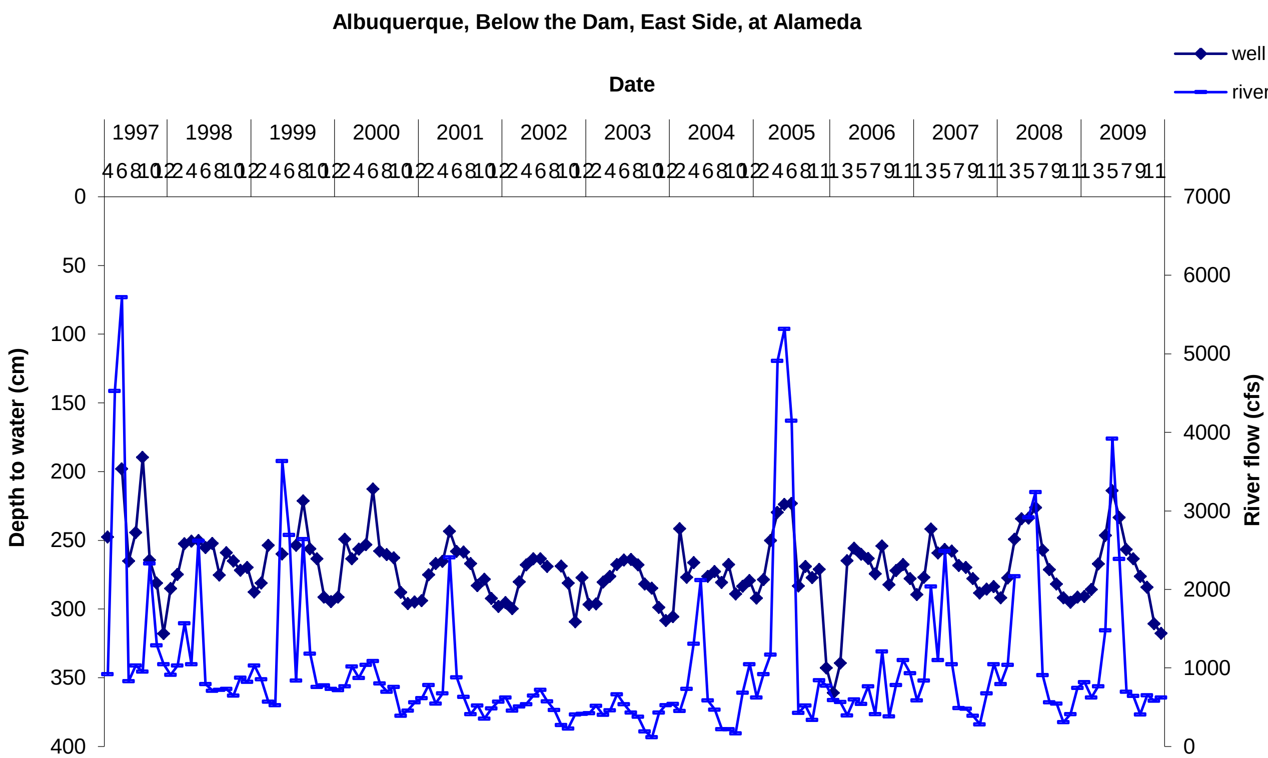


Figure 25. Mean depth to groundwater from ground surface (primary y-axis) below the DWP Diversion Dam in Albuquerque on the east side of the river (Alameda site) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

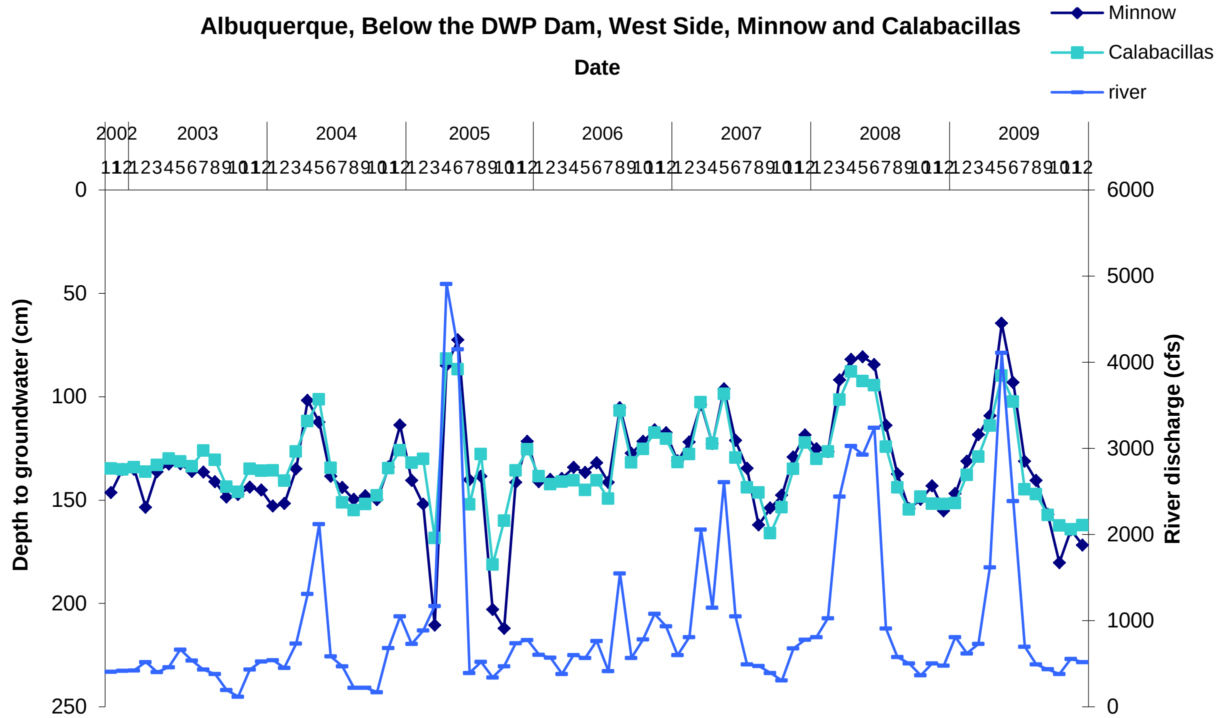


Figure 26. Mean depth to groundwater from ground surface (primary y-axis) below the DWP Diversion Dam in Albuquerque on the west side of the river (Minnow and Calabacillas) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

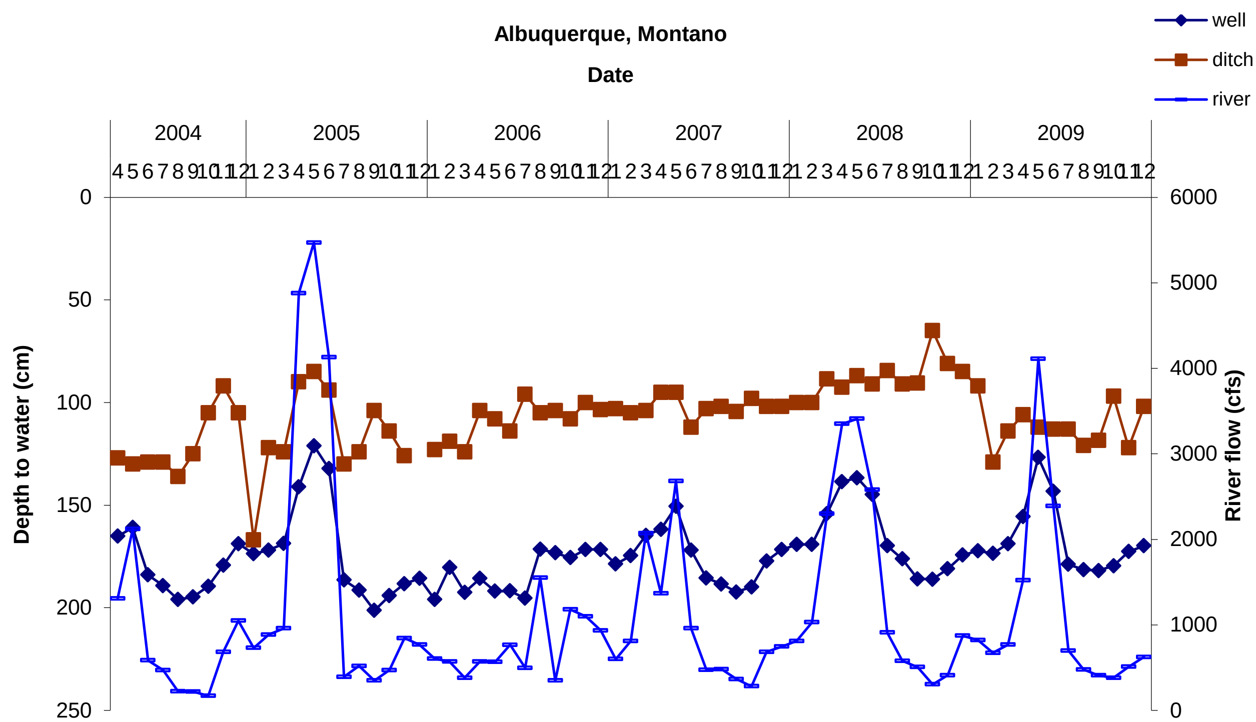


Figure 27. Mean depth to groundwater from ground surface (primary y-axis) in Albuquerque (Montaño) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

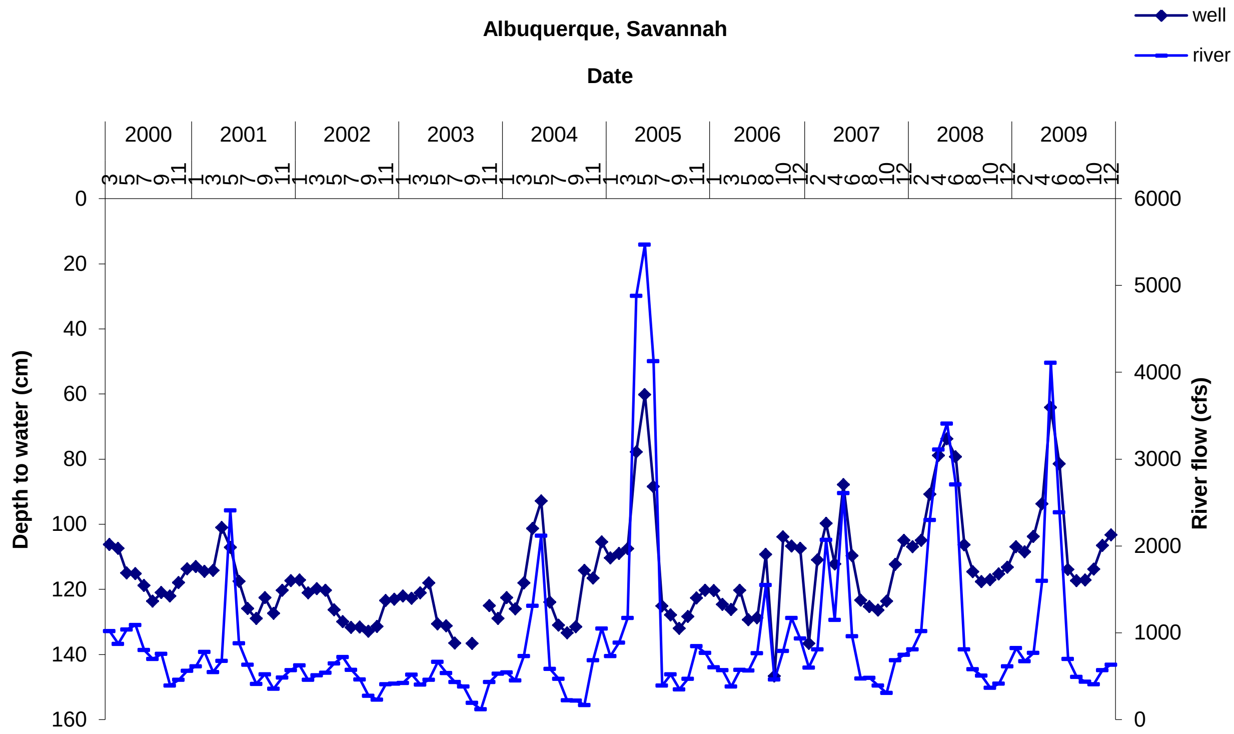


Figure 28. Mean depth to groundwater from ground surface (primary y-axis) in Albuquerque (Savannah) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

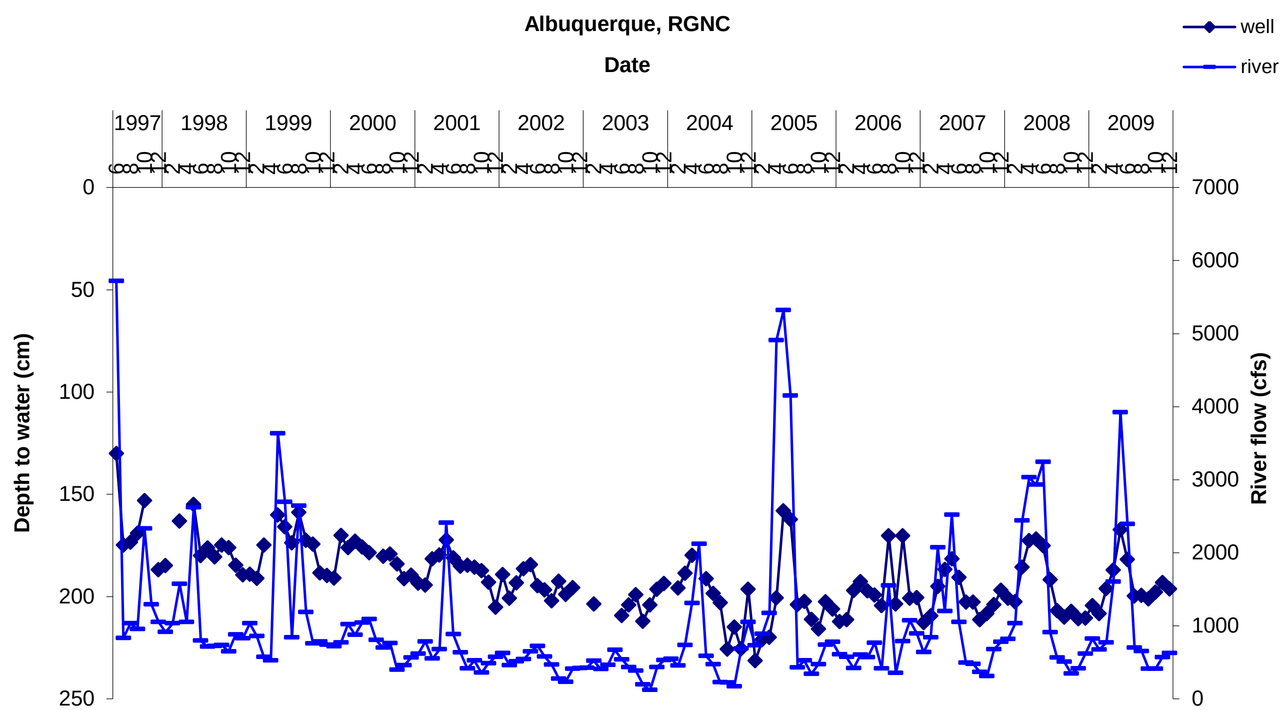


Figure 29. Mean depth to groundwater from ground surface (primary y-axis) in Albuquerque (Rio Grande Nature Center) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

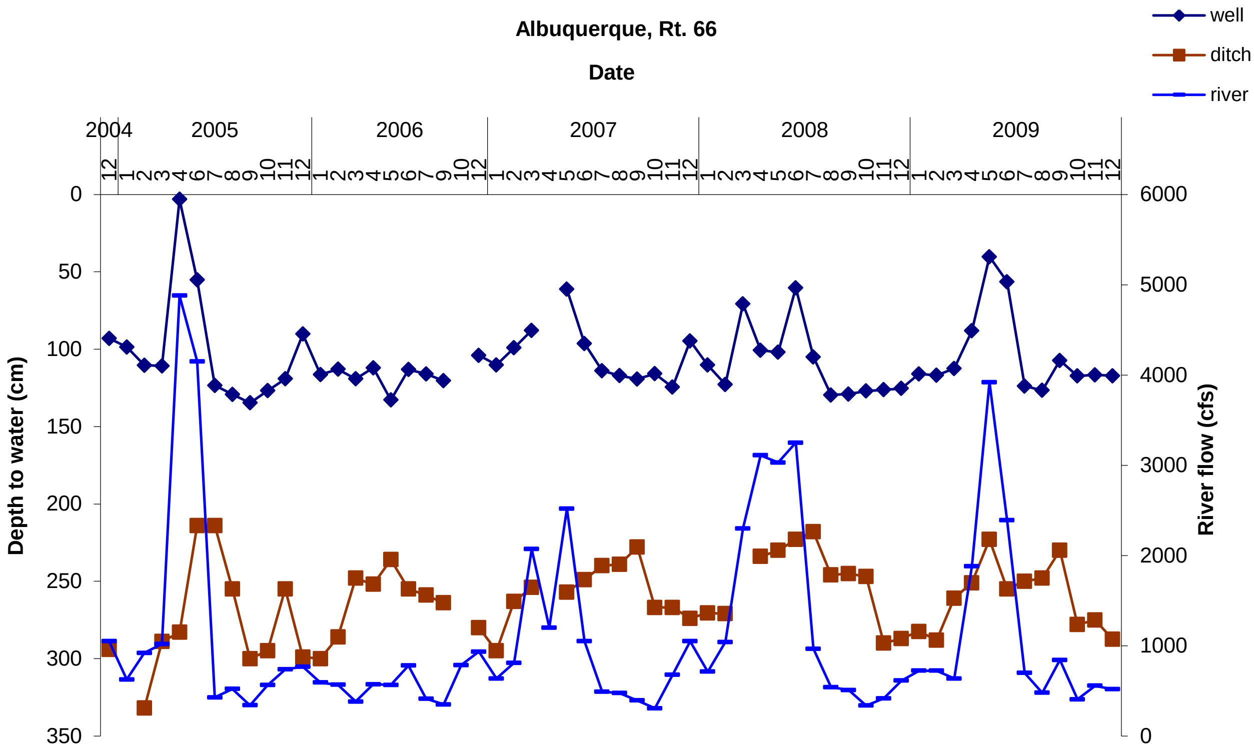


Figure 30. Mean depth to groundwater from ground surface (primary y-axis) in Albuquerque (Rt.66) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

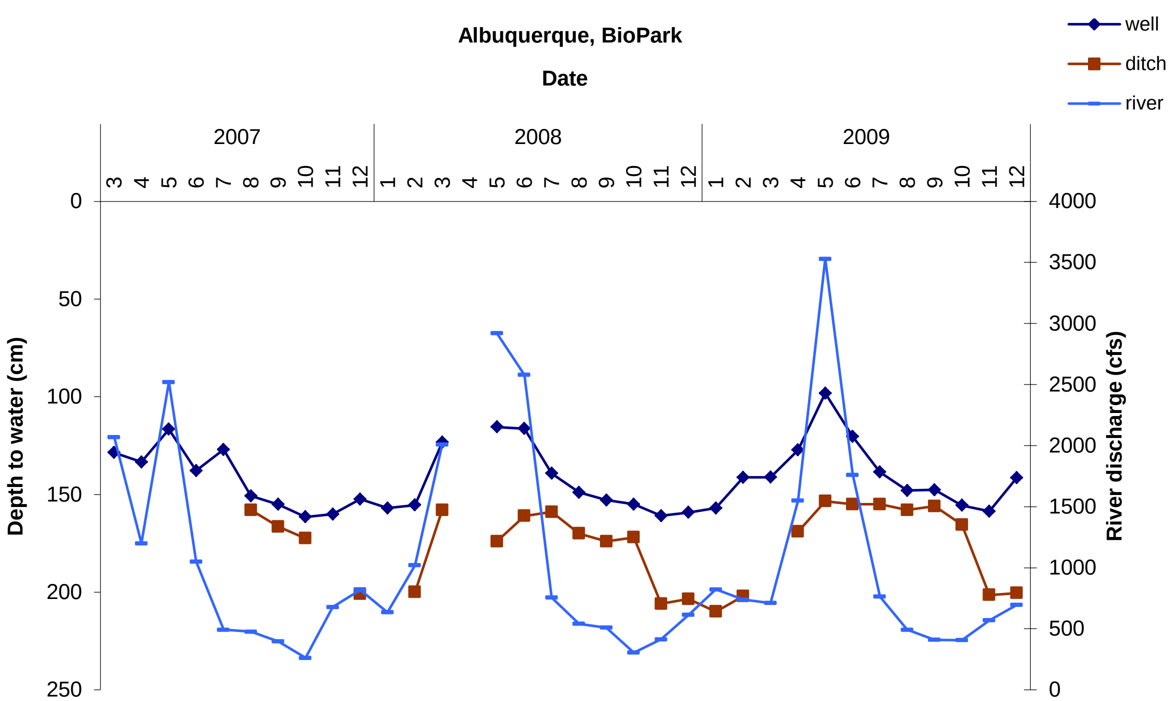


Figure 31. Mean depth to groundwater from ground surface (primary y-axis) in Albuquerque (BioPark) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

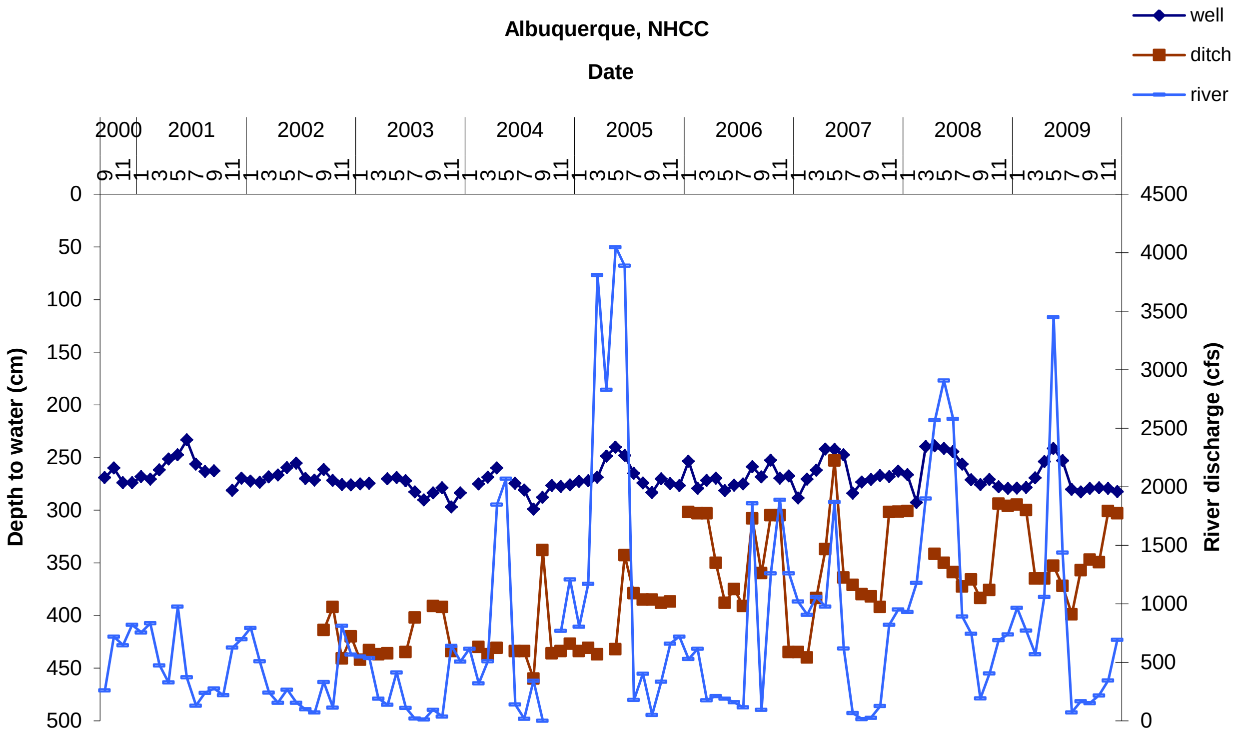


Figure 32. Mean depth to groundwater from ground surface (primary y-axis) in Albuquerque (National Hispanic Cultural Center) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

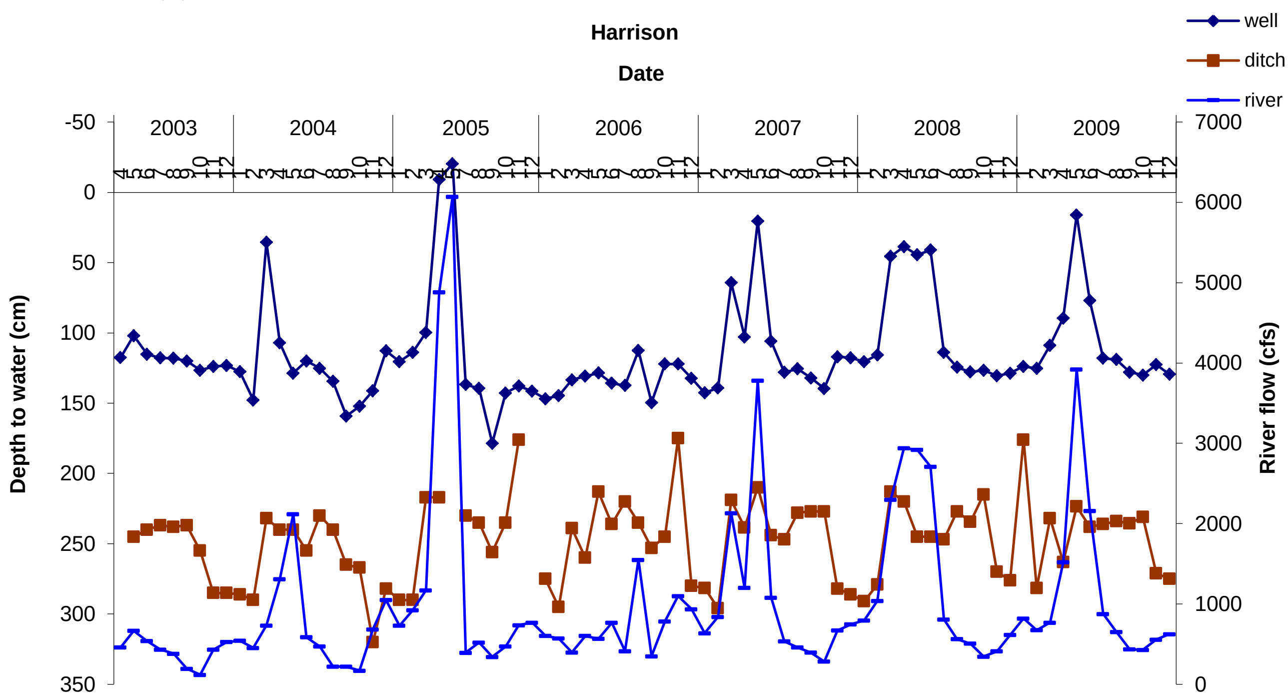


Figure 33. Mean depth to groundwater from ground surface (primary y-axis) in Albuquerque (Harrison) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

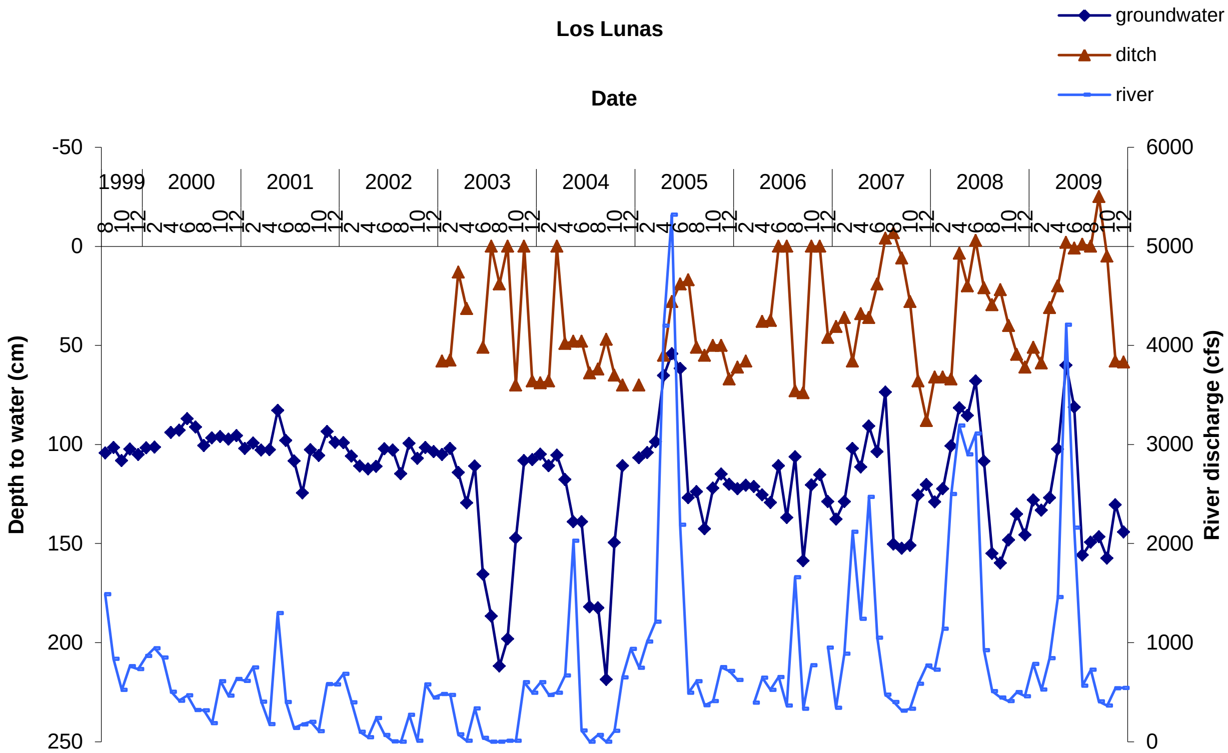


Figure 34. Mean depth to groundwater from ground surface (primary y-axis) in Los Lunas compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

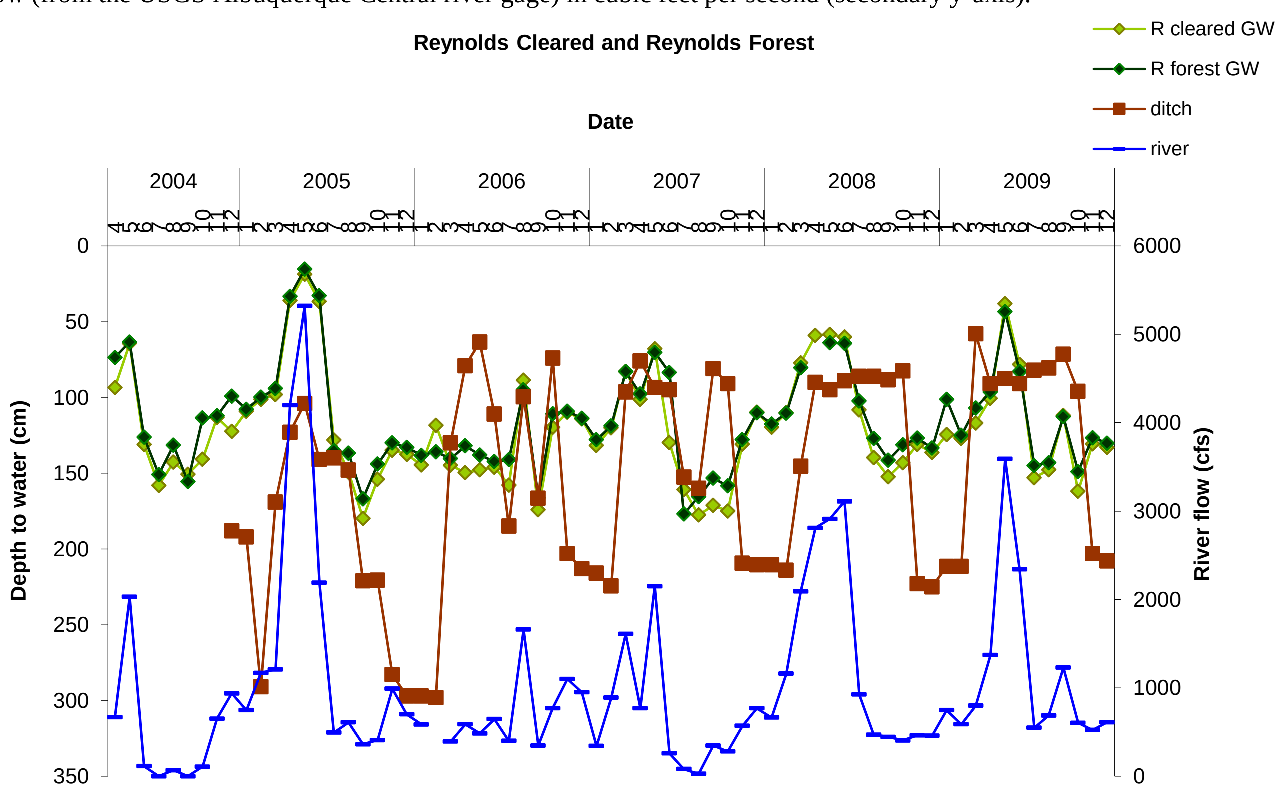


Figure 35. Mean depth to groundwater from ground surface (primary y-axis) in Belen (Reynolds Forest and Reynolds Cleared) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

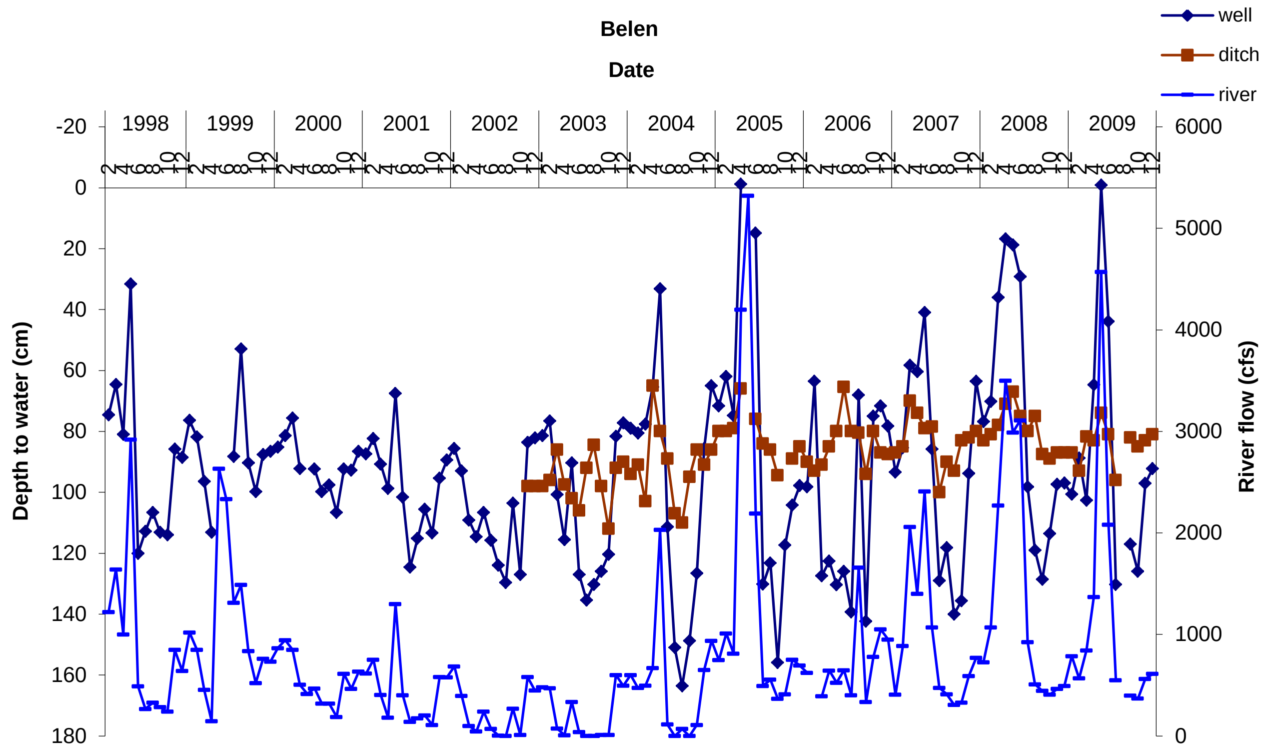


Figure 36. Mean depth to groundwater from ground surface (primary y-axis) in Belen compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

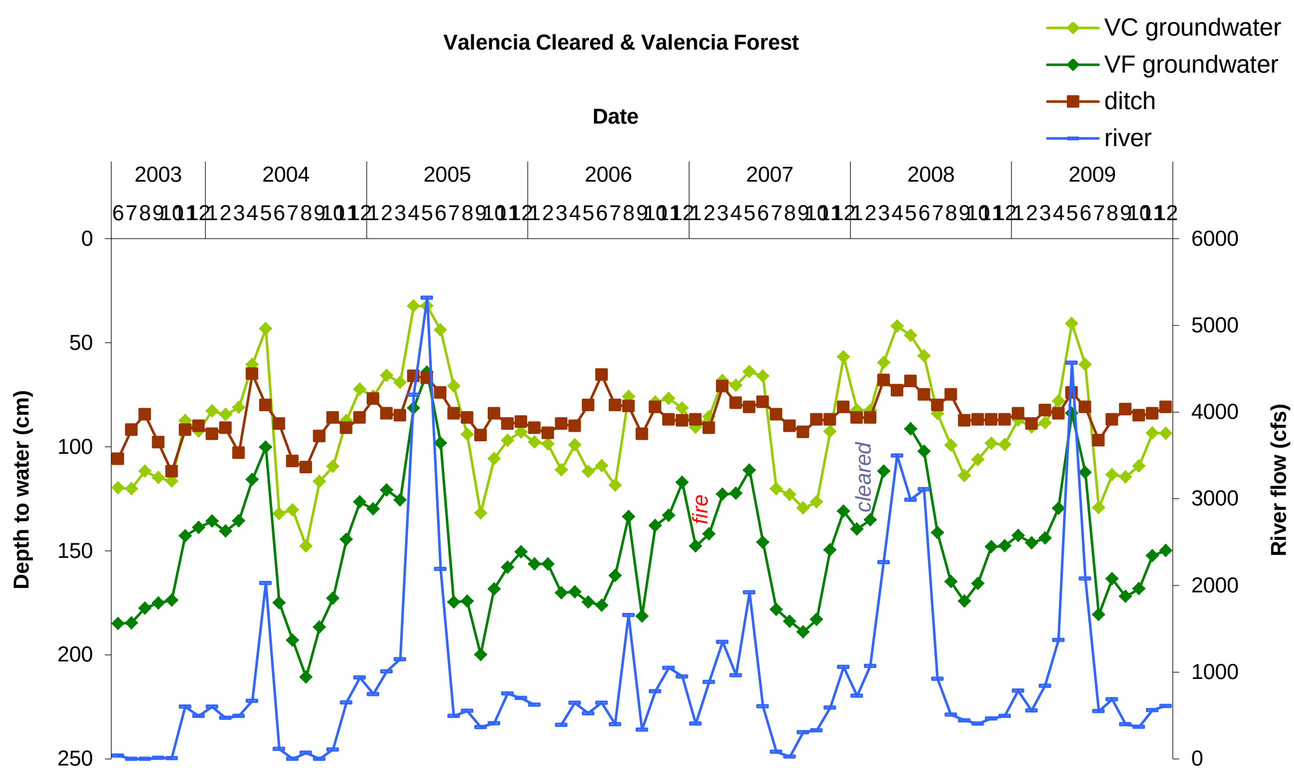


Figure 37. Mean depth to groundwater from ground surface (primary y-axis) in Belen (Valencia Cleared and Valencia Forest) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

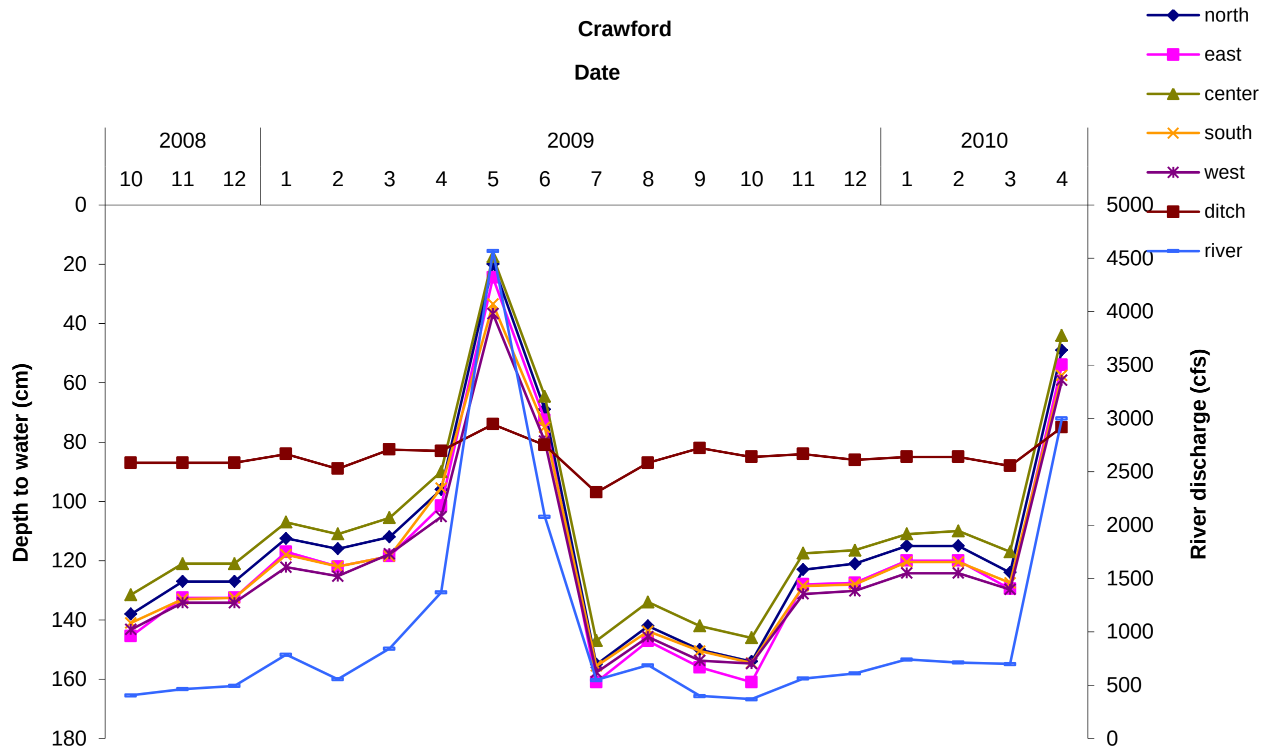


Figure 38. Mean depth to groundwater from ground surface (primary y-axis) in Belen (Crawford) compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

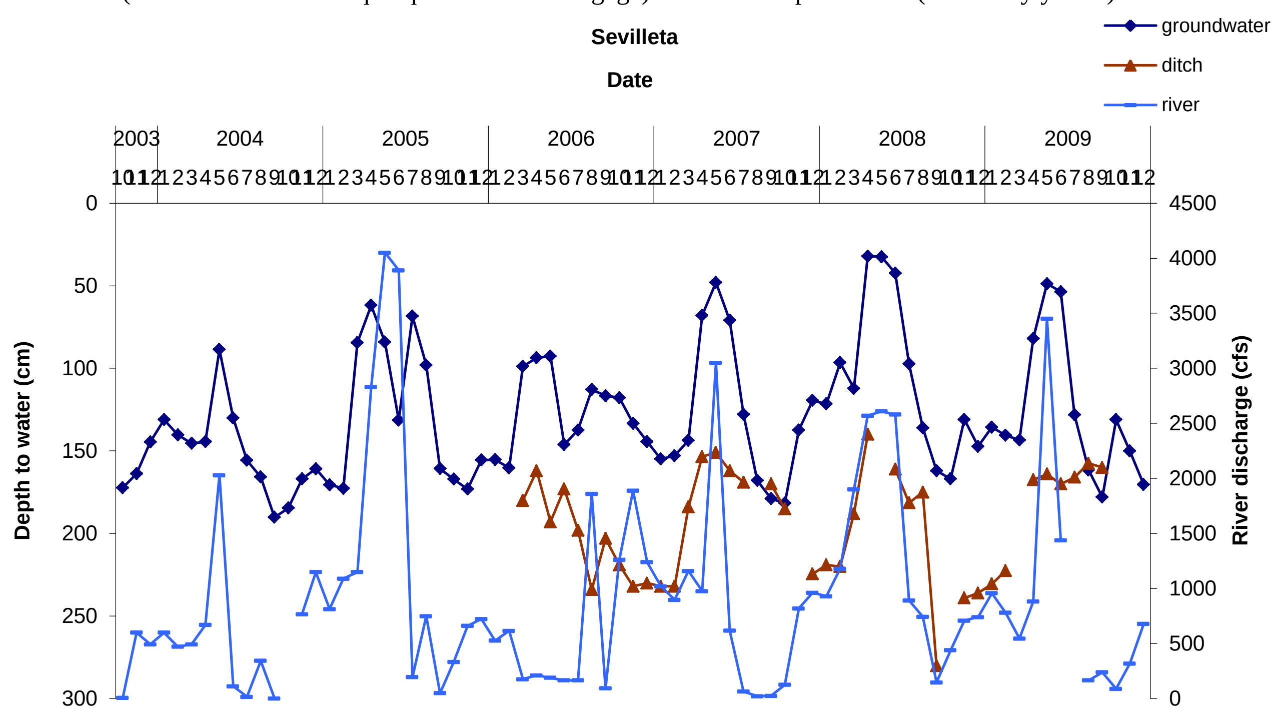


Figure 39. Mean depth to groundwater from ground surface (primary y-axis) in Sevilleta compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

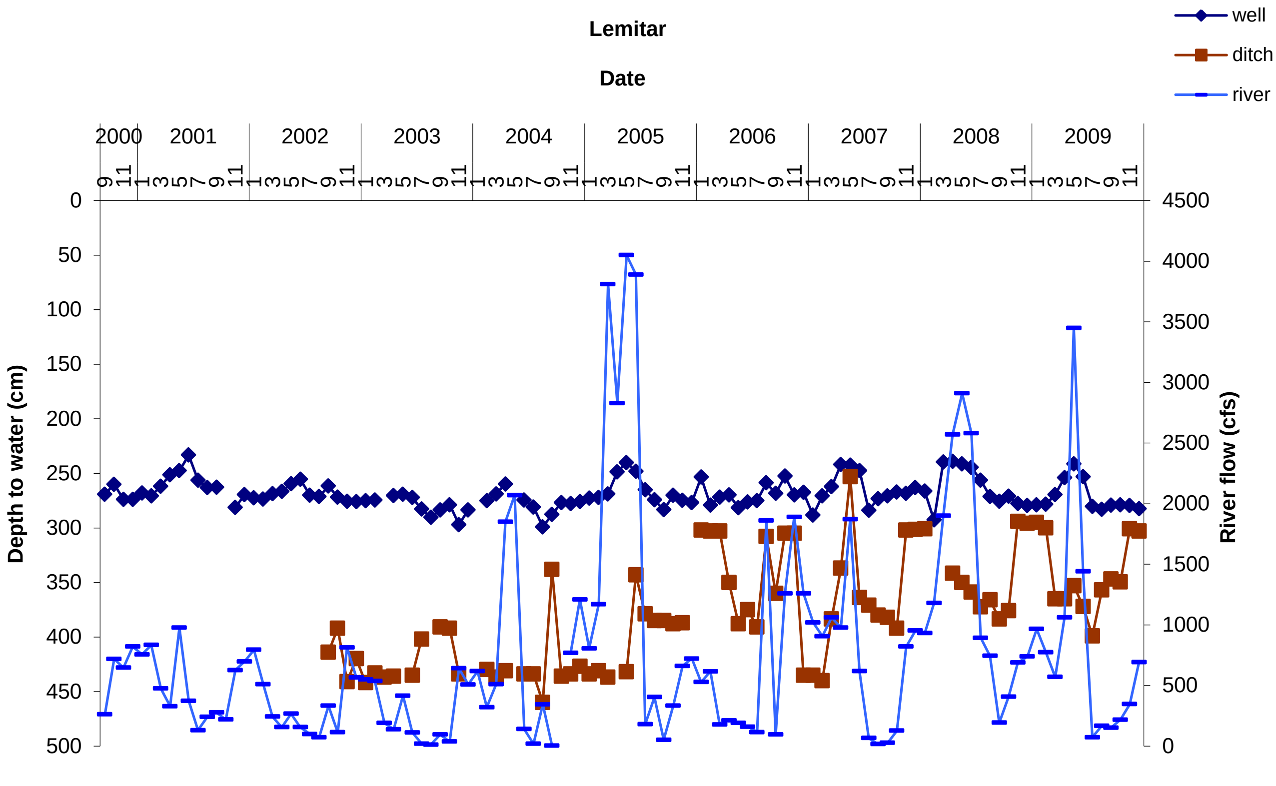


Figure 40. Mean depth to groundwater from ground surface (primary y-axis) in Lemitar compared with Rio Grande flow (from the USGS Albuquerque Central river gage) in cubic feet per second (secondary y-axis).

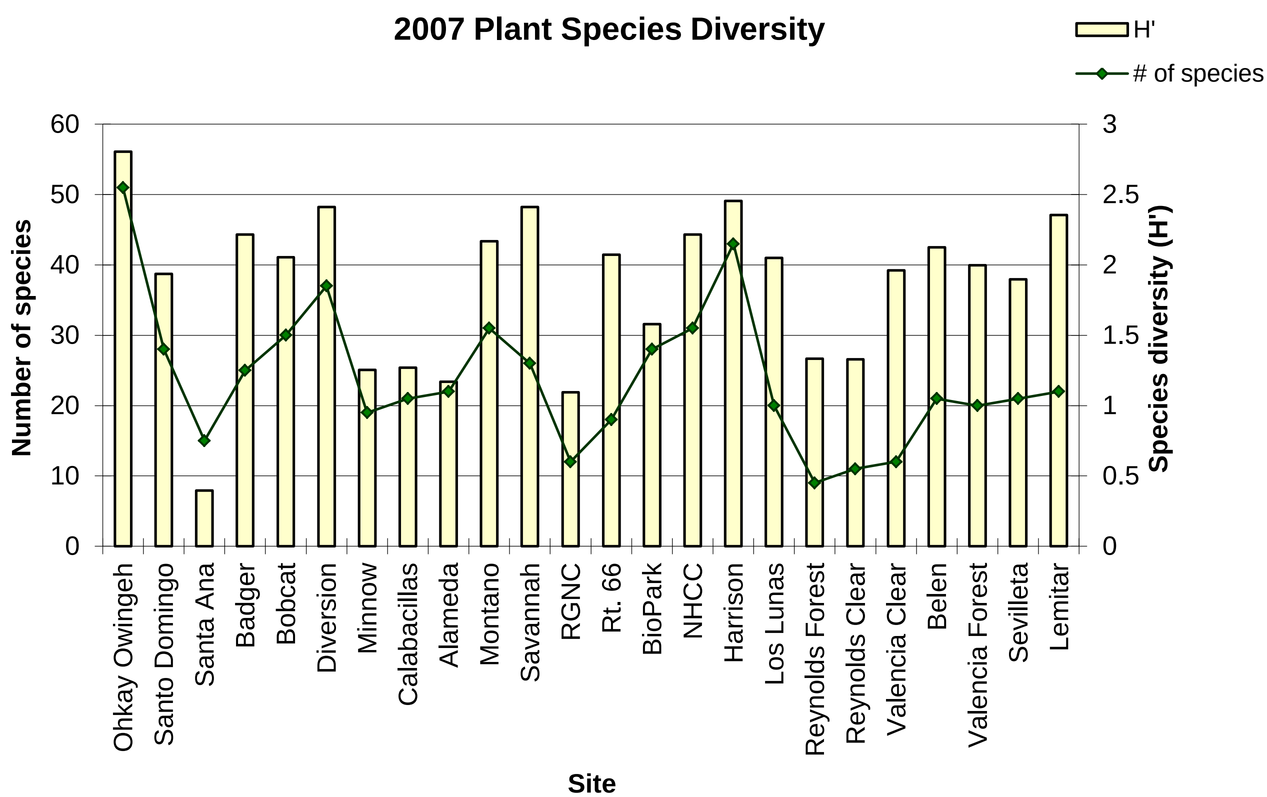


Figure 41. 2007 total number of plant species (primary y-axis) and total plant species diversity, as measured using the Shannon-Wiener index H' (secondary y-axis) across sites (listed north to south).

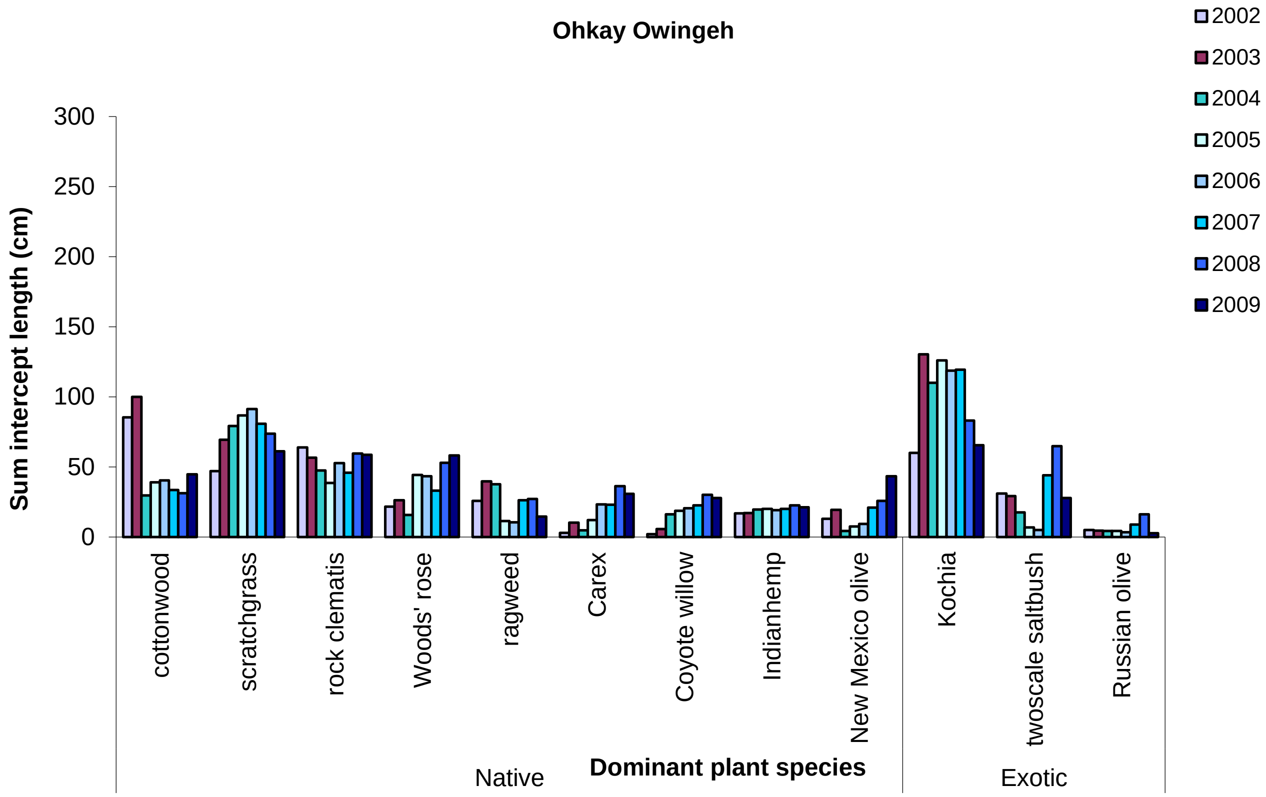


Figure 42. Dominant vegetation cover, divided into natives and exotics, at Ohkay Owingeh. Y-axis is total intercept length summed across all ten 30-m transects. This does not include all species at this site.

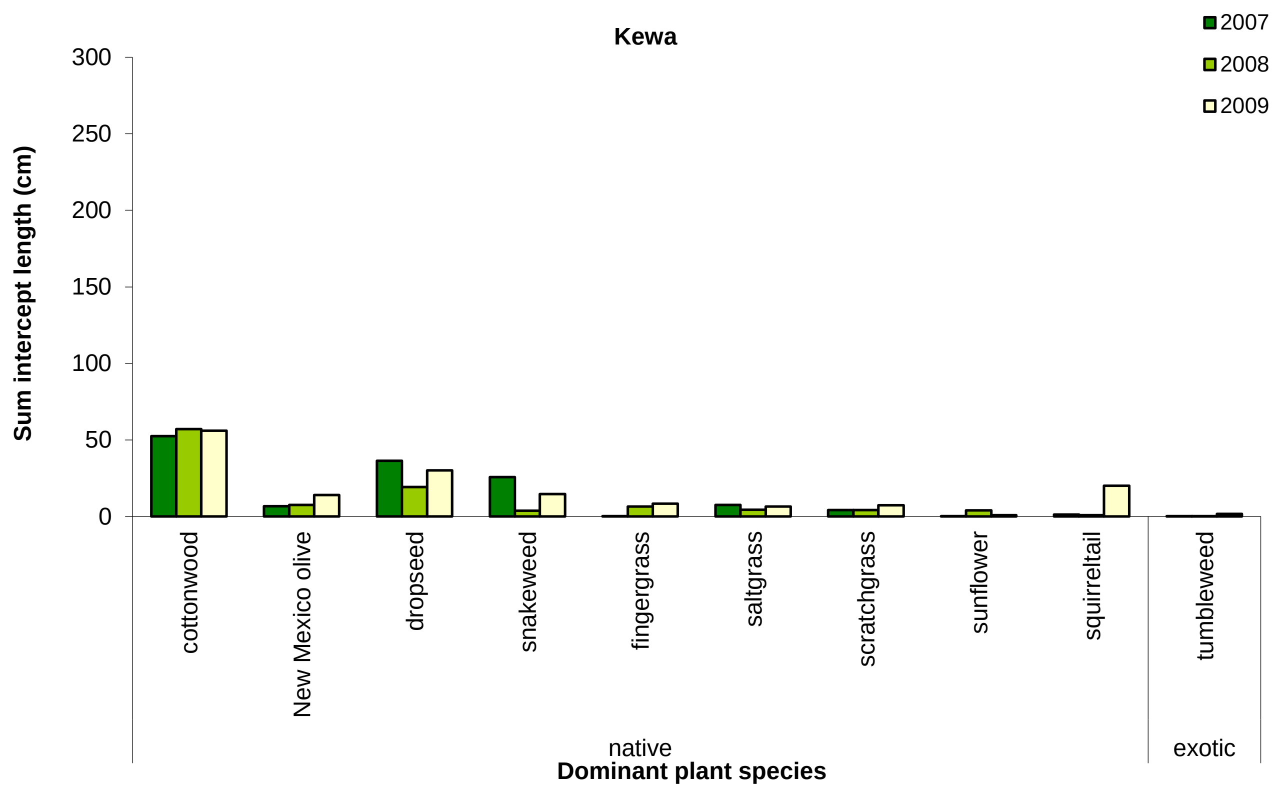


Figure 43. Dominant vegetation cover, divided into natives and exotics, at Kewa. Y-axis is total intercept length summed across all ten 30-m transects. This does not include all species at this site.

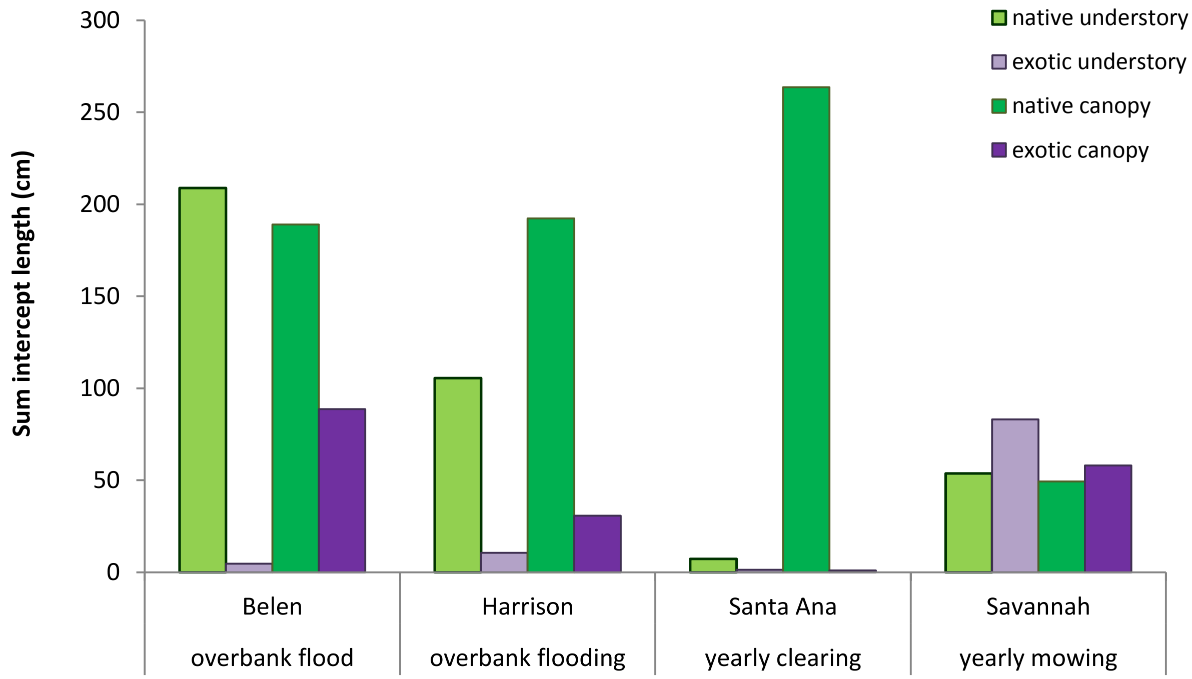


Figure 44. Comparison of 2008 vegetation type and origin at flooded and cleared sites.

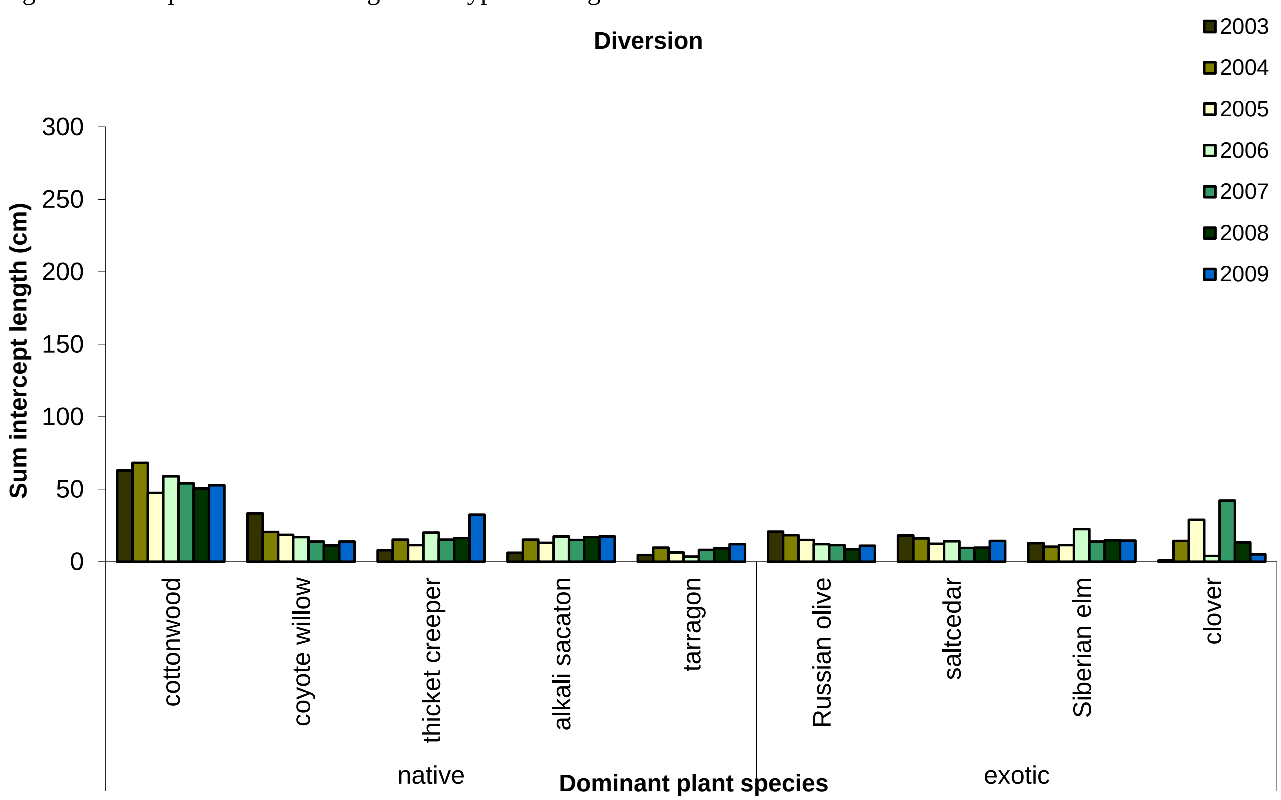


Figure 45. Dominant vegetation cover, divided into natives and exotics, at Diversion. Y-axis is total intercept length summed across all ten 30-m transects. This does not include all species at this site.

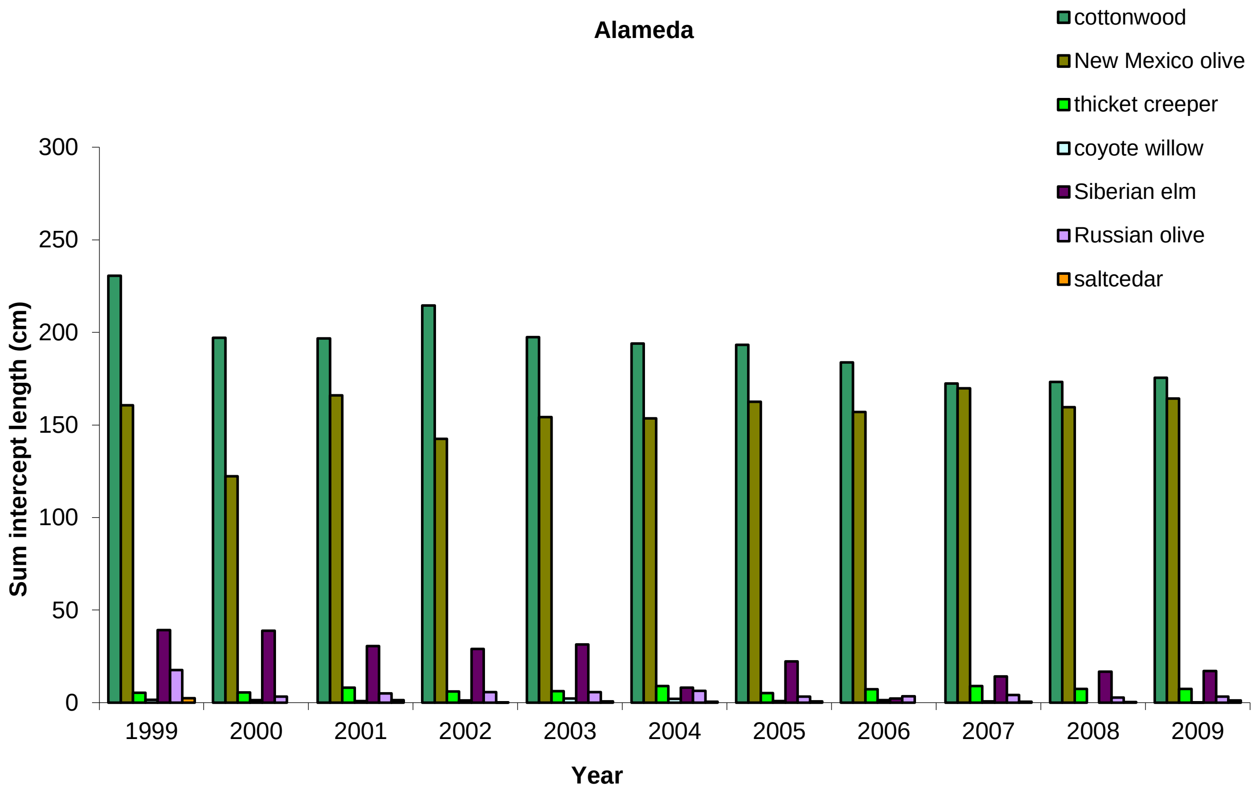


Figure 46. Dominant vegetation cover, divided into natives and exotics, at Alameda. Y-axis is total intercept length summed across all ten 30-m transects. This does not include all species at this site.

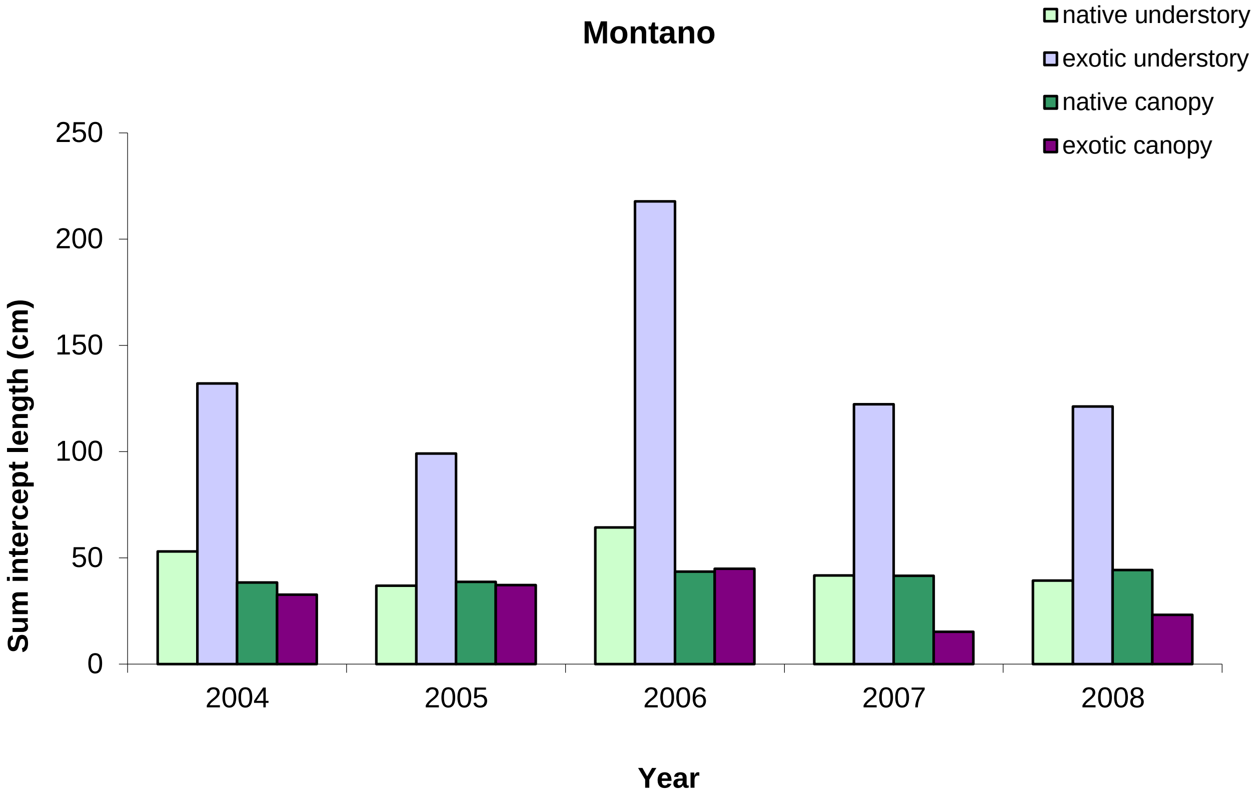


Figure 47. Changes in native and exotic understory and canopy cover at Montaño from 2004 to 2008.

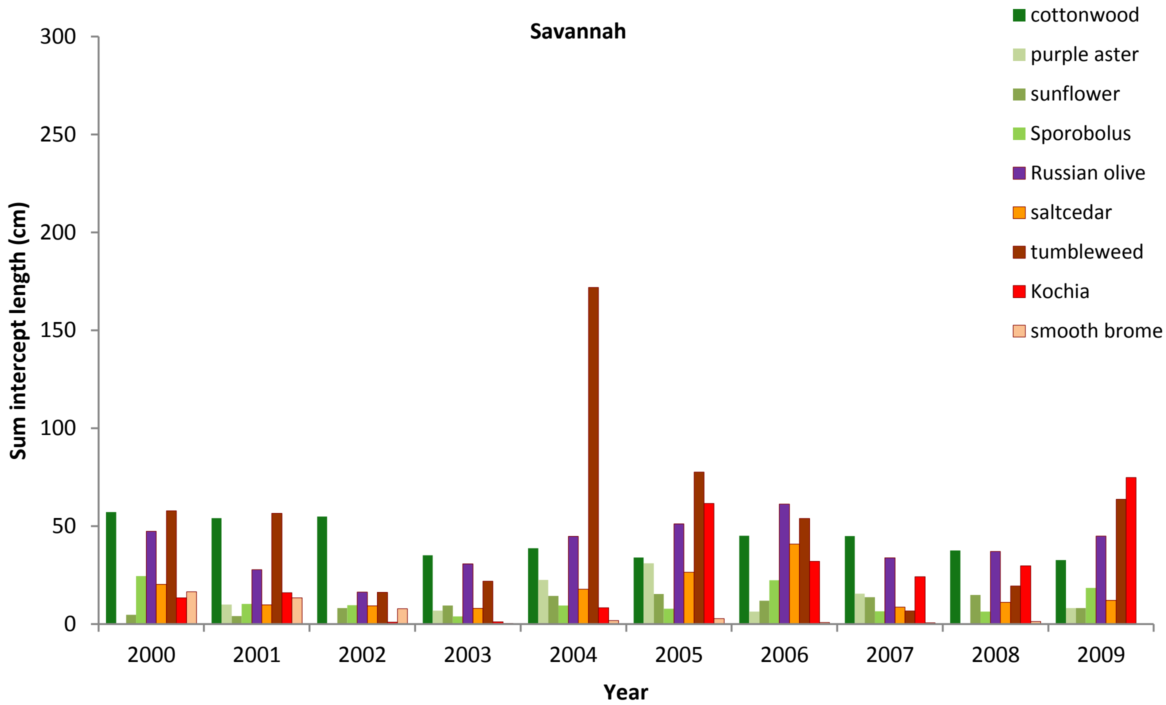


Figure 48. Dominant vegetation cover, divided into natives (greens) and exotics (reds/purple), at Savannah. Y-axis is total intercept length summed across all ten 30-m transects. Not all species are included.

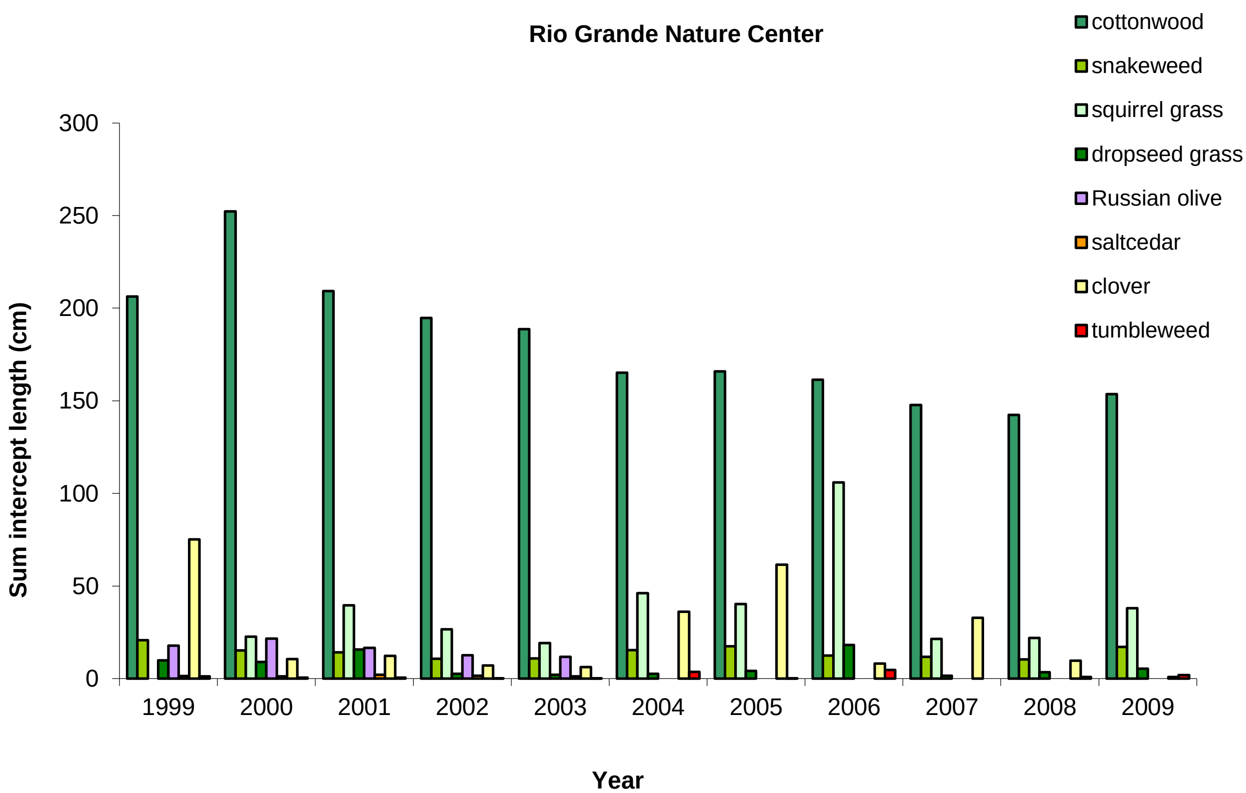


Figure 49. Dominant vegetation cover, divided into natives (greens) and exotics (reds/purple/yellow), at the Rio Grande Nature Center. Y-axis is total intercept length summed across all ten 30-m transects. This does not include all species at this site.

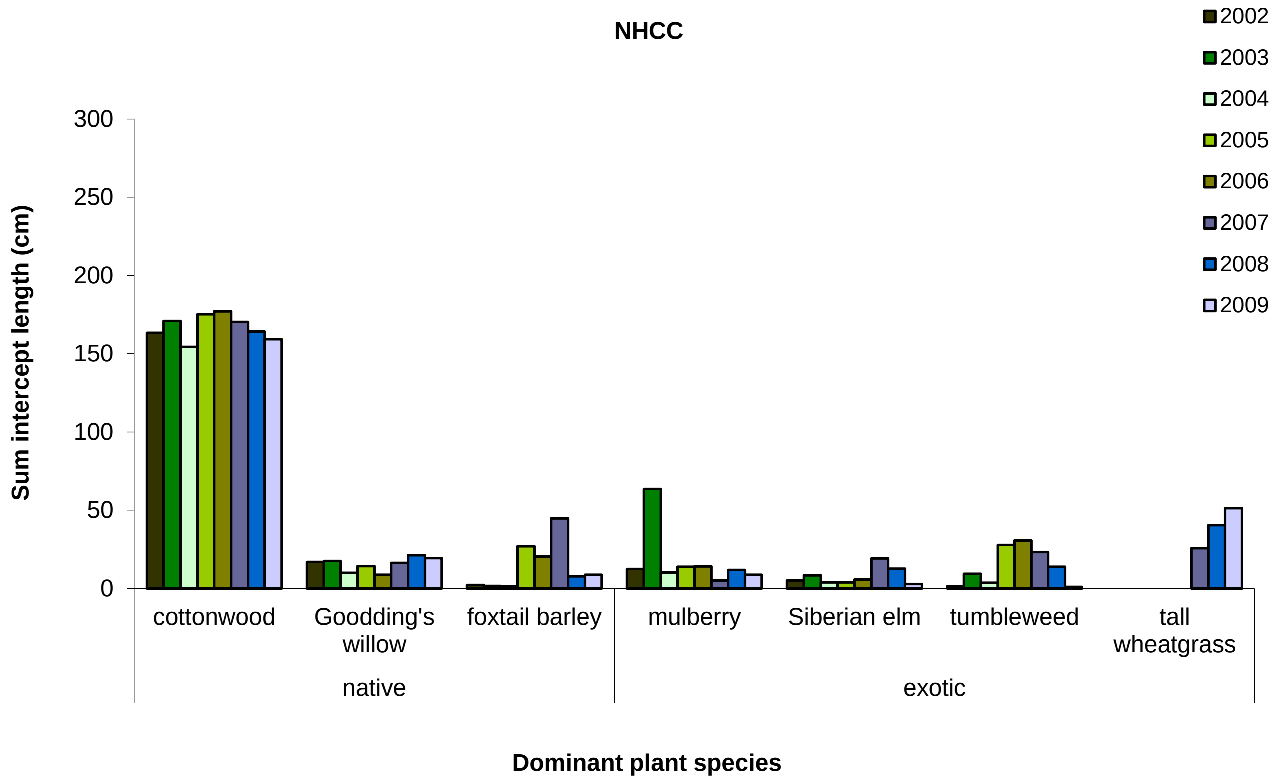


Figure 50. Dominant vegetation cover at the National Hispanic Cultural Center. Y-axis is total intercept length summed across all ten 30-m transects. This does not include all species at this site.

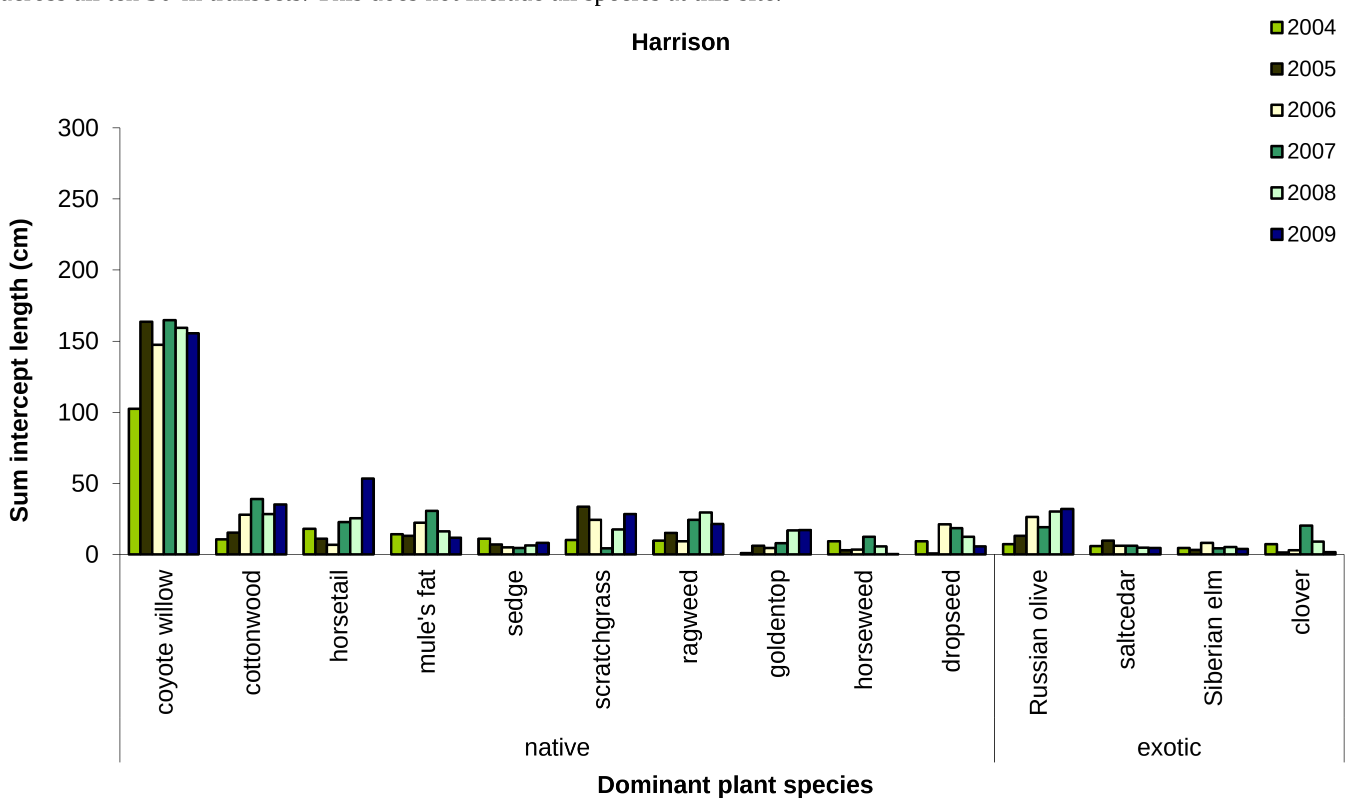


Figure 51. Dominant vegetation cover at Harrison. Y-axis is total intercept length summed across all ten 30-m transects. This does not include all species at this site.

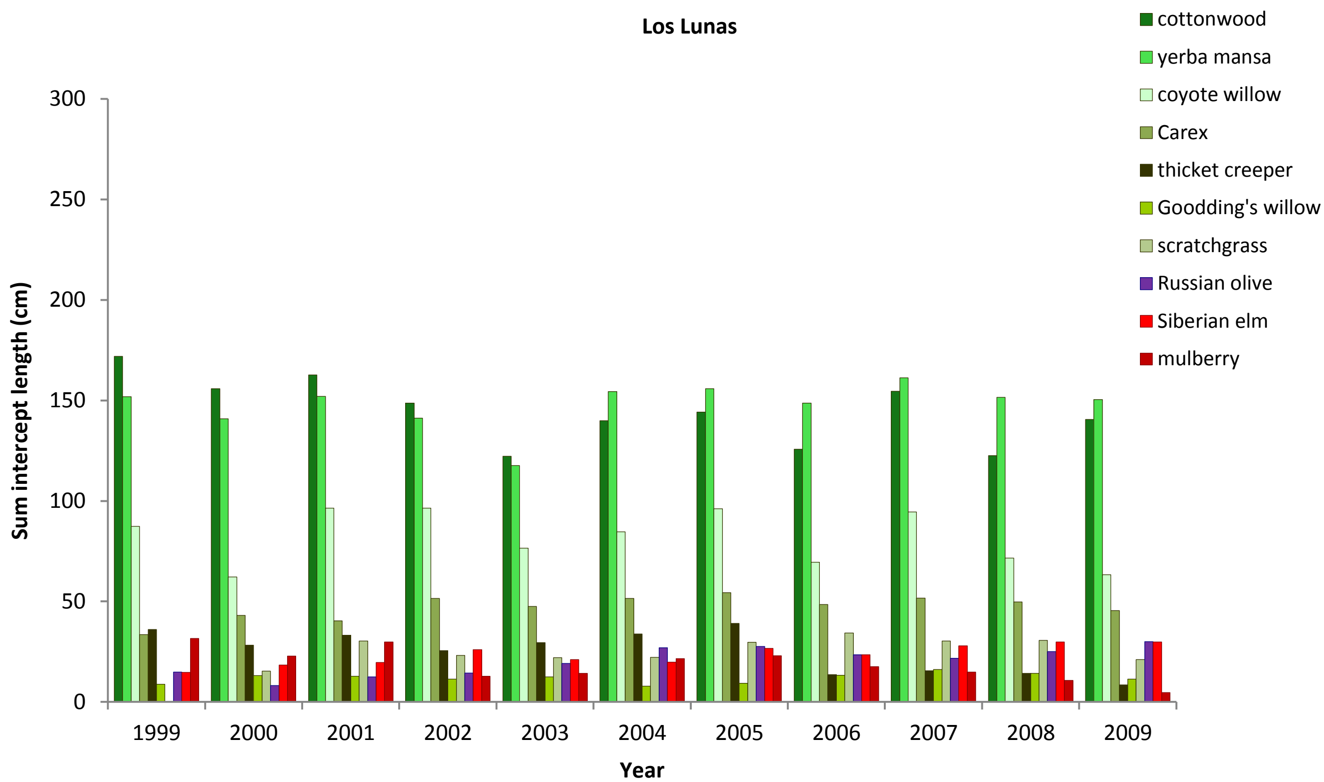


Figure 52. Dominant vegetation cover divided into natives (greens) and exotics (reds/purple), at Los Lunas. Y-axis is total intercept length summed across all ten 30-m transects. Not all species are included.

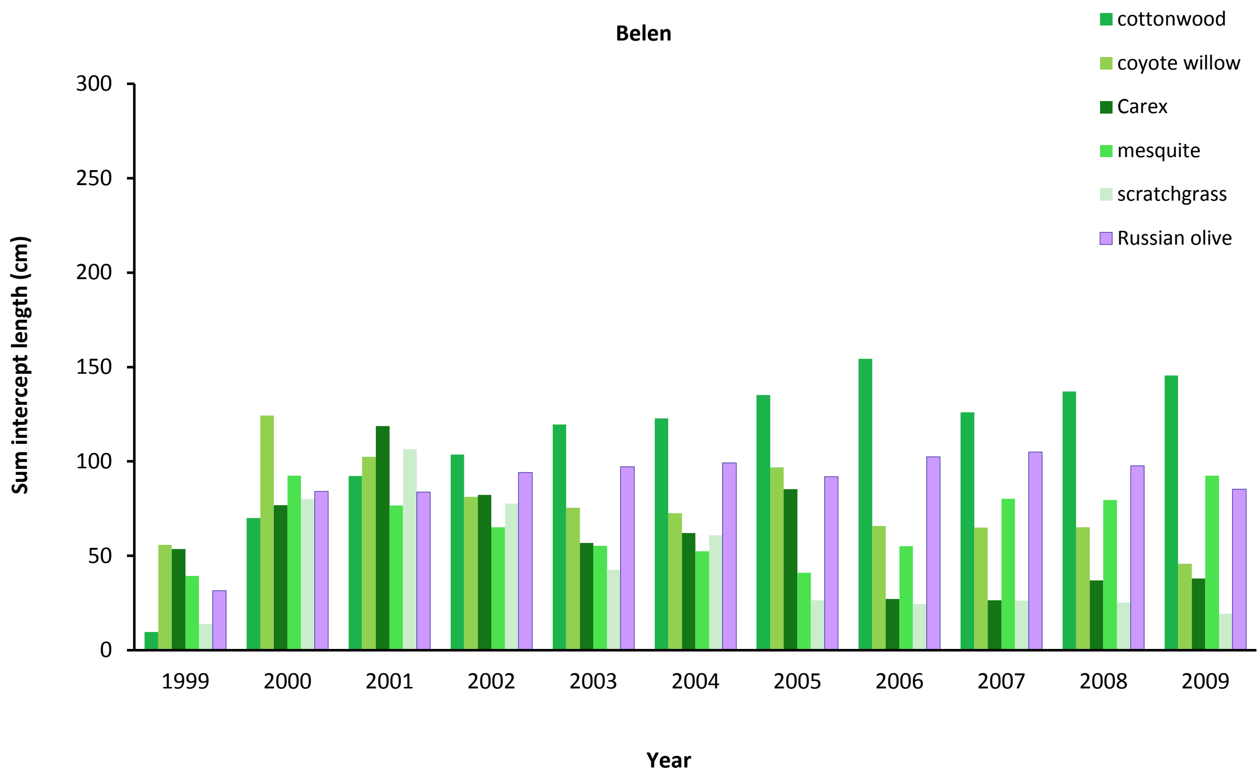


Figure 53. Dominant vegetation cover divided into natives (greens) and exotics (purple), at Belen. Y-axis is total intercept length summed across all ten 30-m transects. This does not include all species at this site.

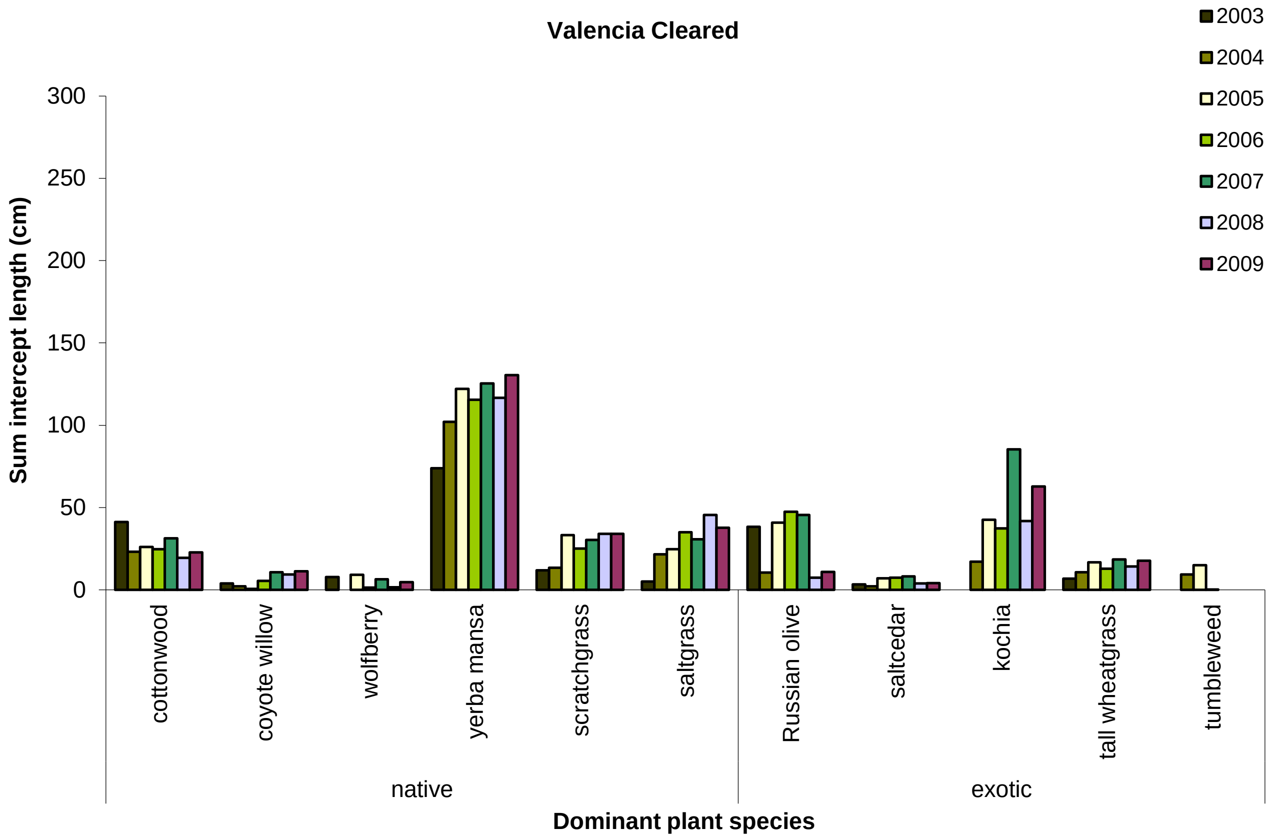


Figure 54. Dominant vegetation cover at Valencia Cleared. Y-axis is total intercept length summed across all ten 30-m transects. This does not include all species at this site.

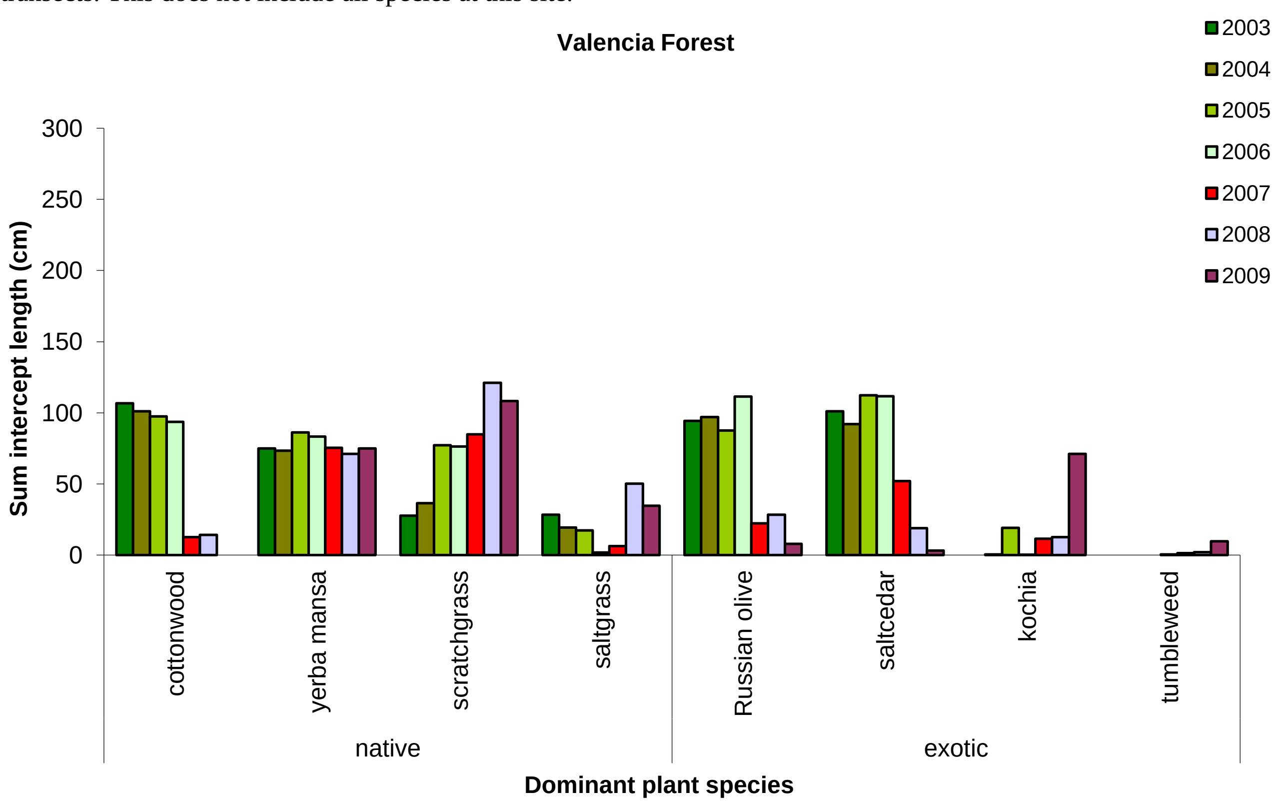


Figure 55. Dominant vegetation cover at Valencia Forest. Y-axis is total intercept length summed across all ten 30-m transects. Fire occurred in 2007, clearing in 2008 and 2009. Not all species are included.

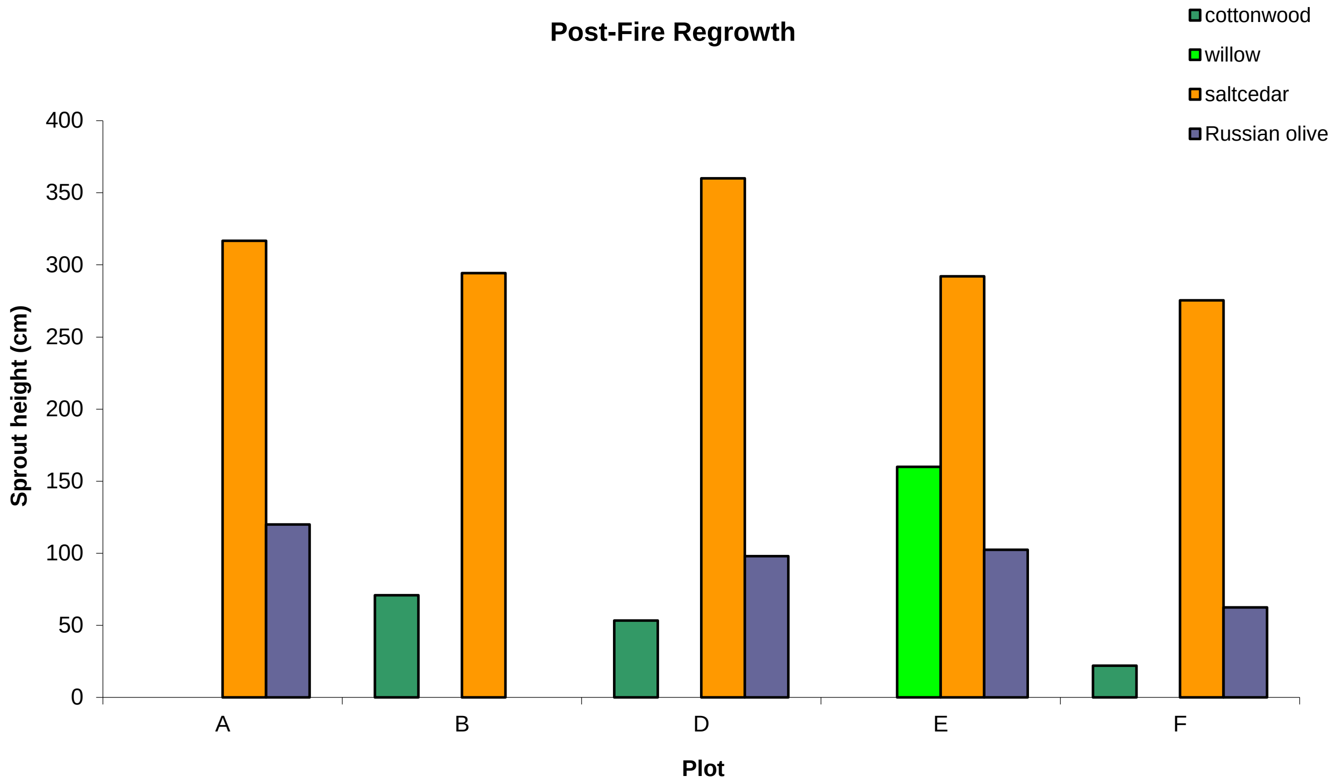


Figure 56. Valencia Forest post-fire tree sprout height measured six months after the fire. Sprouts were from stumps or roots.

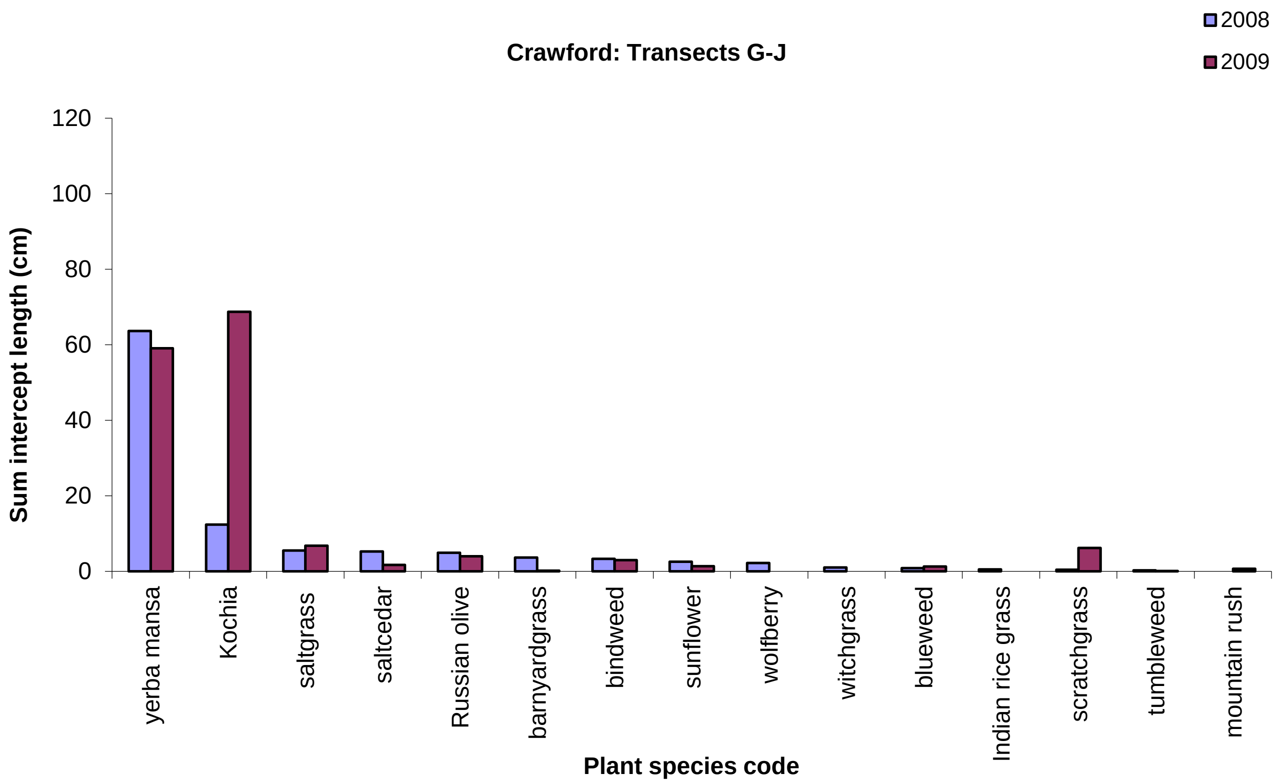


Figure 57. 2008 and 2009 plant species diversity at Crawford, transects G-J, post-burn and clearing. Y-axis is total intercept length summed across four 30-m transects. This includes **all** species found on these transects.

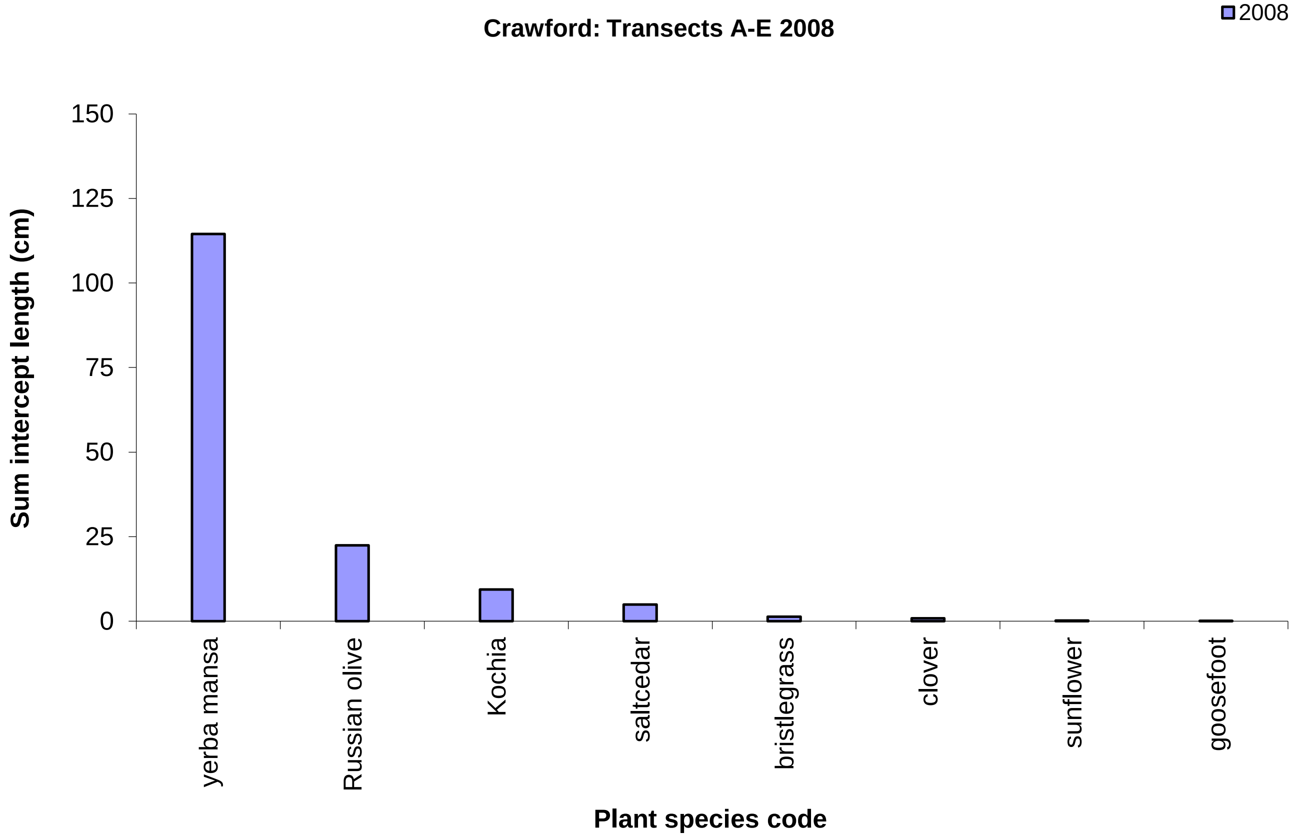


Figure 58. 2008 plant species diversity at Crawford, transects A-E (see pg. 63), post-burn and clearing, pre-landscape lowering. Y-axis is total intercept length summed across five 30-m transects. Includes **all** species.

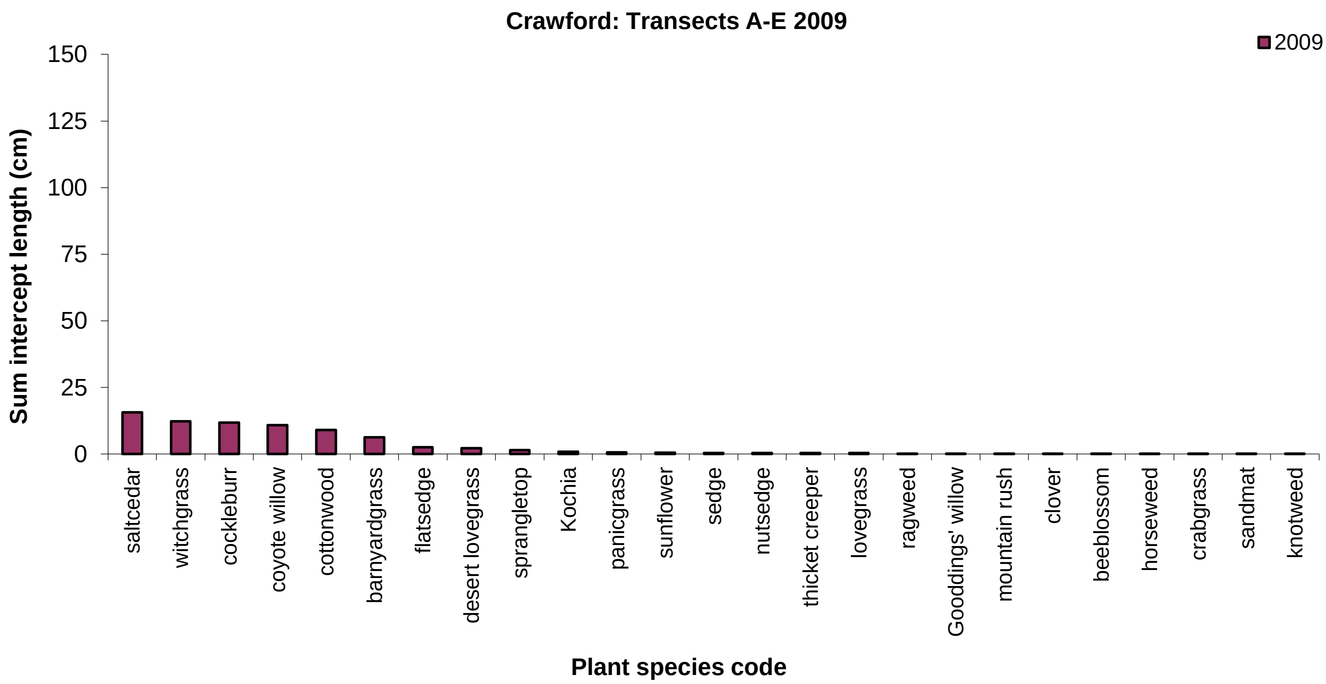


Figure 59. 2009 plant species diversity at Crawford, transects A-E, after landscape lowering and flooding. Y-axis is total intercept length summed across five 30-m transects. This includes **all** species on these transects.

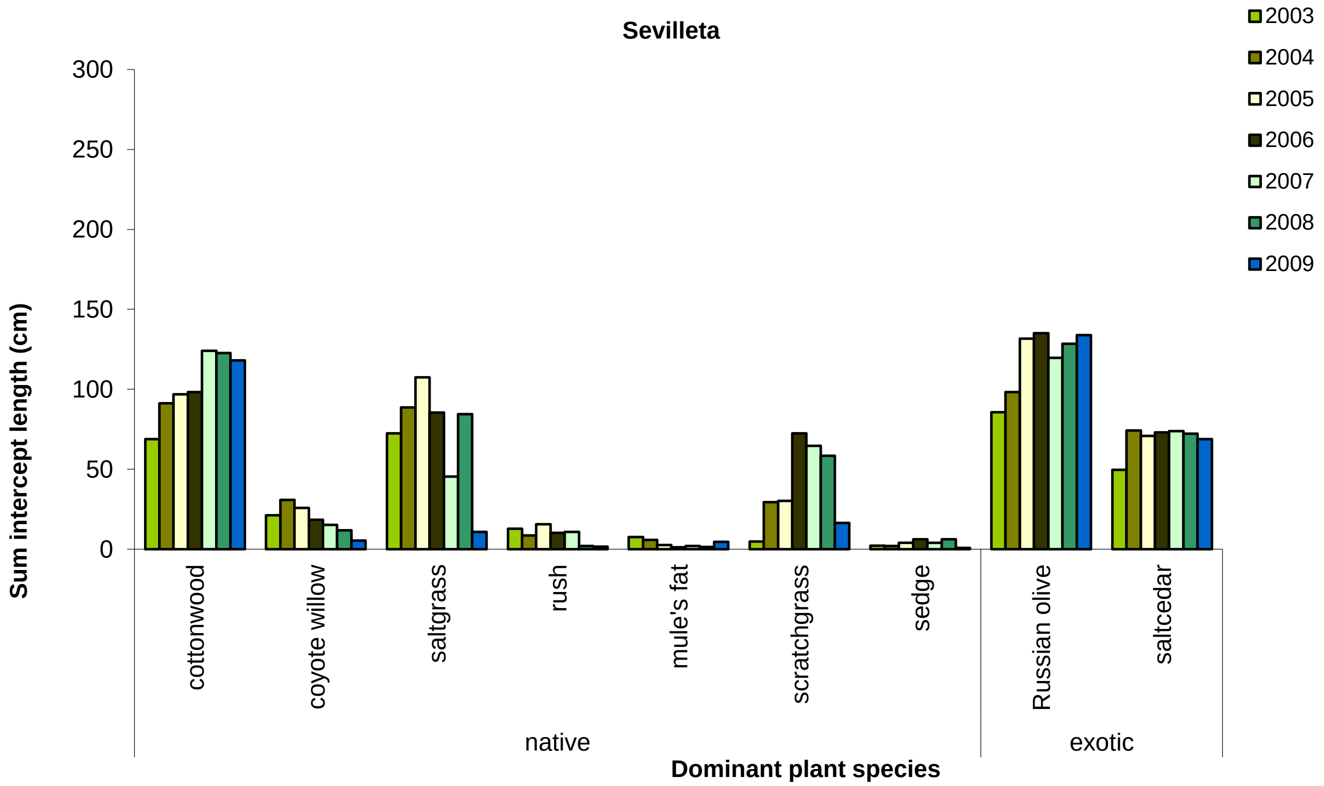


Figure 60. Dominant vegetation cover at Sevilleta. Y-axis is total intercept length summed across all ten 30-m transects. This does not include all species at this site.

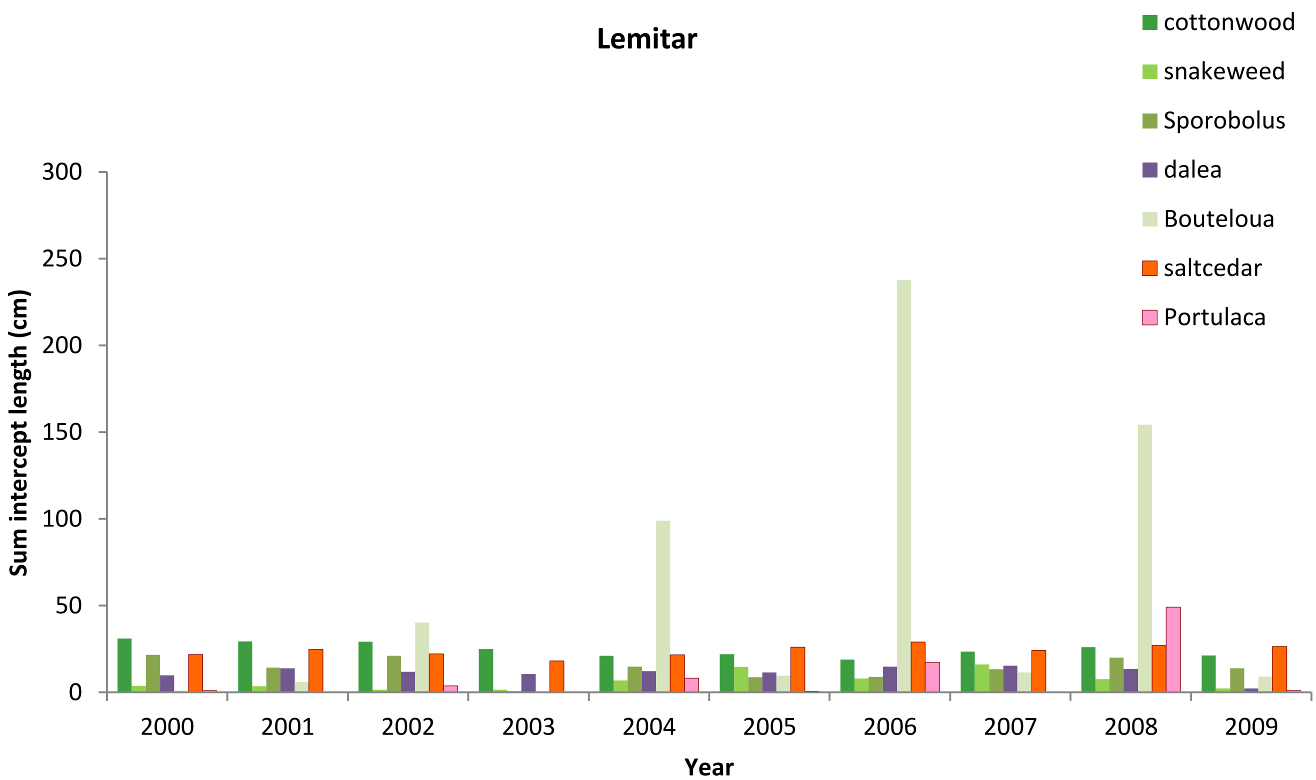


Figure 61. Dominant vegetation cover at Lemitar; shades of green indicate native plants and shades of orange indicate exotics. Y-axis is total intercept length summed across all ten 30-m transects.

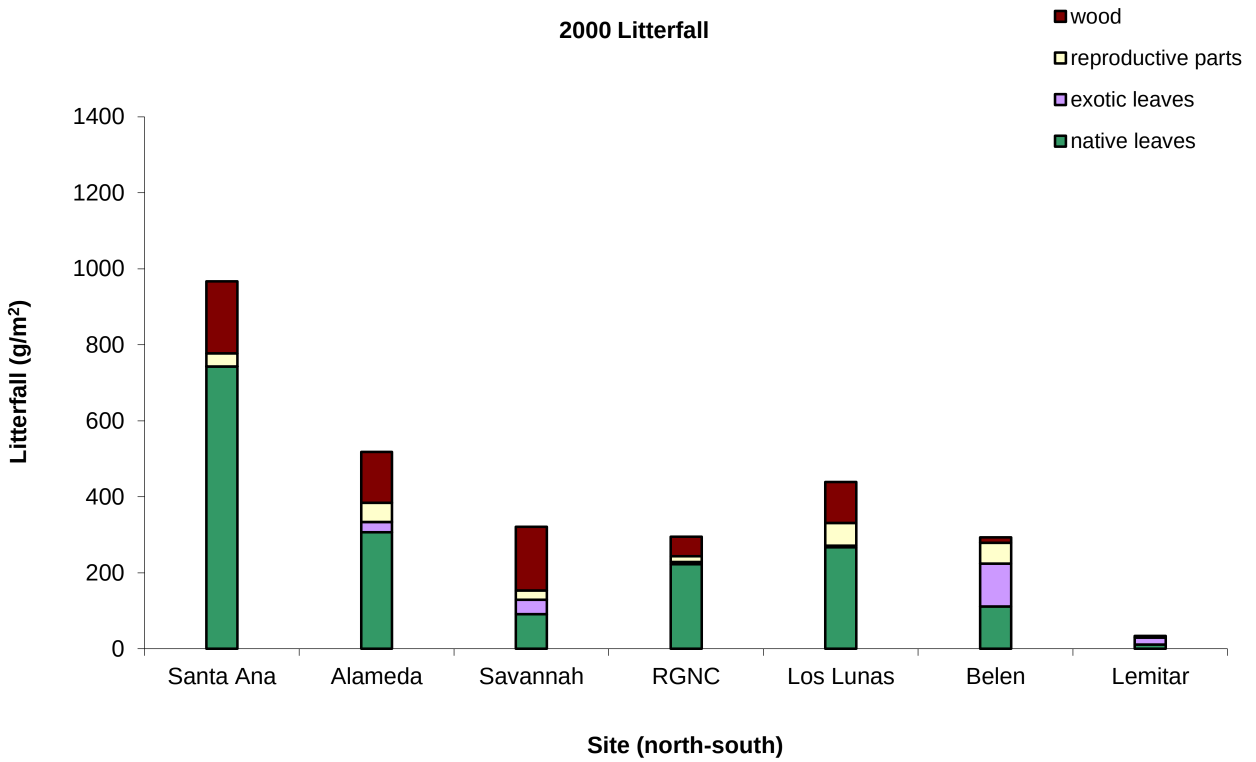


Figure 62. 2000 annual litterfall, divided into dry weight of native leaves, exotic leaves, reproductive parts and wood. Y-axis is the annual litterfall sum, on a scale of 1400 g/m^2 to compare to all sites and years.

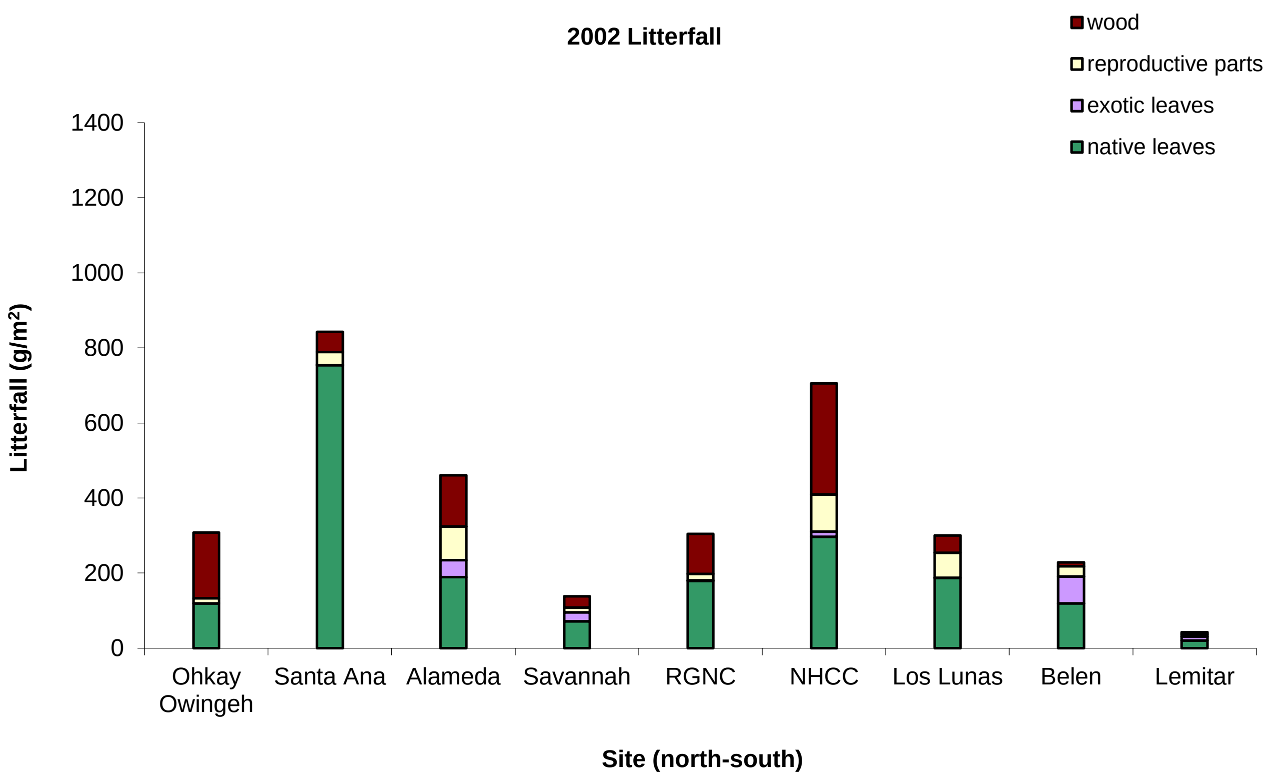


Figure 63. 2002 annual litterfall, divided into dry weight of native leaves, exotic leaves, reproductive parts and wood. Y-axis is the annual litterfall sum, on a scale of 1400 g/m^2 to compare to all sites and years.

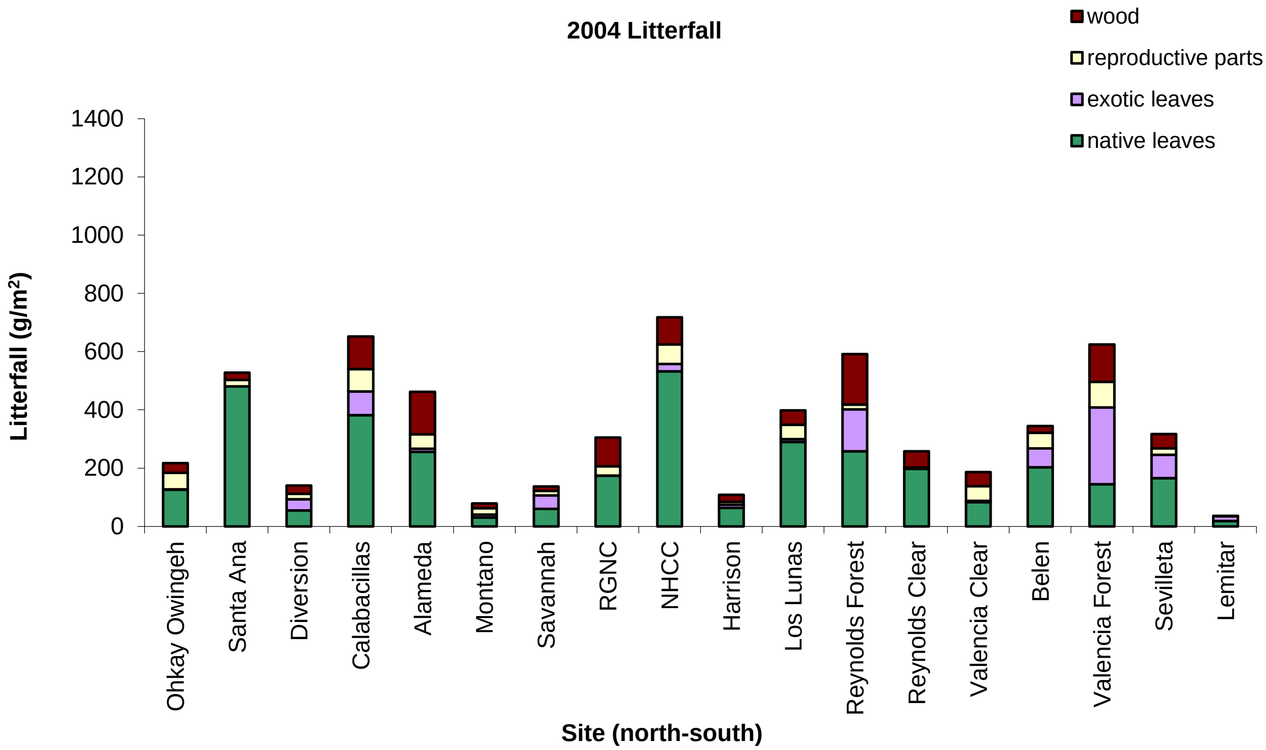


Figure 64. 2004 annual litterfall, divided into dry weight of native leaves, exotic leaves, reproductive parts and wood. Y-axis is the annual litterfall sum, on a scale of 1400 g/m^2 to compare to all sites and years.

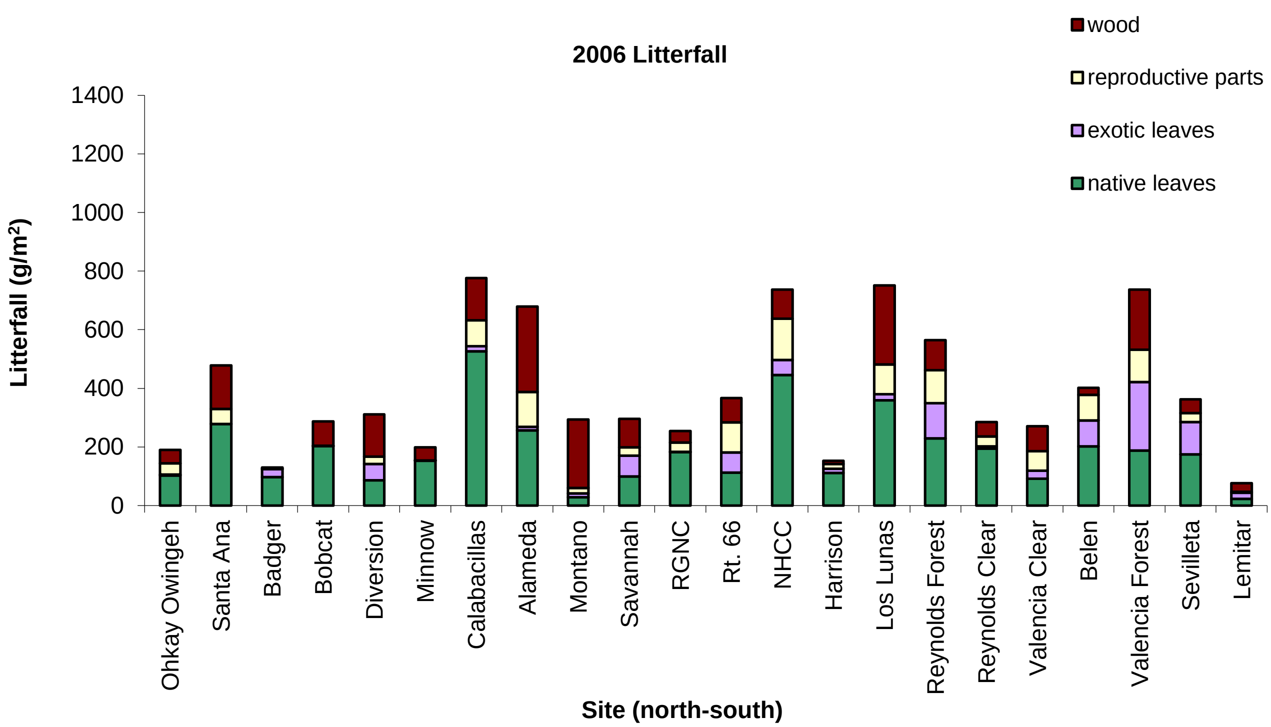


Figure 65. 2006 annual litterfall, divided into dry weight of native leaves, exotic leaves, reproductive parts and wood. Y-axis is the annual litterfall sum, on a scale of 1400 g/m^2 to compare to all sites and years.

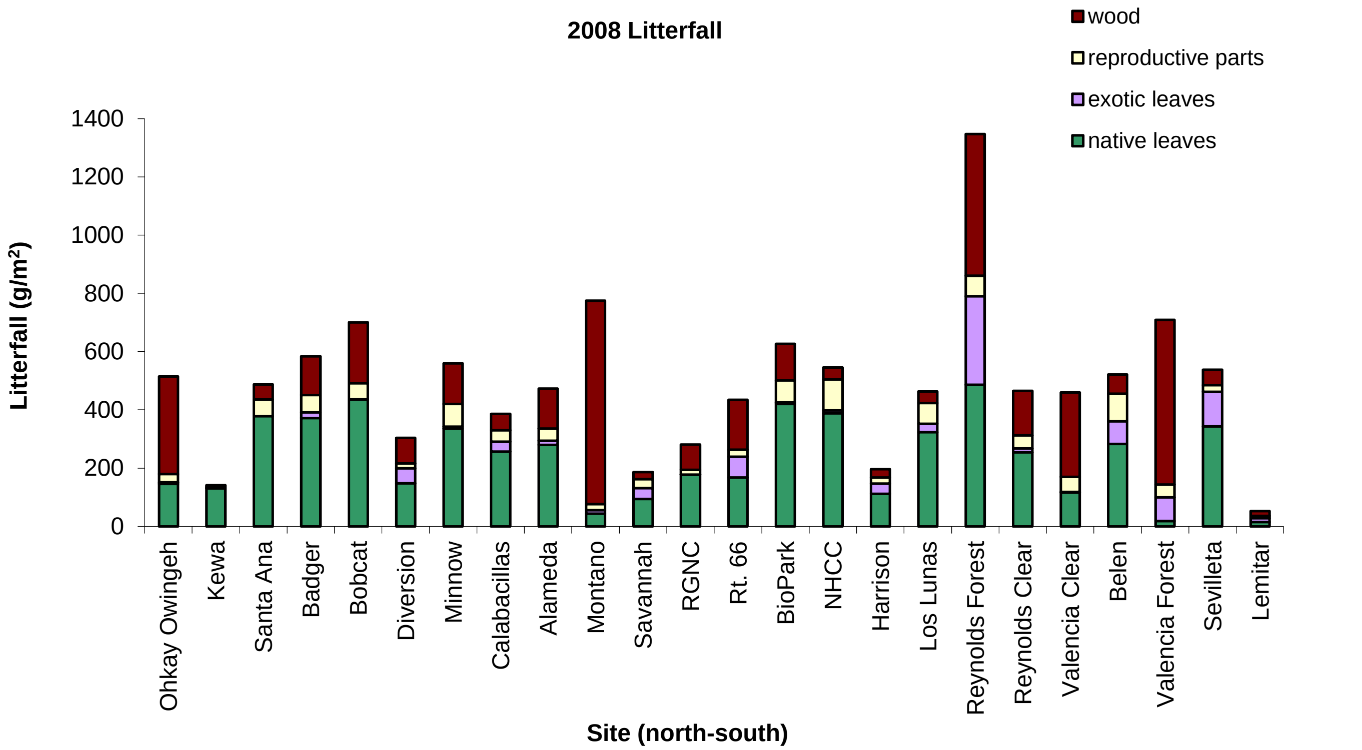


Figure 66. 2008 annual litterfall, divided into dry weight of native leaves, exotic leaves, reproductive parts and wood. Y-axis is the annual litterfall sum, on a scale of 1400 g/m^2 to compare to all sites and years.

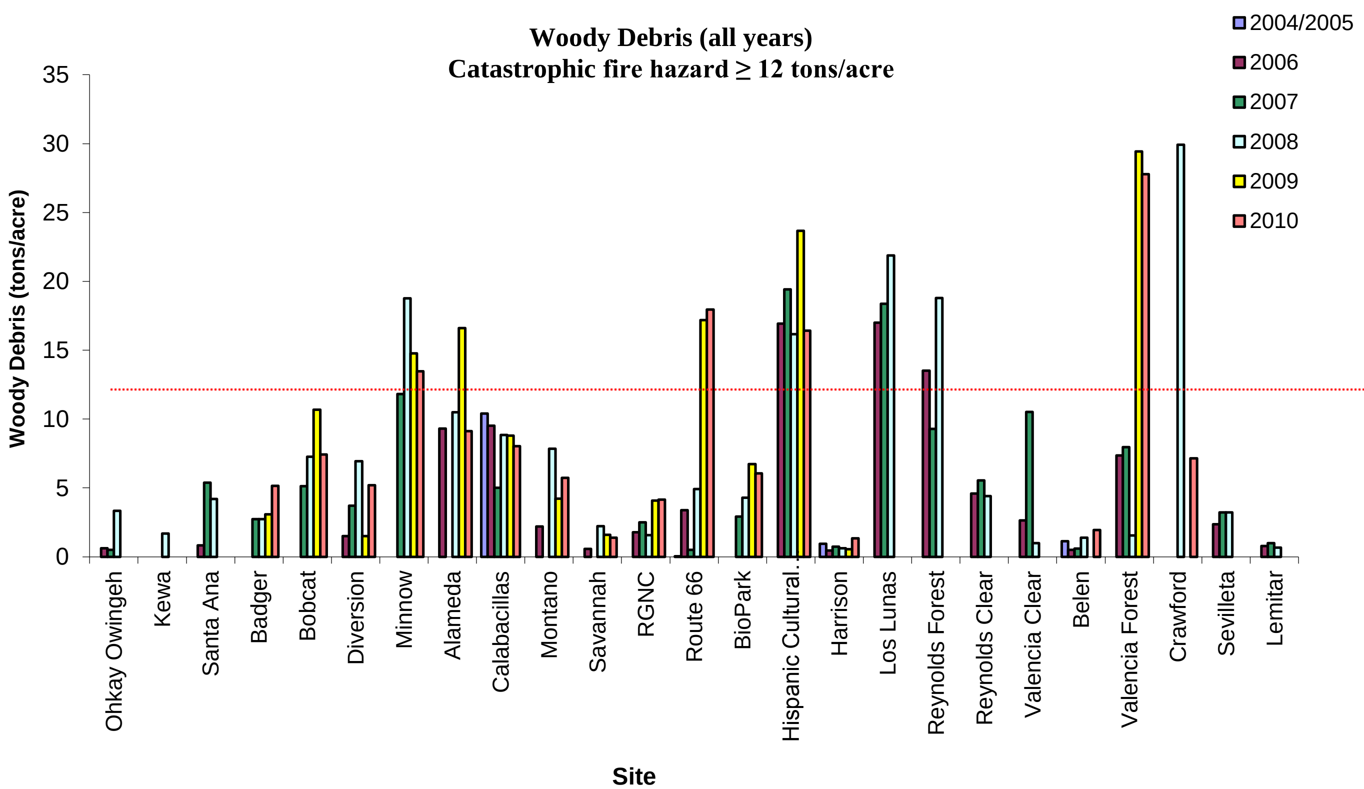


Figure 67. Total fuel load (tons/acre) for each site for years 2004 – 2010. Not all sites were monitored in all years. The red dashed line represents the catastrophic fire hazard load. Sites are listed north to south.

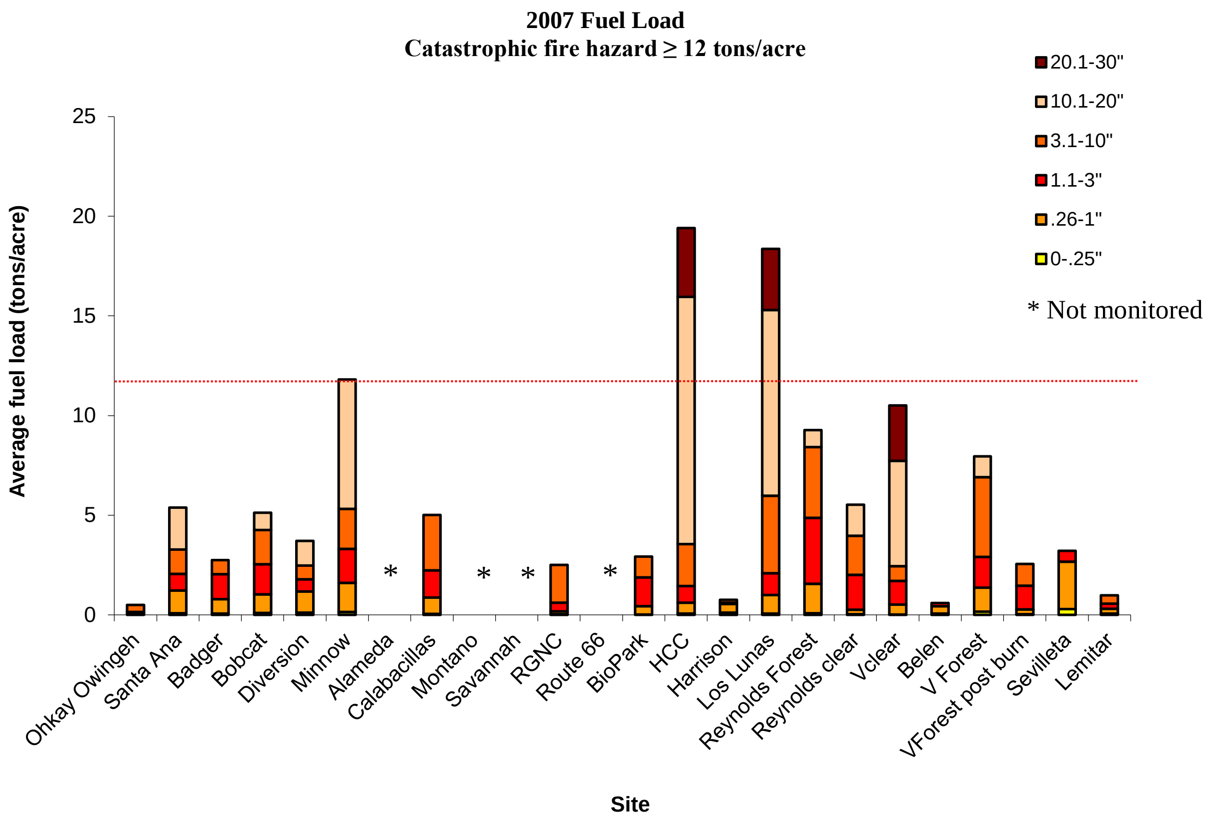


Figure 68. 2007 fuel load broken down by size class of woody debris. Smaller size classes are represented in brighter colors. Larger, less hazardous size classes are in tan and dark brown. Sites are listed north to south.

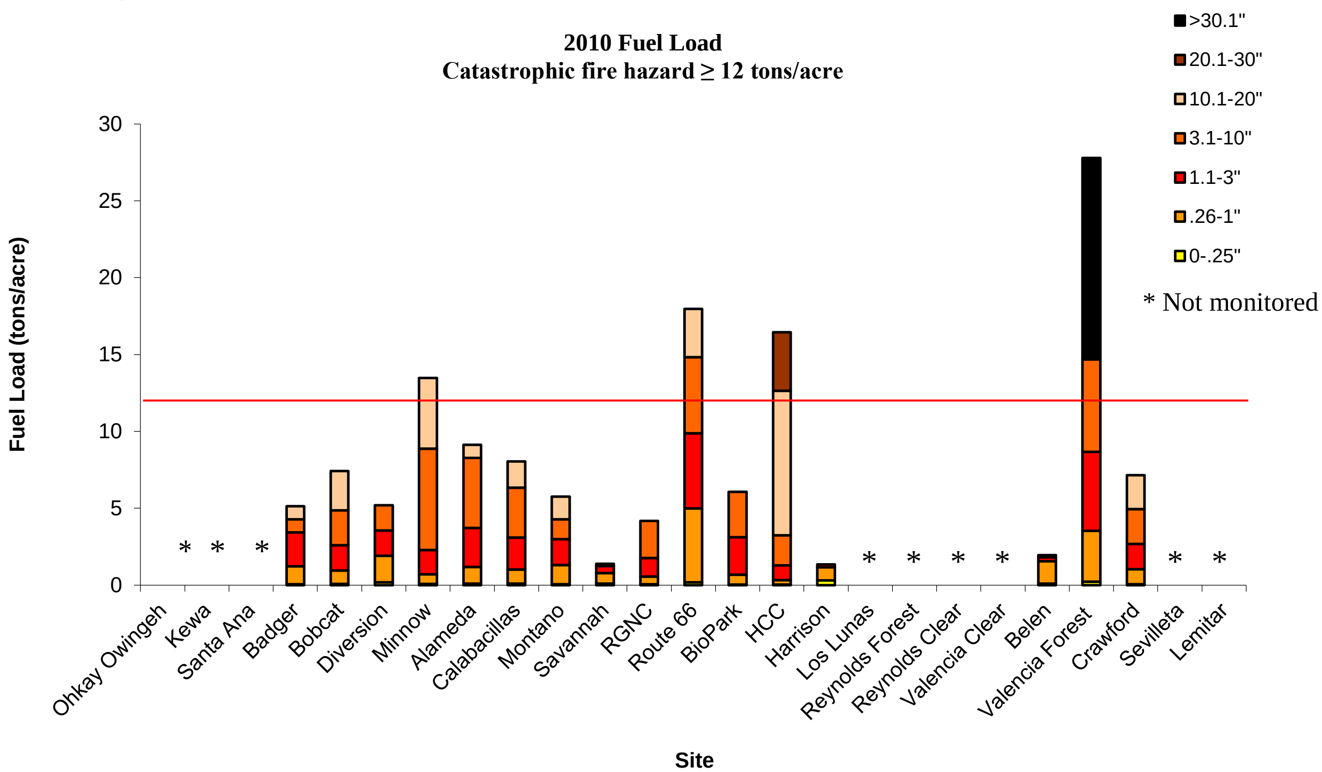


Figure 69. 2010 fuel load broken down by size class of woody debris. Smaller size classes are represented in brighter colors. Larger, less hazardous size classes are in tan and dark brown. Sites are listed north to south.

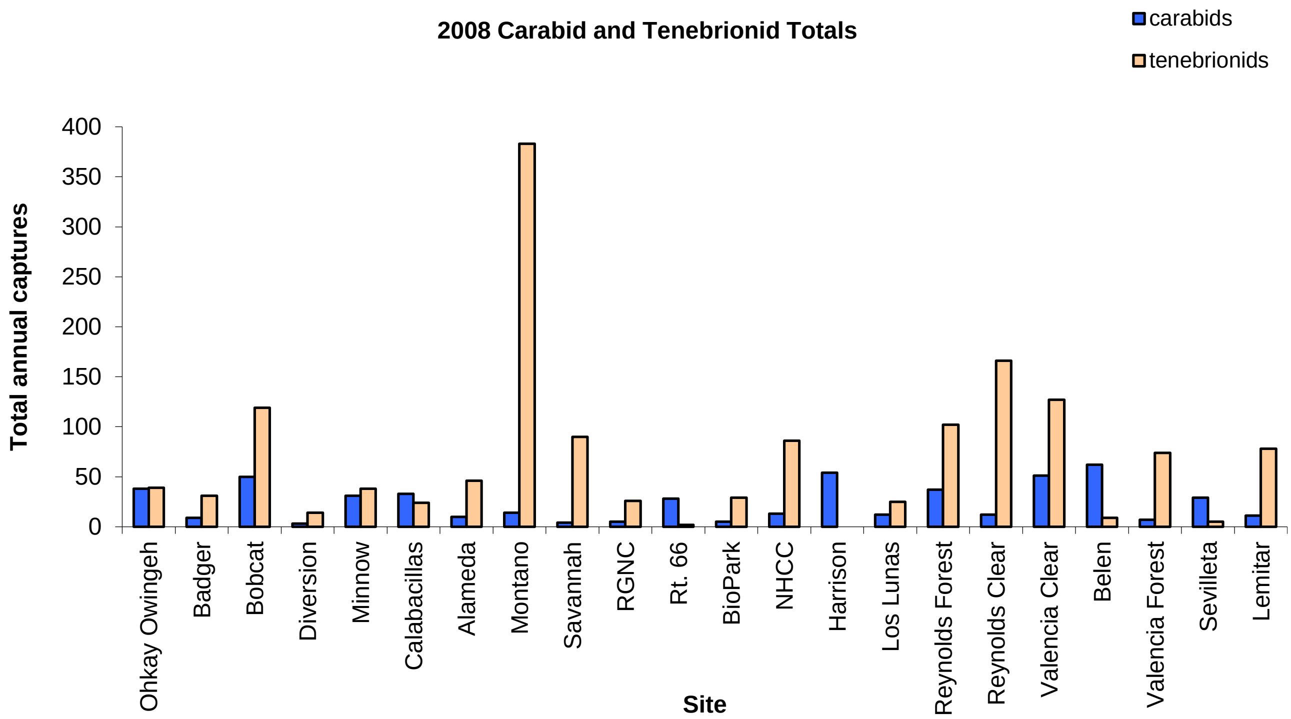


Figure 70. 2008 total annual carabid and tenebrionid beetle captures.

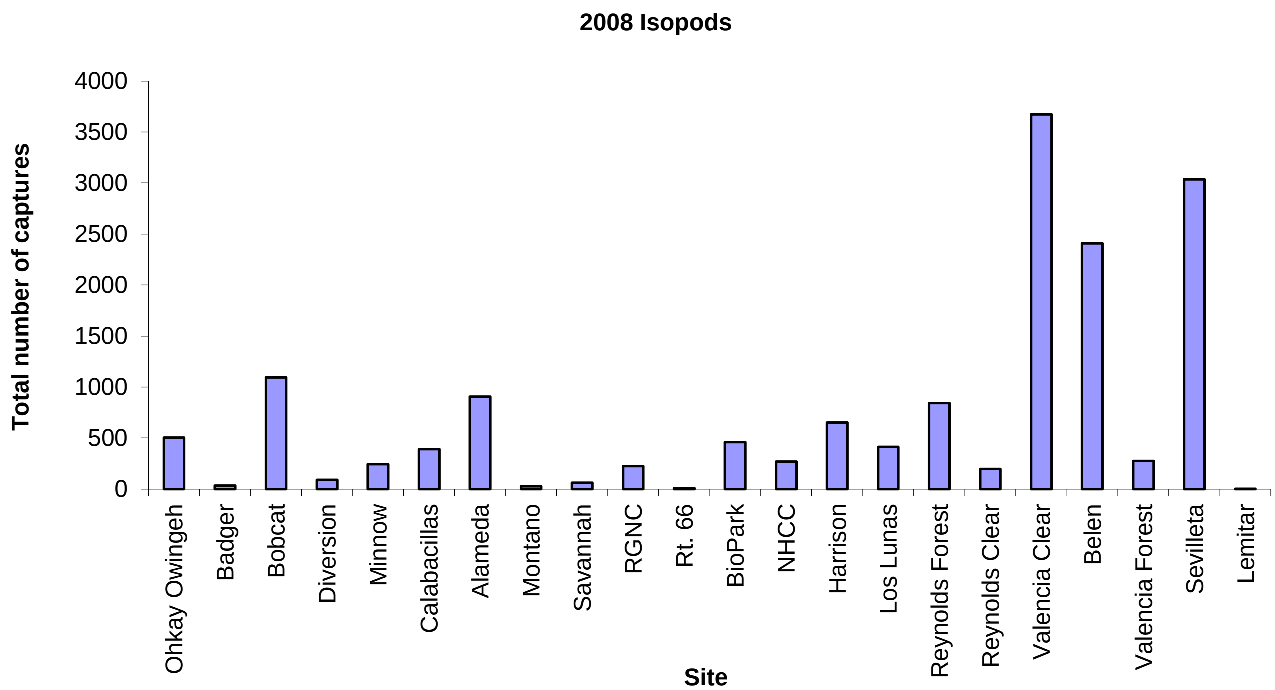


Figure 71. 2008 total isopods captures.

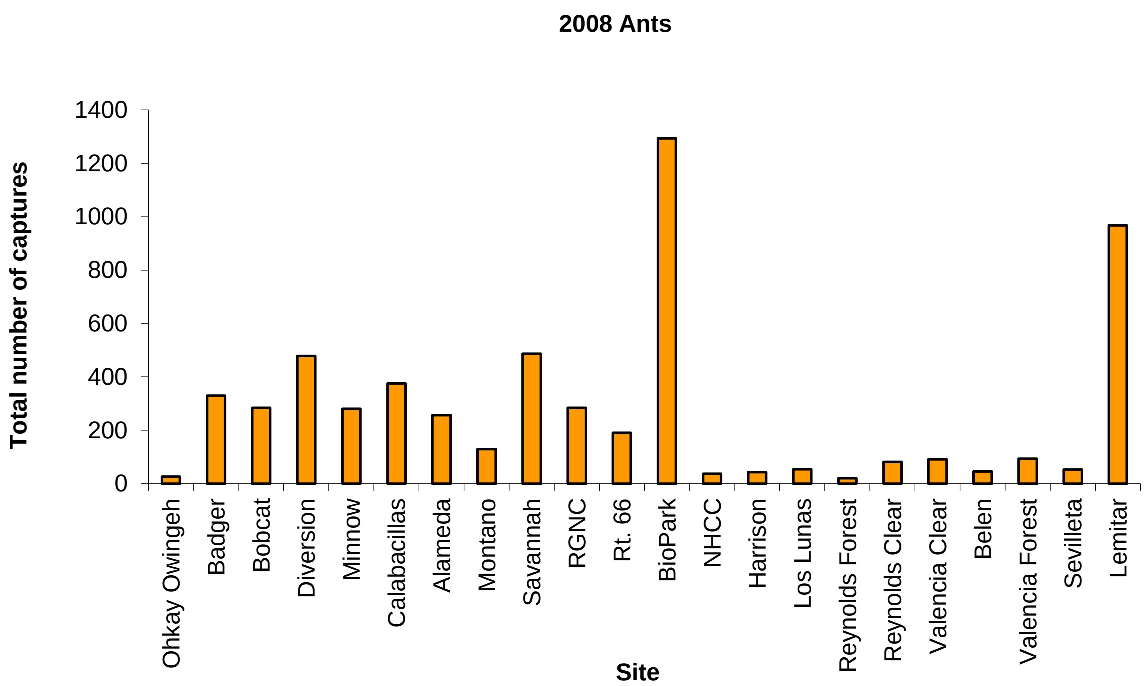


Figure 72. 2008 total ant capture.

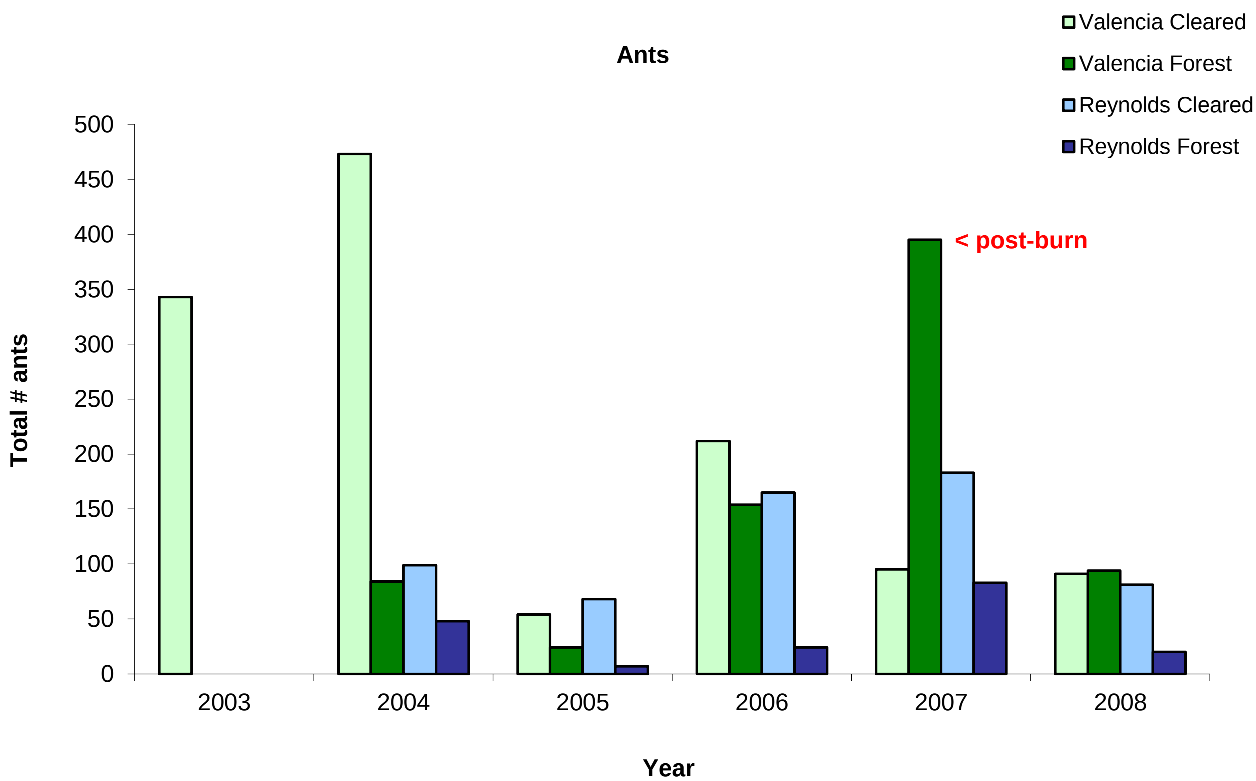


Figure 73. Total ant captures at cleared and forest sites in Belen from 2003 – 2008.

Interpretations

Abiotic Factors

Temperature (Figures 4-9)

Fourteen of the twenty-five BEMP sites have temperature data loggers. Air temperature is monitored by a logger located 2 m high in a cottonwood tree (under the canopy). Ground temperatures are monitored by loggers buried approximately 2 cm below ground; one is directly below the air temperature logger (under the canopy) and the other is near the open rain gauge (in the open). Sites with temperature data loggers include Santa Ana, 30 miles north of Albuquerque; ten sites in Albuquerque; and to the south of Albuquerque, Los Lunas, Belen, and Lemitar. The sites in Albuquerque include the six sites surrounding the DWP diversion dam: above the DWP dam are Bobcat on west and Badger on the east; below the dam are Minnow and Calabacillas on the west, and Diversion and Alameda on the east (Figure 3). In mid-Albuquerque, located near Bosque School on the west side of the river, are Montaño and Savannah. Across the river is the Rio Grande Nature Center (RGNC). The National Hispanic Cultural Center (NHCC), also on the east side of the river, is the last Albuquerque site with temperature loggers.

Mean air temperatures are more similar between sites than mean ground temperatures (Figures 4-9). The warmest sites are Lemitar, the southernmost BEMP site, and the Albuquerque sites, like Diversion, NHCC, Calabacillas, Minnow, RGNC, Montaño, and Alameda (Figure 4). This is understandable, as the urban sites reflect the heat of the paved, industrialized city, and Lemitar, in the southern part of the state, has more bare ground than any other BEMP site (excepting post-fire and post-clearing events).

The ground temperatures under the canopy are less similar between sites than air temperatures (Figures 4 & 5). Diversion and Alameda (both below the DWP dam on the east side of the river) have the broadest fluctuations each year, with the warmest highs and coolest lows of all the sites (Figure 5). Lemitar continues to have some of the highest temperatures of all the sites. Savannah has the smallest fluctuations of any site, with the coolest highs and warmest lows, in spite of its stretches of open grassland. Los Lunas and Belen, to the south, and Santa Ana to the north, are some of the coolest sites (Figure 5). Los Lunas and Santa Ana have dense cottonwood canopies, and both Los Lunas and Belen have thick native understory vegetation.

Ground temperatures in the open are presented by reach (with the sites north and south of Albuquerque presented together). Of the six sites surrounding the DWP dam, Diversion is always warmer than the others during the summer months by 3 to 8 °C (Figure 6). Only during the summer of 2004 was Minnow (across the river from Diversion) as warm as Diversion. Diversion and Alameda have the coldest temperatures during the winter months and are very similar, though Alameda seems to have colder open ground temperatures than Diversion, while the reverse is true under the canopy (Figures 5 & 6). Further downstream, Montaño and Savannah are on the west side of the river, almost directly across from RGNC on the east side. About eight miles downstream is NHCC, also on the east side. None of these four sites has as high a summer temperature or as cold a winter temperature as Diversion (Figures 6 & 7). Both of the Bosque School sites (on the west) are warmer year-round than the two sites on the east side (Figure 7). For the sites outside Albuquerque, Lemitar has the warmest ground temperatures in the open during all months of the year (as opposed to Diversion, which only has the warmest temperatures during the summer months) (Figures 6 & 8). The ground temperatures in the open at Santa Ana, north of Albuquerque, are actually a bit cooler than most of the Albuquerque sites, but are quite a bit warmer than the Los Lunas and Belen sites south of Albuquerque (Figures 6-8). To better illustrate the dynamics between three of the warmest BEMP sites, the maximum and minimum ground temperatures in the open are shown between Diversion, Savannah, and Lemitar (Figure 9). The summer of 2004 was clearly hotter than summers of subsequent years, while the lows of the winter months remain very similar, though the winter of 2006 was the coldest for the Albuquerque sites when considering maximum temperatures (Figure 9).

Precipitation (Figures 10-19)

One of the ways we determine drought status in the Middle Rio Grande valley is by looking at overall precipitation levels averaged over all the bosque sites (Figure 10). Here we can see the high precipitation levels in 1997 were well above average, while the next three years can be considered "average" for this area. Rainfall levels in 2001, 2002, and 2003 ranged between 125 and 150 mm per year, and represent drought years. When considering overall annual trends within the BEMP data, 2004 and 2006 were both above-average years, while 2005 and 2007 were average rainfall years. There was a slight decline in annual rainfall in 2008 and again in 2009 (Figure 10). Figure 11 shows overall annual precipitation levels averaged across all the BEMP sites, but the canopy and open precipitation gauges are averaged separately, showing that, for the most part, open gauges collect more rain than gauges located under a canopy. There are a few exceptions to this at some sites for some months. These exceptions are largely due to interference, whether from mice drinking out of the gauges, high winds influencing the direction of the falling rain (horizontally driven rain is more likely to be intercepted by canopy and fall downward and will not fall as readily into the open gauges), or from vandalism.

When looking at the average monthly rainfall in the bosque, the variation between years can be seen in a different light, as dry spells become apparent (November 2005 through June 2006), as well as seasonal variation between years (Figure 12). Although the start of monsoon rains can vary, precipitation levels often increase in July (Figure 12). The largest peaks in precipitation over the last thirteen years have occurred in August, and once in April (Figure 12).

When comparing average annual site precipitation, it is clear that overall precipitation levels are largely consistent across the various sites, from Ohkay Owingeh in the north, to Lemitar in the south (Figures 13-19). Variations between the sites are not consistent with any north-to-south alignment. Canopy cover does not correlate with collected rainfall. Variation in site precipitation levels most likely reflects larger meteorological trends. However, precipitation variation, timing and abundance can affect competitive advantages of certain flora and fauna at each site.

Depth to Groundwater (Figures 20-40)

Long-term monitoring of depth to groundwater has given us a better understanding of the overall hydrologic connectivity of groundwater to river flow at our sites. Although some sites have a stronger connection of groundwater to river flow than others, none of the BEMP sites is truly hydrologically disconnected from the river, in spite of flooding history. Even Lemitar, which is located outside of the levee and has a low water table, shows some response in groundwater level to higher river flows (Figure 40). Responsiveness of groundwater level to river flow does vary between sites, and is in part determined by permeability and porosity of the soils; proximity to the river; flood history; and outside influences such as nearby wetlands (natural or constructed), ditches, drains or wells.

Monitoring the annual average depth to groundwater is crucial in determining which sites are suitable for cottonwood restoration efforts. Rio Grande cottonwoods are phreatophytes, meaning they are dependent on groundwater instead of precipitation. A water table lower than three meters can lead to the death of young cottonwoods and pole plantings, and cottonwood root cavitation in mature trees (resulting in crown die-back). Another important factor when considering cottonwood restoration is salinity of the groundwater and soil. Sites with a shallow/high water table and strong response to river flow, along with low water and soil salinity, are the best sites for cost-effective restoration. BEMP sites Badger, Alameda, and Lemitar, with groundwater levels approaching 3 m deep, are representative of sites where cottonwood restoration would be more costly and less effective (Figures 20 & 21). When not considering soil and water chemistry, the sites most likely to support cottonwood restoration efforts are Ohkay Owingeh, Valencia Cleared, and Belen; followed by Rt. 66, Harrison, Savannah, Los Lunas, Reynolds Forest, Bobcat, Minnow, Calabacillas, National Hispanic Cultural Center, and Reynolds Cleared (Figures 20 & 21). Although Sevilleta would follow as a site with a high water table, the high specific conductance (high salts) in the groundwater make this a poor site for restoration, especially involving pole plantings (Figures 20, 21 & 39). The salt deposits evident on the surface soils at Valencia Cleared and Reynolds Cleared are also indicative of poor sites for cottonwood pole planting success.

While the water table at Ohkay Owingeh maintains its connection with river flow, it is also very responsive to the flooding of the nearby man-made wetland. This means that there is more flooding at this site than would be accounted for by high river flows (Figure 22). The frequent flooding at this site has been an important contributing factor to the site's high native species plant diversity (Figure 42).

In Albuquerque, the two sites above the DWP Diversion Dam (Badger on the east bank and Bobcat on the west bank) have similar, strong connections of groundwater to river flow (Figure 23). Although it may appear in the graph that groundwater at Badger has a tighter correlation with river flow when compared to Bobcat, this is not the case. These two sites are monitored on different days, and the graphed river flow data are from the days that Badger was monitored. Complete data for both sites, including river flow data on the exact day of monitoring for each site, are available on the BEMP website. As of yet, there are no obvious impacts of either construction or operation of the

DWP dam at the two sites directly above. There is a difference of approximately a meter in the depth to groundwater between the two sites, with the lower water table on the east side of the river (Figure 23).

In Albuquerque, just below the DWP Dam, are a cluster of four sites, two on each side of the river. Directly below the dam on the east side is Diversion, and on the west is Minnow. Further down on the east side is Alameda, and across from Alameda on the west side is Calabacillas. When comparing the four sites, the water table on the east side of the river is consistently about a meter lower than the water table on the west side of the river (Figures 24-26). The groundwater levels at all four sites show a discernable connection to river flow, with a few exceptions at each site during construction of the DWP dam. At Diversion, on the east side directly below the dam, the groundwater levels dropped from September 2005 through March 2006, with a slight rise in December 2005 (Figure 24). At Alameda, further below the dam on the east side, groundwater levels dropped in December 2005 through February 2006 (Figure 25). At Minnow and Calabacillas, on the west side, the groundwater levels dropped during March, September, and October 2005, while most of the construction was occurring on the west side of the river (Figure 26; personal observation). Most of the lowest recorded levels were actually dry wells, and represent the bottom of the BEMP well rather than the true depth of the groundwater. At each of these sites below the DWP dam, there is a drop in the groundwater levels at the end of 2009 that does not correspond to a change in river flow (Figures 24-26). This drop in groundwater levels is seen more clearly in the pressure transducer data which records water levels every 30 minutes, and is likely due to the diversion of river water (operation of the dam).

Near the Montaño Bridge in Albuquerque, at Bosque School, are the Montaño and Savannah BEMP sites. Both sites have groundwater levels that respond rapidly to high river flows and both sites appear to have slight increases in groundwater levels in recent years (Figures 27 & 28). The groundwater is slightly closer to ground surface at Savannah compared to Montaño, though both sites are approximately the same distance from the river (Figures 27 & 28). Across the river from these two sites is the Rio Grande Nature Center (RGNC) site. Here the groundwater still responds to changes in river flow, but the overall depth to groundwater is a bit lower than at the Montaño site (Figures 27& 29). There was a gradual decline in annual groundwater levels at the RGNC site from 1997 until 2003, but they have since leveled out. The apparent stabilization in groundwater levels could be tied to changes in river flow, clearing of exotic trees, and the reduction in amount of water diverted for irrigation by the Middle Rio Grande Conservancy District.

The next three Albuquerque sites are all on the east side of the Rio Grande (Figure 3). Rt. 66, BioPark, and the National Hispanic Cultural Center (NHCC) sites all have hydrologically connected water tables, which vary in depth from 1 meter to 2.5 meters below ground surface (Figures 30-32). The Harrison site is the southernmost Albuquerque site and is located on the west side of the river, just above Albuquerque's wastewater treatment plant. The groundwater levels at Harrison are strongly correlated with river flow ($R^2 = 0.81$), but not with the water level in the nearby ditch (Figure 33). This is to be expected, as the Harrison site is situated partially in the riverbed, away from the ditch. This is a site that experiences overbank flooding during high river flows.

The first site below Albuquerque is Los Lunas (roughly 23 miles south). Groundwater levels do track river flows at this site, most clearly demonstrated by the decreased groundwater levels during times of low to no river flow, in spite of water level in the ditch (Figure 34). Although it is not visible in the graph, this site does experience seep flooding during times of high river flow. The most notable aspects of the water table in Los Lunas are the dramatically lower water levels during June-October 2003 and again from July-October 2004 (Figure 34). These drops in groundwater correspond to times when the river was dry – in 2003 the river flow on monitoring days was measured at 0, 0, 10 and 9 cfs for July-October, respectively (Figure 34). In 2003, the nearby ditch/drain was full for some of these months, while in 2004 when the river was almost dry the water level in the ditch was also low. The low river flows were in part due to the low precipitation levels during 2001-2003, and while 2004 appeared to have average precipitation levels, over 40% of the precipitation that year had occurred by April (Figures 10 & 12). The combined effect of this water shortage is most likely the cause of the relatively large declines in the water table at this site during 2003 and 2004. Groundwater levels in 2004, when there were low flows in the river and ditch, were slightly lower than in 2003, when the river was dry but the ditch was full to the top of the culvert (Figure 34). The year 2003 is recognized as a year of water crisis, when upstream reservoirs were low, irrigation season was ended early, creeks went dry, and bosque fires caught the public's attention (Robert 2005). While groundwater levels at this site have not dropped below two m since 2004, the simultaneous low in river flows and precipitation levels has not reoccurred either. Although river flows on monitoring days have not dropped below 300 cfs since 2004, the groundwater levels have been lower during the late summer/early fall months than they were during the early years of this study (Figure 34).

In Belen, about thirty-four miles south of Albuquerque, there are six BEMP sites. The first two, Reynolds Forest and Reynolds Cleared, are paired (control and cleared) on the east side of the river. Groundwater levels at both of these sites closely track river flow, with little variation between the two sites (Figure 35). An increase in the groundwater levels at the cleared site (either sudden or gradual) could indicate a water 150000recovery after removal of exotic trees, but no such evidence yet exists at this site. The water table at both sites is relatively high, ranging between 15 cm from the ground surface to almost 180 cm deep, usually measuring around 130 cm (Figure 35). The second set of paired sites (Valencia Cleared and Valencia Forest) is across the river, about one mile south. Here, again, the groundwater tracks river flow at both sites, regardless of water levels in the ditch, which is closer to both sites than the river. Within each site, groundwater levels are higher nearer the ditch than those further away, but monthly variation is tied to river flow. The February 2007 fire at Valencia Forest is indicated on the graph, as is the first of several post-fire clearings (Figure 37). There is no apparent recovery in the water table following either fire or clearing. Valencia Cleared has a higher water table than Valencia Forest, and the water table has an overall decline throughout both of the sites from north to south. This is not likely to be due to clearing, but rather to a pre-existing condition before exotic removal. During high river flows, there are areas of seep flooding at the Valencia Cleared site, especially near the levee around the west well, which is occasionally inundated. Due to this periodic saturation of the ground, the salts left behind after evaporation are in evidence across the site.

The Belen BEMP site is next to the river, lined up between the middle of the Valencia Cleared site and the middle of the Valencia Forest site. There is a strong correlation between groundwater levels and river flow at this site, and there have been years with overbank flooding. While the only points on the graph that show groundwater above ground surface are in 2005 and 2009, other years have had overbank flooding, but are not captured in the data if the flood did not occur during the week of monthly monitoring. Here, like Los Lunas, there are evident declines in the water table during the summer and fall months that are lower in recent years (starting in 2004) than the low points in earlier years (Figure 36).

The Crawford site is the southernmost Belen BEMP site, and is the only BEMP site to have had large-scale landscape alterations. This area burned in February 2007, and underwent subsequent clearing and fuel removal. Groundwater monitoring started in October 2008. The bulldozing and land lowering started in late February 2009. Jetty jacks divide the site into two parts. Initially, the jetty jacks were to be removed and the whole area lowered, but due to concern for the railroad bridge to the south, the jacks were left in place and only the southern 40% of the site was not lowered. The lowered area included the north, east, center and west wells. Only the south well remains in a non-lowered area. In order to protect the wells, the ground surrounding each of the wells in the lowered area was left undisturbed, creating 2 ft diameter islands around each well. This means that the “depth to groundwater from ground surface” has technically remained unchanged for these wells, while the true depth to groundwater from the lowered ground surface is now a smaller number. The data show that all wells are still tracking at around the same depth, indicating that while the true depth from ground surface to groundwater is less (important for plant roots trying to reach the water table), the overall elevation of the water table has not changed (Figure 38).

The Sevilleta site is located on the Sevilleta National Wildlife Refuge, just over 60 miles south of Albuquerque. Here the groundwater tracks river flow, but it is also impacted by the San Acacia Diversion Dam. Depth to groundwater ranges between 30 and 190 cm below ground surface (Figure 39). This site can flood during high river flows (mostly seep flooding), which when paired with the high water table makes it look like an ideal location for restoration. However, the extremely high specific conductance at this site (due to high amounts of salts and nutrients) have led to die-back in the existing cottonwood population and would not be conducive to new cottonwood survival (Eichhorst et al. 2006).

The southernmost BEMP site is Lemitar, located about 70 miles south of Albuquerque. The groundwater at this site does respond to high river flows, but the overall changes in groundwater depth are minimal, ranging from 240 cm to 290 cm, corresponding to changes in river flow from 3 cfs to 4050 cfs (Figure 40). The Lemitar site is located outside of the levee, and its distance from the river may be an important factor in the depth to groundwater.

Biotic Factors

Plant Diversity (Figures 41-61)

Plant cover is measured annually (in late August/early September) at all sites along the ten 30m transects that mark the southern edge of the vegetation plots. Every species is recorded along with the transect length covered. This gives us an idea of plant cover at the BEMP sites, along with changes in species dominance over the years. Individual species can have a total sum intercept length of 300 cm for a site, so total cover can be higher than 300 cm. Species diversity can be calculated using the Shannon-Wiener index (H'), which uses both the number of species per site, as well as the proportion of each species (Molles 2002, Eichhorst et al. 2002). While the site H' number may seem arbitrary, it provides an easy way to compare the species diversity between sites (Figure 41). Plant cover is presented here in a number of different ways (by particular species over time; by plant type: grass, forb, shrub, tree; and/or by point of origin: native or exotic) to demonstrate different points at different sites. On the vegetation graphs, the y-axis is on a scale up to 300 cm, as this is the total possible amount of cover for each individual species.

Throughout the years, Ohkay Owingeh has had the highest species diversity of all the BEMP sites (Figure 41; Eichhorst et al. 2004). The yearly flooding from the adjacent wetland has likely played an important role in the high native plant cover and diversity at this site, mitigating the impacts of both mechanical clearing and fire. Here, the majority of the plant species are native, with only a few exotic plants present, though the cover provided by the exotic *Kochia* has remained quite high over the years (Figures 41 & 42). 2003, represented in red on the graph, was the year of the June fire at Ohkay Owingeh; the vegetation transects were read in September that year, so the vegetation graph shows the rapid post-fire recovery for many grasses and forbs (both native and exotic) at this site (Figure 42). Following the fire, native cottonwood cover was reduced by 70% and the New Mexico olive cover was reduced by about 75%. In subsequent years we can see the gradual decline of *Kochia* and the increase in cover by natives such as Wood's rose, *Carex*, coyote willow, and New Mexico olive, though there was very little increase in cottonwood cover (Figure 42).

Kewa, formerly Santo Domingo, is a very open, dry, site, with low canopy cover and few understory plants (Figure 43). The snakeweed and prickly pear cactus found at the site are possible indicators of a low water table and infrequent flooding. This is a native-dominated site with very few exotic plants (Figure 43).

After Ohkay Owingeh, Harrison is the next most diverse site, with both high species diversity and a high number of species present (Figure 41). Yearly overbank flooding, due to Harrison's position along the river and extending into the riverbed is, again, an important factor leading to the high diversity and native cover at this site (Figures 41, 44 & 51). In spite of a very active beaver population here, the cottonwoods continue to dominate this site, and the native cover is far more diverse and extensive than the exotic plant cover (Figure 51).

Diversion also has a relatively high H' (species diversity), though much of this is due to a slight increase in the exotic and native understory following clearing, and more so, to the very low canopy cover (Figures 41 & 45). The low cottonwood cover means there is less discrepancy between species, and therefore a greater evenness, which factors into the species diversity. Alameda, which has lower species diversity and fewer species present than Diversion, has a much greater native tree and shrub cover (Figures 41 & 46). Here the cottonwoods and New Mexico olives continue to dominate the site, and even Siberian elms and Russian olives have not been too severely impacted by the mechanical clearing of these exotics in late 2003 and 2004 (Figure 46).

While Badger, Montaño, Savannah, NHCC, and Lemitar also have a high H', this is more due to the evenness between the species present at these sites, and not as much to the number of species present (Figure 41). Santa Ana and Savannah are both examples of sites that are maintained. Santa Ana has a low overall species diversity, but also is kept clear of exotic species (Figures 41 & 44). Savannah is mowed periodically, and this maintenance has led to a high exotic diversity and higher exotic cover, but low overall cover (Figures 41, 44 & 48). Montaño, the post-burn site adjacent to Savannah, also has a higher exotic understory diversity and cover than native (Figure 47). This is also a very open site, where the cottonwood post-fire resprouts have done better than the pole plantings.

The Rio Grande Nature Center (RGNC) is a site with relatively small cottonwood trees (Eichhorst et al. 2001) and there is an evident decline in cottonwood cover at this site (Figure 49). This is, so far, the only BEMP site where exotic trees were successfully removed (in 2004) and have not yet come back (Figure 49). Since the clearing, there has been a slight increase in exotic understory plants (e.g., tumbleweed), but even that has been nominal (Figure 49).

The National Hispanic Cultural Center (NHCC) has an understory increasingly dominated by exotics, though the canopy is still dominated by natives (Figure 50). There have been a few different clearing events at this site, as it is maintained to be a teaching center and park with walkways.

Los Lunas and Belen, to the south of Albuquerque, are both sites with a relatively high (although not the highest) species diversity, due more to evenness between species than to number of species (Figure 41). Los Lunas is a site with large, mature cottonwoods, and a thick understory carpet of yerba mansa (Figure 52). While the native cottonwoods, willows and variety of understory plants dominate this site, there are a few enduring exotic trees providing relatively low cover, namely Siberian elm, mulberry and Russian olive (Figure 52). Belen is in some ways the antithesis of Los Lunas, with its old, slowly declining Russian olive groves providing a good percent of the canopy cover at this site, while the young, rapidly maturing cottonwoods and willows are slowly increasing the native cover each year (Figure 53). Here, the understory has been completely dominated by native forbs, grasses and sedges until very recently (Figure 53). After the 2007 fire in Belen devastated much of the Valencia Forest and Crawford sites, there have been several clearing events in the nearby bosque. The disturbed ground at Valencia Forest has fostered an increase in the *Kochia* and tumbleweed populations, which have started to blow into the Belen site, spreading seeds. Undoubtedly a new exotic understory component will be added to this site.

Valencia Cleared was completely stripped of exotic trees (and many native trees) in 2003. Native forbs and grasses like yerba mansa, scratchgrass, and saltgrass were able to reestablish from root stock the first year, and have slowly increased their cover (Figure 54). In other areas, exotic tumbleweed, grasses, and *Kochia* were able to establish from seed, and the *Kochia* has maintained a strong presence at this site ever since (Figure 54). Neither cottonwoods nor willows have done well since the clearing, and the pole planted cottonwoods were unable to survive the high salts in the soils. Russian olive trees came back fairly quickly after the clearing and provided a more dominant cover than cottonwoods until the subsequent clearing and cutting of exotics in 2008 (Figure 54).

The Valencia Forest site was to be the controlled comparison for the impacts of clearing at the Valencia Cleared site. In late February 2007, however, the fire in the Belen area burned the entire site, and it has since undergone several clearing/cuttings of exotic regrowth. In April of 2010, the piles of cut saltcedar and Russian olive regrowth, along with the burned limbs of downed cottonwoods, were chipped and spread throughout the site. It is not the immediate effect of fire on plant cover seen in the graph (the bars for 2007 are red for the fire), but rather the recovery after a season of growth. Six months after the fire, cottonwood recovery was very low (down from 95 cm of cover in 2006 to 12 cm in 2007). Russian olive did just a little better (from around 110 cm to 22 cm), and saltcedar recovered the fastest of the trees, regaining half of its original cover (from 110 cm to 52 cm) (Figure 55). Six months after the fire, five of the vegetation plots were monitored for sprout height of cottonwood, willow, Russian olive and saltcedar. Within each of the five plots monitored, saltcedar height was up to or over 3 m tall (Figure 56). Russian olive resprouts occurred in four of the five plots and were just over 1 m tall (Figure 56). Cottonwoods were only found in three of the five plots and measured between 22 and 70 cm, while only two Goodding's willow resprouts were found, measuring about 150 cm high (Figure 56). The dominant native understory plants recovered quickly, and scratchgrass cover has continued to increase since the fire (Figure 55). *Kochia* cover has increased since the fire and subsequent clearings. In April 2008, the Russian olive and saltcedar regrowth was chopped down, and the trees were treated with herbicide. There were at least two more clearing events (probably three) before the end of 2009. In spite of the clearing in early 2008, Russian olive cover increased that year, though saltcedar did not recover from the clearing as quickly. The subsequent frequent clearings have kept these two exotics from increasing, but cottonwood cover is at 0 as of 2009 (Figure 55) and at 11 cm in 2010. The decline in cottonwoods is due in part to high defoliation of the resprouting cottonwoods by the herbivorous cottonwood leaf beetle (*Chrysomela scripta*) in 2007. However, clearing events often result in a decline in the native tree cover at BEMP sites.

One mile to the south of the Belen, Valencia Cleared, and Valencia Forest cluster of sites is the Crawford site. This area had been burned by the February 2007 fire, and had gone through subsequent clearings of regrowth and fuel removal. Originally, the entire site was slated for landscape lowering, but the jetty jacks that crossed between the F and G lines were left intact, so only the first half of the site was lowered. Although the F line is on the lowered side of the jetty jacks, this line is very close to the jetty jacks and so was not lowered, creating an area where the land had been bulldozed, but not lowered, and therefore did not flood. This meant that the reestablishing vegetation was more like the transects in the non-lowered portion of the site (only six species were recorded on this transect). At the southern end of the site (transects G-J), where the post-fire clearing was the only treatment, root sprouts from yerba mansa, saltgrass, saltcedar, and Russian olive are evident in both 2008 and 2009 (Figure 57). The saltcedar and Russian olive trees are resprouting after fire and multiple clearings and herbicide treatments. Present in 2008, but dominating the site in 2009, was the exotic annual, *Kochia* (Figure 57). These results are very similar to the post-burn and post-clearing responses at Valencia Forest (Figure 55). On the other side of the jetty jacks, where the land had been lowered by 2-4 feet and rootstocks removed from the upper layer of soil, there was a very different vegetation response in 2009. Before lowering, the plant cover and species were very similar to the rest of the site (Figures 57 & 58). After the lowering (February-March 2009) and flooding (May 2009), the plants establishing from seed in this portion of the site greatly increased the species diversity on these transects (both through more evenness in cover between species, and through greater species richness) (Figure 59). Here we found a greater cover of newly established saltcedar, cottonwood, willows and native grasses and forbs (Figure 59; Picture 5).

The Sevilleta site, with its high water table (Figure 39) and high total dissolved solids (salts) in the groundwater, remains a site with high native understory diversity, including native grasses, sedges, and rushes (Figure 60). The cottonwood, Russian olive and saltcedar populations appear to be increasing or stable, while the coyote willow is declining (Figure 60). In reality, as of 2009, many of the cottonwoods are dying, and are easily pushed over, exposing dead or rotten roots. This is likely a site where native saltgrass meadows and rushes will dominate, providing a break from cottonwood-dominated bosque.

Lemitar is a site with very low total plant cover and large areas of bare soil (Figure 61). The low canopy cover contributes to the high species diversity at this site, providing more of an evenness between the 22 species (Figures 41 & 61). *Bouteloua* grasses (needle grama and sixweeks grama, both native annuals) seem to increase in years of higher rainfall, especially August rainfall (Figures 12, 19 & 61). Cottonwoods are very slowly declining while saltcedar cover is slowing increasing at this site, which is not surprising considering the low water table (Figures 40 & 61).

Litterfall (Figures 62-66)

Once each month, fallen plant material is collected from ten litterfall tubs at each site. The collected samples are taken back to the UNM or Bosque School BEMP labs, dried for 48 hours, and are then sorted into leaves, reproductive parts, and wood. Leaves are further sorted into specific native and exotic plants. Native leaves identified are cottonwood (*Populus deltoides* ssp. *wislizenii*); willow (includes coyote willow and Goodding's willow: *Salix exigua* and *S. gooddingii*); seepwillow (*Baccharis salicina*); New Mexico olive (*Forestiera pubescens* var. *pubescens*); thicket creeper (*Parthenocissus vitacea*, previously identified as *Parthenocissus quinquefolia*); and desert false indigo bush (*Amorpha fruticosa*). Exotic leaves identified are saltcedar (*Tamarix chinensis*); Russian olive (*Elaeagnus angustifolia*); Siberian elm (*Ulmus pumila*); and mulberry (*Morus alba*). All other leaves are labeled "other." As of 2007, reproductive parts are sorted into cottonwood, willow, saltcedar, Russian olive, and "other." While some herbaceous plants are tall enough to drop leaves or reproductive parts into the tubs, and some older, previously fallen leaves can blow into the tubs, the material collected tends to be an accurate representation of the monthly dropped biomass of shrubs and trees near the tub. Taken on an annual scale, this gives us a good idea of primary production for the dominant perennial species at each site. When compared with the plant cover data, the two datasets continue to cross-validate the work done by students (litterfall collection, sorting, and weighing) and by scientists (plant transect species identification and amount of cover).

As seen in the plant cover data, the three sites north of Albuquerque (all sites on pueblo lands where different types of bosque restoration have been implemented), have mostly native leaf biomass with little to no exotic leaf biomass each year (Figures 62-66). Reproductive biomass is relatively high at Ohkay Owingeh and Santa Ana, but low at Kewa (Figure 66). The woody biomass falling at these sites varies between years, but overall, was low to average except at Ohkay Owingeh in 2008, when wood biomass was high (Figures 62-66). There was no wood fall recorded at Kewa in 2008 (Figure 66).

North of the DWP diversion dam in Albuquerque, the Badger (east) and Bobcat (west) sites had comparatively low native leaf fall in 2006, which increased in 2008 (Figures 65 & 66). These sites had been cleared of exotics in 2004, and Badger has low exotic leaf fall, while Bobcat has almost none (Figures 65 & 66). Directly south of the DWP dam are Diversion (east) and Minnow (west), and just below these sites are Alameda (east) and Calabacillas (west). Like the sites north of the dam, the sites below the dam were cleared of exotic trees in 2003-2004. At Minnow (like Bobcat, also on the west side of the river), there was almost no exotic leaf fall in 2006 and 2008 (Figures 65 & 66). Unlike the two northern sites on the west bank, Calabacillas does have exotic leaf fall, which declined from 2004 to 2006, but increased somewhat by 2008 (Figures 64-66). On the east side of the river, Diversion and Alameda continue to have exotic leaf fall, even after clearing, again confirming the plant cover data (Figures 45, 46, & 62-66).

Montaño and Savannah (west) both have low leaf fall levels, and Savannah's exotic leaf fall continues to be almost equal to the native leaf fall (Figures 62-66). At Montaño, burned in 2003, the falling woody biomass has been increasing, reaching an astounding 698 g/m^2 in 2008 (Figures 64-66). At RGNC (across the river), the decline in cottonwood cover is harder to see in the litterfall data, even when only cottonwood leaf fall is graphed, but it is still evident, especially when looking at all the years.

Rt. 66 has low overall litterfall levels, with exotic leaf fall making up almost half to a third of the leaf fall at this site (figures 65 & 66). BioPark, a cleared bosque near the created wetlands at Tingley Beach in Albuquerque, has high native leaf fall and extremely low exotic leaf fall (Figure 66). NHCC has been cleared occasionally throughout the years, and has an increasing level of native leaf fall and a low level of exotic leaf fall (Figures 63-66). Harrison, a young cottonwood/willow site partially in the riverbed, has had a slowly increasing level of both native and exotic leaf fall, though both levels are still low, and native leaf fall is higher than exotic, as seen in the plant cover data (Figures 51 & 64-66).

Los Lunas has a relatively high native leaf fall (due to the large cottonwoods at this site) and low exotic leaf fall (Figures 62-66). Belen has a steadily increasing level of native leaf fall and reproductive biomass, with a fairly consistent level of exotic leaf fall (Figures 62-66). Again, litterfall data from both of these sites confirms what we know from the plant cover data.

Before the 2007 fire at Valencia Forest, the litterfall data between Reynolds Forest and Valencia Forest, and Reynolds Cleared and Valencia Cleared was very similar, with higher overall levels of leaf fall and more exotic leaf fall at the Forest sites (Figures 64-66). Exotic leaf fall at Valencia Cleared has been increasing over the years, up until repeated exotic clearing in 2008. Reproductive litterfall was higher at the Valencia sites until 2006 (Figures 64-66). Prior to the 2007 fire, exotic leaf fall was higher than native leaf fall at Valencia Forest, and was again in 2008, indicating that exotic post-fire regrowth was faster than native. Woody litterfall was higher in the Forest sites compared to the Cleared sites each year (Figures 64 & 65), and post-fire/post-clearing at the Valencia sites led to high woody litterfall in 2008 (especially at Valencia Forest) (Figure 66). Reynolds Forest also had extremely high woody litterfall in 2008 (Figure 66).

At Sevilleta, a slight increase can be seen in both the native and exotic leaf fall over the years (as indicated by the plant cover data) (Figures 60 & 64-66). At Lemitar, well outside the levee, the litterfall data reflects the low plant cover, with the lowest litterfall levels of native and exotic at any BEMP site (Figures 61 & 62-66).

Woody Debris/Fuel Load (Figures 67-69)

Fuel load, or downed woody debris, is measured when funding is provided for any given site, meaning that most Albuquerque sites are monitored each year, but other sites are not. Specific gravities for cottonwood and Russian olive are used, making the estimate of tons/acre more accurate than using one generic number. Because woody debris can exist at a site for a long time with no noticeable change due to decomposition (especially at sites that do not flood), there is not always a strong correlation between woody litterfall and woody debris/fuel load. Woody debris is presented as total tons/acre for each site, and is also broken down by size class for each site. When smaller diameter woods add up to 12 tons/acre, this is considered to be a “catastrophic fire hazard” (Eichhorst et al. 2006). If the 12 tons/acre is made up of large diameter wood, the fire hazard is considerably less.

For the most part, sites that flood (by either overbank or seep flooding) have low fuel loads. This is to be expected as flooding, or soaking, greatly increases rates of woody decomposition (Molles et al. 1998). Ohkay Owingeh, Harrison and Belen all have very low fuel loads (Figures 67-68). Los Lunas does have seep flooding in some years when river flow is high, but the large, old cottonwoods at this site have contributed to a rather high fuel load that has slowly gotten larger (Figure 67). The fuel load at Los Lunas is mostly made up of large diameter wood, and not the small branches that lead to more catastrophic fires (Figure 68).

Although many of the Albuquerque BEMP sites were cleared of exotics after the 2003 Albuquerque bosque fires, the fuel load at some of these sites has increased to 12 tons/acre or over, especially as of 2009 (Figure 67). When looking at the breakdown of size class, only Rt. 66 (and very nearly Minnow) are above the fire hazard limit in Albuquerque (Figures 68 & 69).

The high woody litterfall at Montaño does correspond to a higher fuel load at this site, especially when compared with Savannah (Figures 66, 67, & 69). An increasing fuel load several years after a fire is to be expected.

NHCC’s low to moderate levels of wood fall do not seem to correspond to the extremely high woody debris (fuel load) levels (Figures 63-67), but the majority of the fuel load at this site consists of cottonwood trunks used to line the walking trails, and so is made up of large diameter wood, not continually falling debris (Figures 68 & 69).

Reynolds Forest and Valencia Forest have extremely high fuel loads and corresponding high woody litterfall that are definitely considered to be "catastrophic fire hazard" fuel loads (Figures 64-69). The fuel load at Valencia Forest has gone through many changes, from pre-burn levels of 8 tons/acre, to immediately post-burn levels of 1.5 tons/acre, to post-clearing levels of almost 30 tons/acre (after exotic regrowth cutting and the felling of some dead cottonwoods) (Figures 67-69). The same trends can be seen at the Crawford site, with lower levels in 2010 after half of the site was completely cleared and lowered (Figures 67 & 69).

Surface-Active Arthropods (Figures 70-73)

Arthropods can be used to track changing environmental conditions at each bosque site. Some of the best indicators of high moisture or even flood conditions are the carabid beetles (ground beetles). The two sites with a history of overbank flooding, Harrison and Belen, have the highest number of carabid beetles captures (Figure 70). Ohkay Owingeh, Rt. 66, Valencia Cleared, and Sevilleta, all sites that have seep flooding during high flows, also had more cararbid beetles captured than other sites (Figure 70). Bobcat, Minnow, and Calabacillas on the west side of the Rio Grande are sites with a higher water table than the corresponding sites across the river (Badger, Diversion, and Alameda). They also had higher carabid beetle captures than the sites with a lower water table (Figure 70).

Tenebrionid beetles (darkling beetles) are often indicative of drier habitats (with the exception of *Eleodes suturalis*, which is found at many of our flooding or high water table sites with thick understory vegetation). The largest captures of tenebrionid beetles occurred at sites like Montaño (post-burn, little plant cover); Savannah (low plant cover, mowed almost annually); NHCC (cleared, low plant cover); Reynolds Forest; Reynolds Cleared (cleared, low plant cover); Valencia Cleared (cleared, low plant cover); Valencia Forest (post-burn and post-clearing); and Lemitar (extremely low plant cover) (Figure 70). At Harrison, a site actively connected to the river, there were no tenebrionid beetle captures in 2008 (Figure 70).

Isopods (roly poly/pillbug, *Armadillidum vulgare* and sowbug, *Porcellio laevis*) prefer sites with vegetation cover and/or a layer leaf litter. Sites with a lot of bare ground (like Lemitar, Montaño, and Savannah) have low isopod captures (Figure 71). Conversely, ants do very well on bare ground, but also do well in sites with more plant cover (Figure 72). When Valencia Cleared was newly cleared, the ant captures were very high (Figure 73). As more understory plants became established, the Valencia Cleared and Reynolds Cleared sites still had higher ant captures than the corresponding Forest sites (Figure 73). In the year following the fire at Valencia Forest, there were more than twice as many ant captures than both previous and subsequent years (Figure 73).

Concluding Remarks

BEMP is recognized as a valuable environmental education program, *and* a valid long-term scientific monitoring program. The acknowledged success of both these goals is its own reward, and yet we keep growing, trying to reach more people. Our outreach numbers have grown beyond expectations; our water data has been requested and used by various state and federal agencies; and we have begun to collect more water *quality* data on the river to help serve some of these same agencies. As has been the case for the last several years, funding remains our most limiting factor. The data from the 25 sites show that each area of the bosque is unique, and even with the obvious overall similarities between sites, the distinct variations within and between sites should dictate that different areas of the bosque should not be treated in a blanket fashion when attempting restoration or site maintenance. Using baseline data, adaptive management practices, and continuing monitoring are still important when trying to restore native dominance, sustainability, or even aesthetics to the riparian forest.

Acknowledgements

National Science Foundation * Bosque School * The Black Institute for Environmental Studies * The Goodman Family * U.S. Army Corps of Engineers * U.S. Fish and Wildlife Service – MRG Bosque Initiative * Middle Rio Grande Conservancy District * Bernalillo County Open Space * Albuquerque Metropolitan Arroyo Flood Control Authority * Stormwater Quality Team * The Rio Grande Nature Center State Park * City of Albuquerque Open Space * State of New Mexico Energy, Minerals and Natural Resources Department, State Parks Division and State Forestry Division * State of New Mexico Game and Fish Department, Project WILD and Watershed Watch Program * State of New Mexico Department of Cultural Affairs * Sevilleta Long Term Ecological Research Site * Long Term Ecological Research Network * Pueblo of Santa Ana * Pueblo of Ohkay Owingeh * Pueblo of Santo Domingo * Good Samaritan Foundation * U.S. Bureau of Land Management * U.S. Bureau of Reclamation * National Hispanic Cultural Center * Educational Foundation of America * Messengers of the Healing Winds Foundation * Albuquerque Community Foundation * N.M. Association of Soil and Water Conservation Districts * N.M. Forest and Watershed Restoration Institute * PNM Foundation * 7 Bar Foundation * McKee/Crawford Foundation * Albuquerque BioPark * Sandoval County * U.S. Geological Survey * Marcel Reynolds * UNM Department of Biology * UNM Provost Office * New Mexico Museum of Natural History and Science * Rogers and Company, Inc. of Albuquerque * All schools, site representatives, and students involved with BEMP

This research was partially supported by an NSF grant to the University of New Mexico for Long-Term Ecological Research

Literature Cited

Cleverly, J.R., K. Vanderbilt, C. Dahm. 2008. Annual Report 2007-2008 – Urban Flood Demonstration Program. Evapotranspiration, Water Table Fluctuations, and Riparian Restoration. Draft.

Eichhorst, K.D., D.C. Shaw, J.F. Schuetz, A.D. Gebauer, and C.S. Crawford. 2006. Bosque Ecosystem Monitoring Program (BEMP): Third Supplement: 2004-2005. Open-File Report 06-4. 56 pp.

Eichhorst, K.D., M.C. Stuever, D.C. Shaw, and C.S. Crawford. 2001. Bosque Ecosystem Monitoring Program (BEMP): First Report: 1997-2000. Open-File Report 01-1. 43 pp.

Falk, S.E., Bexfield, L.M., and Anderholm, S.K. 2011. Estimated 2008 groundwater potentiometric surface and predevelopment to 2008 water-level change in the Santa Fe Group aquifer system in the Albuquerque area, central New Mexico: U.S. Geological Survey Scientific Investigations Map 3162, 1 sheet.

Hink, V.C. and R.D. Ohmart. 1984. Middle Rio Grande Biological Survey. Army Corps of Engineers Contract No. DACW47-81-C-0015. Albuquerque, NM.

Molles, M.C., Jr. 2002. *Ecology: Concepts and Applications*. New York: McGraw-Hill. 2^{nd} edition.

Molles, M.C., Jr., C.S. Crawford, L.M. Ellis, H.M. Valett, and C.N. Dahm. 1998. Managed Flooding for Riparian Ecosystem Restoration. BioScience 48:749-756.

Robert, L. 2005. Middle Rio Grande Ecosystem Bosque Biological Management Plan, The First Decade: A Review & Update. Middle Rio Grande Bosque Initiative, Bosque Improvement Group. Albuquerque, NM. 155 pp.

United States Geological Survey. Real-time water data retrieved from http://waterdata.usgs.gov/nm/nwis/rt.