2000-2011 Lower Mill River Invertebrate Monitoring Report

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Introduction

The invertebrate community in the Mill River downstream of Lake Whitney has been monitored from 2000 through 2011 in an effort to discern any impact from changing flow patterns that might be induced by the South Central Connecticut Regional Water Authority's (SCCRWA) withdrawal of water from Lake Whitney for public water supply. Water had been withdrawn several decades prior to the sampling period, but was discontinued when the associated treatment facility closed. Projected demand in comparison to available supply, particularly during major droughts, prompted design and construction of a new treatment plant and resumption of withdrawal from the Mill River at Lake Whitney. The new water treatment facility came on line in April of 2005, although it has rarely operated near capacity through 2011; withdrawals have averaged 1.4 to 31% of capacity on an annual basis, with peak monthly withdrawal at 85% of capacity. After 11 years of study, including five years of pre-operational data and five years of post-operational data, comparisons between pre-operation years and post-operation years were made in late 2009 and are the subject of a detailed report (AECOM 2010). While no substantial impacts were detected, it was decided to continue monitoring at that time.

Five stations were initially sampled. Stations 1, 2 and 3 (Figure 1) are near each other, and while not truly replicates, they offer similar habitat and represent a freshwater environment with flows from Lake Whitney as the dominant influence on habitat quality and quantity. Stations 4 (East Rock Park footbridge) and 5 (Orange Street bridge) are within the more strongly tidal zone, and have been subject to saltwater intrusion during high tides. Station 5 is routinely affected by saltwater, whereas Station 4 is less impacted by actual saltwater, but is hydrologically influenced by tidal effects. As the differences between stations became apparent and doing more at each station within the constraints of the budget was requested, Station 5 was dropped from the sampling routine in 2006. Consequently, there are very few post-operational data for Station 5 and it was not considered in the 2009 analysis. Additionally, Station 4 was considered separately from Stations 1-3 for most assessments, as the habitat is quite different (e.g., less riffle zone, more rooted plants, slower water velocity, tidal influence).

The examination of ten years of data (2000-2009) for the lower Mill River generated the following observations and conclusions:

1. In general, the macroinvertebrate assemblage observed in the Mill River since 2000 is indicative of intermediate stream community health. The taxa collected in the Mill River may be commonly found in a range of environments (e.g., worms, scuds, prosobranch snails, caddisflies, midgeflies). Most taxa found were typical of urban freshwater habitats, where water quality impacts are common. Midges (Diptera, Chironomidae) are common in a variety of freshwater habitats, but their dominance in a community is often regarded as a sign of degraded conditions. More detailed assessment of chironomid species in the Mill River supports this assessment.

2. Water quality indications of the biotic index are moderate overall, suggesting that water quality in the lower Mill River is suboptimal at all flow levels assessed. However, biotic index values declined with increasing average flow for the 10-week period preceding sampling at all stations, suggesting better water quality with higher flow (lower values for the index represent better water quality). While storm water runoff is a concern in the contributory watershed, water quality features of primary importance to invertebrates are apparently positively influenced by higher flows. This includes temperature and oxygen, and possibly pH, all of which can be altered by detention in upstream Lake Whitney. Note that a separate study indicates low dissolved oxygen at times in the vicinity of the footbridge (Station 4) downstream, but more invertebrate sampling effort is focused upstream of related influences.
3. Flow is a potentially important factor in shaping the invertebrate community of the lower Mill River, and some changes in the invertebrate community may be explained by key flow events, usually high and low extremes. However, invertebrate community features do not closely track any measure of flow gradient.
4. Abundance of the most common taxa observed does not appear to be related to flow. The most common taxa at Stations 1-3 for all years did not exhibit any discernible pattern of increase or decrease in abundance with increased flows. Invertebrate abundance at Stations 1-3 was highest under the lowest flow observed, but similar flow values did not necessarily result in high abundance of these species. At Station 4, the highest invertebrate abundances appear to occur under moderate flows, but increased abundances of some taxa have occurred under both lower and higher flows. Flow itself may be influential in setting habitat, affecting water quality, and washing invertebrates downstream, but is not the sole factor affecting abundance or composition of the invertebrate community, and may not be the primary factor.
5. There appears to be a pattern of alternating years of decreased and increased invertebrate abundance at station 1, with higher values in odd years. This instability has not been adequately explained by any factors we have examined. Increased abundance is usually linked to increases in just a few taxa, suggesting opportunistic activity when resources (space or food under favorable water quality) are available and substantial fluctuations in that availability.
6. No clear patterns are apparent in the analysis of feeding guilds versus flow. Increased flow did not result in increased presence of any one particular feeding group, although decreased flow may favor the scraper group. This is consistent with the ecology of that group, which scrapes attached algae and related organic matter off of rocks and other substrates. Such accumulations will be higher with low flows, while the quantity and quality of suspended particles may be reduced at low flows. However, there was not a clear increase in suspended particulate feeders at high flows, perhaps indicating a confining influence of flow (more specifically velocity) on abundance.
7. High values for any one feeding group are usually related to increased abundance of one or two taxa. Grouping the data as pre-operation and post-operation sets as relates to the water treatment facility does not suggest any patterns in feeding group abundance or

indicate any shifts between feeding groups as a result of the treatment facility operation. A range of flows have been experienced in pre-operation and post-operation years, and the abundance of any one feeding group for a particular range of flows is variable.

8. Lack of stability may be a function of varying flows, but the influence of the water treatment facility withdrawal is very minor in that regard. Wide fluctuations in river flow overshadow any influence of withdrawal for water supply.

As noted in the summary report for the 2000-2004 pre-operational monitoring program (ENSR 2005), changes in the invertebrate community over time may be a consequence of many environmental factors, including the desiccation of the stream during the dry summer months, changes in water quality, altered food abundance and quality, and predation effects. Flow is only one factor, and is likely to have more indirect effects at low levels. Variability in flow, inducing instability, may be a potent factor in structuring the benthic macroinvertebrate community of the lower Mill River, and is linked to water quality issues (including dilution of contaminants from upstream and salinity from downstream), altered physical habitat, and available food resources. Post-operational data support that conclusion and suggest no detectable influence by the water withdrawal since operation of the treatment facility commenced. The withdrawals have simply been too small relative to the other sources of flow fluctuation in the Mill River watershed.

Given the wide variability of river flows, it appears unlikely that operation of the treatment facility in accordance with the SCCRWA's Management Plan has significant potential to result in measurable changes to the invertebrate community. Although monitoring opportunities during extended dry, low flow periods with the treatment facility under full time operation have been limited, data collected during the summers of 2005 and 2007 are reasonably representative of seasonal low river flow during operating conditions.

Based on the results of monitoring for a decade, sampling at Station 4 (footbridge) was discontinued and spring sampling at Stations 1, 2 and 3 also ceased as of the end of 2009. Beginning in 2010, monitoring focuses on Stations 1-3 during August, with an emphasis on detecting any impacts of treatment facility operation during a period of typically lower river flows. These three stations are similar and best represent the impact of flow from Lake Whitney on the lower Mill River. This report takes advantage of data collected for Stations 1-3 over the last 12 years to continue to examine any trends and detect any flow impacts.

Methods

General methods were consistent with previous years, beginning in 2000. Samples were collected in August of 2010 and 2011, at the peak of the tidal outflow (low tide). Sampling locations (Figure 1) include only Stations 1, 2 and 3 from previous years. General habitat features were surveyed and metered water quality (temperature, oxygen, conductivity, turbidity and pH) was assessed to ensure no major changes from previous years, but these are not used in the main analysis of data, which focuses on possible relationships between invertebrates and flow.

Flow is estimated by the SCCRWA using automated lake level measurements at the Lake Whitney spillway. Flow values were recorded as daily means from SCCRWA flow records from the Whitney Dam. As flow on the day of the survey is not an indication of antecedent conditions, SCCRWA flow records were used to derive an average flow for ten weeks (2.5 months) prior to each sampling. Note that drawdown and use of the bypass system through most of the summer of 2004 precluded accurate measures of flow for that period, but flows were obtained for all other summers in the monitoring period. Flow actually ceased at Station 1, allowing use of data for that station during an extended period of essentially zero flow. Variation in flow from Lake Whitney is the dominant influence on water velocity at Stations 1 and 2. Water level changes may occur with tidal influences at Station 3, but saltwater does not intrude this far upstream.

Timed (two minutes) D-frame dip-net sampling was used to collect macroinvertebrates. This method is commonly used as a multi-habitat rapid bioassessment technique (Barbour et al. 1999). Riffle habitats were sampled at stations where riffle habitat is available. Macroinvertebrates were captured in the net by dislodging the substrate up to 1 ft (0.3 m) upstream of the dip-net. Two subsamples per sampling station were collected. Each subsample consisted of a two-minute collection, itself comprised of four 30-second collection efforts at four nearby locations within the site, all in riffle habitat. Subsamples were preserved in 70% ethanol for laboratory analysis. Macroinvertebrates were sorted, identified to the lowest practical taxonomic level, and counted. Primary references include Simpson and Bode (1980), Peckarsky et al. (1993), Merritt and Cummins (1996), and Epler (2001).

Prior to 2006, specimens of the family Chironomidae from the Insecta were taxonomically lumped as a group, as it requires additional effort to identify these to genus or further. Based on concern expressed by interested parties that a significant portion of the invertebrate community was not being adequately characterized, chironomids were identified to the lowest practical taxon beginning in 2006. This creates some limitations in comparison of pre- and post-operational data, but does provide a more complete record of the invertebrate community going forward. Chironomid identification was based on mounted specimens viewed under a transmitted light microscope whenever necessary to properly view identifying features.

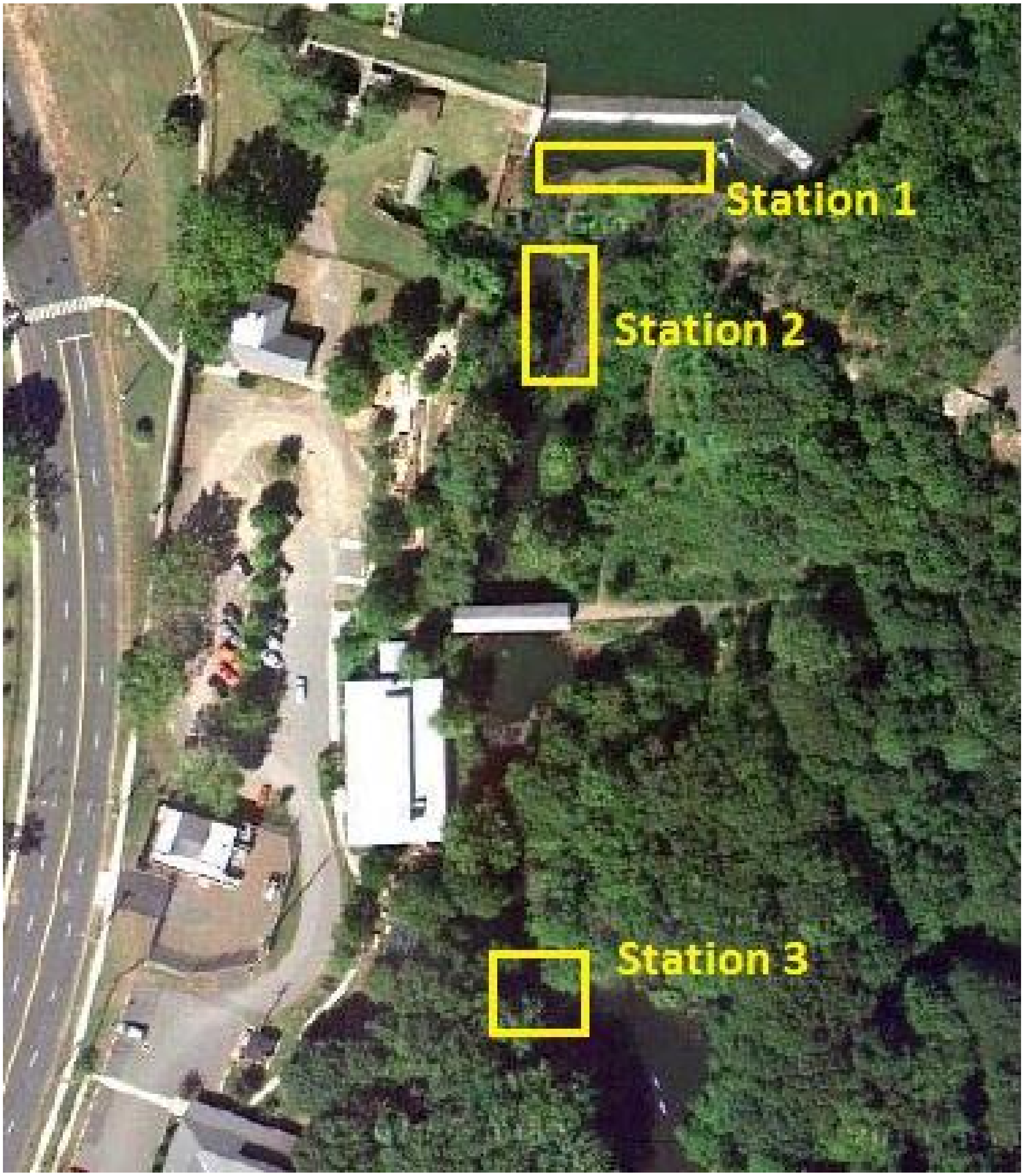


Figure 1. Mill River sampling stations

The two macroinvertebrate subsamples were analyzed separately, but combined into a single sample per station for data analysis. Variability among subsamples was evident, as is expected for such samples, but was not striking in most cases. For example, the subsamples for stations 1, 2 and 3 in 2010 had percent similarity index values of 81, 86 and 63%, respectively; for macroinvertebrate samples, these are very similar. Combining four subsamples for each of the two replicate samples and then pooling the replicate sample data helped minimize spatial variability, which can be naturally very high for macroinvertebrates. Variability not related to flow can obscure flow impacts, so such compositing of samples and results is desirable in this case.

Numerical analysis included relative abundance and dominance patterns for taxonomic and feeding groups, plus species richness and evenness. Species richness was expressed as number of separate, identified taxa. Species evenness quantifies the degree of dominance (or lack thereof) of taxa within a community; it measures the distribution of individuals among taxa present. It is calculated as the ratio of diversity to the maximum diversity achievable for the number of taxa present, and is therefore a number between 0 and 1. Diversity is calculated as the summation for all species of the fraction of the total number of invertebrates represented by each species times the natural logarithm of that fraction. When one or a few taxa dominate a community, diversity is low. The modified Hilsenhoff Biotic Index (HBI), based on a quality value of 0-10 assigned to each taxon multiplied by the abundance of each corresponding taxon and divided by the total number of individuals, was calculated for each station and date. The index was modified to include non-arthropod species (Mandeville 2002).

In response to requests from interested parties for extended data analysis, some additional comparisons have been added for this analysis. Concern was expressed that the 10-week pre-sampling period may not be the only influential flow period for the invertebrates, and also that aspects of that 10-week flow period other than average flow might be relevant. We have therefore added comparisons of all invertebrate measures and flow for the period 10-20 weeks prior to sampling, the lowest 7-day average flow in the 10-week pre-sampling period, the highest 7-day average flow in the 10-week pre-sampling period, and both the standard deviation and coefficient of variation for that 10-week pre-sampling period. The period 10-20 weeks before sampling represents most of the spring, the 7-day low and high flows represent the periods of greatest flow stress, and the standard deviation and coefficient of variation represent flow variability prior to sampling.

Results

The Mill River below the Lake Whitney dam contains a thriving and dynamic invertebrate community (Table 1) which has been assessed every August since 2000. A total of 80 taxa have been identified from three stations (65 with lumped chironomids), including twenty orders representing eight classes, with insects (Class Insecta) representing the most taxa and largest numbers of individuals. The invertebrate community of Mill River, as determined from all August samples from 2000 through 2011 at Stations 1-3, includes mainly caddisflies (Order Trichoptera, seven families), true flies (Order Diptera, six families), scud (Order Amphipoda, two families), flatworms (Order Tricladida, Dugesiidae), beetles (Order Coleoptera, four families) and snails (Order Gastropoda, five families). Most families are represented by multiple taxa, although a single taxon is often dominant within the family. Midgeflies were the taxonomically richest familly with 15 taxa identified from 2006 on, with up to nine taxa per station, although only five taxa were abundant over the monitoring period (based on total individuals counted).

The seven most abundant taxa (Table 2) include a caddisfly (*Macrostemum*, Hydropsychidae), midgeflies (Chironomidae, used collectively because identification beyond family was not performed prior to 2006), a scud (*Gammarus*, Gammaridae), a flatworm (*Dugesia*, Dugesiidae), a riffle beetle (*Stenelmis*, Elmidae), dance flies (Empididae, with *Hemerodromia* and unidentified empidids pooled), and a snail (*Amnicola*, Hydrobiidae). Together, these taxa comprise 93% of all individuals collected over 12 years, and their indications for feeding groups and water quality (biotic index) will strongly affect station values for related calculations. Note that three chironomids make up the bulk of the Chironomidae count, and would be among the top 10 most abundant taxa if not lumped with other chironomids.

This assessment focuses on possible flow impacts on the invertebrate community, facilitated by comparisons of various measurements of flow to quantifiable features of the macroinvertebrate community (Tables 3 and 4). In short, there are no comparisons that suggest that flow, as measured, is a dominant influence on the macroinvertebrate community features assessed. More specifically, comparisons of macroinvertebrate community features vs. the average flow for the 10 weeks prior to sampling (Figures 2-18) exhibit no statistically significant relationships and indicate no potential to explain the rather substantial variability in macroinvertebrate community features with any aspect of the flow regime for the 10 weeks prior to sampling.

Short bursts of very high flows may alter habitat or wash invertebrates downstream, despite an overall lower average flow for the ten weeks prior to sampling. Yet the habitat has not changed appreciably except possibly at station 1 (where additional substrate was added during a construction related drawdown). Additionally, the average flows seem representative of relative flow conditions for the period preceding sampling; there are no cases of flooding interrupting extreme low flow conditions for the period of record. Fluctuations have been observed in the amount and type of plant cover, of the buildup or loss of fine sediments, and of wetted channel

Table 1. Macroinvertebrate data for three stations in the lower Mill River, Connecticut, sampled from 2000 – 2011.

							1-Aug-00			21-Aug-01			19-Aug-02			26-Aug-03			2-Sep-04			23-Aug-05			1-Aug-06			17-Aug-07			17-Aug-08			20-Aug-09			23-Aug-10			23-Aug-11		
Class	Order	Family	Taxon	Feeding Group	Biotic Index Value	Total Indiv (all samples)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Annelida	Hirudinea	Glossiphoniidae	Glossiphonia complanata	Parasite	8	10	5	1	2		2																																	
Annelida	Hirudinea		Unidentified Hirudinea	Parasite	8	71													8			53	10																				
Annelida	Oligochaeta	Naididae	Nais communis	Collector	8	483																367	7	13	5			4			17	45	25									
Annelida	Oligochaeta	Tubificidae	Unidentified Tubificidae	Collector	10	20							20																													
Annelida	Oligochaeta		Unidentified Oligochaeta	Collector	5	31															7	20															4					
Annelida	Polychaeta	Ampheridiidae	Unidentified Ampheridiidae	Detritivore	6	4							4																													
Arachnida	Trombidiformes	Lebertiidae	Lebertia sp.	Predator	6	9												3						1			5															
Arachnoidea	Hydracarina	Arrenuridae	Unidentified Arrenuridae	Parasite	6	4								4																												
Crustacea	Amphipoda	Crangonyctidae	Crangonyx sp.	Shredder	6	197	86	19	18			2							5			67																				
Crustacea	Amphipoda	Gammaridae	Gammarus sp.	Shredder	6	10167	1212	2311	1904	36	540	212	116	92	16	434	103	287		20	27	247	137	264	241	117	316	80	117	54	108	82	242	22	23	24	128	8	340	76	152	80
Crustacea	Isopoda	Asellidae	Caecidotea communis	Collector	8	50										4		3	1						4	0	4		30												4	
Crustacea	Isopoda	Asellidae	Lirceus/Acellus sp. (communis)	Shredder	8	28	9	9	8		2																															
Hydrozoa	Hydroida	Hydridae	Hydra sp.	Predator	5	9		1			8																															
Insecta	Coleoptera	Elmidae	Stenelmis sp.	Scraper	5	1687										6	3	12		13	38	20	24	48	5	4	8	24	3	17	8	36	108			22	12	64	788	128	64	232
Insecta	Coleoptera	Hydrophilidae	Berosus sp.	Predator	5	69		5	7	2	2											20			1												4	4	16		4	4
Insecta	Coleoptera	Psephenidae	Unidentified Psephenidae	Predator	4	8								8																												
Insecta	Coleoptera		Unidentified Coleoptera	Predator	5	7										6		1																								
Insecta	Diptera	Ceratopognidae	Unidentified Ceratopognidae	Predator	6	2										1	1																									
Insecta	Diptera	Chironomidae	Chironominae																																							
Insecta	Diptera	Chironomidae	Chironomini																																							
Insecta	Diptera	Chironomidae	Chironomus riparius	Collector	10	16																			3									5	5	3						
Insecta	Diptera	Chironomidae	Dicrotendipes neomodestus	Collector	8	968																			36	114	22	48	17	9	31	2		10	55		75	35	423	17	37	37
Insecta	Diptera	Chironomidae	Glyptotendipes lobiferus	Shredder	10	246																			4	9	15	32	33			6		34	30	17	22		23	5	5	12
Insecta	Diptera	Chironomidae	Paratendipes albimanus	Collector	6	28																			8	11													9			
Insecta	Diptera	Chironomidae	Polypedilum flavum	Shredder	6	2365																			66	69	35	24	103	7		10	72	24		79	1031	316	326	35	75	92
Insecta	Diptera	Chironomidae	Polypedilum braseniae	Shredder	6	46																										2					38	6				
Insecta	Diptera	Chironomidae	Polypedilum sp.	Shredder	6	46																					1								45							
Insecta	Diptera	Chironomidae	Tanytarsini																																							
Insecta	Diptera	Chironomidae	Paratanytarsus sp.	Collector	6	85																					1											70	14			
Insecta	Diptera	Chironomidae	Rheotanytarsus exiguus group	Collector	6	37																				4	6		17						10							
Insecta	Diptera	Chironomidae	Orthocladiinae																																							
Insecta	Diptera	Chironomidae	Cardiocladius obscurus	Predator	5	75																						8	7	3	6			24	10	3				13		
Insecta	Diptera	Chironomidae	Cricotopus trifascia	Shredder	6	568																			13		44	40	47	13	28	10	17	24	45	89	57	12	10	61	37	22
Insecta	Diptera	Chironomidae	Cricotopus intersectus	Shredder	7	190																			5	9	18	4	13				22				49			70		
Insecta	Diptera	Chironomidae	Cricotopus sylvestris	Scraper	7	18																												5	5	3			4			
Insecta	Diptera	Chironomidae	Eukiefferiella tirolensis	Collector	4	295																									22	10	17	5			173	6	9	31	14	9
Insecta	Diptera	Chironomidae	Tanypodinae																																							
Insecta	Diptera	Chironomidae	Thienemannimyia group	Predator	6	113																												68		45						
Insecta	Diptera	Chironomidae	Unidenitifed Chironomidae	Collector	7	7279	50	336	206	394	188	78	1252	280	140	285	577	712	144	143	275	747	1087	385																		
Insecta	Diptera	Empididae	Hemerodromia sp.	Predator	6	283	8	98	23	42	40		48	20	4																											
Insecta	Diptera	Empididae	Unidentified Empididae	Predator	6	1025										1	67	33	1	20	24	533	227			49	42			1				9	10	8						
Insecta	Diptera	Simuliidae	Simulium sp.	Filterer	5	382	5	6		37	30					42	31		1	50	3	33			44	37					8	18		9	8	12	8					
Insecta	Diptera	Tipulidae	Unidentified Tipulidae	Shredder	4	451																287	7	1	4	17	4					9		2	15	18		4		24	44	16
Insecta	Diptera		Unidentified Diptera	Collector		515										45	45	29	2	37	30	40	80	4	22	51	30	28	13	6	17	36										

Table 1. continued. Mill River macroinvertebrate data.

							1-Aug-00			21-Aug-01			19-Aug-02			26-Aug-03			2-Sep-04			23-Aug-05			1-Aug-06			17-Aug-07			17-Aug-08			20-Aug-09			23-Aug-10			23-Aug-11		
Class	Order	Family	Taxon	Feeding Group	Biotic Index Value	Total Indiv (all samples)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Insecta	Ephemeroptera	Baetidae	Baetis sp.	Collector	6	15																															5	6		4				
Insecta	Ephemeroptera	Caenidae	Brachycercus sp.	Collector	3	302																		1									9							204		8	80
Insecta	Ephemeroptera	Caenidae	Caenis sp.	Collector	6	5	1	2	2																																		
Insecta	Ephemeroptera	Heptageniidae	Stenonema sp.	Scraper	3	5												1																			4						
Insecta	Ephemeroptera	Oligoneuridae	Isonychia sp.	Collector	2	1		1																																			
Insecta	Hemiptera	Gerridae	Rheumatobates sp.	Predator	5	3																								3													
Insecta	Hemiptera	Gerridae	Unidentified Gerridae	Predator	5	1												1																									
Insecta	Hemiptera	Mesoveliidae	Mesovelia sp.	Predator	5	3												3																									
Insecta	Hemiptera	Veliidae	Microvelia sp.	Predator	5	1																								1													
Insecta	Hemiptera		Unidentified Hemiptera	Predator	5	2										2																											
Insecta	Neuroptera	Sisyridae	Sisyira sp.	Predator	5	1	1																																				
Insecta	Odonata	Coenagrionidae	Ischnura/Enallagma sp.	Predator	8.5	69		1						68																													
Insecta	Odonata	Coenagrionidae	Argia sp.	Predator	6	8																												8									
Insecta	Plecoptera	Perlidae	Perlidae sp.	Predator	1	52																									17	18	17										
Insecta	Trichoptera	Brachycentridae	Brachycentrus sp.	Filterer	1	70					1	1	64		4																												
Insecta	Trichoptera	Hydropsychidae	Macrostemum sp.	Filterer	3	28142	1	8	8	264	303	1				743	434	311	3	307	152	7707	2376	24	416	468	401	76	740	87		9		318	660	286	3888	2200	1360	2516	1092	984
Insecta	Trichoptera	Hydropsychidae	Hydropsyche sp.	Filterer	4	287				2			228	40															17														
Insecta	Trichoptera	Hydropsychidae	Parapsyche sp.	Filterer	0	10	9		1																																		
Insecta	Trichoptera	Hydroptilidae	Agraylea sp.	Collector	8	123										1	1	21				20	10	1		1	22							11	15	8	4				4	4
Insecta	Trichoptera	Hydroptilidae	Oxyethira sp.	Predator	3	9		3		6																																	
Insecta	Trichoptera	Leptoceridae	Ceraclea sp.	Collector	3	129	12	36	35	8	12	11						3																				4			4	4
Insecta	Trichoptera	Leptoceridae	Mystacides sp.	Collector	4	13			1			12																															
Insecta	Trichoptera	Leptoceridae	Triaenodes sp.	Shredder	6	1			1																																		
Insecta	Trichoptera	Limnephilidae	Rossiana sp.	Scraper	5	12					10	2																															
Insecta	Trichoptera	Limnephilidae	Unidentified Limnephilidae	Shredder	5	10						10																															
Insecta	Trichoptera	Philopotamidae	Chimarra sp.	Filterer	4	17											13	1																	3								
Insecta	Trichoptera	Uenoidae	Neophylax sp.	Shredder	3	85																									17		42	2					24			
Insecta	Trichoptera		Trichoptera pupae	Inactive	NA	32																															32					
Mollusca	Bivalvia	Sphaeriidae	Pisidium sp.	Filterer	6	104																																	28	12	36	28
Mollusca	Bivalvia	Sphaeriidae	Unidentified Sphaeriidae	Filterer	6	23		1	4		2		4		12																											
Mollusca	Gastropoda	Ancylidae	Ferrissia rivularis	Scraper	6	11		3	5			3																															
Mollusca	Gastropoda	Hydrobiidae	Amnicola limosa	Scraper	5	686				36	62	201	44	40	200			9			3	33					10	8		3			17						16			4
Mollusca	Gastropoda	Physidae	Physa sp.	Scraper	8	143	11	25	4		43			8		19				7								8								2	4	4		4	4	
Mollusca	Gastropoda	Planorbidae	Gyraulus parvus	Scraper	8	379	22	147	117	4	26	19	4	8	12																											20
Mollusca	Gastropoda	Planorbidae	Helisoma sp.	Scraper	6	36										4			2				10														12	8				
Mollusca	Gastropoda	Planorbidae	Gyraulus deflectus	Scraper	8	7		3																				4														
Mollusca	Gastropoda	Planorbidae	Gyraulus circumstriatus	Scraper	8	24			6	2																													16			
Mollusca	Gastropoda	Valvatidae	Valvata tricarinata	Scraper	8	1					1																															
Mollusca	Gastropoda		Unidentified Gastropoda	Scraper	7	8																									8											
Nemertea	Nemertea		Unidentified Nemertea	Predator	8	46										4	1		3			33													5							
Turbellaria	Tricladida	Dugesiidae	Dugesia sp.	Predator	4	4251	325	309	16	50	33	28				9			22	567	32	233	20	7		1								22	3	2	128	660	272	564	696	252
			Total Individuals			63012	1757	3325	2368	883	1305	580	1784	568	388	1606	1276	1430	192	1164	590	10460	3995	749	877	960	982	388	1157	204	288	300	587	596	950	632	5668	3404	3884	3556	2280	1880
			Total Taxa with Chironomid taxa			80	15	21	19	13	18	13	10	10	7	16	11	16	11	9	10	17	12	11	16	16	18	14	13	12	12	15	11	17	18	18	18	16	18	14	17	17
			Total Taxa with lumped Chironomids			65	15	21	19	13	18	13	10	10	7	16	11	16	11	9	10	17	12	11	10	11	11	9	7	9	9	10	8	9	11	12	12	11	11	8	13	13

Table 2. Total individuals for the seven most abundant taxa identified from lower Mill River samples, 2000 – 2011.

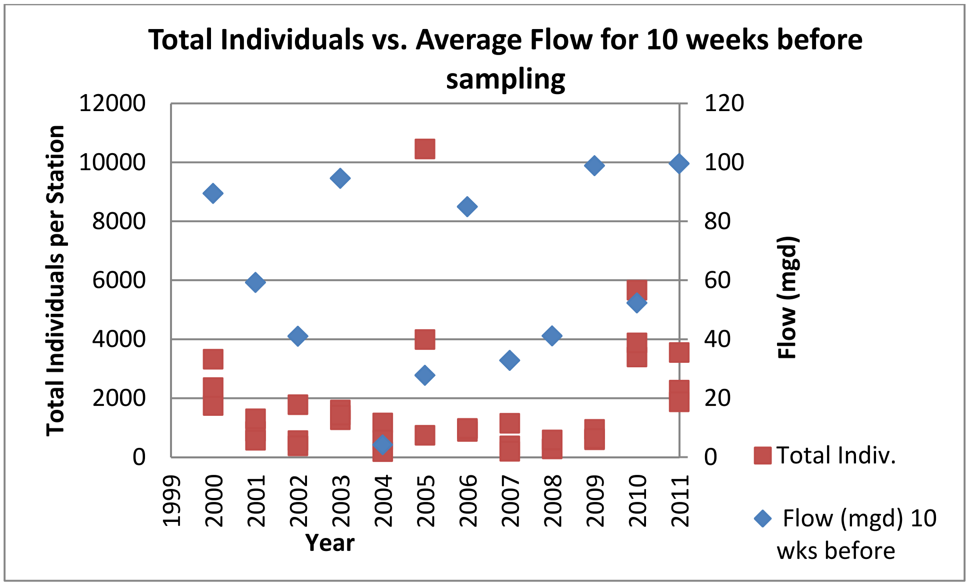
Class	Order	Family	Taxon	Feeding Group	Biotic Index Value	Total Indiv. for all samples	8/1/00	8/21/01	8/19/02	8/26/03	9/2/04	8/23/05	8/1/06	8/17/07	8/17/08	8/20/09	8/23/10	8/23/11
Insecta	Trichoptera	Hydropsychidae	Macrostemum sp.	Filterer	3	28142	17	568	0	1488	462	10107	1284	903	9	1264	7448	4592
Insecta	Diptera	Chironomidae	Chironomidae	Collector	7	12374	592	660	1672	1574	562	2219	492	424	254	645	2708	572
Crustacea	Amphipoda	Gammaridae	Gammarus sp.	Shredder	6	10167	5427	788	224	824	47	648	674	251	432	69	476	308
Turbellaria	Tricladida	Dugesiidae	Dugesia sp.	Predator	4	4251	650	111	0	9	621	260	1	0	0	27	1060	1512
Insecta	Coleoptera	Elmidae	Stenelmis sp.	Scraper	5	1687	0	0	0	21	51	92	17	44	152	22	864	424
Insecta	Diptera	Empididae	Empididae	Predator	6	1308	129	82	72	101	45	760	91	1	0	27	0	0
Mollusca	Gastropoda	Hydrobiidae	Amnicola limosa	Scraper	5	686	0	299	284	9	3	33	10	11	17	0	16	4

Table 3. Flow measures applied to relationships with macroinvertebrate community features, 2000 – 2011.

	Value for Corresponding Period in Each Year of Study											
Flow Measure	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
10 wk avg	89.5	59.3	41.0	94.6	4.2	27.8	85.0	32.9	41.2	98.9	52.3	99.6
10-20 wk avg	116.9	115.4	88.0	142.8	80.3	86.2	118.2	152.1	88.2	101.3	93.3	136.1
7-day low 10 wks	33.6	24.2	23.9	55.3	0.0	8.3	29.2	19.9	20.3	58.9	28.7	42.2
7-day high 10 wks	213.9	176.8	98.4	232.5	29.3	66.2	163.4	57.7	68.8	194.9	80.4	191.3
Std Dev 10 wks	66.4	54.1	16.5	50.5	10.6	25.2	51.9	14.3	18.9	54.7	28.0	66.8
Coeff. Var. 10 wks	0.742	0.912	0.402	0.534	2.530	0.906	0.611	0.435	0.459	0.553	0.535	0.671

Table 4. Macroinvertebrate community features for use in comparisons.

Year	Station	Total Indiv.	Total Taxa	Even-ness	Biotic Index	% Filterer	% Shredder	% Collector	% Scraper	% Predator	% Other	Macrostemum	Chironomidae	Gammarus	Dugesia	Stenelmis	Empididae	Amnicola
	1	1757	15	0.39	5.7	0.9	74.4	3.6	1.9	19.0	0.3							
2000	2	3325	21	0.38	6.0	0.5	70.3	11.3	5.4	12.5	0.0	17	592	5427	650	0	129	0
	3	2368	19	0.29	6.1	0.5	81.5	10.3	5.6	1.9	0.1							
	1	883	13	0.61	5.3	34.3	4.1	45.5	4.8	11.3	0.0							
2001	2	1305	18	0.61	5.4	25.7	41.5	15.3	10.9	6.4	0.2	568	660	788	111	0	82	299
	3	580	13	0.61	5.6	0.3	38.6	17.4	38.8	4.8	0.0							
	1	1784	10	0.47	6.3	16.6	6.5	71.3	2.7	2.7	0.2							
2002	2	568	10	0.70	6.6	7.0	16.2	49.3	9.9	16.9	0.7	0	1672	224	0	0	72	284
	3	388	7	0.59	5.9	4.1	4.1	36.1	54.6	1.0	0.0							
	1	1606	16	0.51	4.6	48.9	27.0	20.9	1.8	1.4	0.0							
2003	2	1276	11	0.57	5.2	37.5	8.1	48.8	0.2	5.4	0.0	1488	1574	824	9	21	101	9
	3	1430	16	0.50	5.7	21.8	20.1	53.7	1.5	2.9	0.0							
	1	192	11	0.42	6.5	2.0	2.8	76.6	1.2	13.6	3.9							
2004	2	1164	9	0.65	4.1	30.7	1.7	15.5	1.7	50.4	0.0	462	562	47	621	51	45	3
	3	590	10	0.68	5.2	26.4	4.5	52.8	6.9	9.4	0.0							
	1	10460	17	0.40	3.8	74.0	5.7	11.4	0.5	7.8	0.5							
2005	2	3995	12	0.46	4.4	59.5	3.6	29.6	0.9	6.2	0.3	10107	2219	648	260	92	760	33
	3	749	11	0.49	6.3	3.2	35.4	53.9	6.4	1.1	0.0							
	1	877	10	0.57	4.5	52.5	38.0	8.8	0.6	0.1	0.0							
2006	2	960	11	0.65	4.4	52.5	22.9	19.0	0.4	5.2	0.0	1284	492	674	1	17	91	10
	3	982	11	0.60	4.7	40.8	44.0	8.6	1.9	4.7	0.0							
	1	388	9	0.86	5.5	19.6	46.4	20.6	11.3	2.1	0.0							
2007	2	1157	7	0.54	4.2	65.4	27.1	6.6	0.3	0.6	0.0	903	424	251	0	44	1	11
	3	204	9	0.68	4.5	42.7	36.4	7.0	9.8	4.2	0.0							
	1	288	9	0.84	5.3	2.8	53.2	30.4	5.6	8.1	0.0							
2008	2	300	10	0.84	4.9	9.0	39.2	33.8	12.0	6.0	0.0	9	254	432	0	152	0	17
	3	587	8	0.77	5.5	0.0	67.3	7.1	21.3	4.3	0.0							
	1	596	9	0.64	4.6	54.9	18.4	5.1	0.8	20.8	0.0							
2009	2	950	11	0.47	4.2	70.5	16.6	9.5	0.5	2.9	0.0	1264	645	69	27	22	27	0
	3	632	12	0.66	4.7	47.2	35.9	2.8	5.0	9.2	0.0							
	1	5668	12	0.39	3.9	68.7	23.4	4.5	0.5	2.3	0.6							
2010	2	3404	11	0.41	3.7	64.6	10.2	3.5	2.2	19.5	0.0	7448	2708	476	1060	864	0	16
	3	3884	11	0.67	4.7	35.7	18.6	17.0	21.2	7.4	0.0							
	1	3556	8	0.41	3.5	72.6	7.8	1.4	3.8	16.6	0.0							
2011	2	2280	13	0.53	3.9	53.0	14.7	3.3	3.2	32.9	0.0	4592	572	308	1512	424	0	4
	3	1880	13	0.59	4.0	56.2	12.3	7.4	14.2	14.2	0.0							
Mean		1676	12	0.57	5.1	30.9	28.6	24.5	7.5	8.2	0.2	2141	1073	896	249	115	119	62



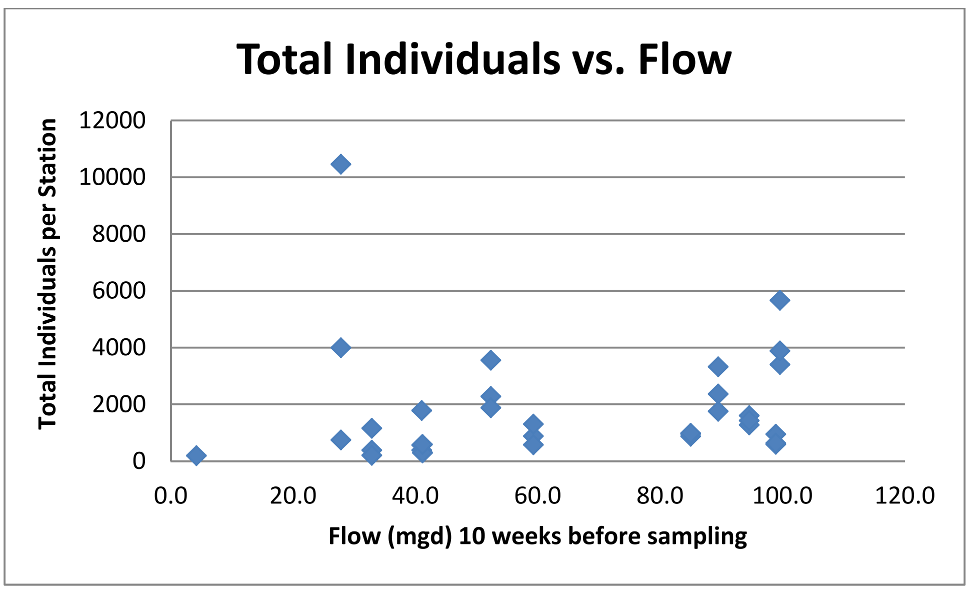
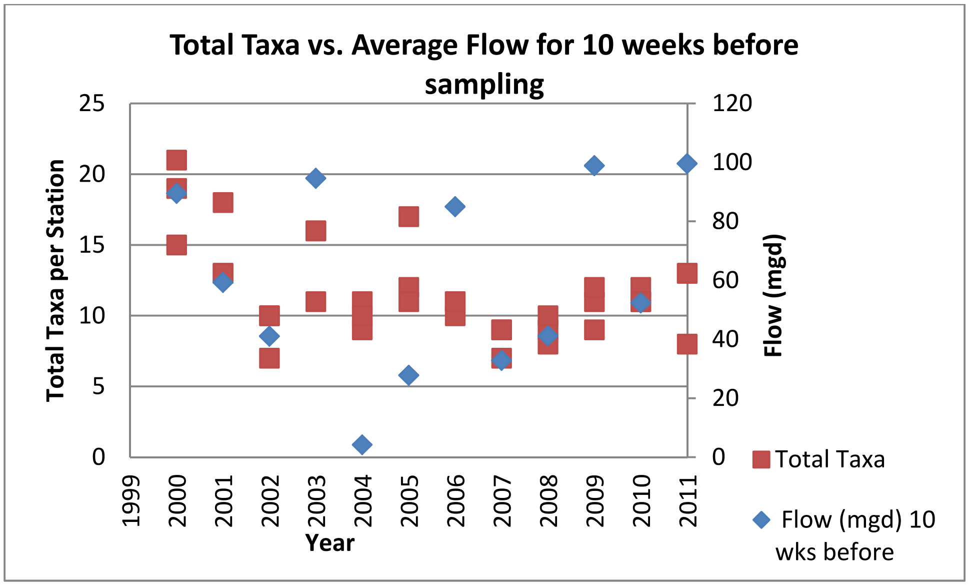


Figure 2. Total individual macroinvertebrates per station at average flow for 10 weeks prior to sampling for each of 12 years.



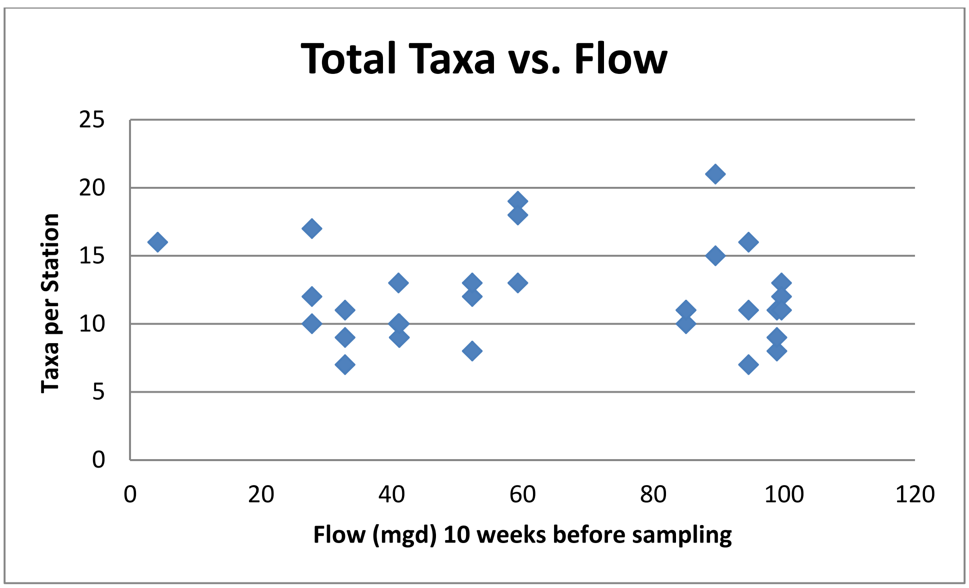
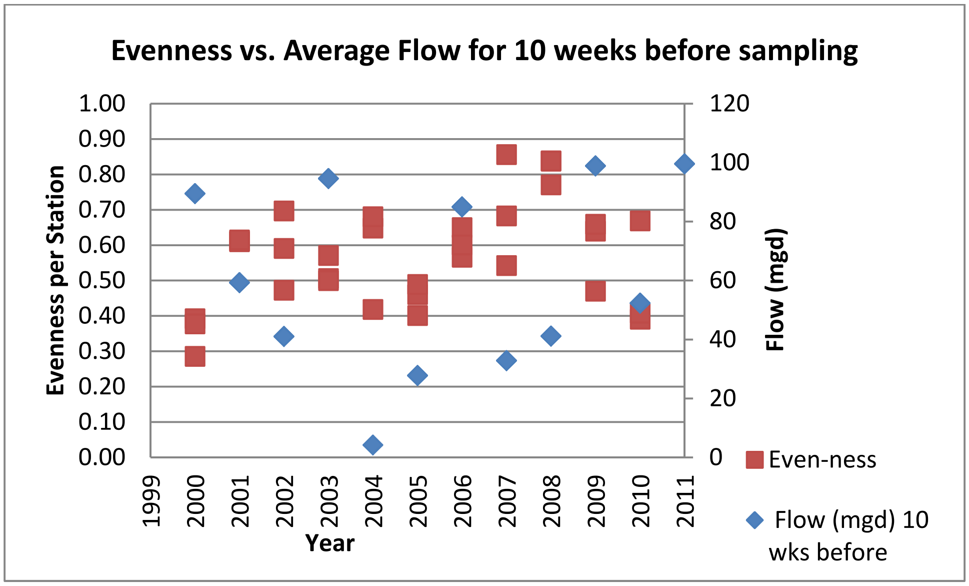


Figure 3. Total macroinvertebrate taxa per station at average flow for 10 weeks prior to sampling for each of 12 years.



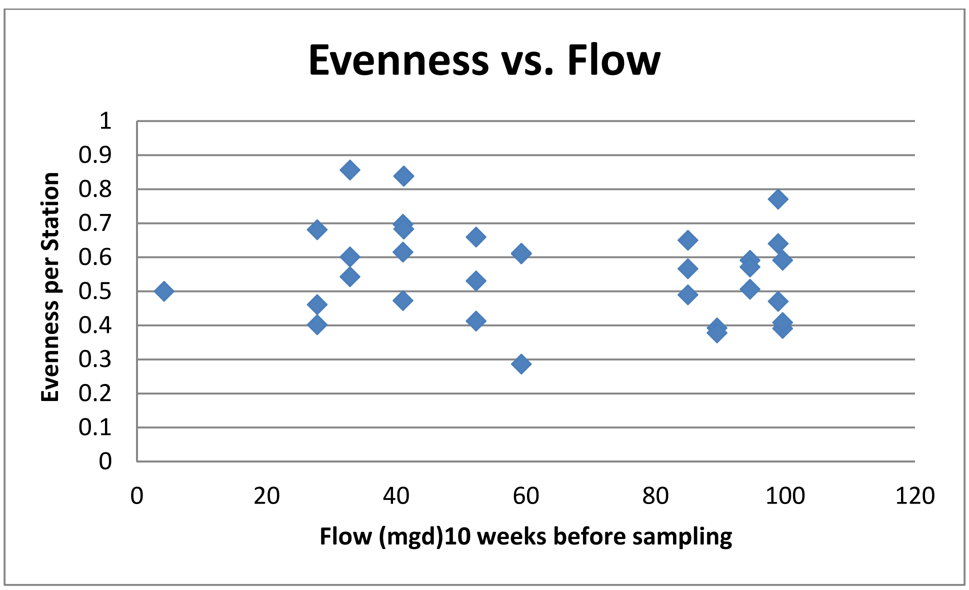
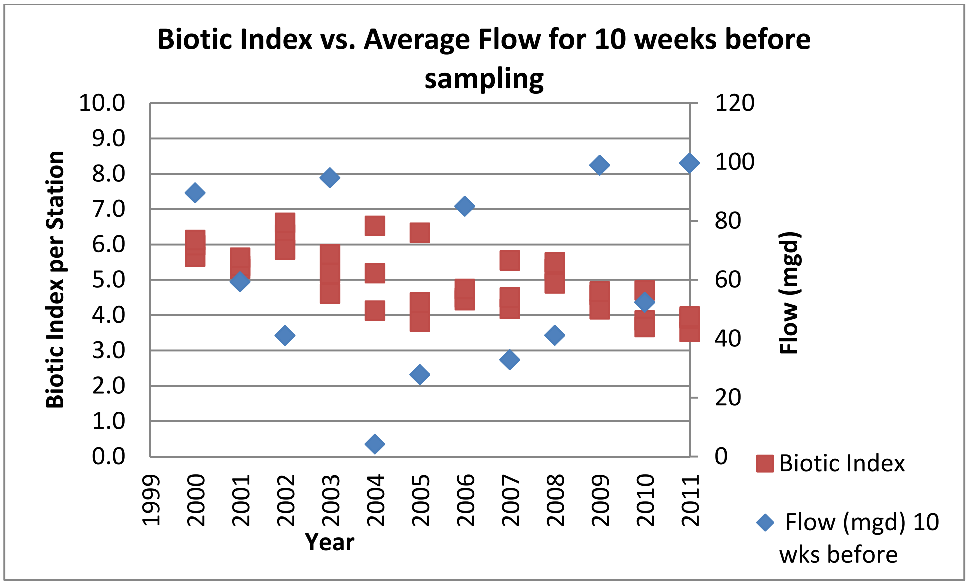


Figure 4. Evenness of macroinvertebrates per station at average flow for 10 weeks prior to sampling for each of 12 years.



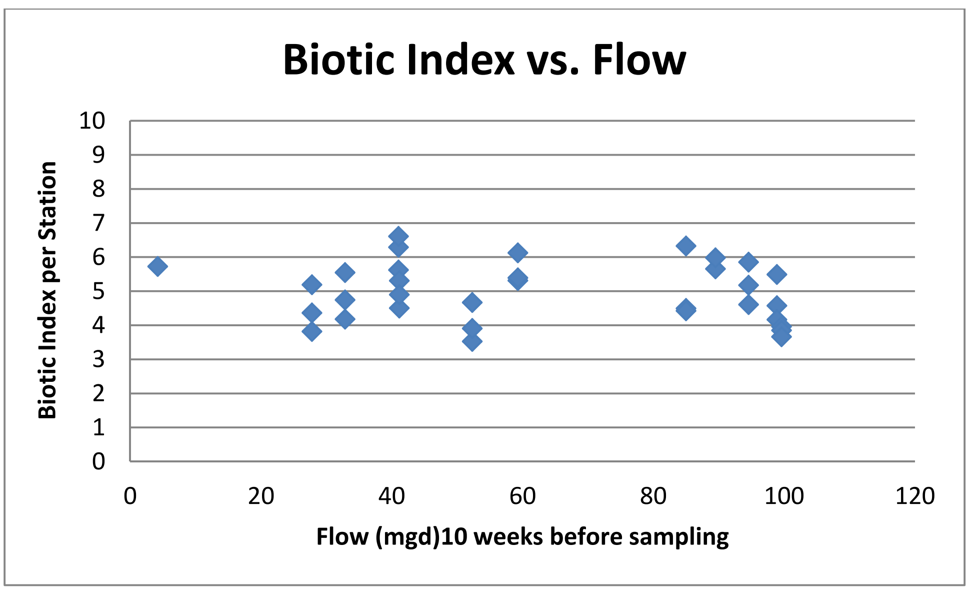
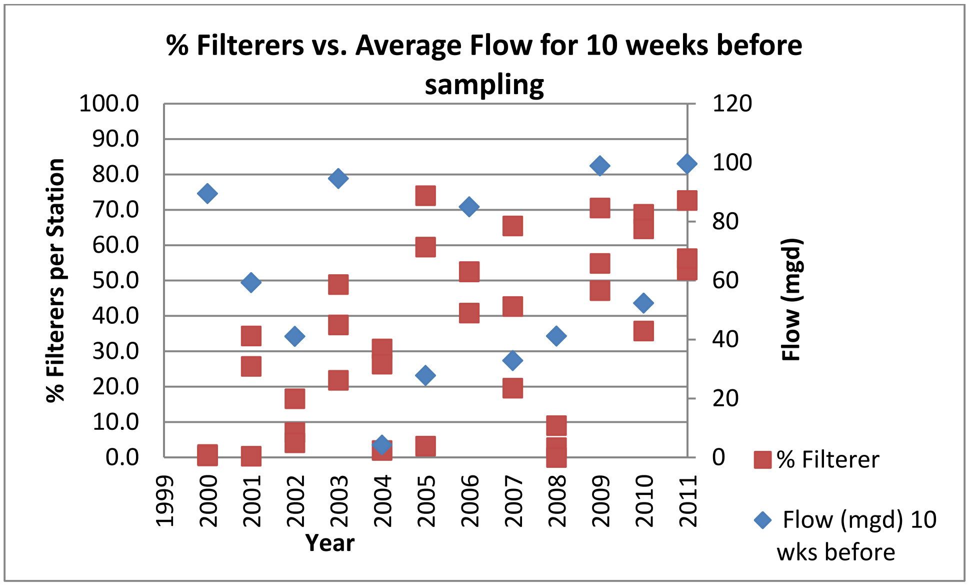


Figure 5. Biotic index for macroinvertebrates per station at average flow for 10 weeks prior to sampling for each of 12 years.



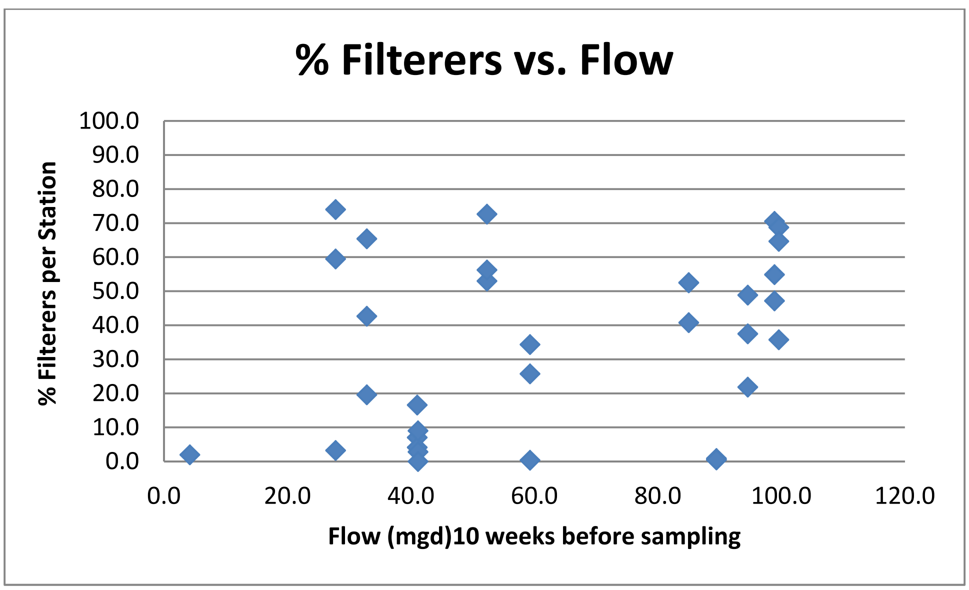
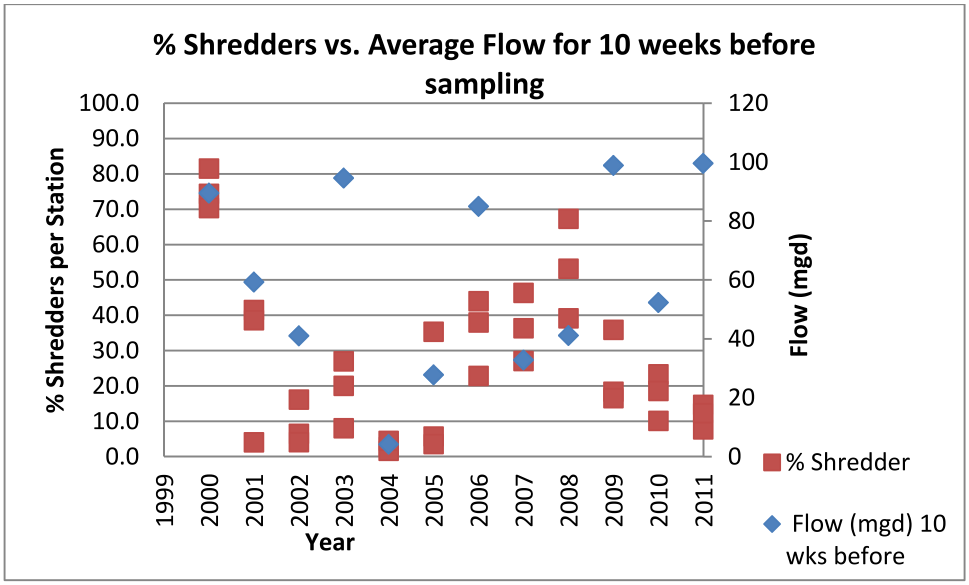


Figure 6. Percent filtering macroinvertebrates per station at average flow for 10 weeks prior to sampling for each of 12 years.



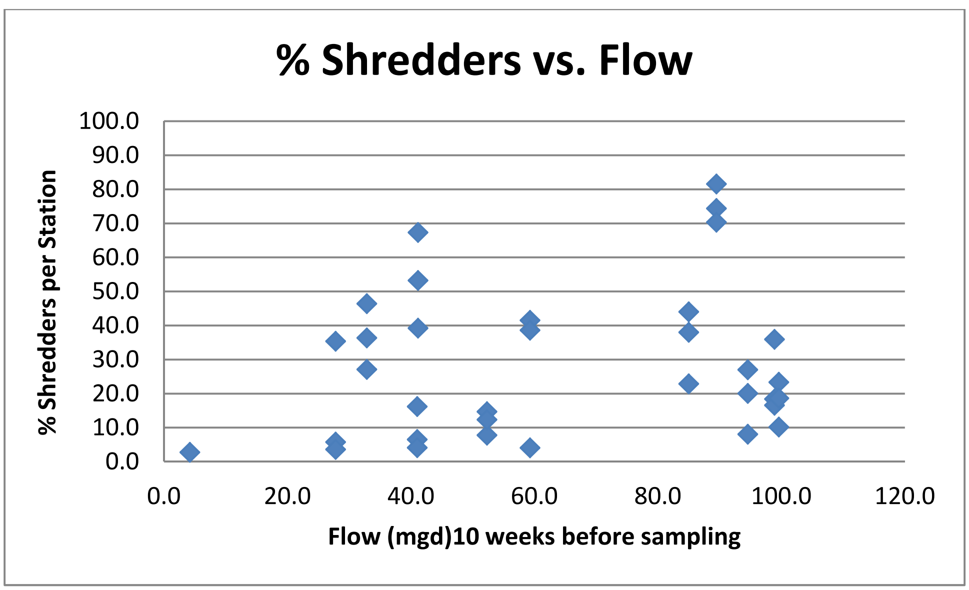
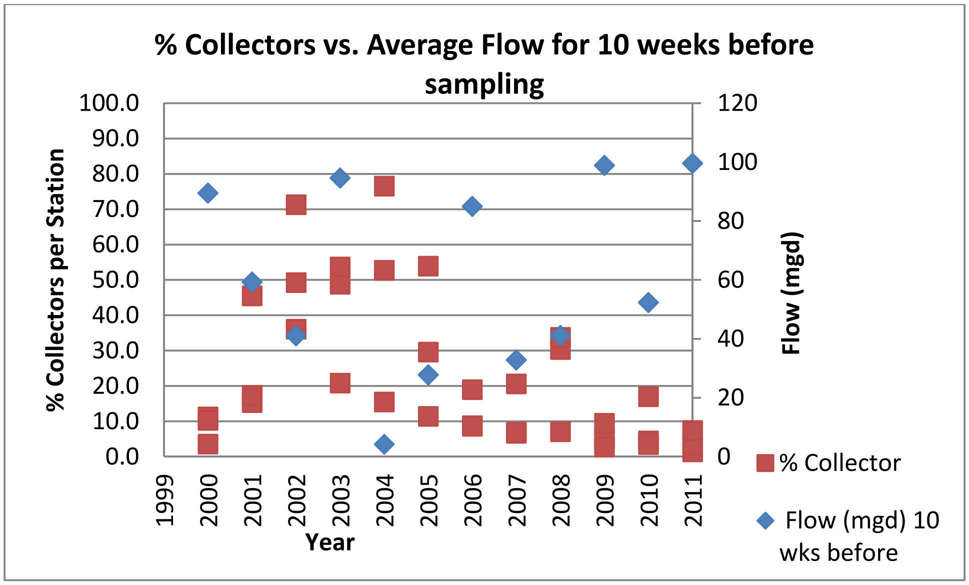


Figure 7. Percent shredding macroinvertebrates per station at average flow for 10 weeks prior to sampling for each of 12 years.



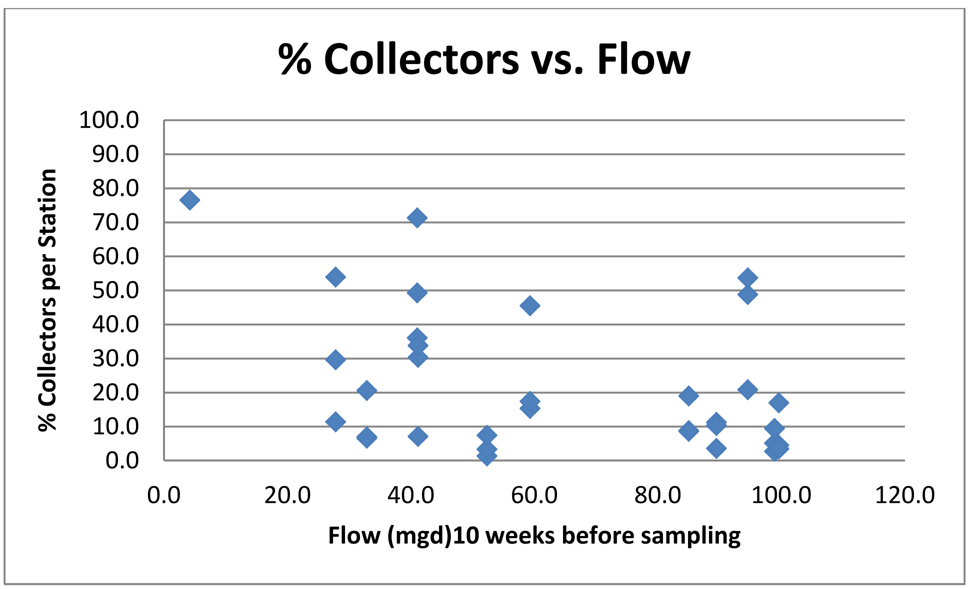
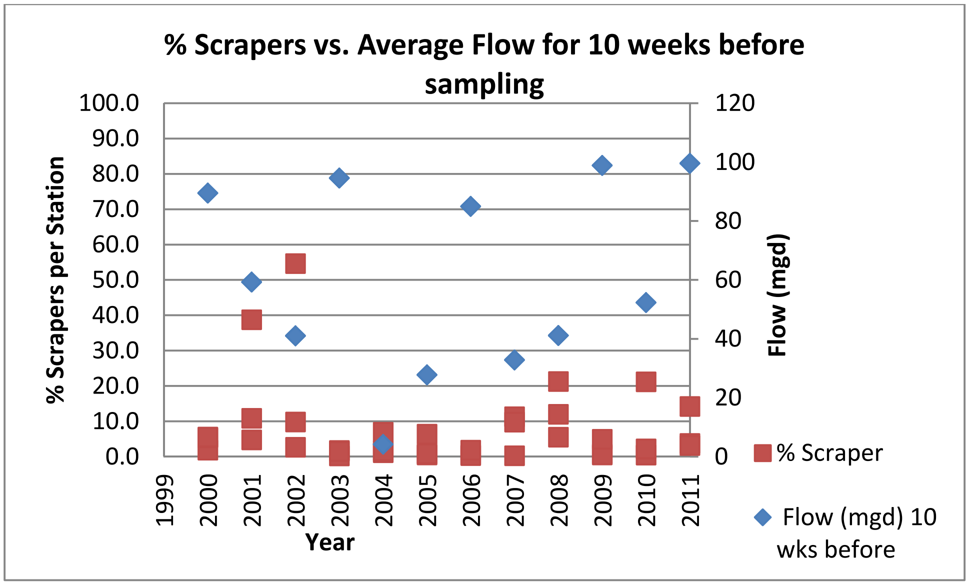


Figure 8. Percent collecting macroinvertebrates per station at average flow for 10 weeks prior to sampling for each of 12 years.



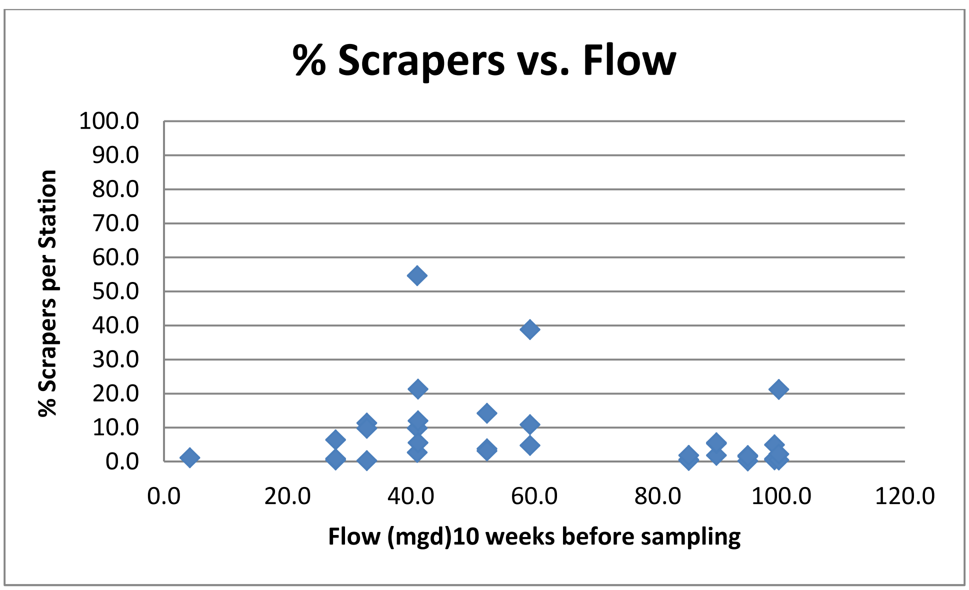
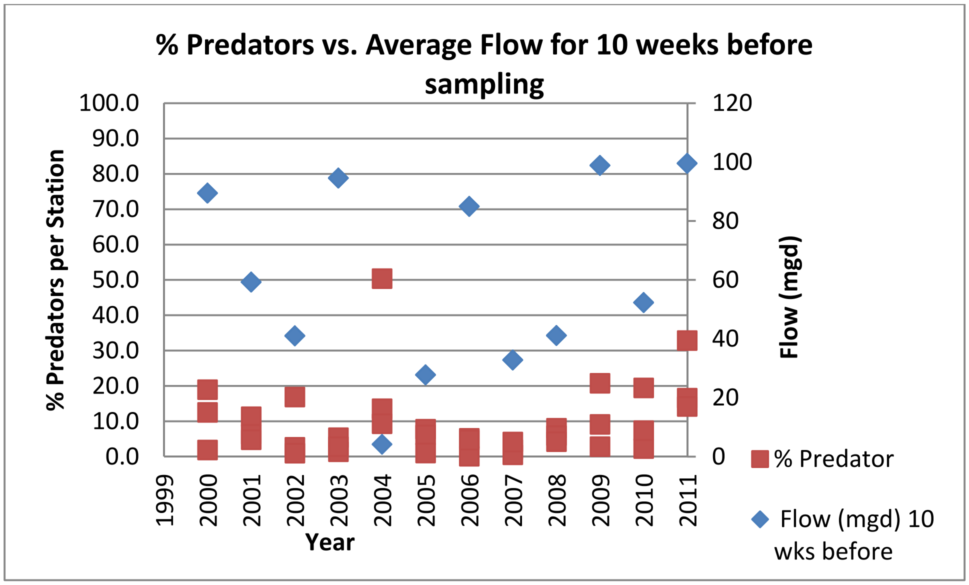


Figure 9. Percent scraping macroinvertebrates per station at average flow for 10 weeks prior to sampling for each of 12 years.



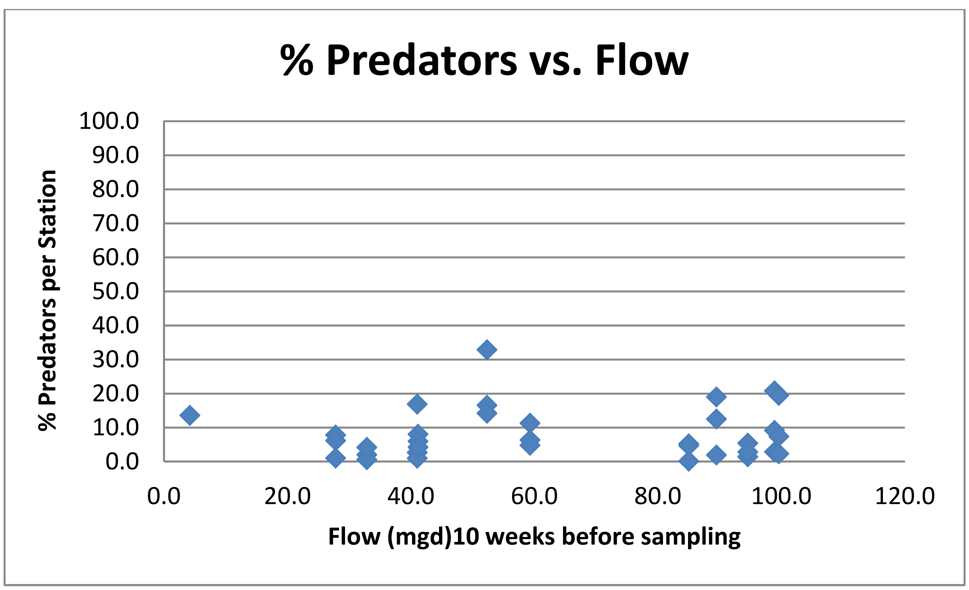
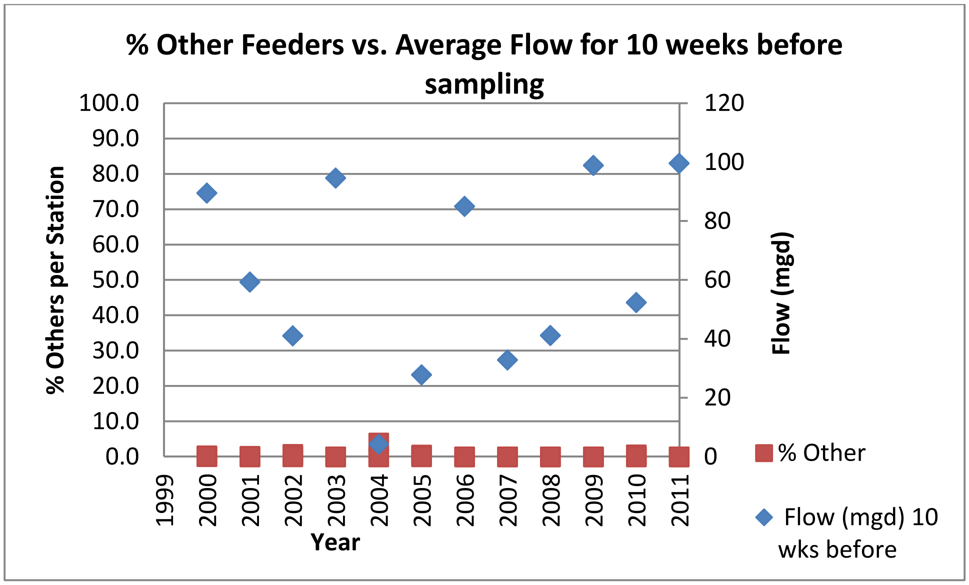


Figure 10. Percent predator macroinvertebrates per station at average flow for 10 weeks prior to sampling for each of 12 years.



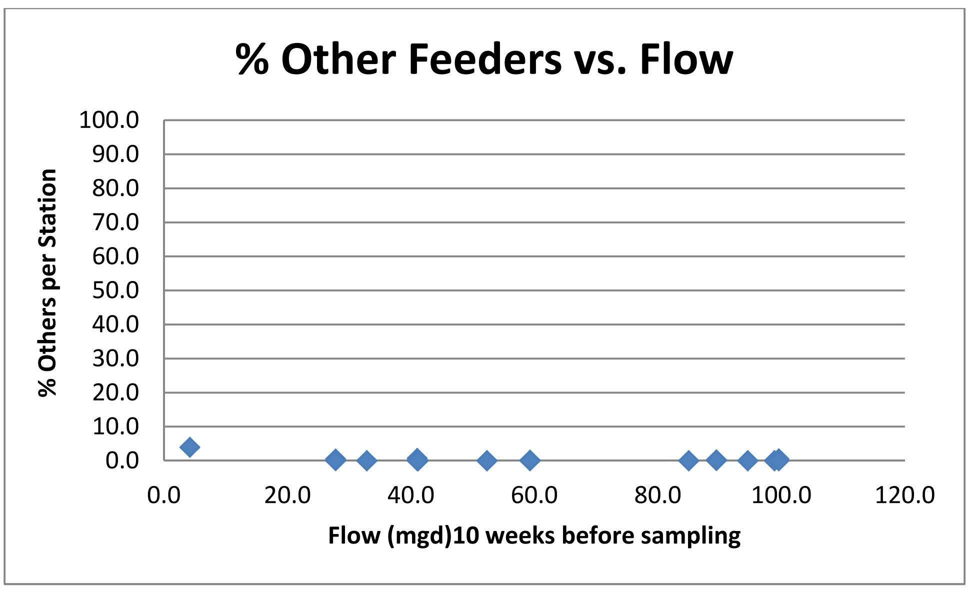
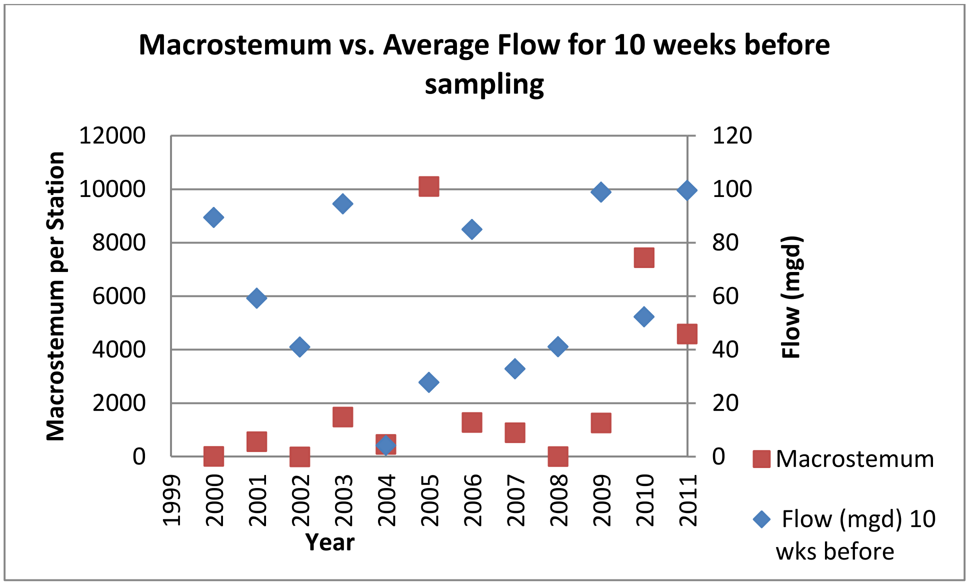


Figure 11. Percent other feeding groups of macroinvertebrates per station at average flow for 10 weeks prior to sampling for each of 12 years.



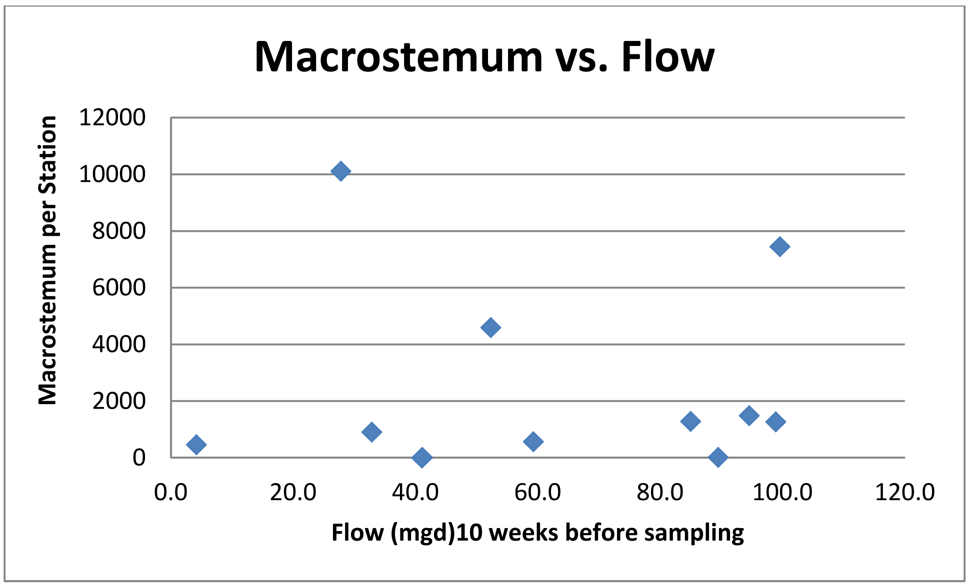
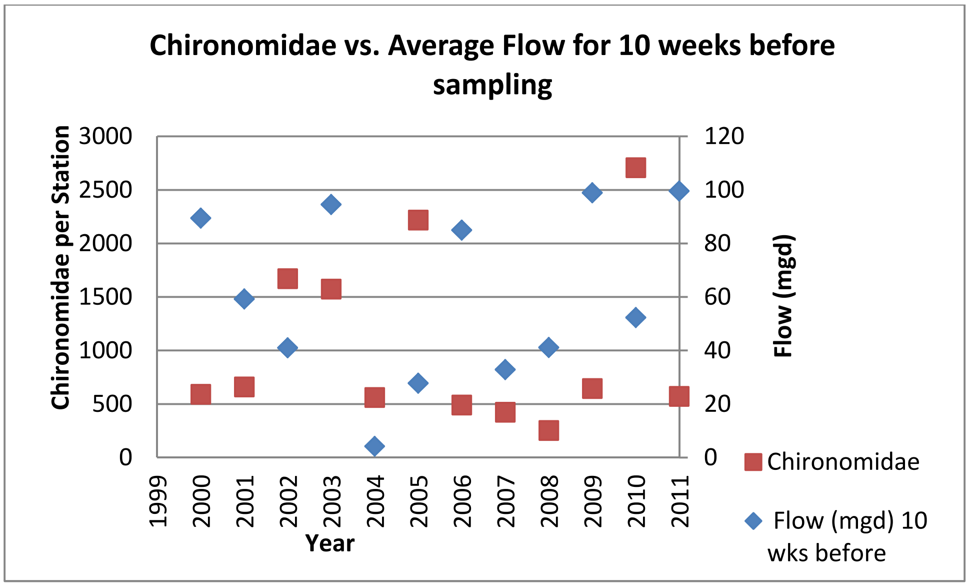


Figure 12. Number of caddisly *Macrostemum* per station at average flow for 10 weeks prior to sampling for each of 12 years.



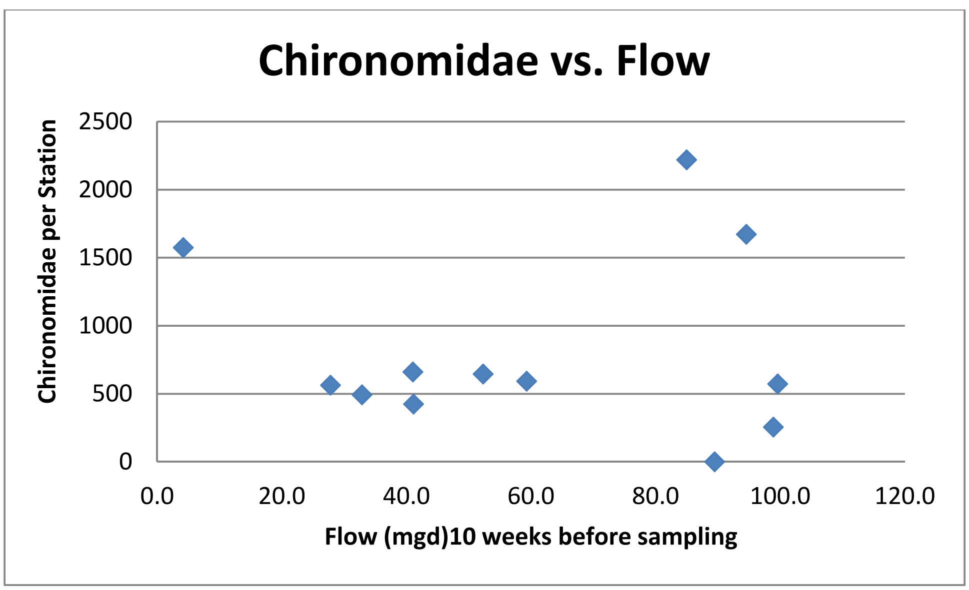
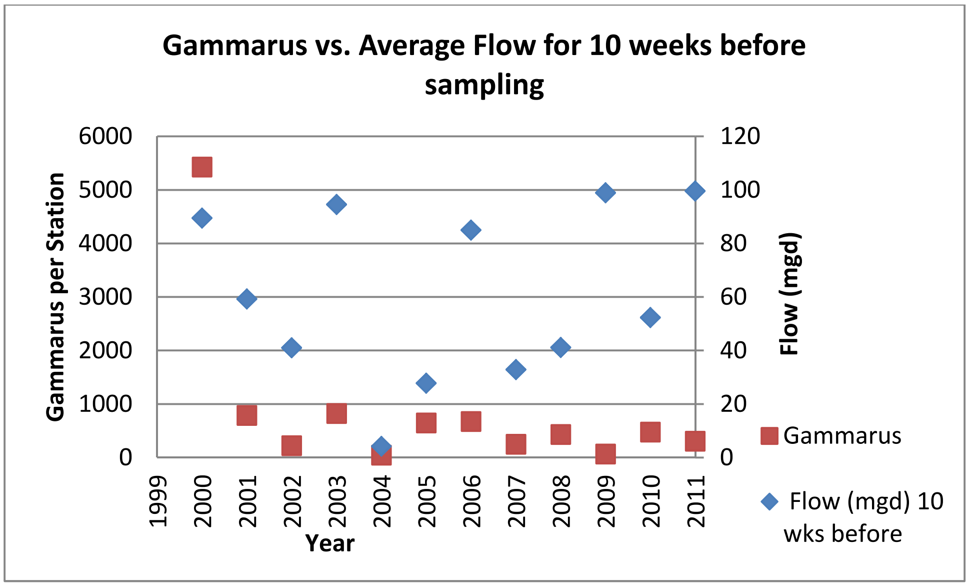


Figure 13. Number of midges (Chironomidae) per station at average flow for 10 weeks prior to sampling for each of 12 years.



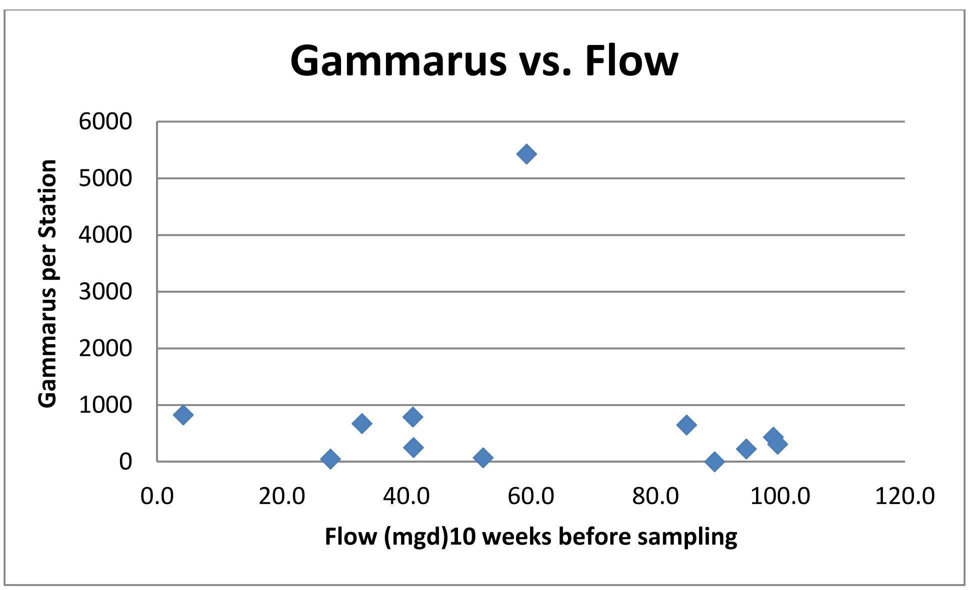
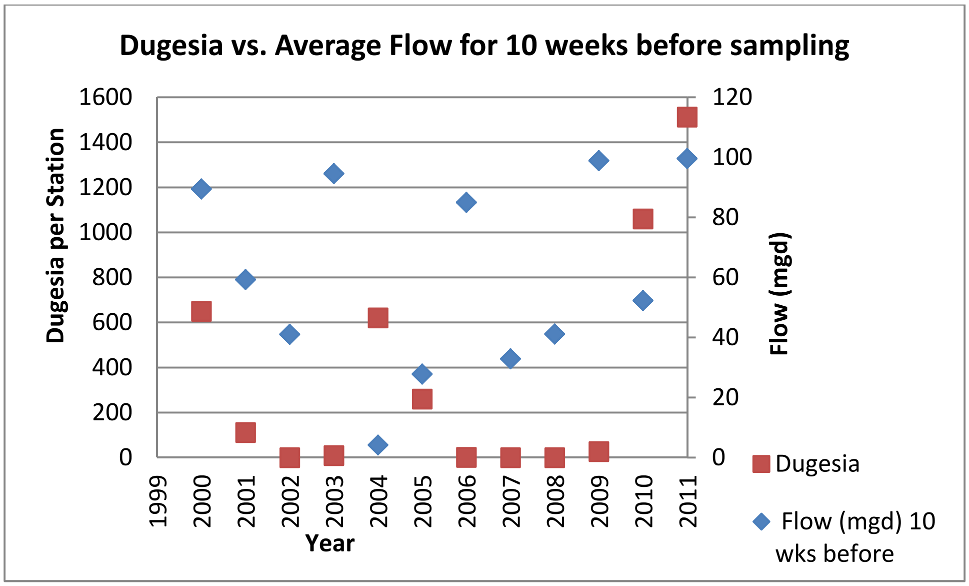


Figure 14. Number of scud *Gammarus* per station at average flow for 10 weeks prior to sampling for each of 12 years.



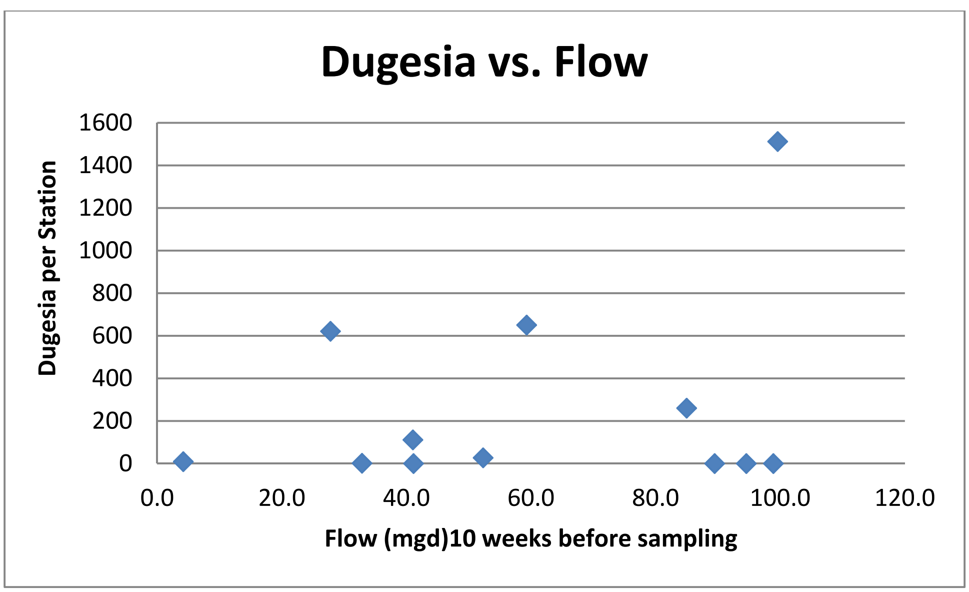
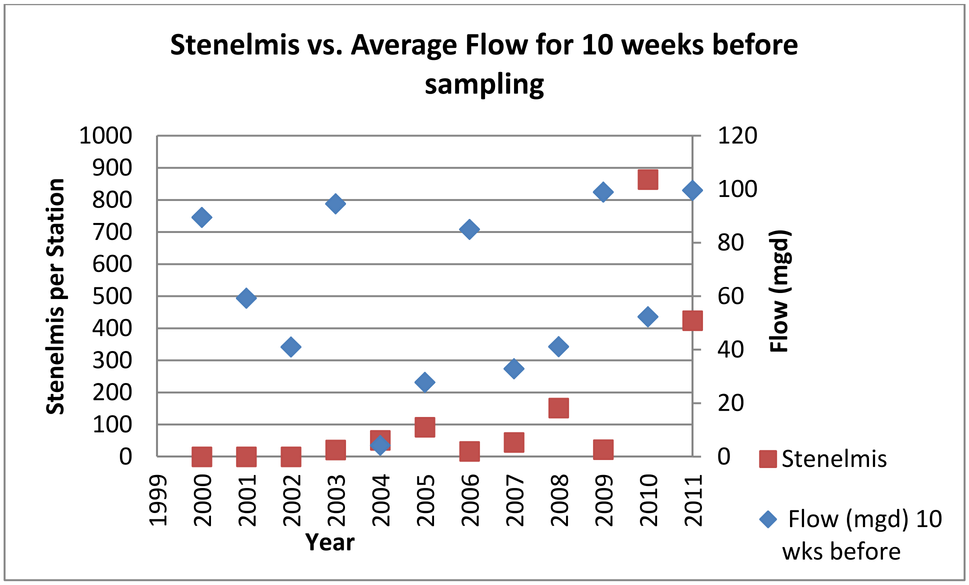


Figure 15. Number of flatworm *Dugesia* per station at average flow for 10 weeks prior to sampling for each of 12 years.



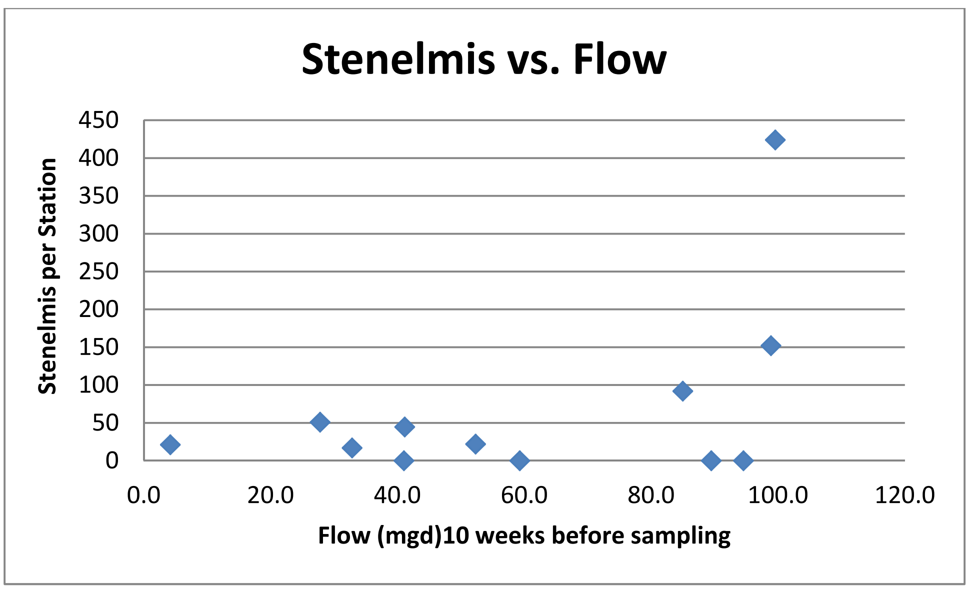
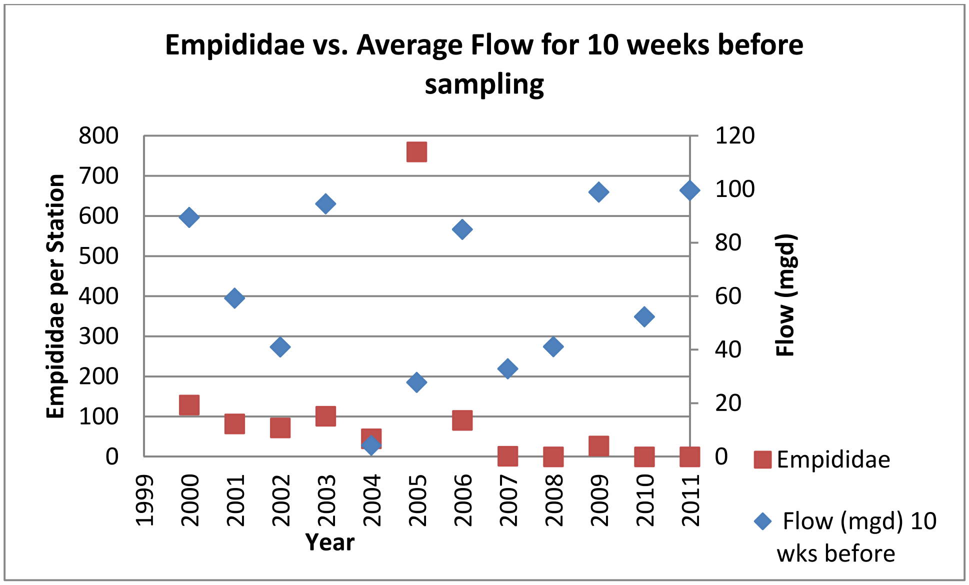


Figure 16. Number of riffle beetle *Stenelmis* per station at average flow for 10 weeks prior to sampling for each of 12 years.



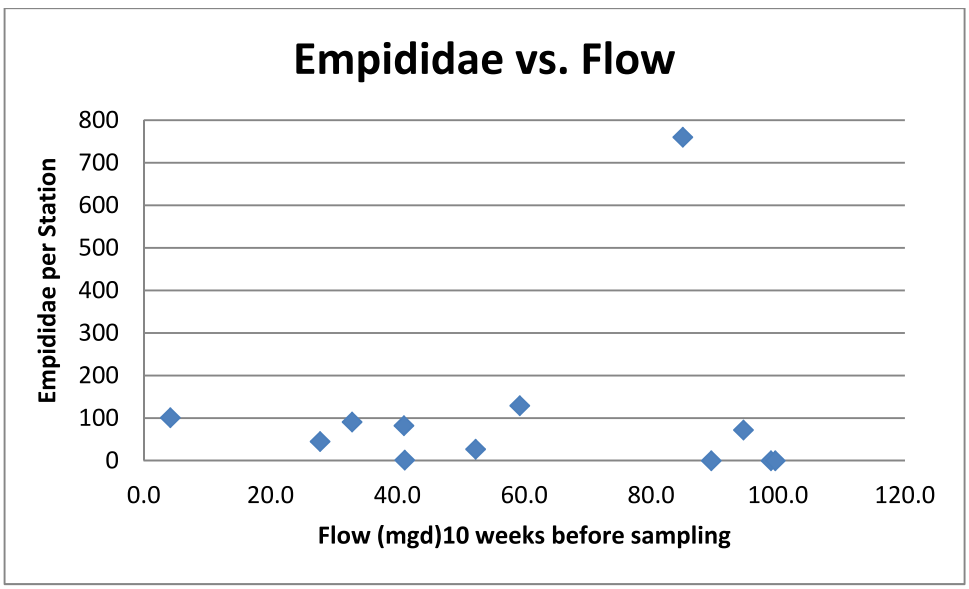
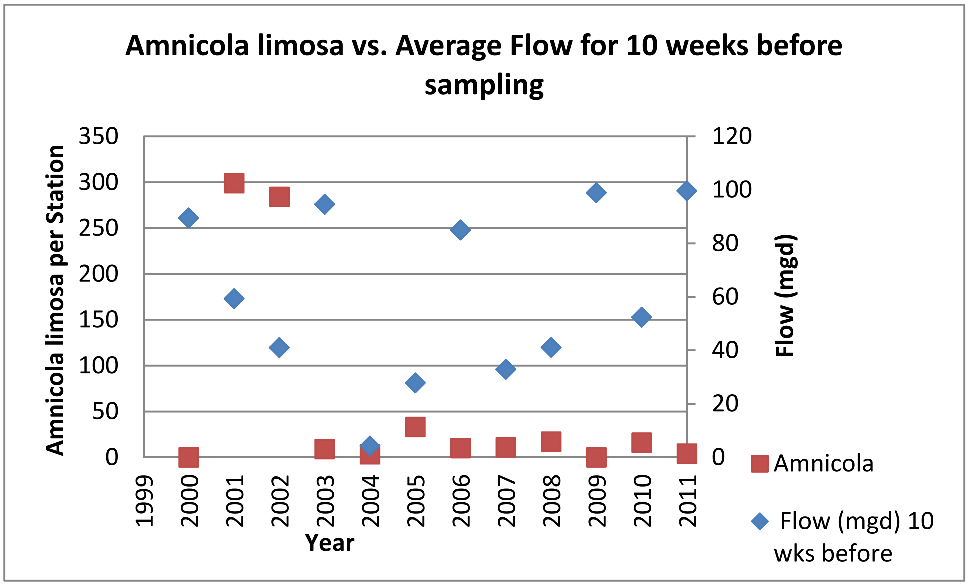


Figure 17. Number of danceflies (Empididae) per station at average flow for 10 weeks prior to sampling for each of 12 years.



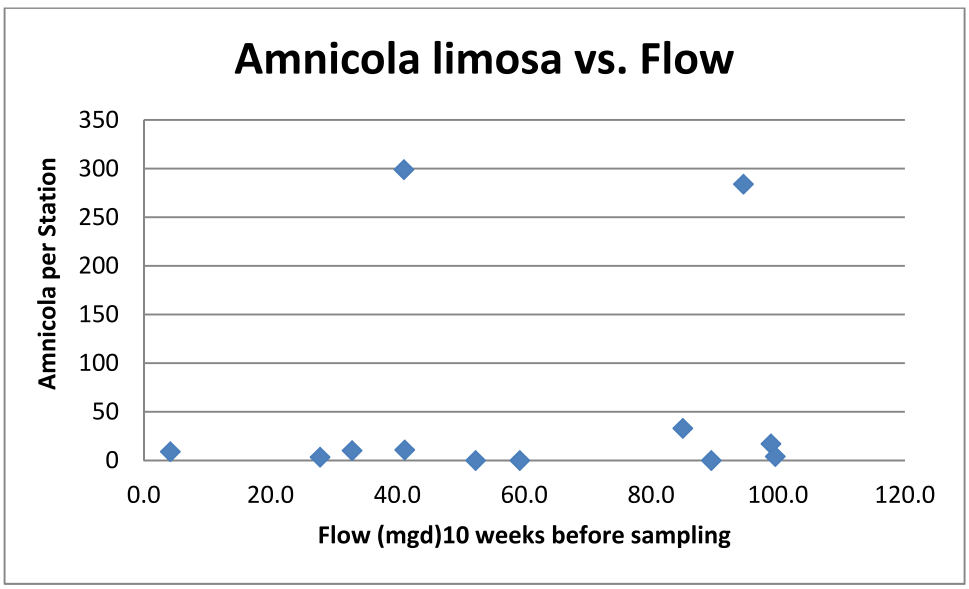


Figure 18. Number of snail *Amnicola* per station at average flow for 10 weeks prior to sampling for each of 12 years.

width and water depth, but the overall conditions represented by ten week average flow do not correlate strongly to any measured feature of the invertebrate community at Stations 1-3.

For the entire period of monitoring, the macroinvertebrate community is comprised mainly of filterers, shredders and collectors (85% of all individuals) among the possible feeding guilds. Scrapers, predators and other feeding types represent more minor components of the community overall, although they may be abundant in some samples. Predators and scrapers are each represented by two species each in the list of the seven most abundant taxa (Table 2), but collectively represent only 13% of all individuals collected. In comparison, the top individual filterer, shredder and collector taxa represent 80% of all specimens collected.

Although taxa per station, evenness, and biotic index are not especially variable over time, there are major fluctuations in taxonomic and feeding groups over time that suggest instability in the system. Even the most abundant taxa for the period of monitoring are not always the most abundant taxa, with five of the seven most abundant species having at least one summer where the abundance was 0 (Table 4). Most fluctuations appear erratic, with no clear pattern over time, but the shredders appear to have declined from 2000 to 2004 then increased again through 2008 with a decline in 2009 through 2011 (Figure 7). In a near reverse of this pattern, collectors increased between 2000 and 2005, declining after that (Figure 8). None of these shifts appears related to average flow for the 10 weeks preceding sampling.

Considering the most abundant taxa, the caddisfly *Macrostemum* and midgeflies exhibit peaks in 2005 and 2010, years with below average flow (Figures 12 and 13). The scud *Gammarus* was most abundant in 2000, and has not exhibited peak abundance since, but is always present in substantial numbers (Figure 14). The flatworm Dugesia exhibited peaks in 2000, 2004, 2010 and 2011 (Figure 15). Accurate data for flow in 2004 are not available, as the dam was largely bypassed to maintain a construction related drawdown, but summers in 2004 and 2011 were relatively wet, while 2000 and 2010 provided near average summers for flow. The riffle beetle *Stenelmis* peaked in abundance in 2010 (Figure 16), while danceflies (Empididae) exhibited a peak in 2005 (Figure 17). The snail *Amnicola* exhibited peak abundance in 2001 and 2002 (Figure 18). Again, no clear relationship to average flow for the 10 weeks preceding sampling is indicated.

As with most recent summers, the summers of 2010 and 2011 were more like a pre-operation period, with very limited operation of the water withdrawal and treatment system during business hours, totaling about 6 to 9% of the legally allowed daily withdrawal. A couple of exceptions occurred, where the facility was operated daily at around 25% of the allowed daily withdrawal, but overall impact on the Mill River flow regime has been minimal since facility start up in 2005. Since water supply operations have been resumed at Lake Whitney, there have been no significant periods of coinciding minimum flows and maximum withdrawal.

Although it seems likely that the 10 weeks preceding sampling would encompass the flows most influential on the macroinvertebrate community, it was considered that spring flows, represented by the period 10 to 20 weeks before sampling, might have some influence on invertebrates. Calculated average flows for the period 10 to 20 weeks before invertebrate collection (Table 3) were compared to the same features of the macroinvertebrate community examined for the 10-week period just before sampling (Figures 19 – 21). No relevant patterns are apparent; spring flow has no clear impact on late summer invertebrate community features.

As many fluctuations in flow can occur in a 10 week period, the potential for a shorter time frame of more severe flows to be more influential on the macroinvertebrate community was explored. The 7-day low flow (lowest flow to occur for seven consecutive days) and the 7-day high flow (highest flow to occur for seven consecutive days) were calculated for the 10-week period preceding sampling (Table 3). Comparison of the 7-day low flow with macroinvertebrate measures (Figures 22 - 24) demonstrates no clear relationships; this seemed like the most likely comparison to yield a significant linkage, but it did not. Comparison of the 7-day high flow with macroinvertebrate measures (Figures 25 - 27) also suggests no obvious linkage between high flows and invertebrate community features.

It is possible that the actual flows are less critical than the variability in flow, and both the standard deviation of flow and coefficient of variations (standard deviation divided by the mean) were calculated for the 10-week period preceding sampling for invertebrates (Table 3). Comparison of these measures of flow variability with invertebrate community features reveals nothing of utility applying the standard deviation (Figures 28 - 30), but there are glimmers of a relationship using the coefficient of variation (Figures 31 - 33). The relationship with number of taxa explains 20% of the variation in number of taxa, with taxa increasing as flow variability increased. This is not a large percentage, but is consistent with expectations that disturbance induced by flow variation can open more niches and support more taxa. Evenness declined slightly with increasing coefficient of variation (CV), but CV explained only 7% of the variation in evenness. No other relationships were apparent.

As no feature of the flow regime appears to provide a useful predictor of macroinvertebrate community features as listed, it was considered that some transformation of macroinvertebrate measures might provide a better correlation. However, nearly all of the macroinvertebrate measures are not readily amenable to any transformation. The one exception is the total number of individuals, with the square root function as the most appropriate transformation. Comparison of total individuals per sample with the average, 7-day low, and 7-day high flow for the 10 weeks preceding invertebrate sampling (Figure 34) suggests that the square root conversion of total macroinvertebrates per sample did not improve the level of prediction offered by flow measures.

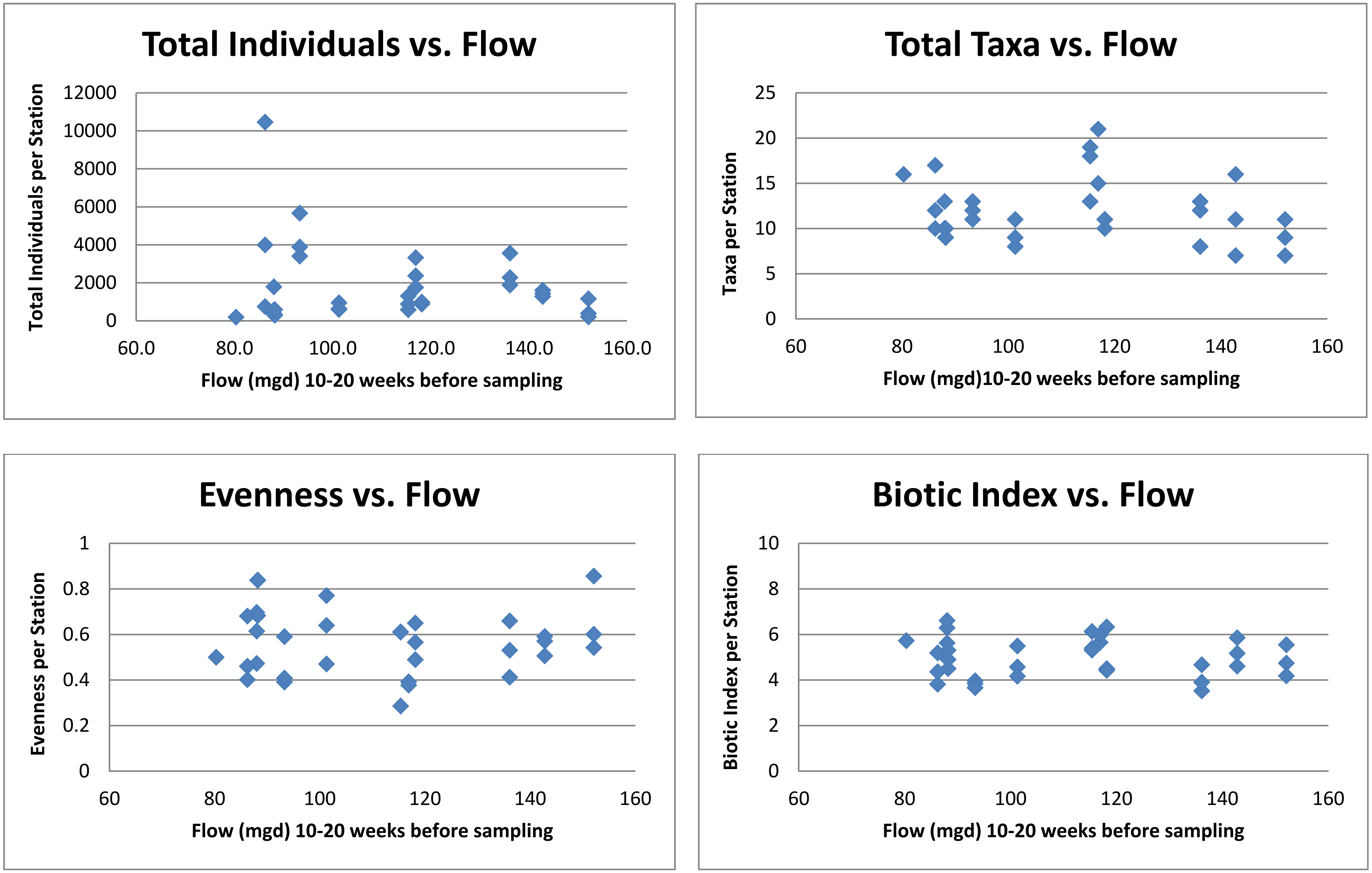


Figure 19. Macroinvertebrate features vs. average flow 10 to 20 weeks before sampling – Part A

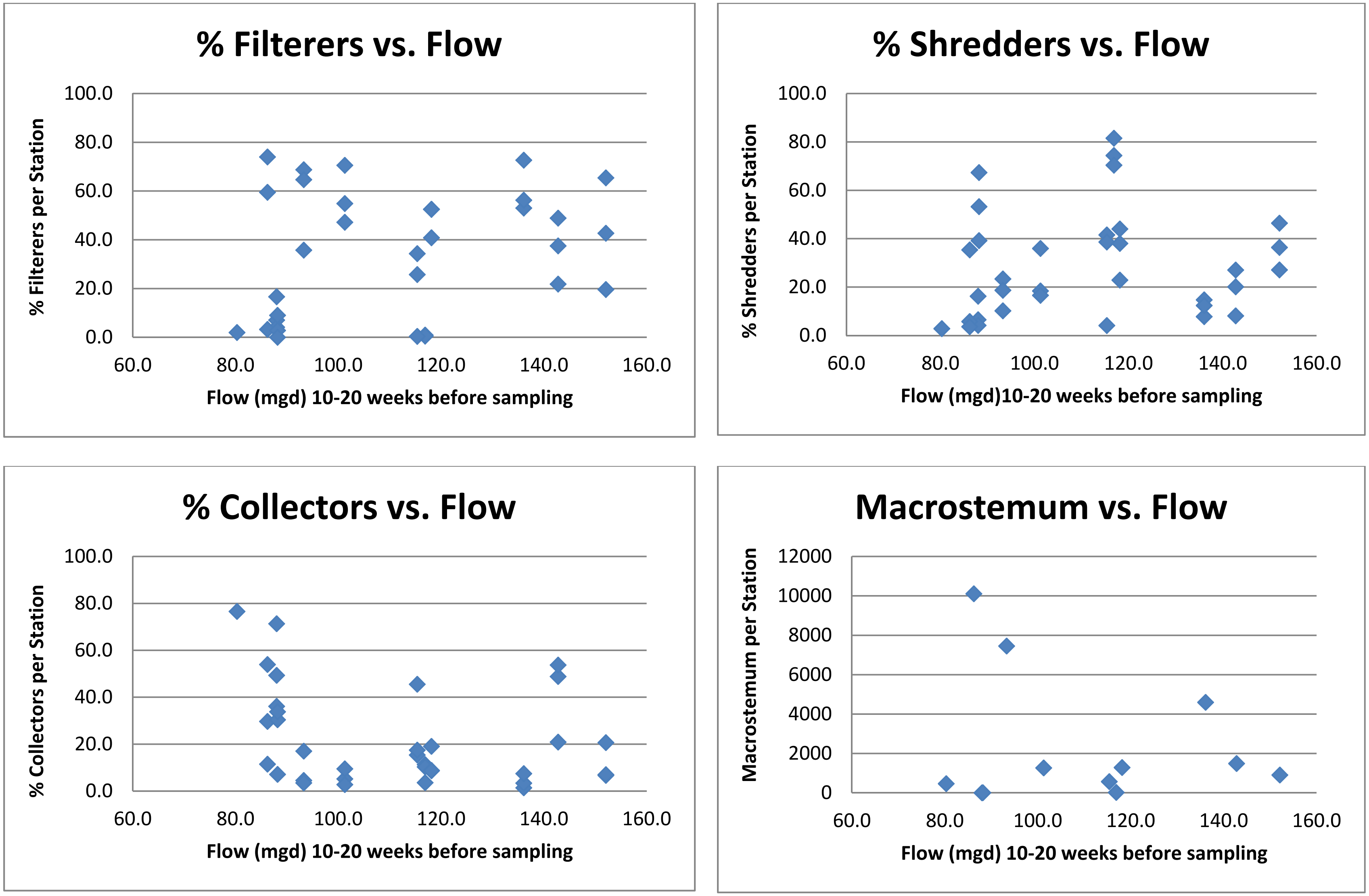


Figure 20. Macroinvertebrate features vs. average flow 10 to 20 weeks before sampling – Part B

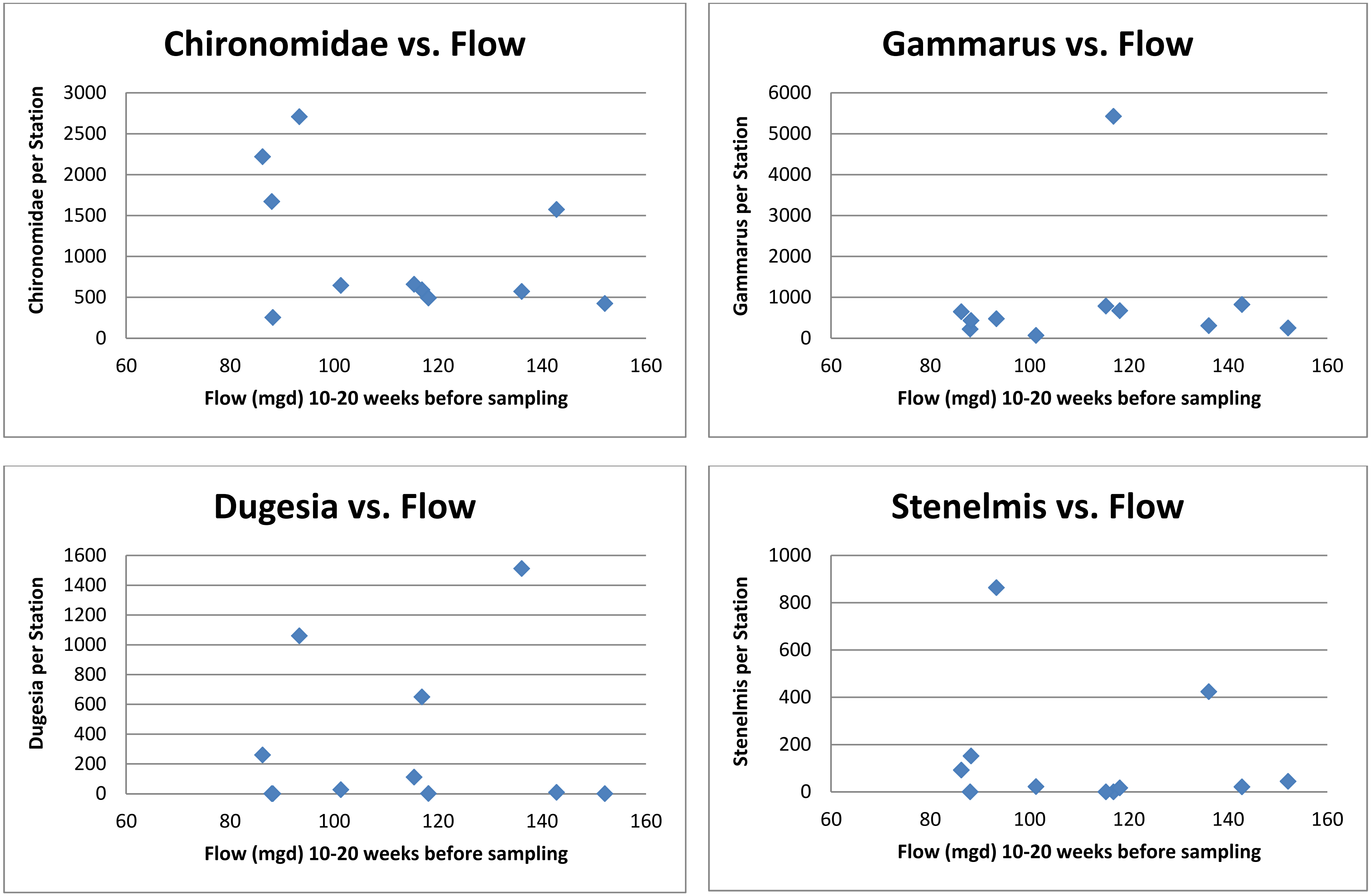


Figure 21. Macroinvertebrate features vs. average flow 10 to 20 weeks before sampling – Part C

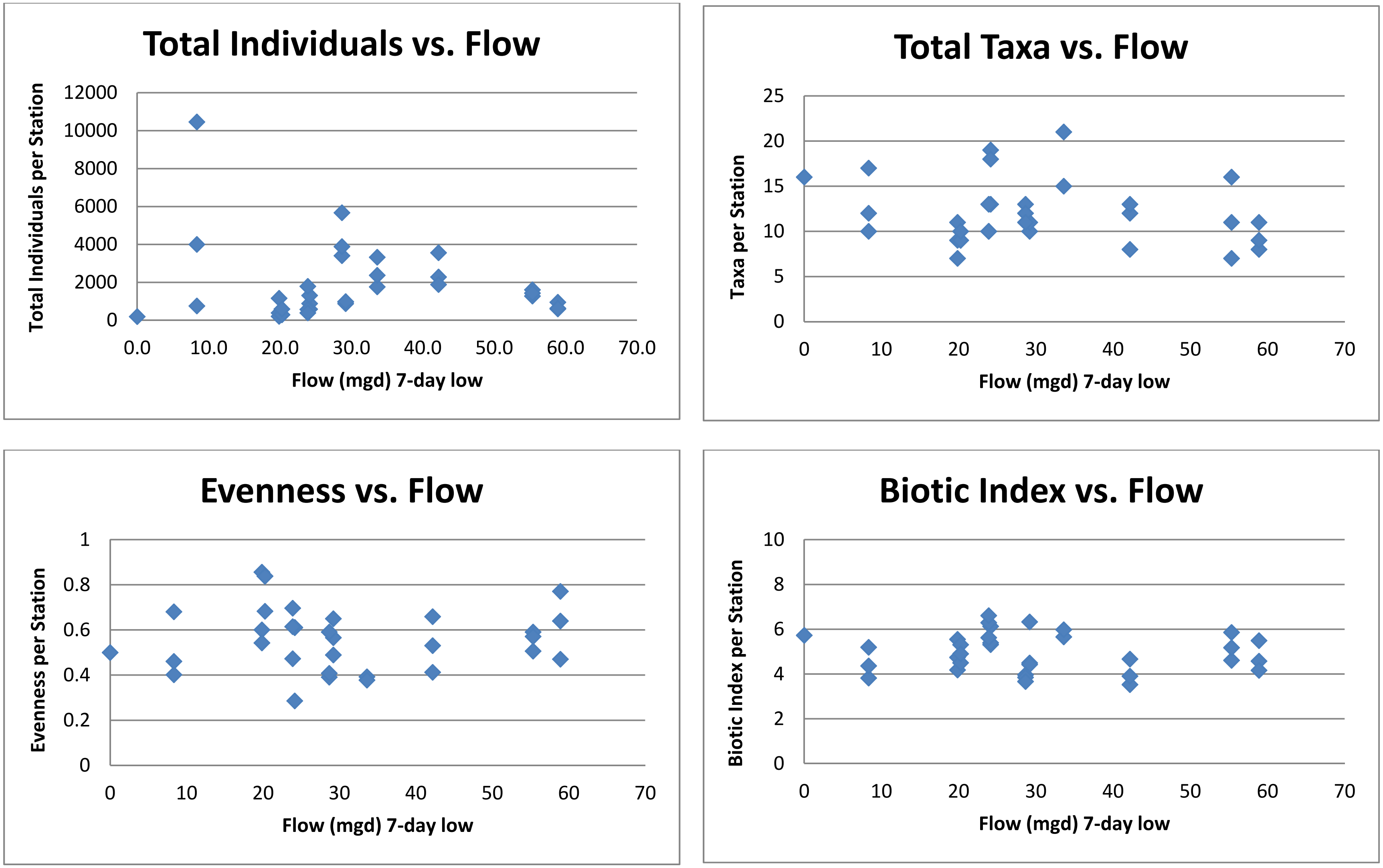


Figure 22. Macroinvertebrate features vs. 7-day low flow during the 10 weeks before sampling – Part A

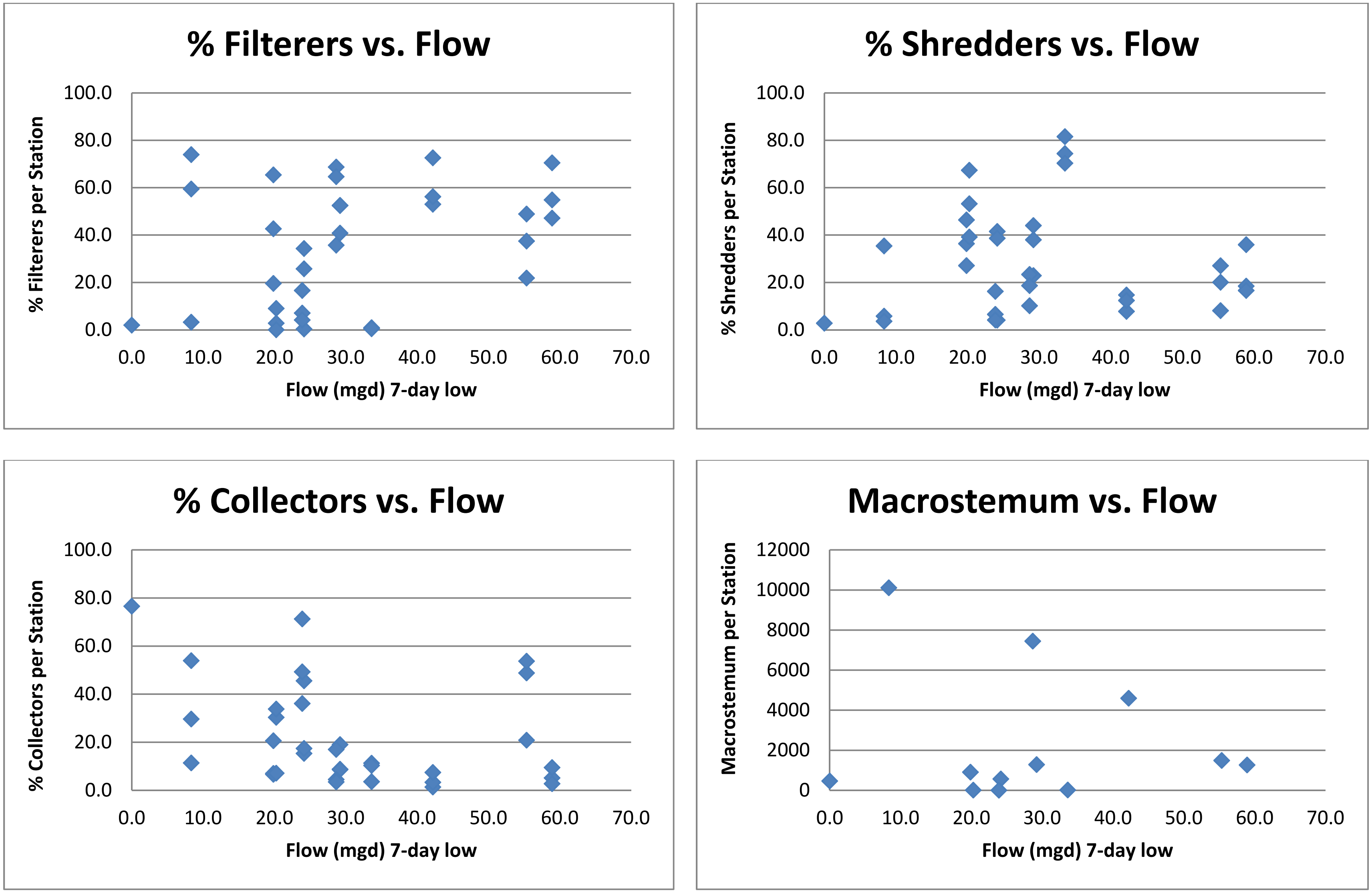


Figure 23. Macroinvertebrate features vs. 7-day low flow during the 10 weeks before sampling – Part B

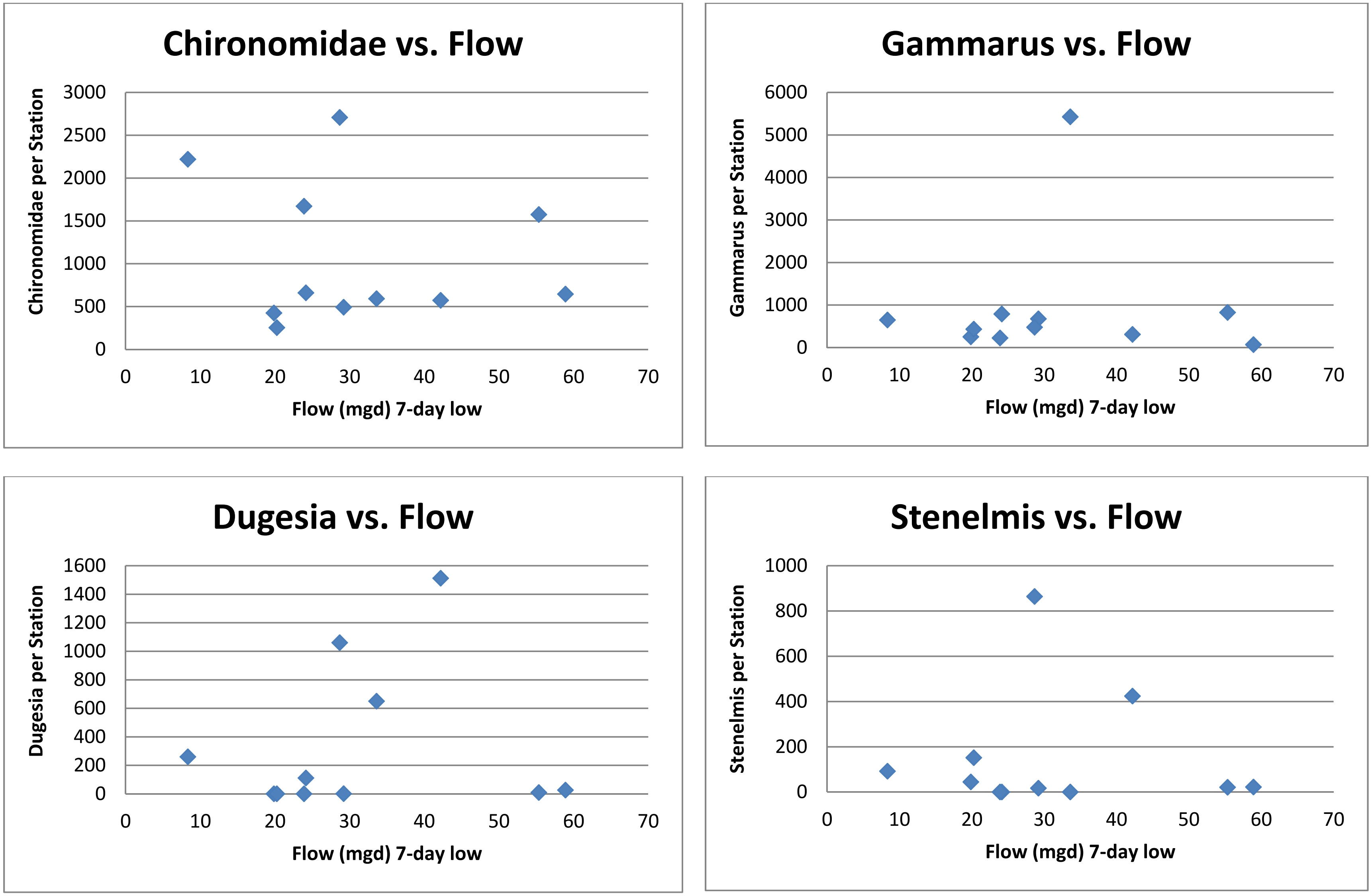


Figure 24. Macroinvertebrate features vs. 7-day low flow during the 10 weeks before sampling – Part C

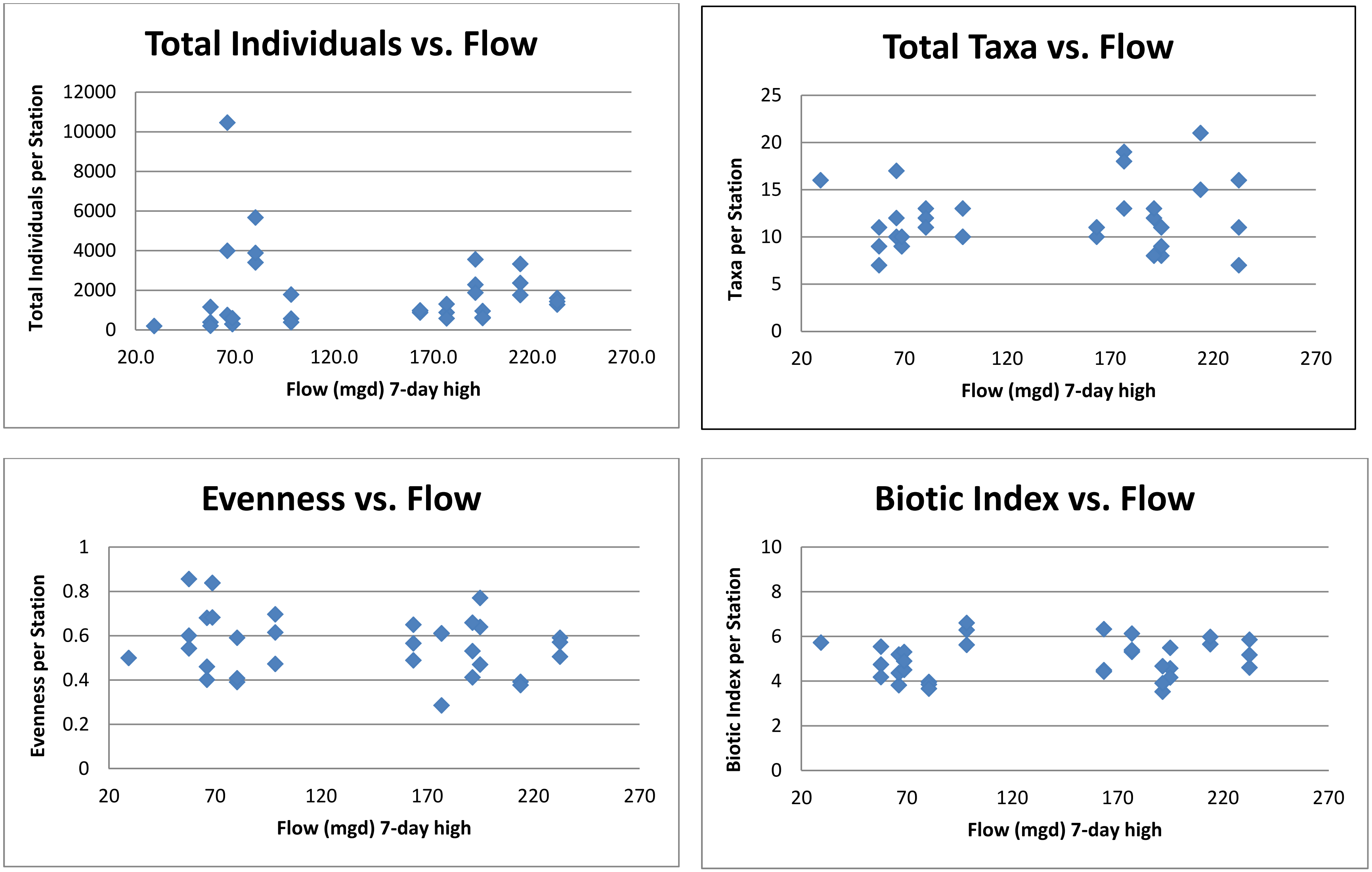


Figure 25. Macroinvertebrate features vs. 7-day high flow during the 10 weeks before sampling – Part A

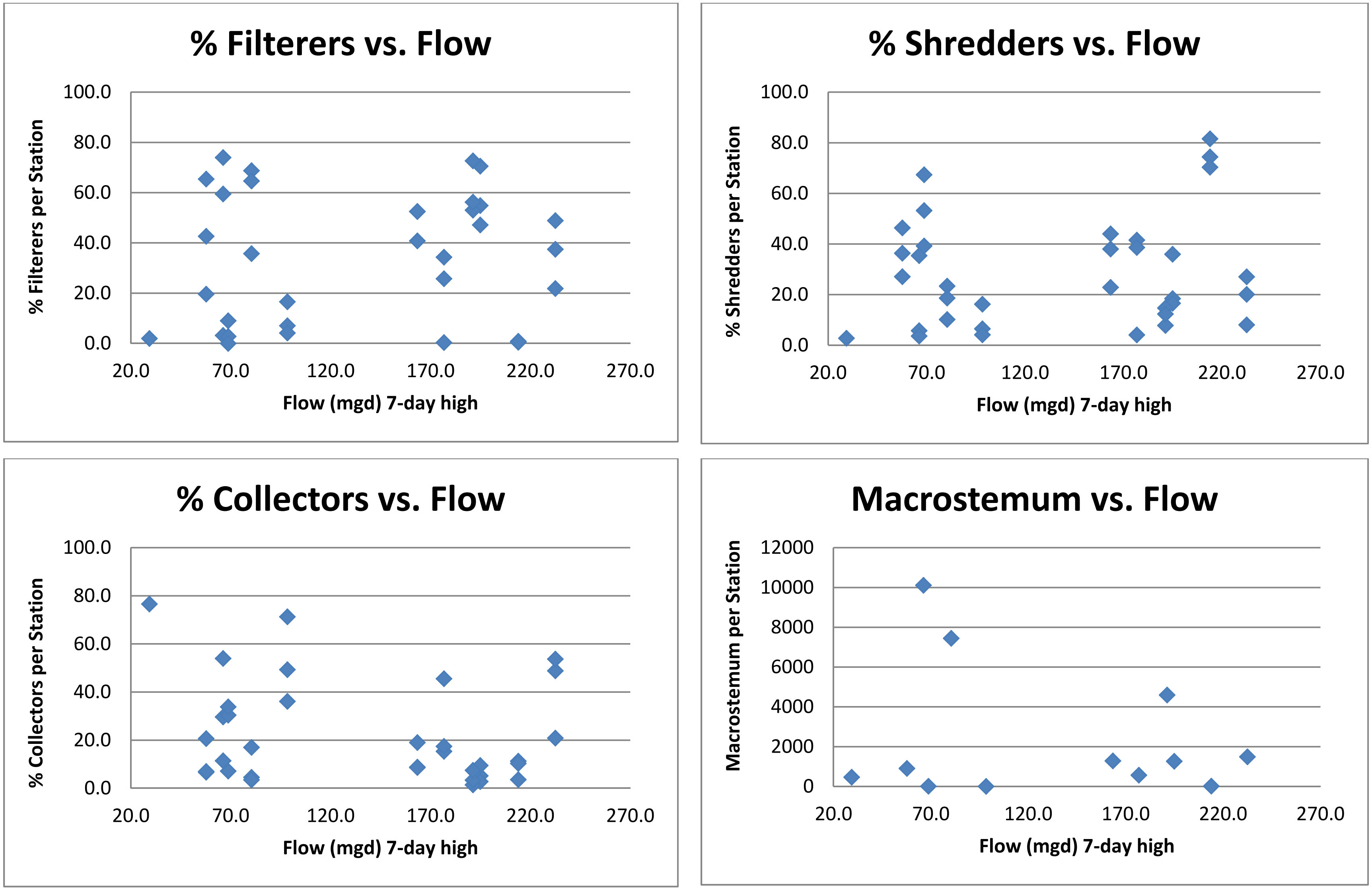


Figure 26. Macroinvertebrate features vs. 7-day high flow during the 10 weeks before sampling – Part B

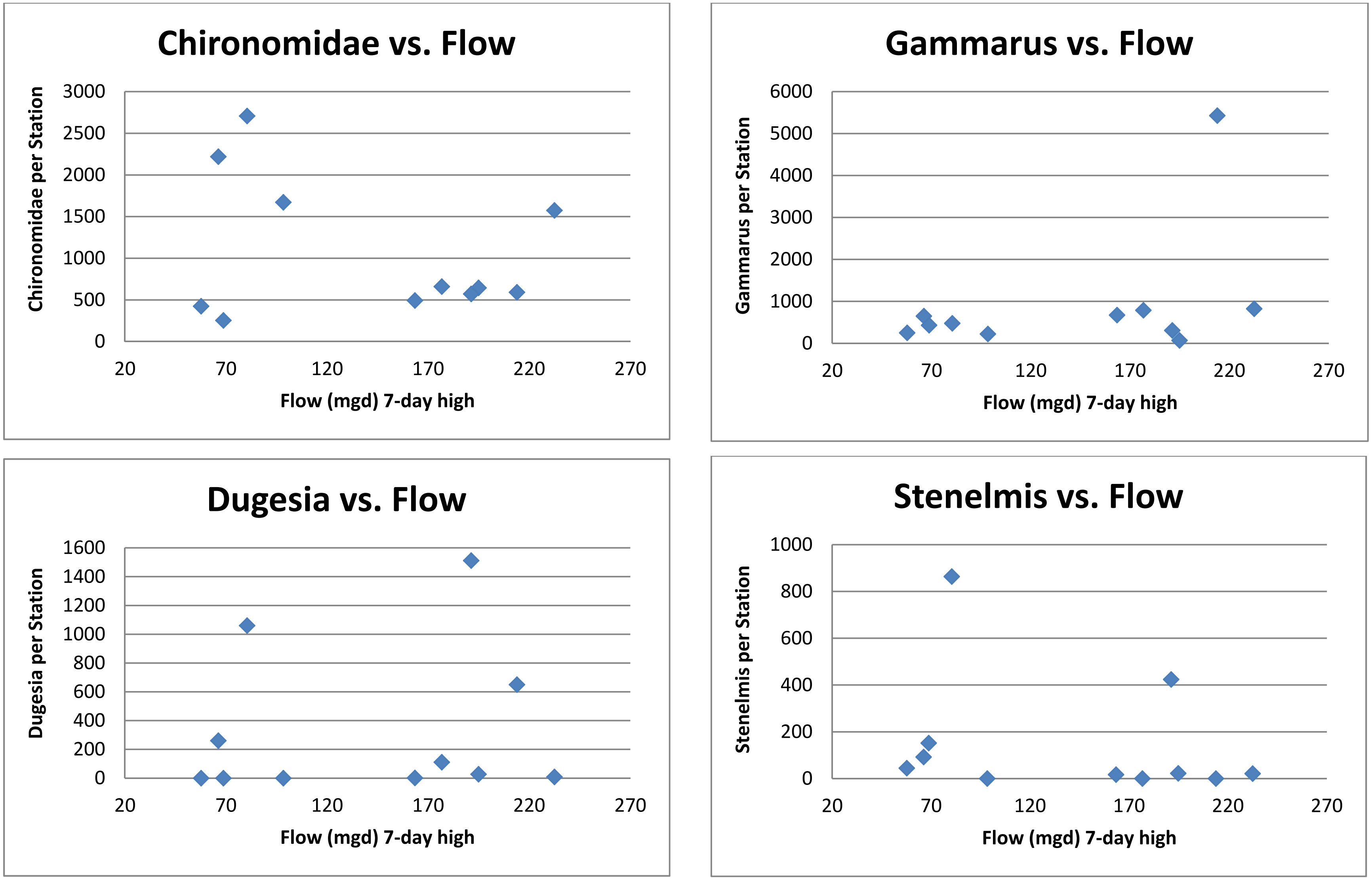


Figure 27. Macroinvertebrate features vs. 7-day high flow during the 10 weeks before sampling – Part C

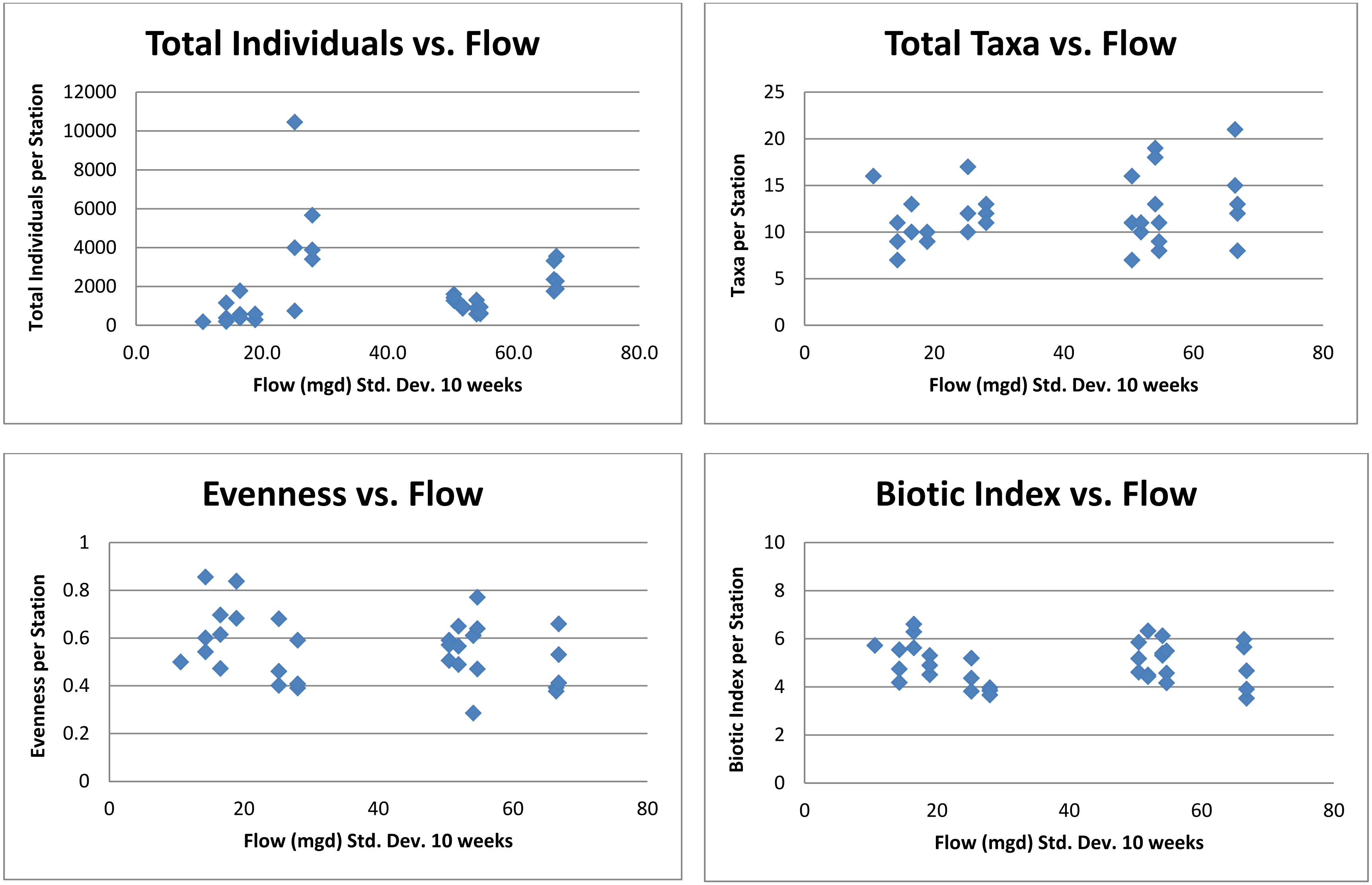


Figure 28. Macroinvertebrate features vs. standard deviation of flow during the 10 weeks before sampling – Part A

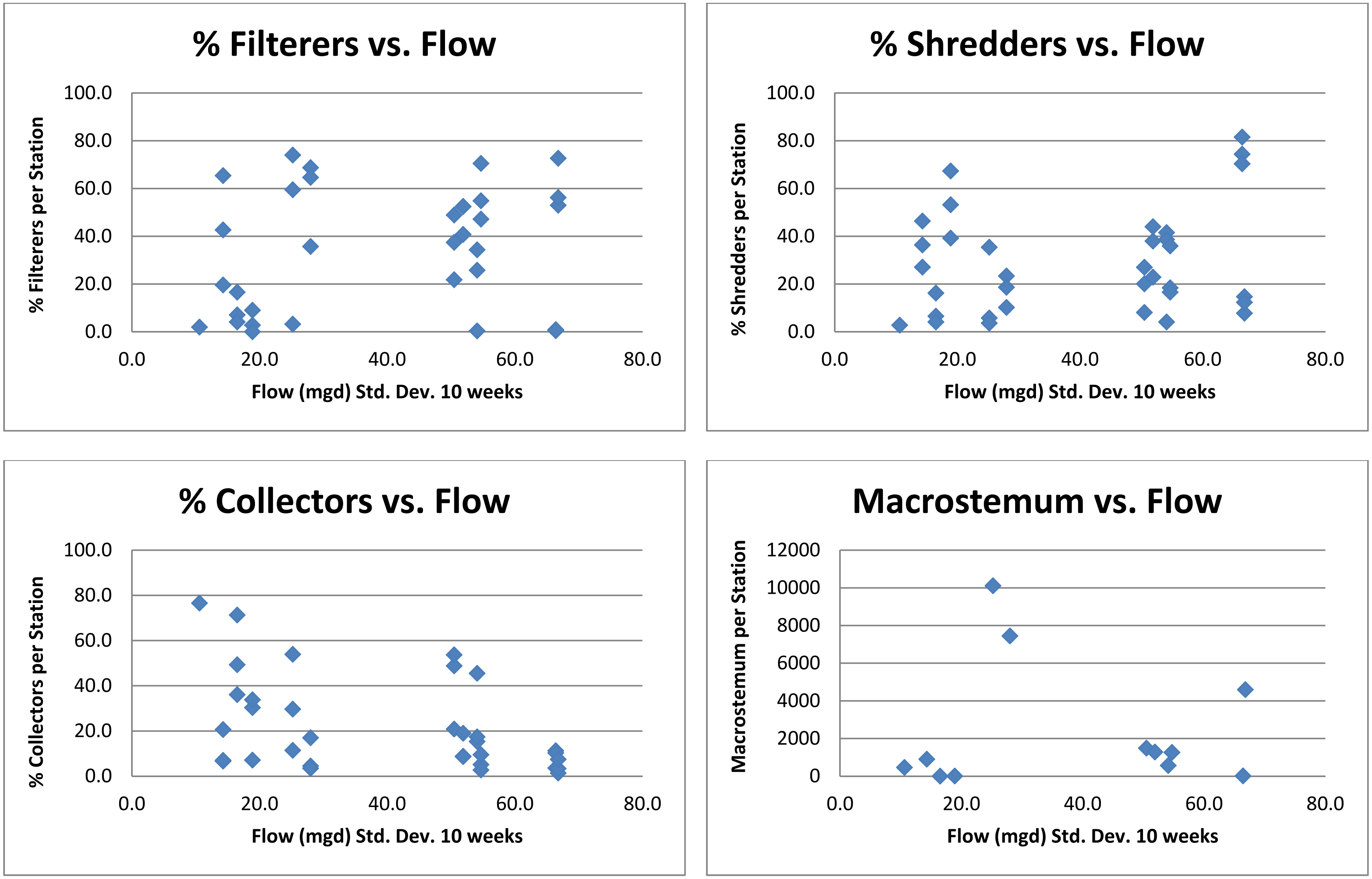


Figure 29. Macroinvertebrate features vs. standard deviation of flow during the 10 weeks before sampling – Part B

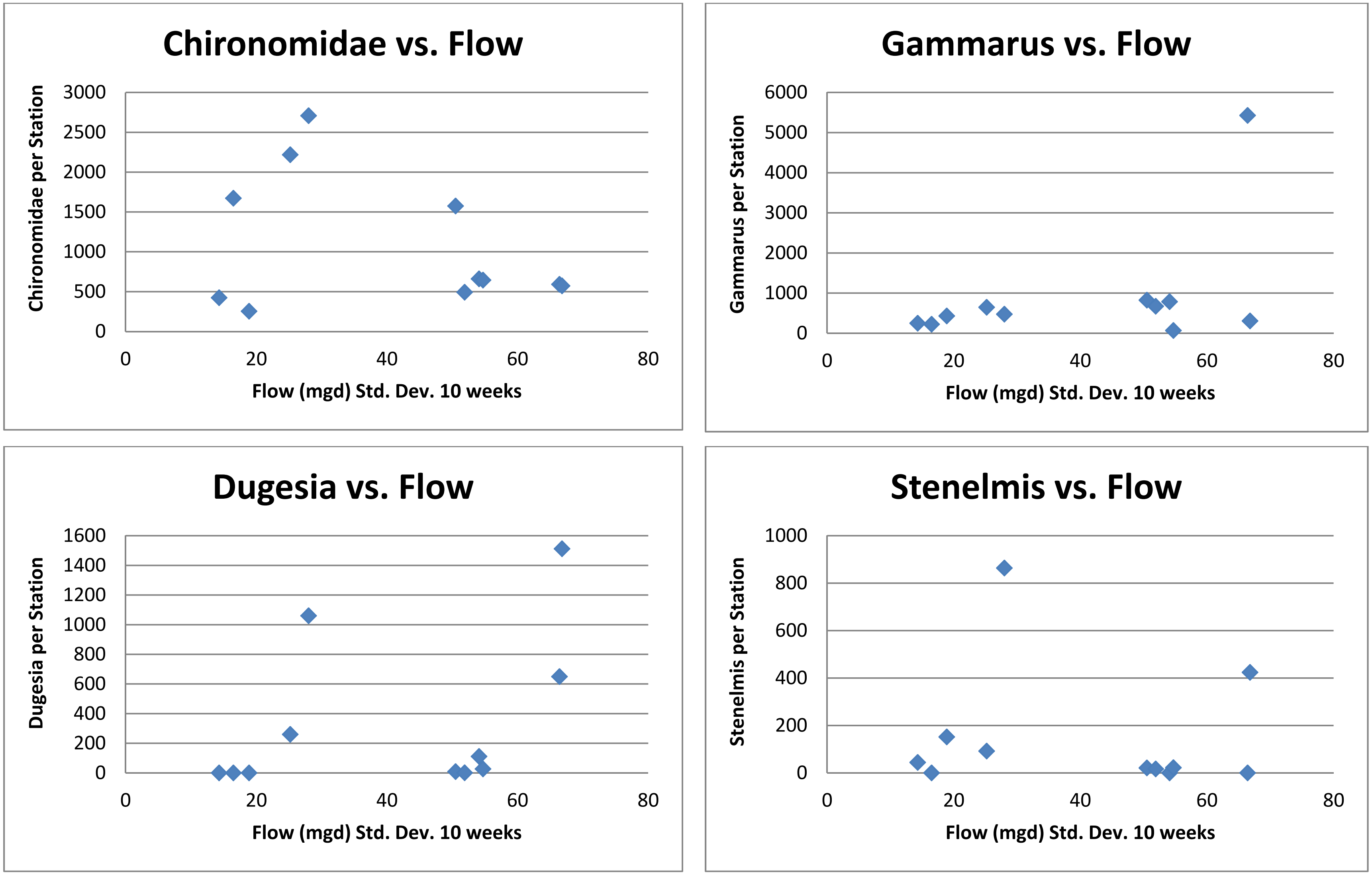


Figure 30. Macroinvertebrate features vs. standard deviation of flow during the 10 weeks before sampling – Part C

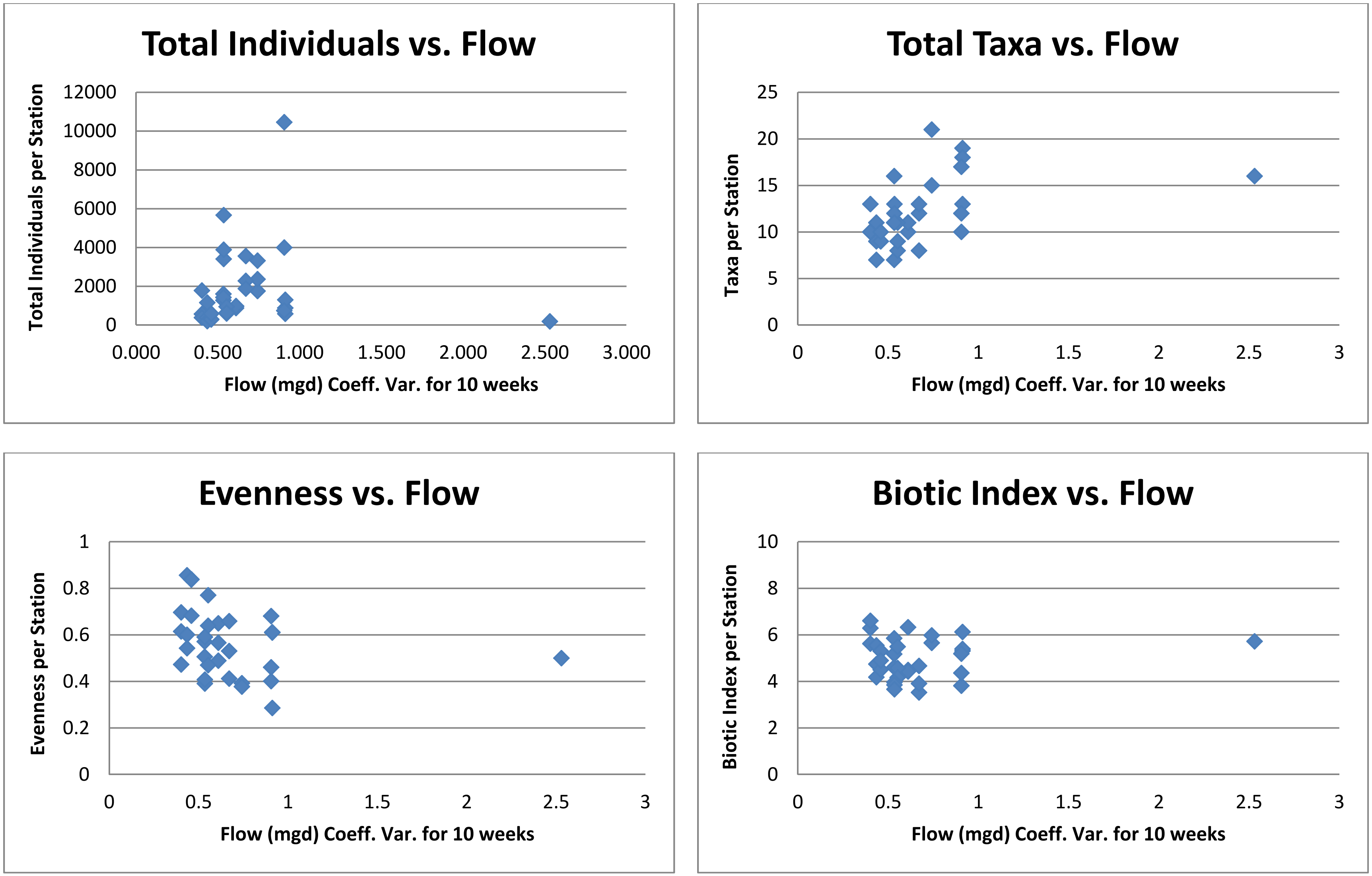


Figure 31. Macroinvertebrate features vs. coefficient of variation of flow during the 10 weeks before sampling – Part A

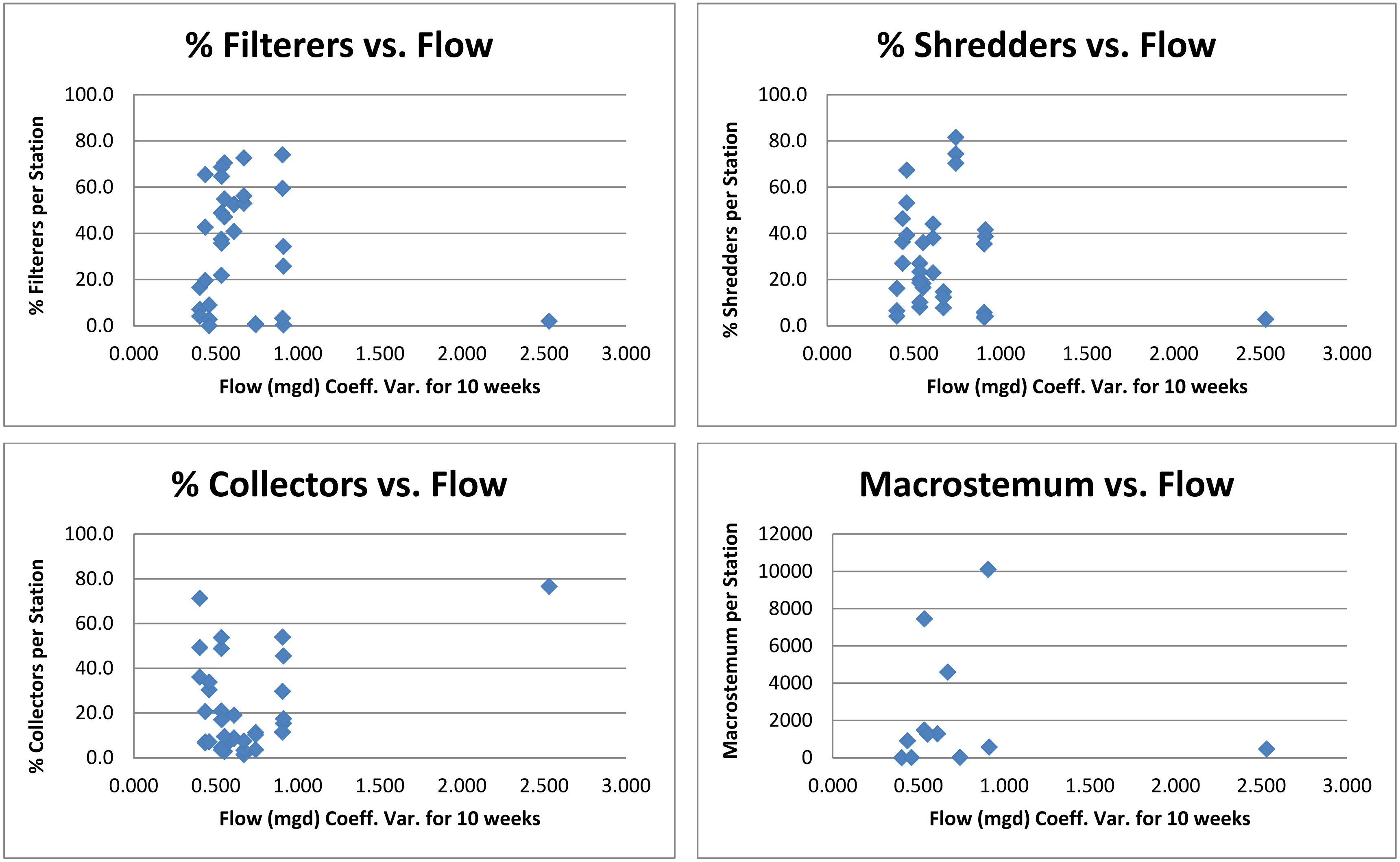


Figure 32. Macroinvertebrate features vs. coefficient of variation of flow during the 10 weeks before sampling – Part B

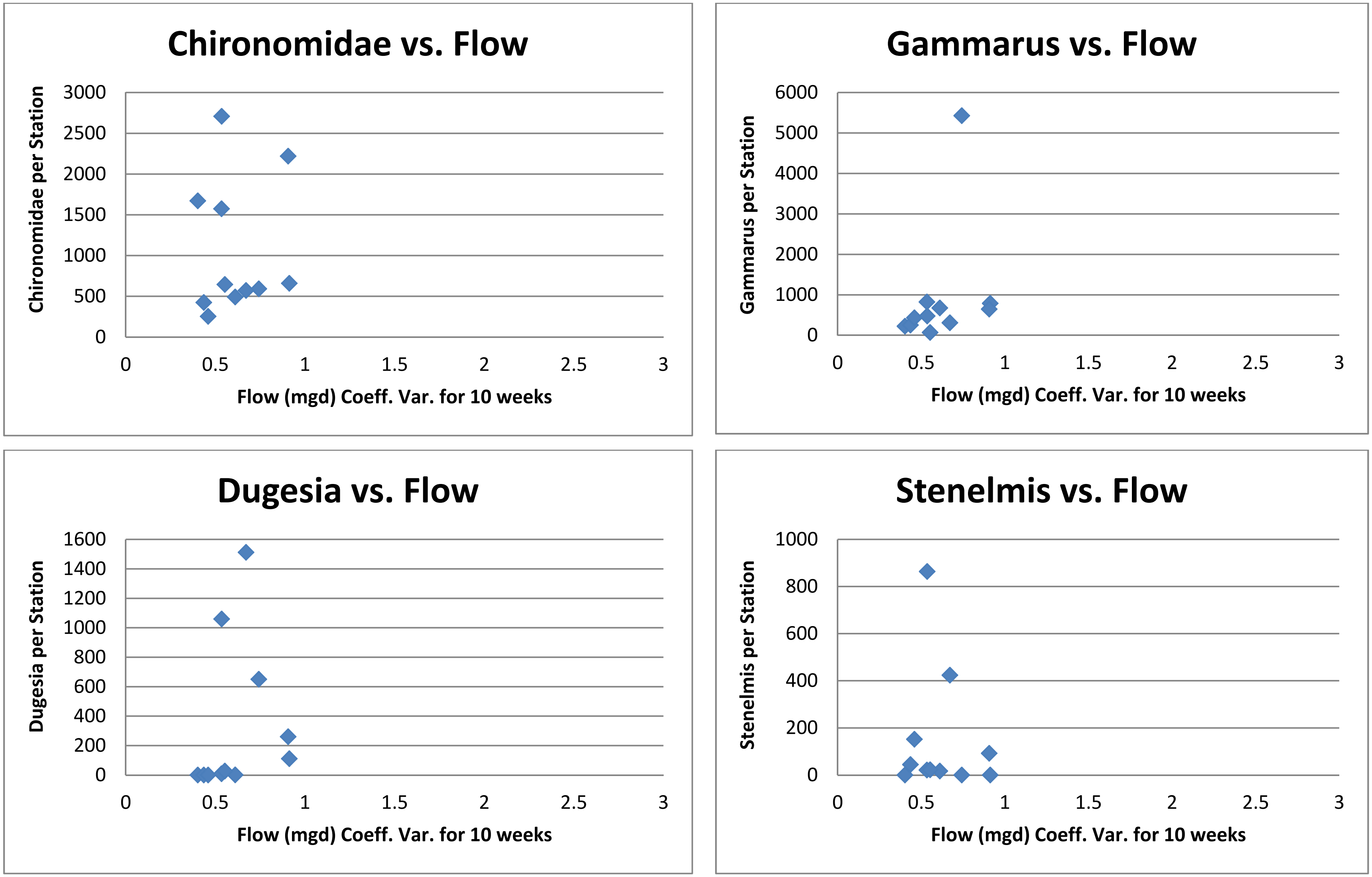
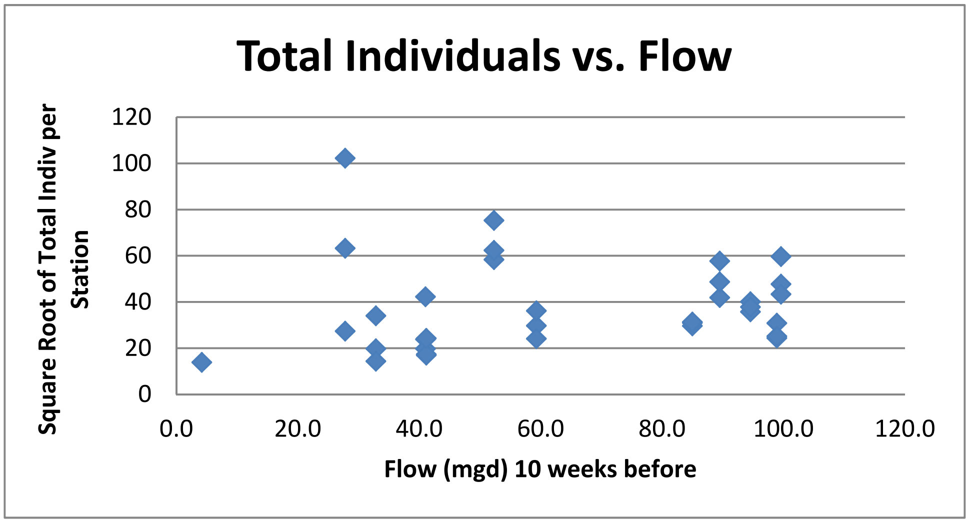
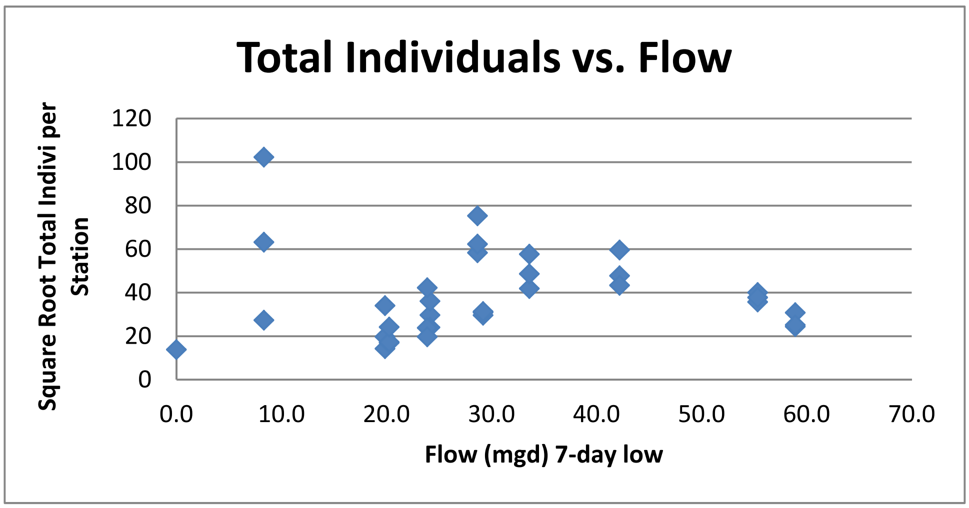


Figure 33. Macroinvertebrate features vs. coefficient of variation of flow during the 10 weeks before sampling – Part C





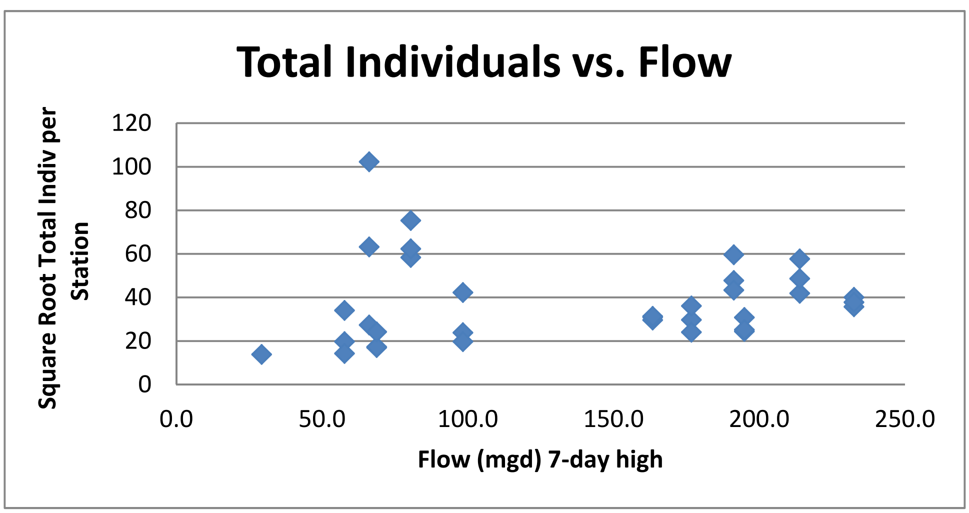


Figure 34. Square root of total individuals vs. three flow measures.

Discussion

The influence of Lake Whitney on the lower Mill River at Stations 1-3 is apparent in the data. The production of algae and conversion of coarse particulate matter favors the filterer and collector feeding guilds, and to some extent the shredders, although shredders tend to do well anywhere that leaves enter the stream system. Scrapers would be expected to be more abundant in a stream without an impoundment just upstream, as available nutrients for periphyton growths are limited by the impoundment. Predators are typically not a dominant component, as they depend on other more plentiful invertebrates as a food supply. The observed community is therefore consistent with expectations based on the presence of an impoundment and related ecological processes, as discussed in previous annual reports and described in publications such as Hynes (1970) and Allan (1995).

Water quality in the Mill River is not ideal, given considerable upstream development and inputs of a variety of contaminants, but Lake Whitney moderates possible effects, and key water quality features such as oxygen and pH are usually well within an acceptable range for aquatic life at Stations 1-3. Species with extremely high tolerance for pollution are absent, as are species with very little tolerance, maintaining the biotic index in the moderate range for these stations on all dates.

Flow is variable from Lake Whitney, and key features such as water velocity, wetted channel width, and water depth vary daily to weekly at Stations 1-3. The dam moderates flow influence to a minor extent, reducing peak flows with some limited storage and prolonging the period of elevated flow until the lake returns to its dry weather level, but fluctuations are obvious in the flow record. The use of an average flow for ten weeks prior to sampling does not capture all variability, but does appear to represent overall summer conditions fairly well. With a range of 30 to 100 mgd for over a decade of monitoring, the corresponding invertebrate data should exhibit correlation to mean flow if it is a dominant influence on a summer seasonal basis. The absence of such correlation does not mean that aquatic invertebrates do not respond to changes in flow, but it does indicate that low flows are not clearly deleterious and that other influences have a major role in shaping the community. Detecting the influence of a relatively small water withdrawal within the context of the overall variation in flows remains a challenge.

It has been suggested by outside reviewers that analysis of alternative measures of flow might prove insightful, or that conversion of invertebrate data might yield better correlations. Examination of macroinvertebrate measures in relation to the maximum and minimum flows with seven day duration and the standard deviation and coefficient of variation of flow over the ten week pre-sampling period did not uncover any strong relationship between flow and macroinvertebrate features. Evaluation of relationships between macroinvertebrate community features and flow features ten to twenty weeks before sampling (roughly the spring period) also produced no meaningful predictive relationships; analysis of flow farther in time from the sampling date does not appear useful in this system.

The erratic pattern of taxonomic abundance for many individual taxa suggests the potential for high flows to wash out much of the community and allow it to reset itself through immigration and reproduction, with opportunistic taxa taking advantage of available resources. High flows may be more influential than low flows at Stations 1-3 in the lower Mill River. The predator species may shape the community to some extent, and there is some potential for water quality to alter the invertebrate community through elevated contaminant loads, low oxygen, or extreme pH on a sporadic basis, but these do not appear to be major continuous influences.

The invertebrate community undoubtedly responds to changes in flow, but the influence of what are so far minor withdrawals for water supply is not apparent when superimposed on the variable background flows through Lake Whitney. The greatest concern lies with a period of extended maximum withdrawal to meet water supply needs during a period of prolonged low background flows. The SCCRWA's Management Plan is designed to minimize this combination of circumstances, which have yet to occur. Given the variability inherent in the data, it is likely to take a major shift in the macroinvertebrate community to detect any impact from extended full operation at low flows.

The ability of the benthic macroinvertebrate community to recover from disturbance in the Mill River system is encouraging. Despite major fluctuations in abundance in response to a range of factors, a thriving and fairly diverse aquatic macroinvertebrate community exists downstream of Lake Whitney and upstream of saltwater influence. Recovery times for the assessed invertebrate community features is generally in line with timeframes suggested by Ward (1992) for post-disturbance recovery, and are typically between one and two years. This could explain the every other year periodicity of some observed fluctuations in community features, although those fluctuations may not be related to flow. If there was any impact from withdrawal during a period of low flow, it should be temporary; the community at Stations 1-3 has demonstrated its recovery ability in response to multiple stresses. For example, the construction work on the dam in 2004 left station 1 dry for several months and altered the physical pattern of flow to station 2. Yet no lasting impacts from this change in flow are evident in the data.

Lack of relationships between flow features and the macroinvertebrate community suggests that continuation of monitoring is not worthwhile on a regular basis. Should a period of very low flow match up with a period of much higher withdrawal than observed since 2005, sampling in the year following the period of potential impact might be worthwhile to assess possible impacts, but in the absence of such a combination of low flow and high withdrawal, the expense of additional monitoring of the invertebrate community of the Mill River is not justifiable. If high withdrawal and low background flows do match up, it is suggested that sampling in the following year be conducted in August, to match up with the substantial data base already accumulated. This will aid comparisons and also allow some time for recovery of the invertebrate community, which is expected and would indicate no lasting impacts from the withdrawal under drought conditions.

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