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Drying Events in the Rio Grande: Effects on Hydrology, Riparian Vegetation, and Arthropod Communities

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DRYING EVENTS IN THE RIO GRANDE: EFFECTS ON HYDROLOGY, RIPARIAN VEGETATION, AND ARTHROPOD COMMUNITIES

by

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DEDICATION

This thesis is dedicated to my parents, Ernie and Jan Villescas, who encouraged me to be curious and introduced me to this wonderful, special place called the *bosque*.

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Lastly, I would like to thank the tens of thousands of BEMP citizen scientists for helping to collect the data used for analysis in this research.

SUMMARY

1. Anthropogenic-induced river intermittency is an increasing global concern with far-reaching ecological consequences. Cessation of flow outside of a river's natural regime can have cascading effects on aquatic and terrestrial community composition and structure. Water abstraction during summer months often leaves the Rio Grande below Isleta Diversion Dam dry. This research investigates differences in hydrology, riparian vegetation, and arthropod communities within the Rio Grande floodplain, known locally as the 'bosque,' between perennial and intermittent reaches of the river.

2. Despite the high degree of interannual variability, a spatio-temporal analysis of stream discharge revealed a trend of declining flow in both reaches throughout the study period. The intermittent reach showed between 15 – 210 days per year with recorded discharge values low enough to be potential riverbed drying events. An increasing trend of low flow and no flow events was seen for the period of record.

3. The floodplain bordering the perennial reach throughout Albuquerque is dry and disconnected from the river due to the high degree of river incision, which rarely has overbank floods. The groundwater table in the perennial reach is significantly deeper than in the intermittent reach, but is more responsive to higher flows. The intermittent reach is less incised because it flows through an aggrading section of the river, lending to more overbank and seep flood events despite the annual drying events.

4. Vegetation cover and plant species diversity were significantly greater within the intermittent reach of the Rio Grande. Plant species richness was significantly greater in the sites adjacent to the perennial reach. Community composition varied among reaches with significantly more native shrub and tree species found throughout the perennial reach. Significantly more exotic trees, weeds, grasses (native annual, native perennial) and forbs (native annual, exotic annual, native perennial), and sedges were found throughout the intermittent reach.

5. Significantly greater abundance of arthropods, including indicator groups Carabidae, Tenebrionidae, and Isopoda, were found in the southern sites adjacent to the intermittent reach of the river. Functional groups were dominated by detritivores within both reaches. There was no significant difference between reaches for herbivores, ants, or predator arthropod species.

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INTRODUCTION

Anthropogenically-induced river intermittence is a growing environmental problem. In recent history, more than seven of the world's largest rivers now have dry riverbeds for at least part of the year: the Colorado, Mekong, Indus, Amu Darya, Nile, Yellow, and Syr Darya (Gleick *et al*., 2003). Cessation of flow outside of the river's natural flow regime can result in extensive ecological impacts on aquatic and terrestrial community structure, composition and resilience resulting from the loss of essential habitat, top predators, and subsequent species interactions (Soulé *et al*., 2005; Rolls *et al*., 2012). Intermittent rivers are largely understudied ecosystems despite recent work showing their global proportion is likely to be greater than 50% (Datry *et al*., 2014). They are often overlooked by both aquatic and terrestrial scientists because they are considered to be outside the scope of either aquatic or terrestrial ecology (Larned *et al*., 2010). Current research on temporary waterways is expanding exponentially (Datry *et al*., 2011); however, most intermittent river studies exist on waterways where intermittence is a natural part of their flow regime (Larned *et al*., 2010).

The Rio Grande, an aridland stream stretching 3,200 km across the Southwest, is subject to nearly annual anthropogenically-induced drying events south of Albuquerque, NM. Excessive abstraction and diversion during summer months when water demand is greatest, often completely dewaters the river south of the Isleta Diversion Dam. The strictly managed Rio Grande supplies water to millions of people in three US states and four Mexican states through an intricate system of levees, dams, and diversions. These human manipulations have altered the natural flow regime, consequently altering biotic and abiotic components of the bordering riparian forest (Crawford *et al.,* 1993).

Historically, high flows from annual spring snowmelt runoff typically caused overbank flooding, clearing the forest floor of litterfall and woody debris accumulations and priming the soil for riparian plant seed dispersal (Crawford, 1996). Habitat heterogeneity, created by inter-annual variability of flows and a highly meandering and braided riverbed, has been altered through anthropogenic manipulation. Infrastructure installation and reduction of river sinuosity have created an incised channel with reduced potential for overbank flooding, consequently reducing wetland habitat and creating a more homogeneous bordering riparian forest (Crawford *et al*., 1993).

Two reaches of the Rio Grande are under investigation for this study and are referred to in this document as *perennial* and *intermittent*. The perennial reach maintains continuous flow from San Felipe Pueblo through Albuquerque, NM, and the intermittent reach, which often dries during summer months, begins south of Isleta Pueblo and extends through San Acacia, NM. Differences in channel geomorphology have generated varying hydrologic responses between the reaches. The perennial reach is more constrained, and incised, and carries less sediment load than the intermittent reach (Crawford *et al*., 1993; Parametrix, 2008). The intermittent reach is described as "a single-thread channel with slight sinuosity that may increase over time as further channel narrowing occurs as more islands attach to banks," (Parametrix, 2008). Riverbed aggradation within the intermittent reach slows the rate of flow. This allows sediment to drop which raises the riverbed elevation and increases the potential for floodplain inundation.

Data for this project were collected by the Bosque Ecosystem Monitoring Program (BEMP). BEMP is a non-profit collaborative organization between the University of New Mexico (UNM) and Bosque School in Albuquerque, NM. This organization, where I have been employed for the past five years, was established in 1996 as a result of the recognized need for monitoring the biological quality and ecosystem integrity of the bosque as stated in the Bosque Biological Management Plan (Crawford *et al*., 1993). BEMP tracks long-term changes in the bosque through monitoring key biotic and abiotic parameters from 30 research sites along 560 km of the Rio Grande bosque throughout NM. Data from ten of the 30 BEMP sites were used for this research primarily because of their longer period of record, similar site history, and lack of extreme disturbance events.

BEMP data are collected by citizen scientists including students in grades K-12, teachers, and volunteers. Quality assurance is provided by BEMP staff, contracted experts, and graduate and undergraduate students enrolled in a BEMP class offered through the UNM Department of Biology. The data are provided to federal, state, and local management agencies including the U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, the Middle Rio Grande Conservancy District and others who use it to better understand the impacts of their efforts within the bosque.

The objective of this research was to understand how flow intermittence impacts the hydrology, riparian vegetation, and arthropod communities within the Middle Rio Grande bosque. Spatio-temporal variation of depth to groundwater, surface water flow, and precipitation were examined to determine their influence on plant cover and diversity, as well as arthropod abundance, indicator species, and functional groups. Community composition of vegetation and arthropods within the perennial and intermittent reaches were also examined.

STUDY SITES AND METHODS

Selected study sites were located within the Middle Rio Grande (Figure 1), an area in central New Mexico created by the Rio Grande rift. The Rio Grande flows in a moderately sinuous fashion through this rift valley starting just below Cochiti Dam and proceeding 257 km south to Elephant Butte Reservoir (Ellis, 2003). The river is constrained laterally by paralleling levees, and there exists within the narrow constraints produced by the levees, the longest continuous stretch of cottonwood forest in the Southwest (Crawford *et al*., 1993; Howe & Knopf, 1991).

Site Descriptions – North to South

Sites were selected based on their longer period of record (the earliest starting in 1997), their location within the Middle Rio Grande reach, and similar site histories. Sites with shorter periods of record or that experienced extreme disturbances such as major fires were not selected for this analysis. A summary of the site histories are provided in Table 1.

Diversion (DIV) – installed in 2002, located 0.5 km south of Alameda Bridge in Albuquerque along the east side of the river. Exotic species were mechanically removed in 2003. The northern 20 m of the site was removed in 2005, due to the construction of a fish passage created around the newly installed San Juan Drinking Water Project Diversion Dam. The 20 m was extended onto the southern end of the site. Beavers were active in the site in 2009, 2010, and highly active in 2011, leaving very few cottonwood trees standing at the site. The exposed soil is dry and sparsely vegetated with primarily upland plants including prickly pear cactus, and some recent plantings of various native woody species.

Alameda (ALA) – installed in 1997, located 0.5 km south of Diversion BEMP site on the east side of the river. The site is dominated by an overstory of old growth cottonwood trees and a dense understory of New Mexico olive. Herbaceous ground cover is minimal and a thick accumulation of woody debris litters the forest floor. The site experienced mechanical removal of saltcedar, Russian olive, and Siberian elm in 2004.

Rio Grande Nature Center (RGNC) – installed in 1997, located near the Rio Grande Nature Center State Park on the east side of the river. The site has a thick canopy of smaller old-growth cottonwoods with an open understory, the result of a successful clearing of exotic trees in 2004. The forest floor is vegetated by mixed native and exotic grasses and forbs.

Hispanic Cultural Center (HCC) – installed in 2001, adjacent to the National Hispanic Cultural Center on the east side of the river. Extensive exotic plant removal occurred in 2004, which coincided with the removal efforts of historic flood-control structures called 'jetty jacks.' Annual exotic plant removals occurred between 2006 and 2010 with minimal disturbance to the site. HCC consists of a mature cottonwood canopy, exotic tree understory, and dense exotic bunch grasses along the forest floor. This site experiences heavy foot and bike traffic along well-established trails.

Harrison (HAR) –installed in 2003, on the west bank on an established sandbar across from the Southside Wastewater Reclamation Plant outflow. The site periodically inundates during high flow events through multiple small channels. This connection maintains a healthy stand of coyote willows and annually variable forb and grass cover, with many open sandy areas. Cottonwoods are dispersed around the site and Russian olive dominates southern portions of the site. Semi-circles were dredged into the bank along the east side of the site in 2012, creating wetland habitat that inundates during high flows. This restoration project cut into several vegetation transect lines.

Los Lunas (LL) – installed in 1997, along the west bank of the river 40 km south of Albuquerque in the intermittent reach in Los Lunas, NM. Overstory cottonwoods shade a dense yerba mansa carpet and an understory of coyote willow and Russian olive. The site seep floods during high surface flow events, and woody debris has accumulated throughout the site, as cottonwoods have aged and dropped their limbs.

Reynolds Forest (RF) – installed in 2004, in Belen, NM on the east side of the Rio Grande 1 km north of HWY 309. The site was originally installed as the control for a paired site that was cleared of exotics. However, in early 2012 the site was heavily cleared of all understory species and chipped. This extensive management produced a thick layer of variably sized wood chips on the forest floor, largely impenetrable to most vegetation besides tumbleweed and kochia. A secondary clearing and herbicide treatment in 2014 further reduced understory species such as Russian olive and saltcedar that had grown back post-clearing.

Belen (BEL)– installed in 1997, near Willie Chavez State Park 56 km south of Albuquerque in Belen, NM along the west side of the river. Occasional overbank floods maintain thick stands of young cottonwoods and coyote willows along the river and dense Russian olive thickets beneath a mature cottonwood canopy. The site was partially mowed to remove exotics prior to its installation. A small ground fire in 2007 minimally impacted the southern end of the site.

Valencia Cleared (VF) –installed in 2003, immediately southwest of the Belen BEMP site. The site has a thick ground cover of yerba mansa, an understory of Russian olive and Gooding's willow, and a mature cottonwood overstory. The site was mechanically cleared of exotics in 2003 and 2008.

Lemitar (LEM) – installed in 2002, 115 km south of Albuquerque in Lemitar, NM along the west side of the river. This sparsely-vegetated site is the only BEMP site located outside of the levee system. Vegetation is composed of upland shrubs, smaller scattered cottonwoods and saltcedar, and annually variable forbs and grasses. This site has not experienced any major disturbances since its installation.

Data Collection

Surface Flow

River discharge data are collected by the US Geological Survey (USGS) through a series of instream monitoring gages. Eight gages, spanning 182 km of the Middle Rio Grande, are used in this research. Three of the gages, San Felipe (gage ID: 08319000), Alameda (08323319), and Central Bridge (08330000), are in the 61 km-long perennial reach and the remaining five gages, Isleta Lakes (08330875), Bosque Farms (08331510), HWY 346 (08331510), Bernardo (08332010), and San Acacia (08354900), are installed throughout the 105 km-long intermittent reach. The river discharge data are gathered through a series of steps, beginning with the continuous monitoring of stage height or the height of the water (Sauer & Turnipseed, 2010). There are many methods for measuring stage height, but the gages in this study use one of two. One method used by the Alameda, HWY 346, and Bernardo gages (personal communication with Jeb Brown, USGS Hydrologist), involves a stilling well located on the riverbank with a subsurface pipe connecting the stilling well to the stream. Surface water infiltrates the structure at the same elevation as the river and the height of the water in the gage is measured using a radar sensor (Sauer & Turnipseed, 2010). This sensor measures the elevation every 15 minutes and automatically sends the reading out through via satellite for instantaneous delivery online at www.waterdata.usgs.gov. The remaining five gages measure stage height through the measurement of a pressure differential created by the steady release of a gas bubbled into the stream (Sauer & Turnipseed, 2010). There is a direct relationship between the height of water and the pressure at the tube outlet within the stream; as stream volume increases, more pressure is required to push the gas into the water (Sauer & Turnipseed, 2010).

Stage height is translated into discharge by applying the stage-discharge relationship. This relationship is developed for each stream gage by physically measuring stream discharge during various flow conditions using handheld current meters and identifying the corresponding stage height measurement (Sauer & Turnipseed, 2010). The in-stream discharge is calculated by measuring flow velocity along the cross section of the channel in small subsections. The subsection area multiplied by the velocity provides the discharge value for the section, and the sum of all section values provides the total river discharge (Sauer & Turnipseed, 2010).

The channel substrate within the Rio Grande consists of cobble and sand in the northernmost 20 km of the study area then transitions to a completely sandy bottom streambed for the remainder of both study reaches (Sixta *et al*., 2003). This highly-mobile sediment is easily displaced by flow, creating highly variable stream cross sections. Field discharge measurements within the Middle Rio Grande are made about every 45 days or on an as need basis depending on flow conditions (George Sieber, USGS Hydrologist, personal communication). This cross-sectional variability reduces the accuracy of the stage-discharge relation for the gages. The gages are generally within

15% of the actual flow, however, this can vary widely depending on flow conditions (Anning, 2002). On numerous occasions, field observations by BEMP staff reported dry riverbeds within the intermittent reach when online discharge measurements recorded flow as being present. During low flow events, the stream can move away from the gage when water does not extend from bank to bank. Additionally, sediment can be deposited on the end of the bubblers, creating an artificially higher flow reading. The most accurate gages used in this study are San Felipe, Central Bridge, HWY 346, and Bernardo, with the latter two gages in the intermittent reach (George Sieber, personal communication).

Depth to Groundwater

BEMP research sites contain five groundwater wells in a cross section spaced 40 m apart from the central well in the cardinal directions (Figure 2). Each well is constructed from two-inch polyvinylchloride (PVC) pipe with the bottom meter slotted with 2 mm gaps to allow groundwater infiltration (Crawford *et al*., 2013). Wells are hand drilled to around 300 cm depending on soil conditions. Citizen scientists are aided by trained BEMP interns and staff when using the Solinst Water Level Meter (beeper) to measure water table elevation. Well casings are marked with an exact measurement location so that depth to groundwater is collected at the same location every time. Beepers are comprised of a long waterproof tape with centimeters marked and a sensor at the bottom that beeps as it comes in contact with the water. The sensor is lowered into the well and a measurement is taken (to the nearest half centimeter) at the marked location on the well when the meter beeps. Above-ground casing heights are recorded for each well, and this value is subtracted from the depth to groundwater measurements in order to obtain true groundwater depth.

Precipitation

BEMP sites contain two Tru-Check Direct precipitation gages - one under a tree canopy and the other out in the open. Only data from the open gages were used for this research in order to obtain true, unobstructed rainfall measurements. Gages are read in both millimeters and inches and are filled partially with vegetable oil during the month prior to collection to ensure precipitation does not evaporate. Precipitation data are gathered monthly by citizen scientists with training and oversight.

Vegetation Transects

Vegetation monitoring occurs annually in August and September along ten 30 m transects spaced 20 m apart at each site. Professional botanists measure the distance covered by each plant that crosses the plane above or below the transect (to the nearest millimeter). Plants can be at the ground surface up to the top of the canopy. Overlapping plants of the same species are considered continuous; therefore, any one species can have up to 100% cover. Shrubs are considered continuous if species gaps are less than 5 cm, and canopy tree species gaps less than 1 m (Crawford *et al*., 2013). Species are identified to genus and species level (when possible) and recorded using the unique four letter species code created by the US Department of Agriculture (USDA, NRCS, 2015). Vegetation data prior to 2000 were not used in the analysis due to differing collection methodologies.

Plants were placed into categories according to their life history, form, and place of origin using the USDA plant database as a categorical reference guide. The following vegetation groups were used for analyzing spatio-temporal trends of community composition:

Grasses: native annual / native perennial / exotic annual / exotic perennial / unknown origin

Forbs: native annual / native perennial / exotic annual / exotic perennial / unknown origin

Shrubs: Native / exotic

Trees: Native / exotic

Sedges, **rushes**, and **lichens**: all places of origin

Surface-Active Arthropod Pitfall Trapping

Arthropod collections occurred three times per year: late spring, summer, and early fall. The southern edge of every other vegetation plot contained a line of four pitfall traps spaced ten meters apart for a total of 20 traps per site. The traps consisted of two plastic cups inserted into the soil, flush with the ground surface. A square wooden shade with two inch screws in each corner was placed over each trap when it was opened to protect the contents from precipitation and direct sun. After being opened for 48 hours, all trap contents were collected in plastic bags, sealed and immediately frozen for later identification. Arthropods were identified using an extensive reference collection from the UNM Arthropod Division of the Museum of Southwestern Biology. A unique assemblage specific to Rio Grande riparian ground arthropod fauna was created by Manuel Molles and Clifford Crawford with the assistance of taxonomic specialists (Cartron *et al*., 2003).

Contents of the collection bags, including dirt, were examined under a dissecting microscope to ensure tiny arthropods were not missed. Arthropods were counted and identified down to the lowest taxonomic group identifiable. UNM interns assisted with identification under the observation of BEMP staff. The period of record for analysis of arthropods was from 2003-2013, because data prior to this date was inconsistently gathered and identified.

All arthropods were assigned to a functional group (predator, herbivore, detritivore, ant, or unknown), using Ellis *et al.* (2000) and the Iowa State University Department of Entomology online reference (www.ent.iastate.edu) as resource guides. The abundance of indicator families such as Carabidae, which are indicative of environmental conditions including flooding (Cartrón *et al*., 2003), Tenebrionidae, which indicate dry habitats (Ahearn, 1970), and Isopoda, which indicate moist soil conditions (Paris, 1963), was analyzed by reach. Any site missing two collections in one year was excluded from that year's analysis.

Statistical Analyses

Hydrology: To plot the spatio-temporal variation in surface flow (Figure 3), we used the mean daily flow for three gages in the perennial reach, and three gages in the intermittent reach. The discharge values were assigned a color and plotted using MatLab R2014a. To assess the difference in streamflow between reaches (Figure 4), we first took an average of the mean annual discharge from the three USGS gages in the perennial reach and the five USGS gages in the intermittent reach. We then used a two-sample student t-test assuming unequal variances using Excel 2013 to compare statistical difference. In order to analyze the annual percentage of low flow events, (Figure 5) we averaged the mean daily flow from the three gages in the perennial reach and the five gages in the intermittent reach. The number of days below 200 cfs were counted by year and reach and divided by the number of days for the year. Annual depth to groundwater analysis by reach (Figure 7) was calculated by averaging the depth measured in each of the five wells at each of the ten BEMP sites. Each site's average annual depth to groundwater was calculated and subsequently averaged with the other four sites in each study reach. The difference between the reaches was analyzed using a two-sample student t-test assuming unequal variances. The temporal groundwater elevation change by site was created using R-studio Version 0.98.1103 © 2009-2014. Data for the mean depth to the groundwater for the five wells per site were entered into the program which calculated and graphed the mean, 25 %, 75 %, maximum, minimum, and outlier values for each year. Precipitation values by reach were calculated by taking an average of the annual precipitation for all sites in the perennial reach and all sites in the intermittent reach. Using a two sample student t-test, we tested for significant difference between years.

Vegetation: In order to analyze the difference in total vegetation cover between reaches and years (Figure 10), we initially took the average of the total plant cover across the ten vegetation transects in each site. We then averaged all of the sites according to their study reach and compared them for statistical difference using a two sample student t-test assuming unequal variances. Analysis of the vegetation community composition groups (Figure 13) according to reach was completed by summing the total cover for each group of plant at each site and each year. All sites within the same reach were averaged together by group and by year. The difference between each vegetation group was analyzed for significance using an ANOVA Type III Sum of Squares performed in SAS Version 9.3. Species richness analysis was done by counting the number of species found at each site every year. The number of plant species found within the adjacent sites in the perennial reach was compared to the number of plant species within sites adjacent to the intermittent reach using a two sample student t-test assuming unequal variances. Vegetation species diversity analysis was calculated for each site using the Shannon-Weiner diversity index, which takes into account the proportion of the total cover each plant species covers. Comparison for species diversity between the reaches was done by using a two-sample student t-test assuming unequal variances.

Arthropods: Comparison of the intermittent and perennial reaches for the abundance of arthropods by year (Figure 14) was done by summing the number of arthropods counted in each line of pitfall traps (four traps per line, five lines), and then averaging the five lines for each site. The difference in abundance between reach and by year was examined using an ANOVA Type III Sum of Squares analysis using SAS Version 9.3. Differences in the abundance of indicator family groups Carabidae and Isopoda by reach and by year were also determined using an ANOVA Type III Sum of Squares analysis. Type 1 Sum of Squares ANOVA was used for the Tenebrionidae group due to the low numbers of captures. Arthropod functional group analysis comparison between reaches used a two sample student t-test assuming unequal variances in order to test for significant difference.

RESULTS

Hydrology

Surface Flow

Spatio-temporal trends of daily river flow exhibit high interannual variability even with flow regulation infrastructure in place (Figure 3). There also is strong seasonal variability in flow throughout the period of record. The gages show a decrease in flow with downstream distance, about 40% less during summer months in the intermittent reach compared to the perennial reach. The number of days with low flow events increases with downstream distance through to the Bernardo gage. Agricultural return flow from the riverside drains re-enters the Rio Grande between the Bernardo and San Acacia gages, increasing surface flows for the remainder of the intermittent study reach.

Annual discharge, averaged by reach, followed the same temporal patterns, but with significantly lower flows in the intermittent reach. An overall decline in annual flow was noted throughout both reaches throughout the period of record. Initially, a rapid decline from high mean flows in 1997 at 1,400 cubic feet per second (cfs), declined down to 300 cfs through 2003, a period of drought in the Southwest (Figure 4). Two years later, snowmelt runoff created much higher flows in 2005, with mean annual flows increasing to 1,600 cfs. Discharge dropped considerably in 2006 down to 600 cfs, which was followed by another strong flow year in 2008 with flows averaging 1,500 cfs. Flow declined down to about 400 cfs during another period of drought for the remainder of the study through 2013.

Gage inaccuracies did not allow for the analysis of days with zero flow, so low flow analysis was done in its place (Figure 5). Discharge values reported below 200 cfs are considered to be low flow and have the potential for riverbed drying within segments of the intermittent reach. Temporal trends in low flow show considerable interannual variability within the intermittent reach. The percentage of the year with average daily flows reported < 200 cfs follows the same trend as mean annual discharge (Figure 4). Wet years in 1997, 2005, and 2008 showed less percentage of low flow events. Dry years in 2000 - 2003 and 2010 - 2013 had a considerable part of the year exhibiting reduced discharge. The greatest percentage of low flow days in the intermittent reach was 48 % in 2003.

A flow duration curve for the perennial reach was produced using an average of the daily flows from 1997-2013 for the three gages in the perennial reach (Figure 6). The flow duration curve for the intermittent reach was produced using the average flows for the five gages in the intermittent reach. Greater discharge is shown in the perennial reach for the period of time greater than 60 - 100 % flow duration (low flow periods) and similar discharge values are shown below 60 % (high flow periods). Flows in the perennial reach never dropped below 53 cfs; flows below 10 cfs occurred at intermittent gages 2.6% of the time.

Groundwater

The average depth to groundwater is significantly deeper in the perennial reach compared to the intermittent reach (Figure 7). Sites within the perennial reach show a groundwater table depth increase of 11.3 cm from 1998 to 2013 and sites in the intermittent reach have declined by 69.6 cm. Large variances, however, exist on an individual site basis. Eight of the ten BEMP sites show a decline in depth to groundwater for the duration of the study. Only Harrison and HCC in the perennial reach show a trend towards a rising elevation of the subsurface water table during the period of record.

Groundwater quantiles demonstrate that sites within the intermittent reach show greater variability in subsurface water level during years of drought, except for Lemitar, which is outside of the levee system and is a much greater distance from the river compared to the rest of the sites (Figure 8). During years of higher mean annual flow, the difference in groundwater elevation has equal variability within both reaches.

Changes in groundwater elevation in response to maximum annual flow show the opposite response (Table 2). Sites within the perennial reach show a greater response to maximum surface discharge events. Correlation analysis of the change in subsurface water elevation versus annual peak flow provides a clear separation between stream types. R-squared values were statistically different between perennial and intermittent reaches. High river flows and stages in the Rio Grande generate a stronger rise in water levels in wells within the perennial reach than in wells within the intermittent reach.

Precipitation

Mean annual precipitation for the perennial and intermittent reaches is shown in Figure 9. The pattern of precipitation was more variable in the intermittent reach during earlier years of the study, but followed more closely with the trends in the perennial reach post 2002. A large, isolated storm event occurred over the Los Lunas site in the intermittent reach in July 2002 which created a large spike for the intermittent reach at that time. The remainder of the sites experienced precipitation similar to the sites in the perennial reach. None of the years received significantly different amounts of precipitation by reach.

According to the Western Regional Climate Center, average annual precipitation for the Albuquerque area is 220 mm (POR 1914-2005). For the duration of this study, 13 of 17 years in the perennial reach received below-average precipitation. Years of above-average precipitation were 1997, 2004, 2006, and 2007. Average annual precipitation for Belen, NM (mid-way through the intermittent reach) is 193 mm (POR 1981-2010). Nine of the 16 years in the intermittent reach received lower than average annual precipitation.

Vegetation

Plant Cover

Vegetation cover across all sites from 2000-2013 followed similar, yet muted, patterns to river discharge (Figure 10). Vegetation cover within both reaches declined from 2000 to 2003, a period of drought, and increased from 2004 through 2007, a timeframe with higher than average precipitation and river flow. From 2008 through 2012, river flow and precipitation were low, and vegetation cover again declined. The steep 2006 drop in river flow did not result in a decrease in vegetation cover. Two small increases in cover in 2010 and 2013 for sites in the intermittent reach corresponded to years of increased precipitation.

There was a statistically significant difference ($p < .0001$) in vegetation cover between the reaches, with less cover at sites along the perennial reach. Both reaches exhibited an overall declining trend in total plant cover throughout the period of record, with sites within the intermittent reach declining faster than the northern sites within the perennial reach. Correlations between mean annual river flow and mean vegetation cover at the sites were weak, however, four of the five sites within the intermittent reach had stronger correlation coefficients than sites in the perennial reach.

Species Richness and Diversity

Significantly greater plant species richness ($p < .0001$) was exhibited throughout the perennial reach. Vegetation species diversity using the Shannon-Wiener diversity index exhibited the opposite trend, with significantly less diversity ($p < .0001$) in the perennial reach using the equation below (Nolan & Callahan, 2006).

$$^{q}D = \left(\sum_{i=1}^{R} p_i^q\right)^{1/(1-q)}$$

There was no significant correlation between species diversity or richness with years of high or low river flow. Similarly, there was no correlation with years of high or low precipitation.

Plant Community Composition

The community composition of the vegetation varied greatly among individual sites (Figures 11 & 12). Sites along the perennial reach had statistically less native annual grasses ($p < .001$), native perennial grasses ($p < .001$), exotic annual forbs ($p <.01$), native perennial forbs ($p < .0001$), sedges ($p < .0001$), and exotic trees ($p < .0001$) compared to the intermittent reach. The perennial reach had statistically more native shrubs ($p <.01$), native trees ($p < .01$) and forbs of unknown origin ($p < .01$) (Figure 13).

Arthropods

Abundance

The average abundance of arthropods was significantly lower ($p <.0001$) at the sites adjacent to the perennial reach compared to the intermittent reach from 2003 –

2013 (Figure 14). Abundance within the intermittent reach was highly variable throughout the period of record, with large increases in abundance in 2004 (high precipitation year), 2007, and 2012 (drought year) and large declines in 2005 (high river flow year), 2011 (drought year), and 2013 (drought year). Abundance within the perennial reach increased throughout the ten year study period with smaller peaks and valleys compared to the intermittent reach. Trends were similar between the reaches from 2003 to 2009. The trend then began to take on opposite patterns for the remainder of the study. For the final year of the study, the perennial reach showed a greater abundance of arthropods than in the intermittent reach.

The number of arthropods collected in 2007 within the intermittent reach was significantly greater ($p < .0001$) than all other years of collection besides 2004 and 2012. Correlation of abundance with precipitation and river flow were weak and insignificant. Arthropod species diversity could not be analyzed for this study because the depth of taxonomic identification varied according to the scientist identifying the arthropods.

Indicator Groups

Analyses of arthropod indicator families Carabidae, Tebebrionidae, and order Isopoda were all found to have significantly lower abundances ($p <.0001$ Isopods and Carabids, $< .001$ Tenebrionids) within perennial reach (Figure 15). Carabid abundance increased throughout the period of record for both reaches, with a greater increase in the intermittent reach. A peak of carabid beetles in 2007 was significantly greater than all other years of collection, however, this did not correlate with a period of high precipitation or river flow. Tenebrionid beetles showed a declining trend in abundance for the period of record for both reaches, with a greater decline in the perennial reach. The pattern for isopod abundance was very similar to the pattern of total arthropod abundance, particularly within the intermittent reach. An average difference of only 14 arthropods existed between the total arthropod abundance and the isopod abundance throughout the decade within the intermittent reach. The perennial reach exhibited less similarity between the total arthropod abundance and the isopod abundance. Additionally, less inter-annual variability throughout the perennial reach was seen for isopod abundance, with one noticeable, although insignificant, rise in abundance in 2011.

Functional Groups

Arthropods were divided into one of four categories for functional groups: predators, herbivores, detritivores, and ants (Figure 16). Detritivores were significantly more abundant ($p < .0001$) than all other trophic categories. The abundance of detritivores was significantly less ($p < .0001$) within the perennial reach compared to the intermittent reach. No other functional group showed significant differences between reaches.

DISCUSSION –

The Middle Rio Grande spans 260 river km throughout central New Mexico from Cochiti Dam to Elephant Butte Reservoir (Ellis *et al*., 2003). This straightened and channelized reach is longitudinally constrained by levees with paralleling ditches and drains for water control and transportation (Crawford *et al*., 1996). The narrow stretch of riparian forest between the two impoundments is dominated primarily by a nearly continuous canopy of mature cottonwood trees with mixed native and exotic understory (Crawford *et al*., 1993, Howe & Knopf, 1991). The homogenous habitat of today is highly altered from the diverse mosaic of habitats created by the meandering and braided river system that existed before human manipulation (Phillip *et al*., 2011). Grasslands, oxbow lakes, patches of cottonwoods of varying ages, and multiple wetlands bordered the historic dynamic river. Annual spring flooding was the primary driver behind the ecosystem heterogeneity (Molles *et al*., 1998).

From the headwaters of the Rio Grande through Albuquerque, the river maintains perennial flow. Instream flow of 100 cfs at the Central Bridge gage is required by the Environmental Protection Agency throughout Albuquerque for maintaining habitat for the endangered Rio Grande Silvery Minnow (*Hybognathus amarus*), (U.S. Fish and Wildlife Service, 2007). Twenty kilometers south of Albuquerque, the river is often dewatered at the Isleta Diversion Dam during summer months. The water is redirected into two lateral channels on either side of the river, Peralta Main Canal and Isleta Riverside Drain, which are used primarily for irrigation purposes. The 105 km stretch between the Isleta Diversion Dam and the San Acacia Diversion Dam is spatially intermittent. Water is returned to a few sub-reaches from the outflow of the waste water treatment plant in Los Lunas and Belen. However, the water typically infiltrates into the subsurface after some distance. Additionally, the remainder of the water diverted at Isleta Diversion Dam that was not used for irrigation is returned to the main channel of the Rio Grande 17 km upstream of San Acacia Dam.

The hydrology of the Rio Grande throughout the period of study showed large variances between years. According to Dettinger *et al*. (2011), who examined annual coefficients of variation for streamflow and precipitation throughout the United States, New Mexican rivers can have coefficients of variation up to ~ 0.6 on a national scale from 0.1 - 0.7. This indicated high flow variability. The coefficients of flow variability for the perennial and intermittent segments of the Rio Grande in this study from 1997-2013 are 0.4 and 0.5 respectively. This shows the natural flow regime of the Rio Grande is highly variable despite numerous human modifications of this system designed to reduce flow variability.

The decline in surface flow and increase in intermittency seen throughout the period of record are likely a result of a combination of factors including natural variation, increase in demand from urban populations, and a changing climate. The San Juan-Chama transbasin diversion was completed in 1970, which allowed 110,000 acre-feet of water per year from the San Juan River in Colorado to flow through the Rio Grande (Phillip *et al*. 2011). The San Juan-Chama Drinking Water Project was completed in 2008, which allowed the San Juan River water to be used in order to help slow the overdraft of groundwater pumping. Water demand for municipal purposes has been increasing along with the rise in population in urban areas. According to the US Census Bureau, the population in Albuquerque has increased by nearly 200,000 people since 1990 to present day. Albuquerque is only one of many growing cities along the Rio Grande that uses San Juan River flow.

According to Gutzler (2013), areas near the US-Mexico border and in the Southwest are seeing and will continue to see rising air temperatures, decreased winter precipitation and snowpack that melts earlier in the year, and a possible increase in monsoonal rainfall. These climatic factors alone are enough to impact the hydrology of a river system. A changing climate in combination with the anthropogenic infrastructure and manipulation explains the decrease in surface flow and increase in intermittency throughout the study.

The groundwater table was significantly deeper within the perennial reach despite the continual presence of water in the system. This is a result of the geomorphological differences between the two reaches. The perennial reach is more incised than the intermittent reach. Surface flow infiltrates the subsurface deeper along the bank and further from the floodplain. This physical difference in channel form is also likely responsible for the trend seen for change in the groundwater elevation response to peak river flow (Table 2). With the floodplain at a greater distance from the surface of the river in the perennial reach, high surface flows can reach a higher stage height, allowing the groundwater table to rise higher. The low banks in the intermittent reach do not allow river stage to rise as high, limiting the rise in groundwater elevation to the height at which overbanking occurs.

The trend for declining groundwater tables in the intermittent reach reflects the declining surface flows and the increase in intermittency. The perennial reach showed a rising groundwater table. However, this trend was dominated by two of the five sites. Harrison, which is located on a sandbar in the river, and HCC, showed an average of 10 cm increase over the period of record, the other sites were declining. The box plots (Figure 8) demonstrate the individual site variability. The sites with the greatest elevation changes are the sites that experience overbank flooding, Harrison (perennial reach) and Belen (intermittent reach).

Vegetation patterns reflected the groundwater table trends within both reaches. The shallower subsurface water table supported greater vegetation cover within the intermittent reach. However, as the water table dropped, the vegetation cover declined. Additionally, the intermittent reach experienced nine years with below-average precipitation levels throughout the period of record that likely influenced the decline in cover as well. The plant community composition groups with significantly greater cover in the intermittent reach were mostly groups with short root structures. With its deeper groundwater table and 13 years with below average precipitation, the perennial reach was unable to support as much cover by these understory grasses, forbs, and sedges. There were more native trees and shrubs and plants with deeper roots within the perennial reach. Many of the shrubs are indicative of upland, drier, habitats. The total cover within the perennial reach was more variable than in the intermittent reach. The sites with increasing subsurface water elevations similarly showed an increase in vegetation cover. Sites with declining groundwater elevations showed a reduction in total plant cover. These patterns of cover within both reaches were also impacted by various management strategies used throughout the period of record.

Removal of exotic species including saltcedar (*Tamarix chinensis*), Siberian elm (*Ulmus pumila*), and Russian olive (*Elaeagnus angustifolia*) occurred at six of the study sites, two of which subsequently received extensive wood-chipping. Bank restructuring at two of the sites also impacted the total vegetation cover as bulldozers and other heavy equipment were brought in to the sites and removed sections of the bosque that crossed through some of the vegetation transects. These events are seen as a reduction in cover at the sites and during the years the management action took place.

A few extreme ecological events during the period of record potentially influenced the plant community composition of various groups and total plant cover. Specifically, an abnormal deep freeze in February of 2011 could have impacted the cover of some of the woody species. According to the National Oceanic and Atmospheric Administration (www.srh.noaa.gov), Albuquerque temperatures were below freezing for 88 consecutive hours, dropping to a low of -20˚C. Additionally in late July and August of 2011, ash and charcoal from a large fire upstream (Las Conchas fire) washed into the river during the summer monsoons. This sudden influx of debris and sediment caused severe oxygen sags in the river (Dahm *et al*., 2015), likely impacting groundwater oxygen levels as well. According to Dorais and Pepin (2011), oxygen deficiency can reduce plant growth and productivity. The monsoons in 2011 took place prior to the vegetation sampling, so a reduction of plant cover could have resulted from these extreme water quality excursions.

Overbank flooding and seep flooding are more common throughout the intermittent reach. Occasional flooding along with periodic absence of flow are likely reasons for the greater diversity of vegetation throughout the intermittent reach. The intermediate disturbance hypothesis indicates that, “species diversity within a given ecosystem should be highest at intermediate frequencies or intensities of disturbance,” (Hobbs & Huenneke, 1992). Both the overbank flooding and the absence of flow are examples of ecological disturbances. These disruptions create a wider, more diverse range of conditions for vegetation to establish. The decline in groundwater and increase in intermittence is likely to further disrupt this trend in the future. Less water availability will result in fewer overbank and seep floods with longer timeframes with low or zero flow. This will potentially foster the dominance of more drought tolerant plant species and thereby reducing diversity.

A one-year study along the spatially intermittent Rio Puerco, in Arizona (Stromberg *et al*., 2005), analyzed vegetation response to flow cessation. Their research revealed similar results to this study including a decline in plant cover and a shift in vegetation community composition with increased intermittence. The Rio Puerco is a free-flowing (un-dammed) river system, unlike the highly modified Rio Grande, and does not exhibit any major differences in channel morphology between the intermittent and perennial reaches. Kopeć *et al*. (2014), performed a long-term study on the riparian vegetation community along the historic floodplain of the highly modified and dammed Bzura River in Poland. The study found similar results to this research in that the progressively drying floodplain favored an increase in exotic plants. Additionally, they saw an increase in cover for annual plant species, which was not seen throughout this research project.

Arthropod abundance was much greater within the intermittent reach and exhibited greater inter-annual variability compared to the perennial reach. The abundance was dominated by isopods (*Porcellio laevis* and *Armadillium vulgare*), which prefer environments with moister soil (Paris, 1963). The higher groundwater table in the intermittent reach created soil conditions that are more suitable for these detritivores than the soil throughout the perennial reach. Two sites, Los Lunas and Valencia Cleared, dominated the trend for isopod abundance in the intermittent reach. Both of these sites experience seep flooding and have an extensive groundcover of yerba mansa (*Anemopsis californica*). This forb has large leaves and grows in dense mats, which shades the soil and prevents evaporation. The majority of the floodplain in the sites within the perennial reach is drier and not as conducive to supporting large populations of isopods despite the ample availability of their food supply, litterfall and woody debris. The variation in abundance of these terrestrial crustaceans did not consistently correspond to trends in precipitation or surface flow.

The beetle indicator families examined, Carabidae and Tenebrionidae, were significantly more abundant in the intermittent reach. Carabid beetles are indicative of flooding and prefer to live in moist environments similar to isopods. Belen, Harrison, and Valencia Cleared, two overbank flooding sites and a seep flooding site, had the greatest abundance of Carabid beetles. Tenebrionids tend to live in dry environments and were found in greatest abundance at Diversion, Lemitar, HCC, and Valencia Cleared. These sites exhibited a wide range of habitat variation from sites with large expanses of exposed sandy soil to sites with dense vegetation and moist soil. Both wet and dry habitats were well represented within the intermittent reach during the occasional floods and summer river drying events, providing sufficient habitat for both indicator beetle families.

The deep freeze in February of 2011 likely impacted some of the arthropod species in addition to the riparian vegetation. There was a decline in carabids for both reaches, for tenebrionids in the perennial reach, and for isopods in the intermittent reach from 2010-2011. This could have been a result of the intense winter freeze. Overall trends in abundance for the beetle indicator families did not appear to correlate with precipitation or river flow patterns.

Comparable arthropod research along the San Pedro River in Arizona by McCluney and Sabo (2012 & 2014), found that drying events shifted the composition of terrestrial arthropods, induced changes in diversity, and produced declines in the abundance of certain taxa including carabid beetles. In their two manipulative experiments of similar design and methodology, McCluney and Sabo reported contrasting results. Their 2012 study reported a reduction in arthropod diversity near artificial pools that were dried, however their 2014 study showed no response in arthropod diversity to the drying of water. Cortí and Datry (2014) sampled for terrestrial arthropods along the spatially intermittent Albarine River in France. Their results indicated that the flow cessation had no impact on the structure of the arthropod communities. This mixture of results demonstrates the need for further investigation within this area of research.

This research project was enhanced due to its long-term data from multiple sites along a river with two distinct regimes: one reach with perennial flow, and the other reach with spatial intermittence. Another valuable aspect, was that much of the data for this research were collected by citizen scientists. The data from students in grades k-12 college graduate and undergraduates were used to analyze the hydrology, vegetation, and arthropods within the bosque ecosystem. Throughout the study, the Rio Grande showed an increase in intermittence and a declining subsurface water table. The vegetation cover was greater throughout the intermittent reach, but declined throughout the study, and arthropod abundance was greater within the intermittent reach and was dominated by isopod species. There is a need for more studies on anthropogenically-induced intermittent river systems. In addition, there is a lack of research on temporary river systems despite their prevalence on every continent and their proportion being greater than 50 % of the global river network (Datry *et al*., 2014).

Most research on these systems has occurred in streams that experience drying as a natural part of their flow regime, and the focus is primarily on aquatic species such as fish, aquatic invertebrates, and algae (Bonada *et al*., 2007). Recently, interest in intermittent river systems has grown (Leigh *et al*., 2015), partially due to the rising number of large rivers undergoing anthropogenically-induced drying. There is a critical need to better understand the impacts of these non-natural drying events on all aspects of the aquatic and terrestrial ecology of rivers because flow intermittence is an increasing global phenomenon.

FIGURES AND TABLES

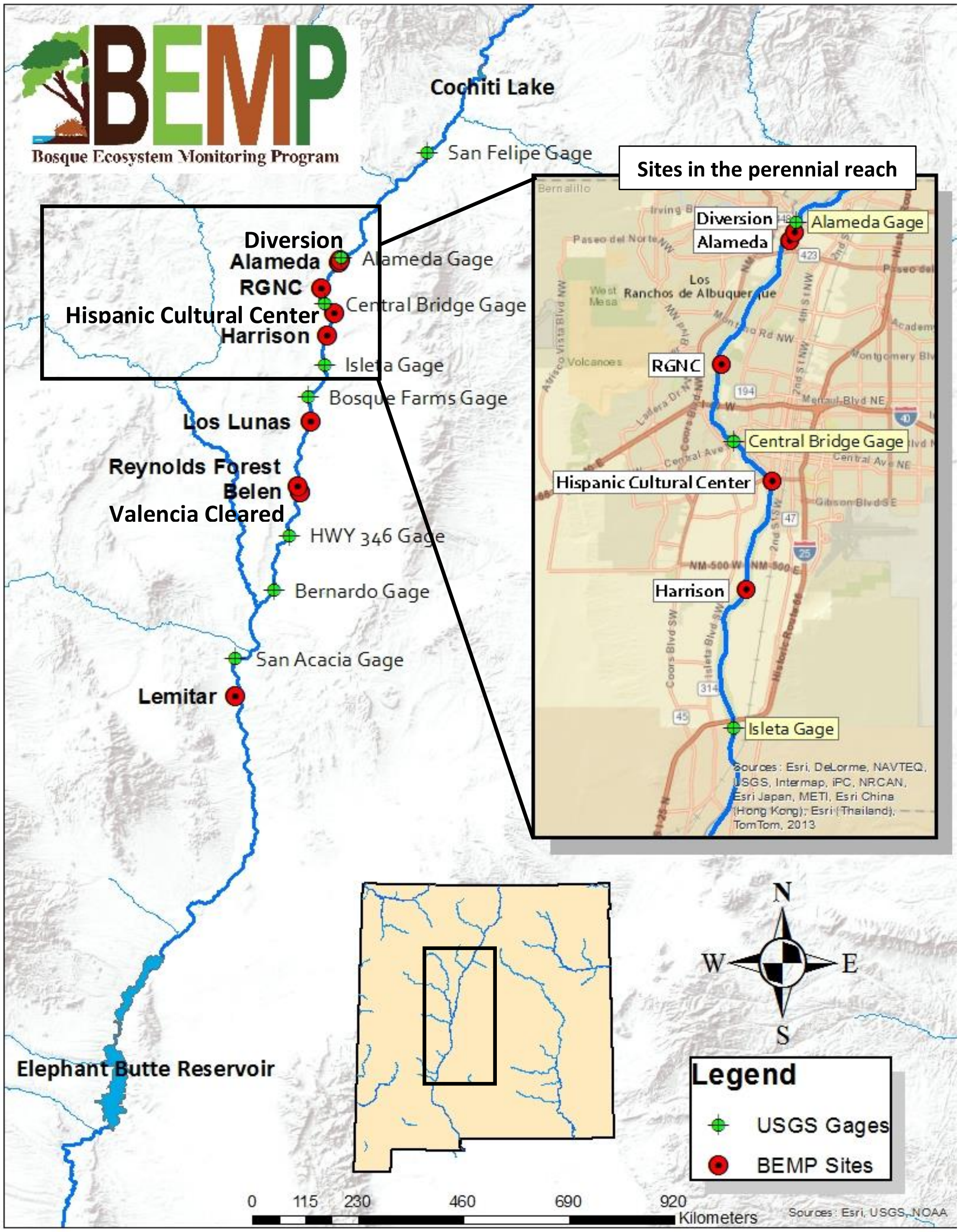


Figure 1: The ten BEMP study sites and eight USGS gages are located within the Middle Rio Grande Valley between Cochiti Lake and Elephant Butte Reservoir. Perennial sites within Albuquerque are shown in greater detail in the expanded section on the right.

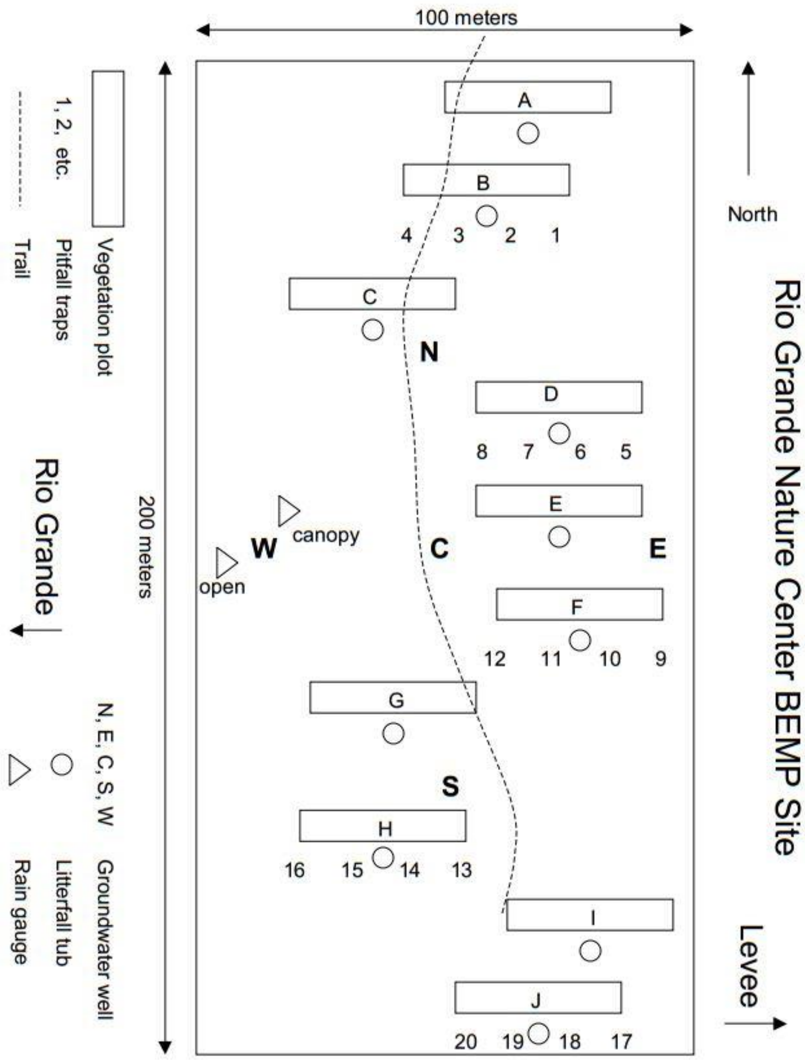


Figure 2: Rio Grande Nature Center site map. All sites are standardized to the same dimensions and contain the same number of wells, rain gages, pitfall traps, vegetation plots, and litterfall tubs (not used for this study). Vegetation plots located at random distances from the side of the site.

Table 1: Site histories of the ten BEMP study sites placed in order from north to south along the Rio Grande

	Site Name	Abbreviation	Site #	Date Established	Treatment Type & Date	Flooding condition
Perennial Sites (in Albuquerque, NM)	Diversion	DIV	10	Nov 2002	2003: mechanical removal of exotic plant species; 2005, Drinking Water Diversion Dam (DWDD) construction started immediately upstream and cut into northern 20 m of site for project development. High beaver activity in 2009, 2010, and 2011; 2012: Cottonwood pole and native plantings	non-flood
	Alameda	ALA	1	Apr 1997	June and November 2004; site cleared of exotics; Mar 2007: site mulched near east well and east of main trail; Feb 2012: work being done on dam - diverted water to west side of channel	non-flood
	Rio Grande Nature Center	RGNC	2	Jun 1997	2004: mechanical removal and herbicide treatment of exotic plants prompted by a nearby bosque fire	non-flood
	Harrison	HARR	13	Spring 2003	2006: flood buried E well; July 2007: side channel created; May 2008 flood; Apr-May 2010: flood; Mar 2012: wetland habitat created in site (cutting into several vegetation plots); Aug 2012: flash flood (3,000 cfs), 2013: flash flood (4,200 cfs).	overbank & seep flood
	Hispanic Cultural Center	HCC	8	fall 2001 started, finished Apr 2002	2004: removal of woody debris and mechanical clearing of exotic species, also removal of jetty jack lines; 2006-2010: annual removal of exotic species with minimal disturbance to the site	non-flood
Intermittent Sites (south of Isleta Diversion Dam)	Los Lunas	LL	3	Oct 1997	Seep floods in 1997, 1999, 2005 and May 2009	seep flood
	Reynolds Forest	RF & R. Forest	19	Spring 2004	2012: mechanical clearing and chipping of entire understory - thick layer of woodchips on the ground.	non-flood
	Belen	BEL	4	Feb 1998	overbank flooding in 1998, 1999, 2004, 2005, 2008, 2009 and 2010; low ground fire along southern edge in 2007; east bank lowered in 2009 so the site floods at 2500 cfs	overbank flood
	Valencia Cleared	VC & V. Cleared	15	Spring 2003	2003: mechanical clearing and chipping of exotic species; 2008: re-cleared and herbicide treated; Feb 2012 partial clearing and branches scattered; road through eastern edge of site Sept 2012	seep-flood
	Lemitar	LEM	4	Sep 2002	no management - site located outside of levee system	non-flood

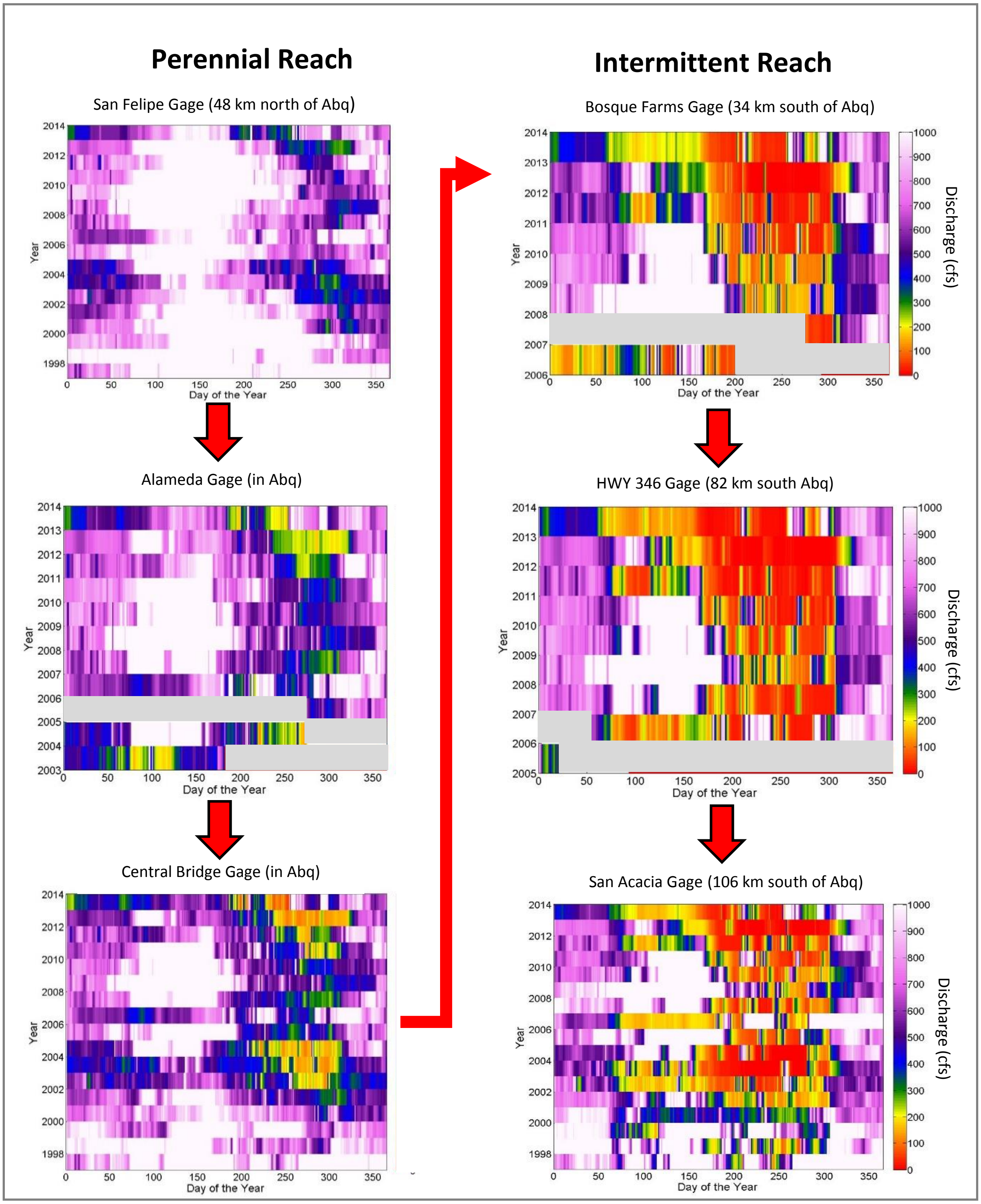


Figure 3: Spatio-temporal variation in average daily discharge from six USGS gages within 182 km of the Middle Rio Grande. Higher flows are shown in blue, purple and white. Green, yellow and red indicate low flows. Note the increase in red within the intermittent reach as the graphs progress towards more recent dates. Grey indicates no data

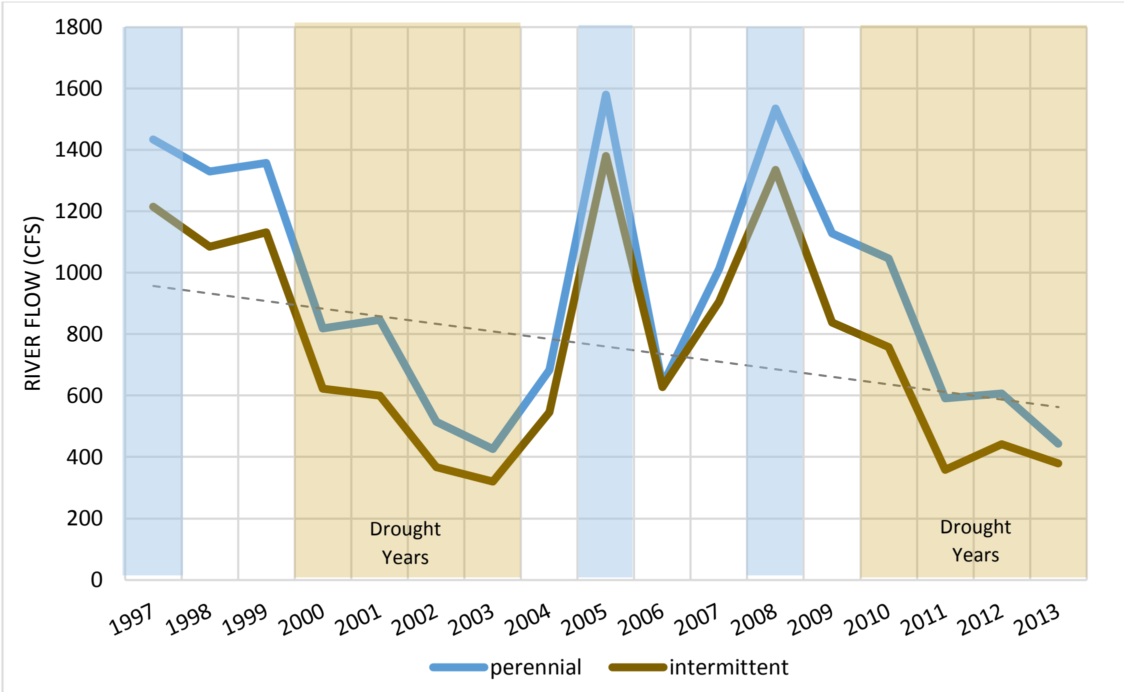


Figure 4: Mean annual river flow from perennial and intermittent reaches of the Rio Grande throughout the study period of record. Low flow years are shaded in brown and high flow years shaded in blue.

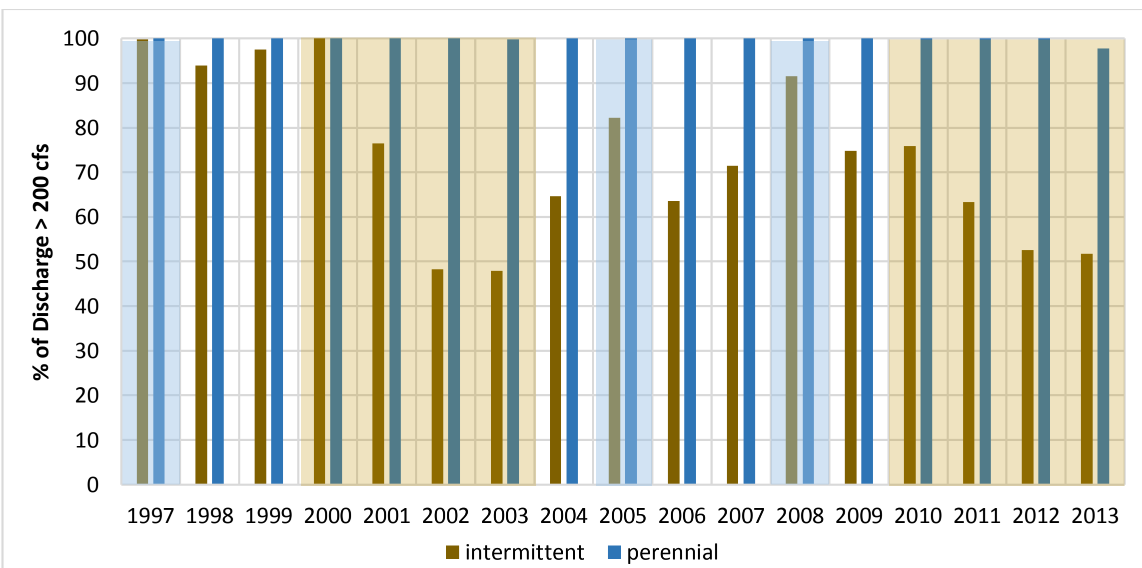


Figure 5: Annual percentage of flows > 200 cfs, from 1997- 2013. Values are the average of the three gages in the perennial and five gages in the intermittent the reach. Low flow years are shaded in brown and high flow years shaded in blue.

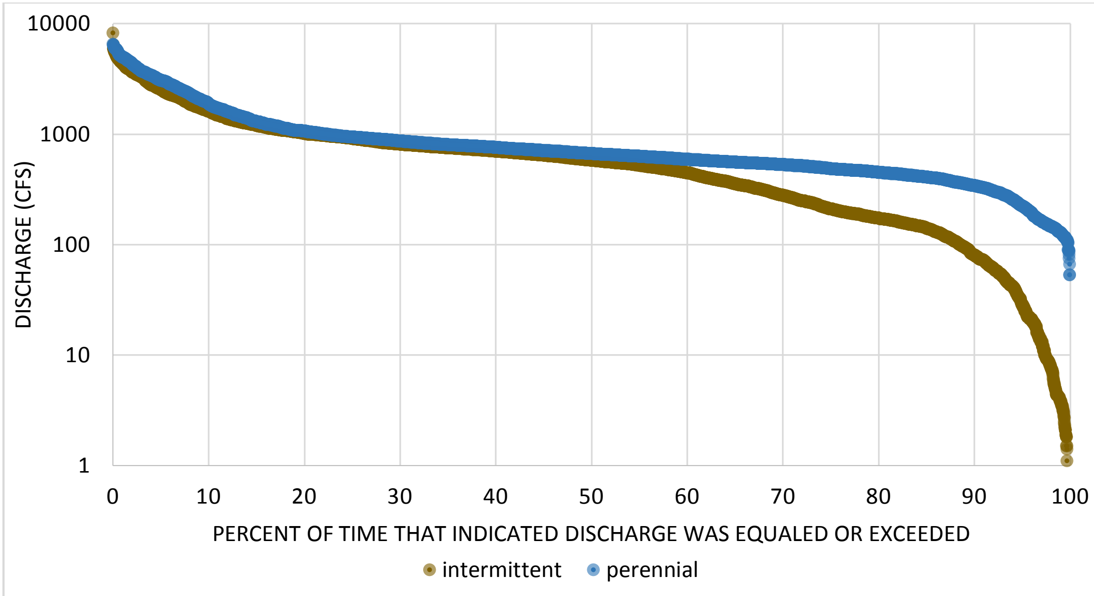


Figure 6: Flow duration curves for average of the three gages in the perennial and five gages in the intermittent the reach. Note the greater percentage of time low flows persist within the intermittent reach.

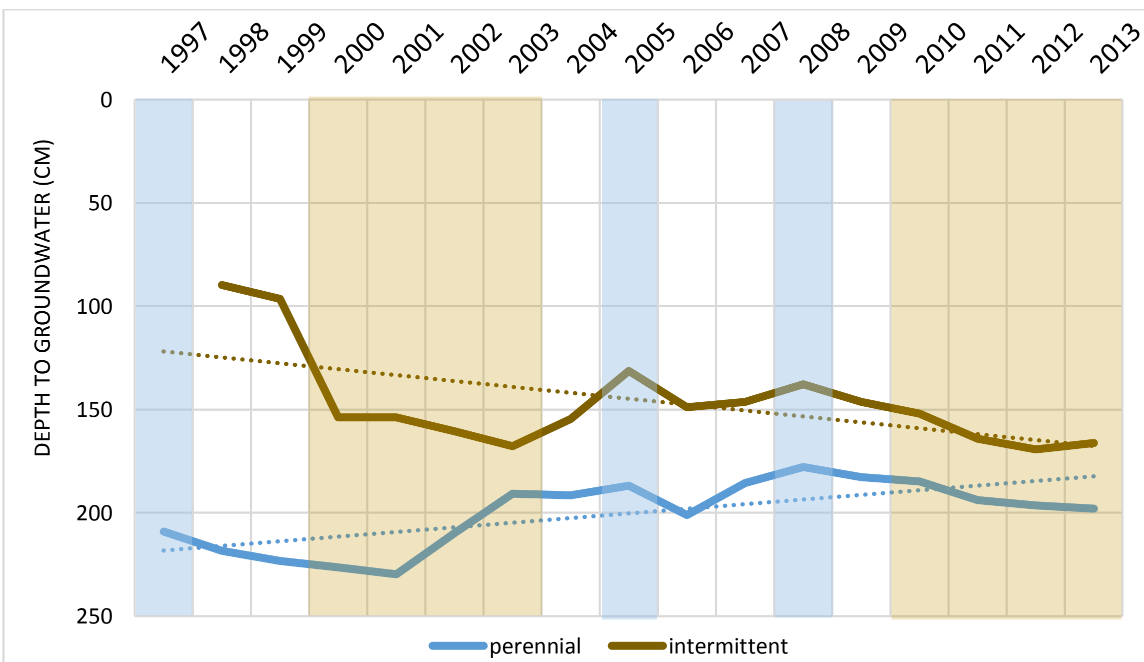


Figure 7: Annual depth to groundwater averaged by reach. Note the Y-axis is reversed so ground-level is at the top of the graph. Sites in the intermittent reach show a declining trend, sites in the perennial reach show a gaining trend.

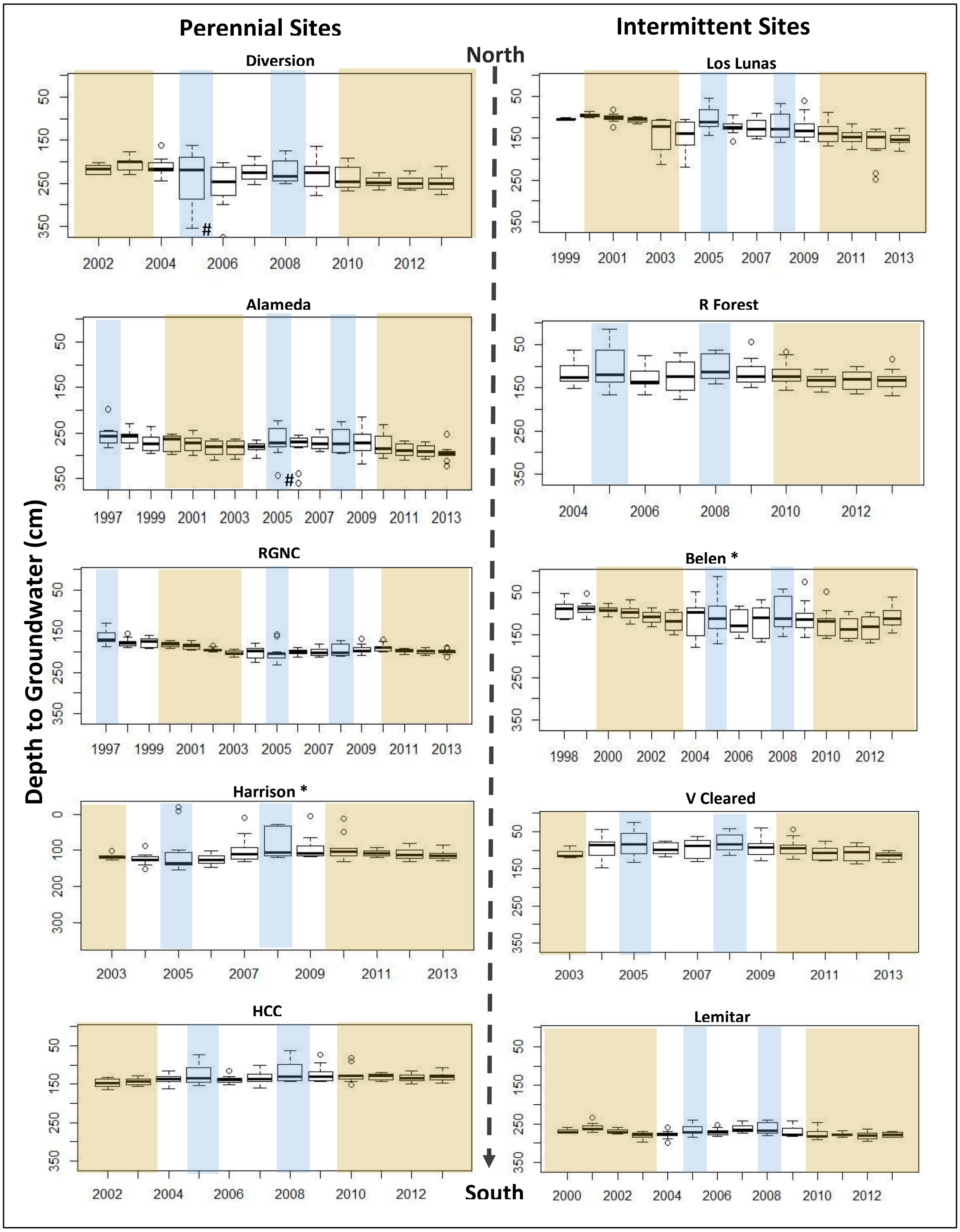


Figure 8: Temporal groundwater elevation change by site and reach. Box plots display the max, min, mean, 25 %, and 75 % quantiles (circles indicate outliers). Sites that overbank flood are denoted with an asterisk. The # sign indicates an artificial drop in groundwater as a result of the installation of the San Juan Drinking Water Project Diversion Dam as the river was diverted away from Diversion immediately upstream of the site. Note the sites within the intermittent reach show greater variation in depth to groundwater within years of drought, particularly 2010-2013.

Table 2: Correlation coefficients (R^2-values) between annual peak river discharge and change in annual groundwater elevation.

Groundwater elevation changes -vs - annual peak flow (cfs)		
Reach	**Site**	**R^2 value**
Perennial	HCC	**0.79**
Perennial	Harrison	**0.68**
Perennial	RGNC	**0.62**
Perennial	Alameda	**0.53**
Perennial	Diversion	**0.49**
Intermittent	Belen	**0.36**
Intermittent	R. Forest	**0.31**
Intermittent	Lemitar	**0.14**
Intermittent	Los Lunas	**0.06**
Intermittent	V. Cleared	**0.04**

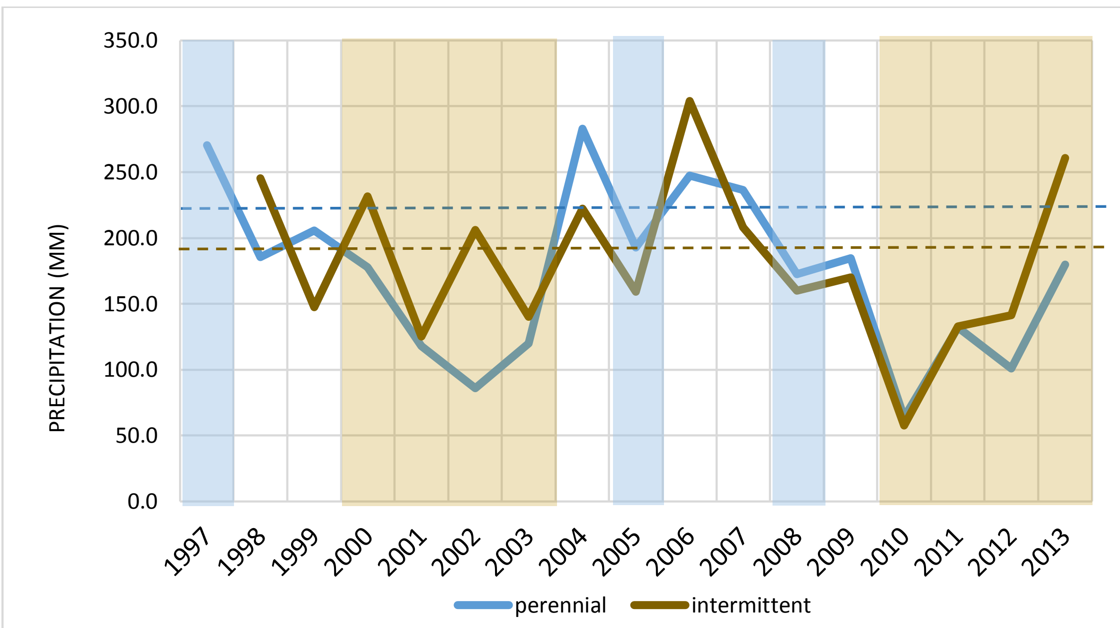


Figure 9: Mean annual precipitation for the intermittent and perennial reaches. The dashed blue and brown lines indicate the average annual precipitation for the perennial and intermittent reaches, respectively. Note the high precipitation years: 1997, 2004, 2006, 2013 and low precipitation years: 2000-2003, 2008-2012. Blue and brown highlighting shows periods of high and low river-flow.

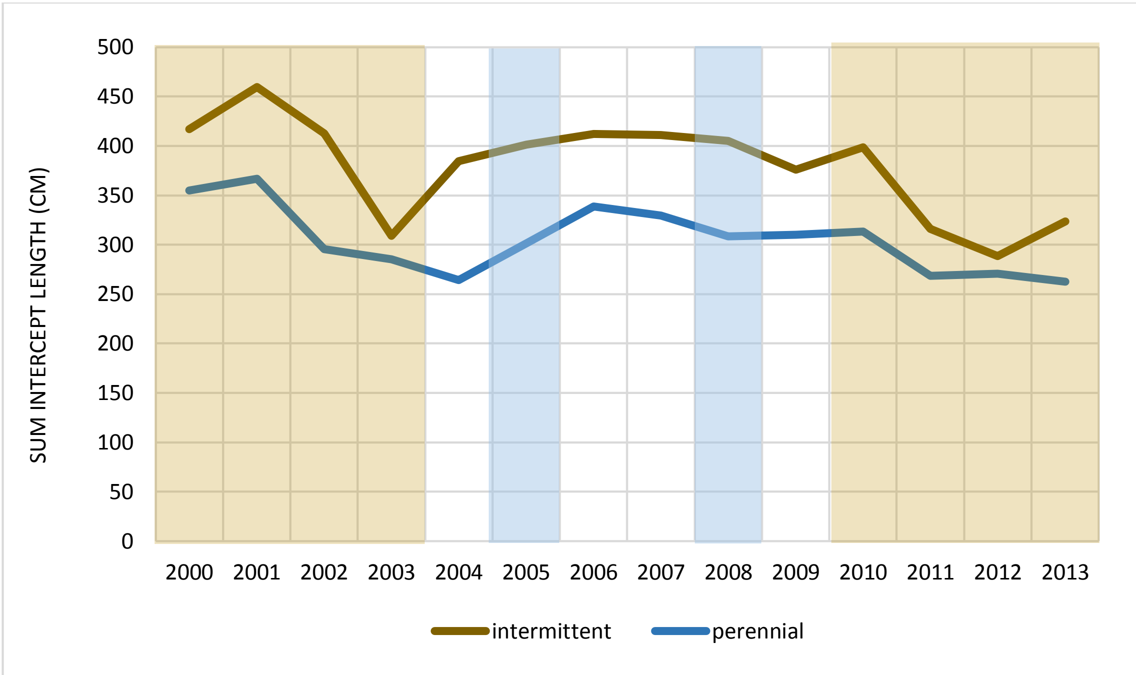
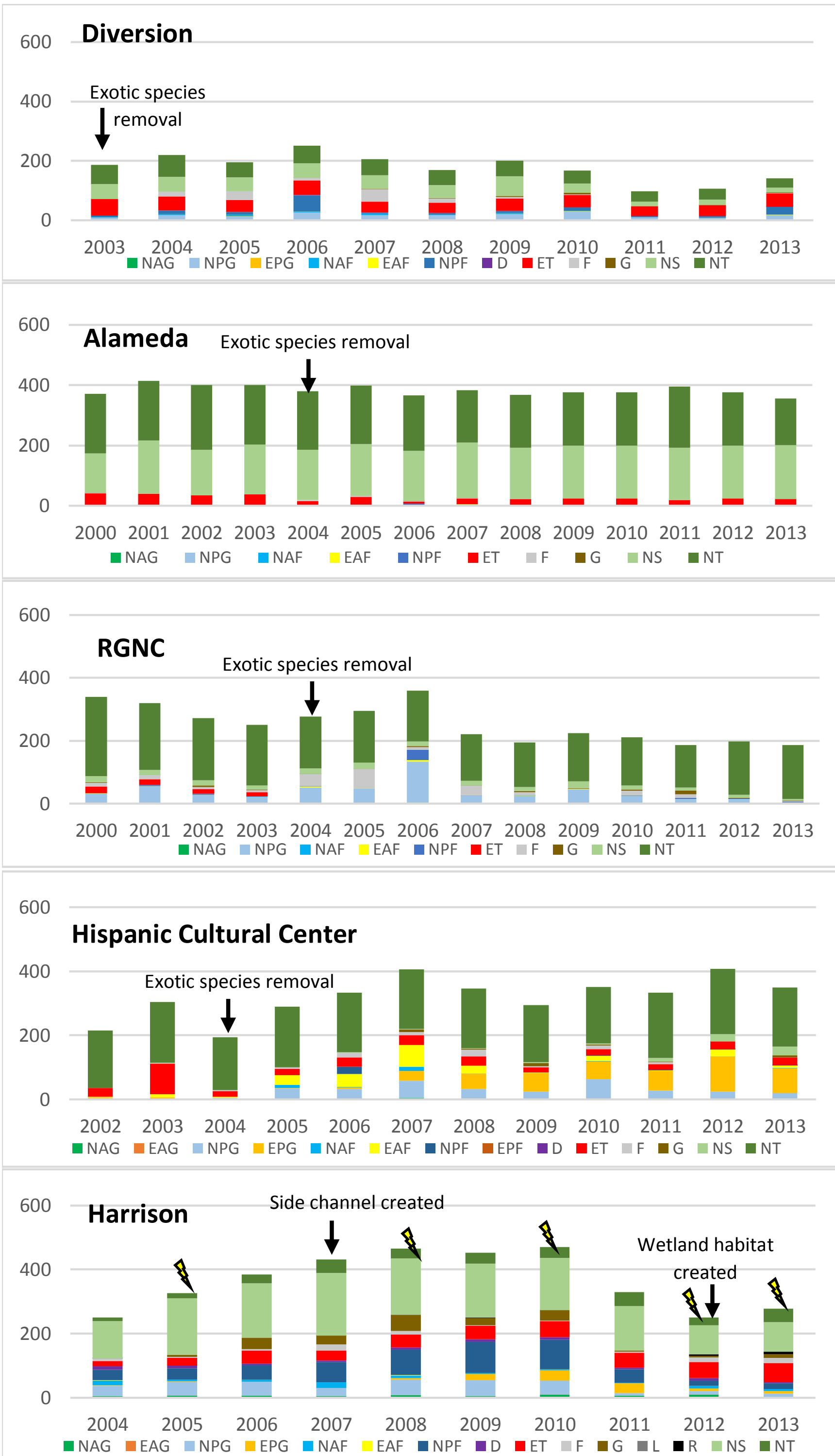


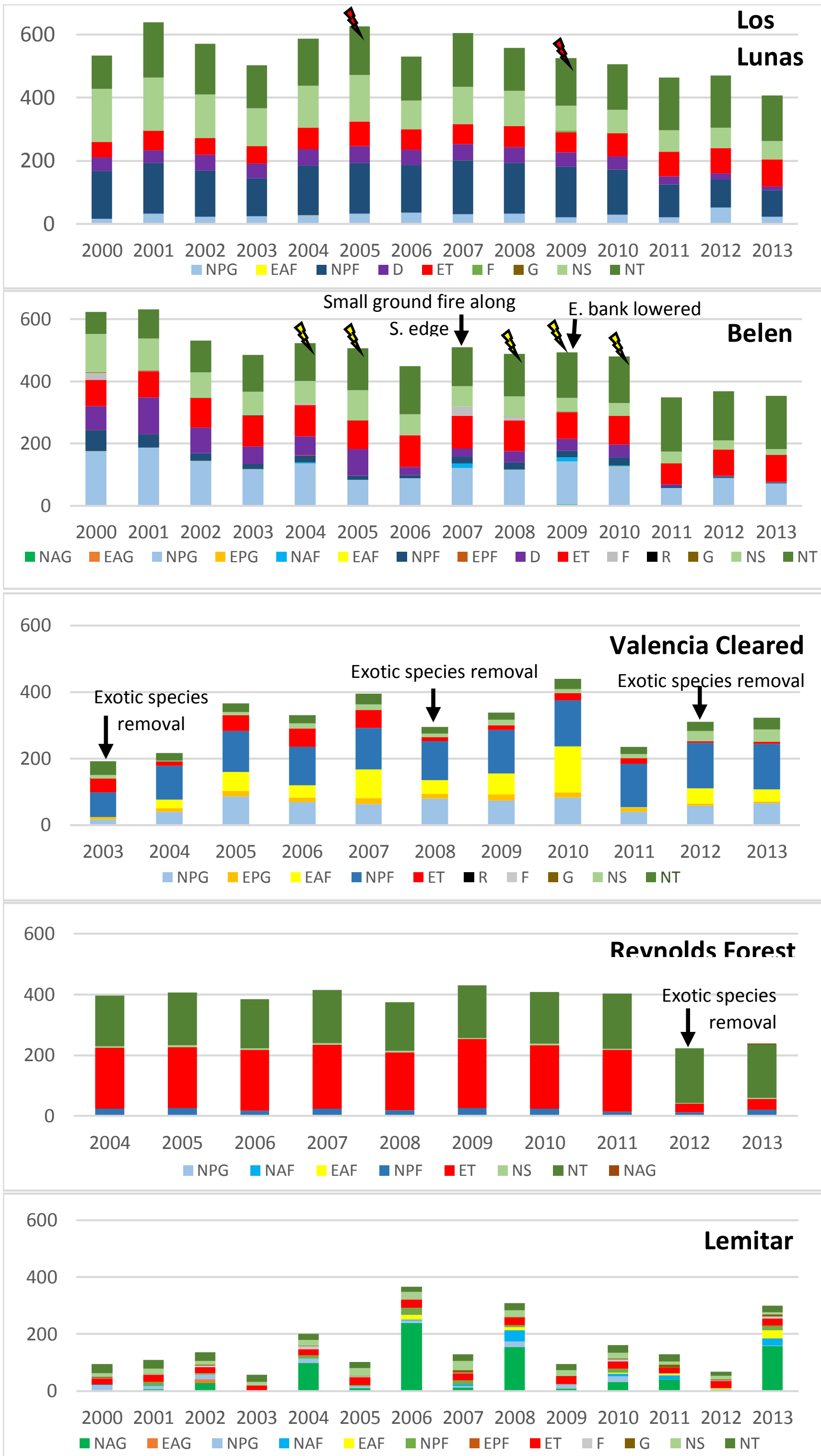
Figure 10: Total vegetation cover for intermittent and perennial reaches. The blue and brown highlighting shows periods of high and low river-flow.

Figure 11: Vegetation community composition for sites within perennial reach from north to south. Greens and blues indicate native vegetation, reds, oranges, and yellows indicate exotic vegetation. Note the greater amount of native woody species in this reach. ⚡: indicates overbank flooding events.



NAG = Native Annual Grass
EAG = Exotic Annual Grass
NPG = Native Perennial Grass
EPG = Exotic Perennial Grass
NAF = Native Annual Forb
EAF = Exotic Annual Forb
NPF = Native Perennial Forb
EPF = Exotic Perennial Forb
NS = Native Shrub
G = Grass (unknown origin)
F= Forb (unknown origin)
D = Sedge
R = Rush
L = Lichen
NT = Native Tree
ET = Exotic Tree

Figure 12: Vegetation community composition for sites within intermittent reach. Greens and blues indicate native vegetation, reds, oranges, and yellows indicate exotic vegetation. Note the greater amount of exotic plants within this reach. : Indicates seep flooding; : indicates overbank flooding.



NAG = Native Annual Grass
EAG = Exotic Annual Grass
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NPF = Native Perennial Forb
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NS = Native Shrub
G = Grass (unknown origin)
F= Forb (unknown origin)
D = Sedge
R = Rush
L = Lichen
NT = Native Tree
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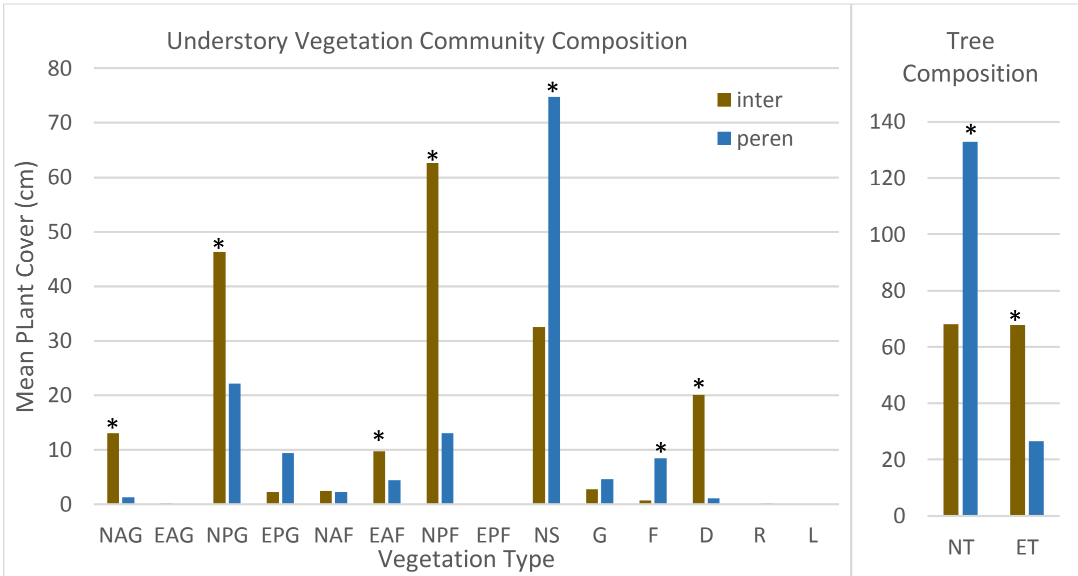
Figure 13: Vegetation community composition means by reach. * Denotes a significant difference.



NAG = Native Annual Grass / **EAG** = Exotic Annual Grass / **NPG** = Native Perennial Grass / **EPG** = Exotic Perennial Grass / **NAF** = Native Annual Forb / **EAF** = Exotic Annual Forb / **NPF** = Native Perennial Forb / **EPF** = Exotic Perennial Forb / **NS** = Native Shrub / **G** = Grass (unknown origin) / **F**= Forb (unknown origin) / **D** = Sedge / **R** = Rush / **L** = Lichen
NT = Native Tree / **ET** = Exotic Tree

Figure 14: Average arthropod abundance for intermittent and perennial reaches. Significant differences in abundance was exhibited in the intermittent reach between the following years: 1998 > 2004, 2004> 2002, 2003.

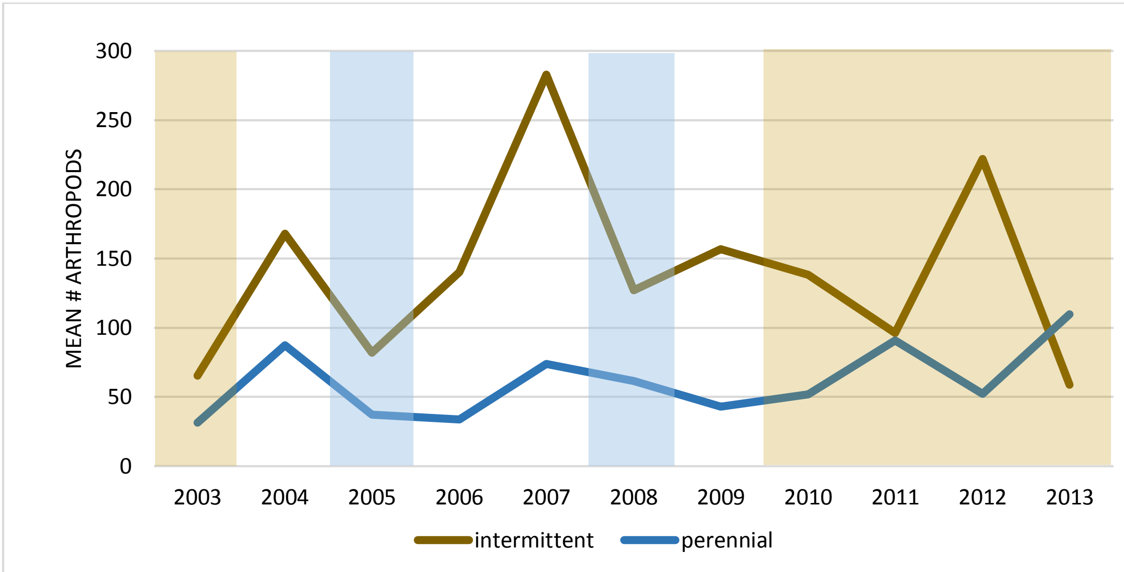


Figure 15: Average abundance of arthropods in indicator family groups: A) Carabidae, B) Tenebrionidae, and C) Isopoda by reach. Asterisk indicates year of significant difference.

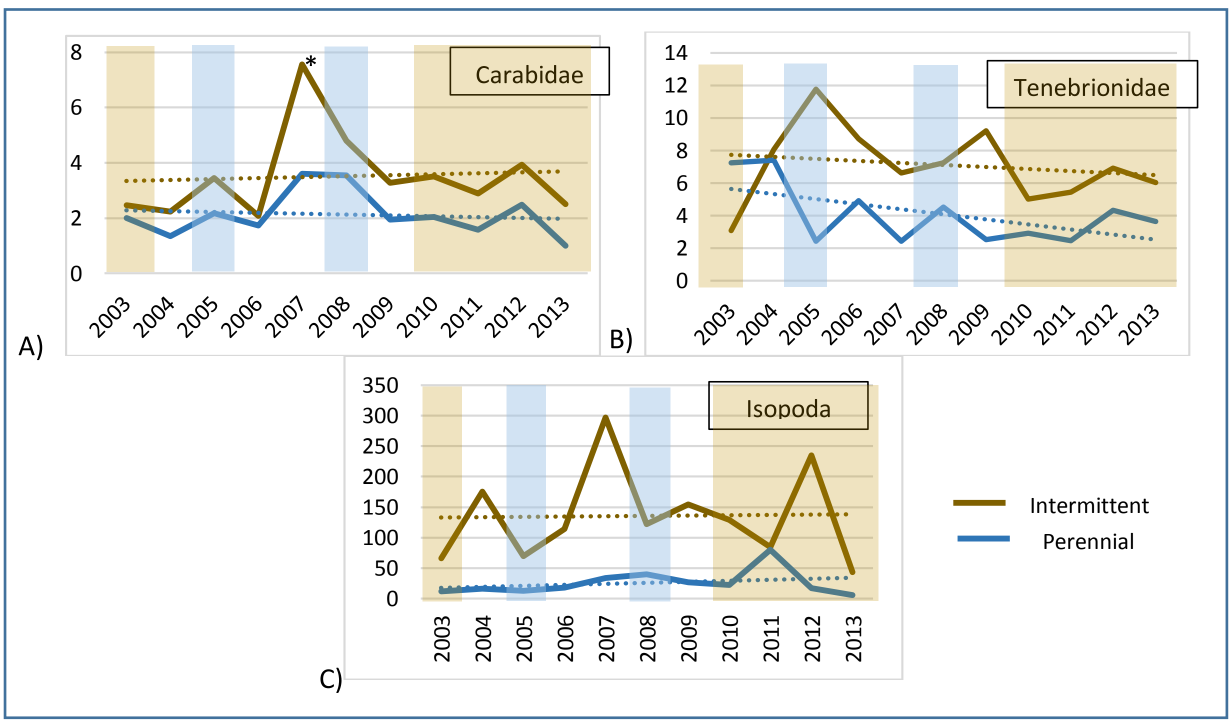
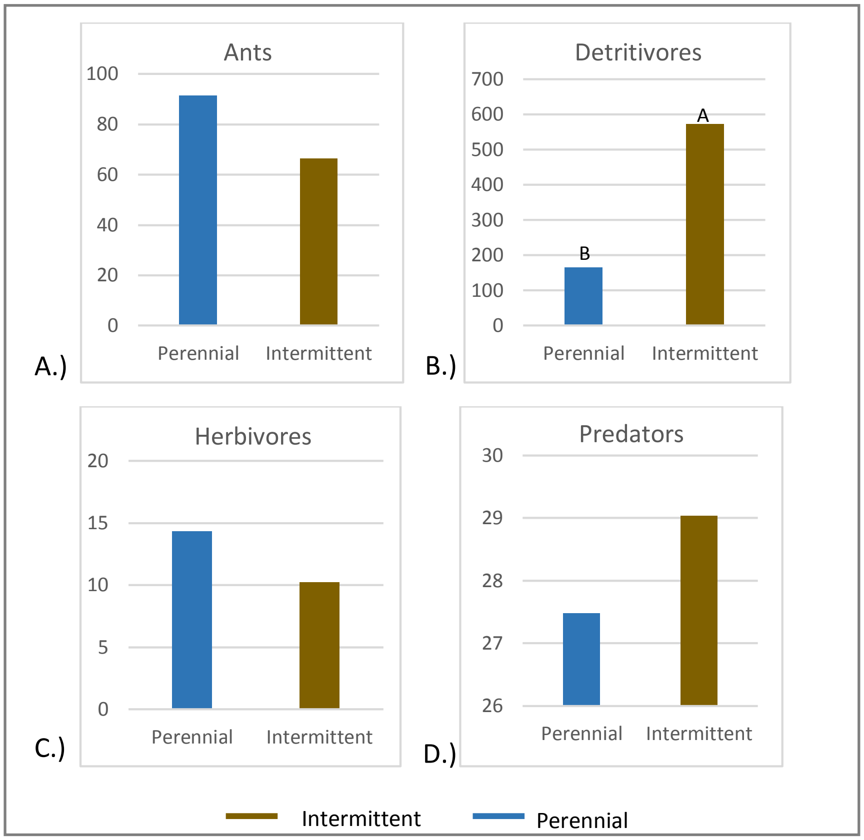


Figure 16: Functional groups of arthropods including A.) Ants; B.) Detritivores; C.) Herbivores; D.)Predators. Different Letters denote significant difference. Note the Y-axes use different scales.



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