Pyrethroid Pesticide Contamination of Urban Runoff in Stormwater Detention Ponds

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Abstract Stormwater detention ponds are an effective way to mitigate the effects of toxins in stormwater runoff before they reach surface waters. Pesticides are one of the greatest sources of this toxicity. Pyrethroid pesticides are the most common class of insecticide used in urban environments today with over 700,000 lbs being used every year for residential use in California. This study looked for the presence of pyrethroid pesticides at three different stormwater detention ponds in Alameda County and one pond in Marin County, California. Water samples were taken at the inlet and outlet of each pond during two rain events in the winter and spring of 2008-2009. Water samples were tested for concentrations of pyrethroids as well as toxicity to the test species *Hyalella azteca*. Species samples for *H. azteca* were also taken at the beginning and end of the rainy season to determine the effects of the pesticides on the resident amphipod community. Overall, toxicity was found in 66% of the samples. Each location was found to be toxic on at least one occasion. Some of the concentrations of pesticides were among the highest that have ever been documented in an urban setting. The ponds did show an ability to reduce pesticide levels with reductions as high as 90% in some cases. Population levels of *H. azteca* were greatly reduced over the course of the rainy season. This study showed the benefits of using stormwater detention ponds and outlined the effects that pesticides have on the benthic aquatic community.

Introduction

Urban stormwater runoff is a major water quality issue in California. The potential negative impacts of urban stormwater runoff on aquatic ecosystems have been demonstrated in multiple studies (Flint 2003, Marsalek *et al.* 2002, Ownby *et al.* 2004, Weston *et al.* 2009). There are many abiotic factors that affect the amount of toxicity in urban runoff as well as the bioavailability of contaminants in storm water. Such factors include water temperature, dissolved oxygen, water chemistry, total organic carbon and total suspended sediments (Yang 2006). Much of the toxicity encountered in urban runoff is due to the use of pesticides by commercial applicators and homeowners (Amweg *et al.* 2006). Sediment samples from 20 different creeks in California have shown concentrations of pesticides in almost every sample (Amweg *et al.* 2006, Weston *et al.* 2005, Weston *et al.* 2006). In nearly all of these instances, the levels of pesticides in the samples were found to surpass the toxicity thresholds of sensitive invertebrates. Laboratory testing with the amphipod *Hyalella azteca* has shown heavy mortality with sufficient concentrations of pesticides to explain this acute toxicity (Weston *et al*. 2009). These pesticides have been shown to have a half-life of anywhere from a few months to over a decade in some cases. Bioaccumulation occurs in many instances, with pesticide residues even found in fish fillets (Ownby *et al*. 2004, Gan *et al*. 2004)

Pyrethroids are the most common class of pesticides found in urban stormwater. Pyrethroids are sediment associated pesticides which have been favored in recent years due to their high toxicity, low application rates and relatively short persistence. Residential use of pyrethroids increased greatly since the two most widely used organophosphate pesticides were removed from the market in 2001 and 2004 respectively (Oros and Werner 2005). All products containing the common organophosphates, chlorpyrifos or diazinon, were suspended due to concerns over human toxicity and pyrethroids took over as the dominant class of pesticides used for residential applications. Because of these legislative changes, the use of pyrethroid products in California increases every year (www.cdpr.ca.gov).

A common myth is that pesticides are used primarily for agricultural use. In California, non-agricultural use of pyrethroid pesticides far exceeds agricultural use of pyrethroids. Agricultural use of pyrethroids in California has been reported at 300,000 lbs/yr, whereas non-agricultural use is currently reported at nearly 700,000 lbs/yr (www.cdpr.ca.gov). Cypermethrin is the most commonly used pyrethroid pesticide in California for urban applications, followed by bifenthrin and permethrin. All of these pesticides are used primarily for structural pest control (Oros and Werner 2005, Weston 2005). The four major urban uses of pesticides are structural pest control (making up 96% of total pyrethroid use in urban areas), landscape maintenance (1.3%), public health pest control (2.4%), and public right-of-ways (0.01%) (Oros and Werner 2005). The urban applications which present a heightened risk of contamination to surface waters include: applications to surface water directly, storm drains, outdoor impervious surfaces, other outdoor locations, sewers, spill cleanup and washing of treated items (clothing, pets and skin) (TDC 2005). Commercial pesticide companies account for the vast majority of urban pesticide use (Amweg *et al.* 2006). In general, pesticide concentrations are higher in drainage areas of newer residential communities because of frequent professional application of pesticides for structural purposes and landscape maintenance. The most commonly reported use of pesticides around the home by individual homeowners is for ant control. Nearly every yard care product, including major brands Ortho, Bayer and Scotts also contains pyrethroids (Flint 2003). All of these products can be easily obtained at retail chain stores.

Pyrethroid pesticides have been utilized since the 1980s, but they were first synthesized from a molecule found in the chrysanthemum flower in the late 1970s. The pyrethriods are neuro-inhibitors which work by keeping the sodium channels open in the neuronal membranes of insects, effectively causing paralysis (He *et al.* 2008). Sediment associated pesticides, such as pyrethroids, are extremely hydrophobic. These pesticides will exist in water for a matter of days but bind to sediments and organic matter, remaining toxic for many months (Oros and Werner 2005). Contamination of surface water by pyrethroids is usually caused by the loading of fine particles in the water column which bind the hydrophobic pyrethroids (Gan 2004). Sediment contamination by pyrethroids can have potentially long lasting effects due to the high toxicity of the pesticides to a wide range of water column and benthic aquatic organisms (Ownby 2004). The toxicity threshold for sensitive organisms varies depending on the amount of organic matter in the water, the temperature, and the concentrations of other nutrients (Yang et al. 2006). In water, the approximate lethal concentration to half of the organisms (LC50) for *H. azteca* is around 5 parts per trillion whereas the LC50 in sediment is around 5 parts per billion (Weston unpublished).

Recent efforts have been made to mitigate the toxic effects of urban runoff by the use of storm water detention ponds. There are countless pond designs all of which serve the purpose of preventing flooding in urban drainages. Storm water ponds also clean pollutants, like heavy metals and pesticides, out of the water to lessen the effects of toxins before they reach surface waters and eventually the ocean (Marsalek 2002). However, the ability of these ponds to remove pyrethroid pesticides has not been studied. Stormwater detention ponds provide habitat for wildlife and a large number of aquatic organisms. Efforts have been made to inventory the relative abundance of different taxa in these detention ponds in an effort to see what sort of community structure these ponds support and which benthic organisms are most abundant in the community (Lunde unpublished). However, none of these studies have ever compared the population structure of a benthic organism to the relative concentrations of pyrethroid pesticides. A comparison of an aquatic population to pesticide concentrations lends important information about the ecological effects of pyrethroids on sensitive benthic aquatic organisms (Maxted 2007).

This study of stormwater detention ponds in Northern California tested for the presence of pyrethroids in stormwater runoff and the efficacy of the ponds at removing these pesticides. Effects of toxic stormwater runoff on the population levels of a sensitive aquatic amphipod, *Hyalella azteca* were also studied. The questions which this study focused on were: what are the concentrations of pyrethroid pesticides flowing into and out of the detention ponds? Are there high enough concentrations of pyrethroids flowing into the ponds to cause toxicity to the sensitive test organism *H. azteca*? What are the effects of pyrethroids on the *H. azteca* populations in the stormwater detention ponds? To test for the presence of pyrethroids in stormwater runoff, an extensive water sampling study was employed at four different stormwater detention ponds in Northern California. Laboratory toxicity testing with *H. azteca* was used to characterize the toxicity of the runoff water. Populations of *H. azteca* were also sampled from the detention ponds before and after the water sampling.

I expected to find detectable concentrations of pesticides at every sampling location. Since concentrations of pesticides depend on many factors such as: Amount of storm water flowing into the pond, size of the pond, pond design, and dominant land use type of drainage area, it is difficult to predict which ponds would be most effective in reducing pesticide load. However, I did expect to see the lowest concentrations of pyrethroids at the Marin County detention pond because it is located in an older neighborhood with fewer single family residential homes. In ponds with high pyrethroid concentrations I expected to see reductions in the populations of the amphipod, *H.azteca.*

Methods

Study Design To test for the presence of pesticides and their effects on the population levels of *H. azteca* in the stormwater detention ponds, water samples and species samples were taken at four sampling locations. The sample sites in Alameda and Marin Counties, California, represented a range of urban development types. Samples were taken at Tule Ponds and Tysons Pond, both in Fremont (Alameda County), and Heron Bay stormwater detention pond in South Oakland (Alameda County). The last pond, Scottsdale Pond, was located in Novato in Marin County (Table 1).

Table 1: A comparison of the sampling sites including the neighborhoods which drained into the four different stormwater detention ponds

Location	Pond Size (ha)	Dominant Vegetation	Dominant Land-use Type	Age of Neighborhood (years)	Average Lot Size (ha)
Tule Ponds	0.30	~30% cattails, 70% open shore	Single family residential homes	5-15	0.06
Tysons Pond	1.22	~70% cattails	Single family residential homes	5-15	0.06
Heron Bay	0.23	~60% cattails	Single family residential homes	5-15	0.04
Scottsdale Pond	3.90	~20% cattails	Residential homes, mixed use commercial	20-30	0.09

Species sampling, conducted on November 5th, 2008 and on March 27th, 2009, examined changes in population levels over the winter. Water sampling was conducted during two significant rain events on November 1st, 2008 and February 15th, 2009 as well as once on March 27th, 2009 that did not occur after a rain event. Sampling only occurred after one half inch of rain or more had fallen in a 24 hour period to ensure that there was adequate flow into the detention ponds (Fig. 1).

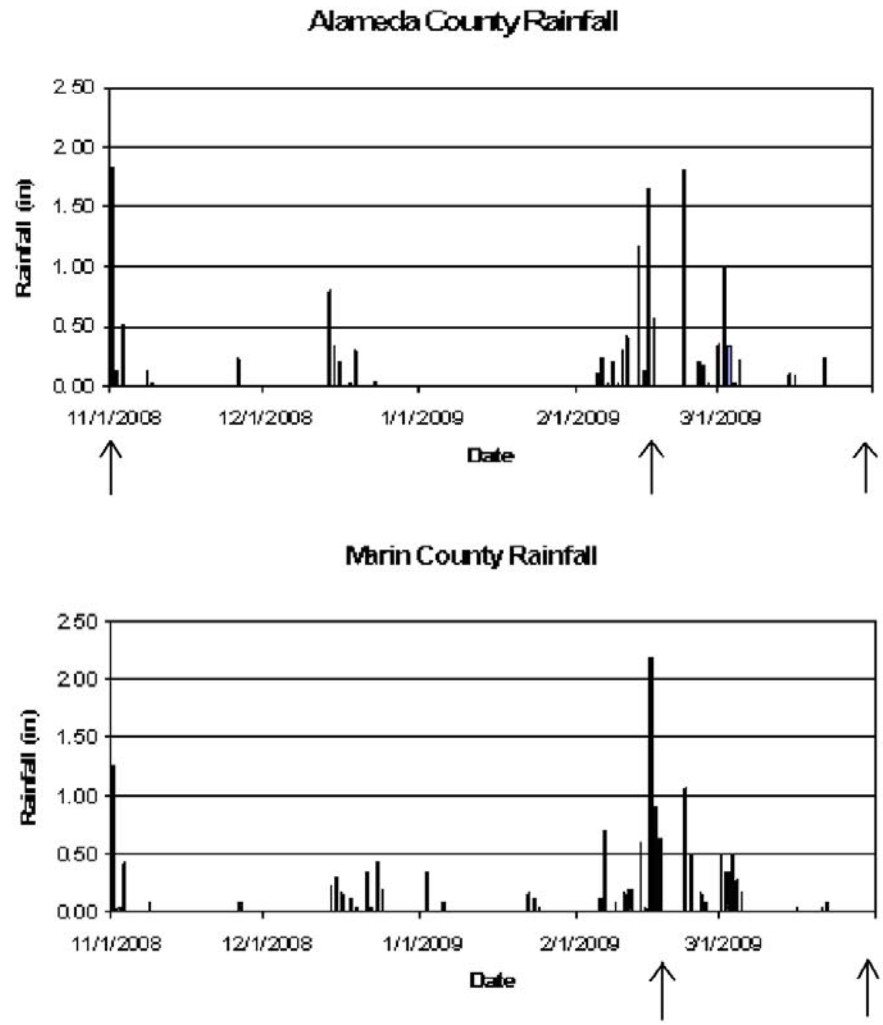


Figure 1: Rainfall in Alameda and Marin Counties with arrows showing the days that sampling occurred at each location

Field Sampling Species sampling for *H. azteca* was conducted using a 500 micron D-net. Samples were taken one to two meters away from the edge of the ponds. Fifteen samples were collected at each location by scooping from the top of the water, down through the water column, and along the bottom of the ponds to ensure a proper representation of the entire water column. Sampling locations around each pond represented the vegetation cover at the waters edge to mimic the composition of the pond. If two thirds of the pond was surrounded by one type of vegetation, then two thirds of the fifteen scoops were collected amongst that vegetation. For each location, the contents of all 15 scoops were placed in one bucket and then concentrated using a 500 micron sieve. The samples were then placed in alcohol to preserve them for identification at the laboratory. The resident *H. azteca* were removed from the samples and enumerated.

Water samples were gathered at the inflow and outflow of each pond during rain events, when rainfall exceeded one half inch at the sampling location. Only one sample was taken during each rain event because of time constraints. In locations with multiple inflows, crude estimates of flow were calculated for each drain. Once proportional flow rates were known, the samples were combined in this ratio so that for each location there was one inflow sample and one outflow sample per rain event. The water temperature was noted at each location at the time of the water sample. Samples were collected for toxicity tests, chemistry tests, total suspended solids, particulate organic carbon and dissolved organic carbon. Water samples were collected in four-liter, solvent cleaned borosilicate bottles for toxicity tests. Samples were obtained at each location by filling the jars directly at the mouth of the drain coming into the ponds at the inflows and immersing the jar below the surface of the water at the outflows. One-liter borosilicate bottles were filled for chemistry tests, 500 ml bottles were used for total suspended solids, and 40 ml glass vials were used for particulate organic carbon tests and dissolved organic carbon tests. Samples were held on ice until returned to the laboratory where they were refrigerated at 4 °C.

Sampling Analyses Water samples were liquid:liquid extracted following US EPA method 3510C, meaning all pesticides were extracted from the water and dissolved into dichlromethane (U.S. Environmental Protection Agency 2000). After addition of surrogate standards (4,4′-dibromooctafluorobiphenyl and decachlorobiphenyl; Supelco, Bellefonte, PA, USA), 1 L of sample was poured into a 2 L separatory funnel and extracted with three separate additions of 60 ml dichloromethane. The first addition of 60 ml dichloromethane was used to rinse the sample container, and all dicloromethane extracts were sunsequently combined. The sample was reduced to a volume of 10 ml using heat a stream of nitrogen, for shipment to the analytical laboratory. Samples were analyzed by Dr. Lydy of Southern Illinois University for pesticides following Yang *et al.* 2009 using a Hewlett Packard 6890 Series Gas Chromatograph System, HP6890GC with electron capture detector (Agilent Technologies, Palo Alto, CA, USA).

Toxicity Testing Toxicity tests were performed using 7 to 14 day old *H. azteca* following standard EPA methods for toxicity testing with aquatic invertebrates (U.S. Environmental Protection Agency, 2000). *H. azteca* was used because of its sensitivity to pyrethroid pesticides. Pesticide concentrations that are safe for *H. azteca* should be considered safe for most other organisms. Tests were done in 80 ml glass beakers containing 80 ml of water (five replicates per sample), 10 amphipods were added to each beaker. For controls, moderately hard water, reconstituted by addition of salts to milli-Q purified water, (Millipore, Billerica, MA, USA) was used. Tests were run between 17 °C and 23 °C (depending on the temperature of the ponds when sampled) under a 18:6-hr light:dark cycle for 4 days. On day two the water was changed and the amphipods were fed with YCT (yeast, cerophyll, trout chow). Temperature and dissolved oxygen measurements were taken each day. After a 4 day exposure, counts were made of both swimming and surviving amphipods. The survival rate, relative to the control was assessed by t-test using Cetis software (Tidepool Scientific Software, McKinleyville, CA, USA).

Samples that were found to be toxic were then subject to a toxicity identification evaluation (TIE) to determine the source of toxicity. TIEs were performed using piperonyl butoxide (PBO). PBO is a synergist molecule that works with pyrethroids to greatly increase toxicity without individually causing any toxicity. It is known to increase the toxicity of pyrethroids twofold, while decreasing the toxicity of organophosphate pesticides and showing no effect on the toxicity of cadmium, DDT, or flouranthene (Weston *et al.* 2007). The toxic water was diluted with moderately hard water from milli-Q purified water to a 25%-100% concentration. For each toxic sample, five replicates were tested with PBO and five replicates were tested without PBO. Replicates with PBO were spiked with 50 µg/L PBO in a methanol carrier, with methanol concentrations never exceeding 12.5 µl/L. Solvent controls were tested with moderately hard water and 12.5 µl/L methanol without PBO. The TIE was carried out under the exact same conditions as the toxicity test and survival in the PBO replicates was compared to survival in the replicates without PBO using a t-test calculated with Cetis software.

Data Analyses Toxicity data was analyzed using Cetis software. TIEs were determined to be significant using a one sided t-test. Significant reductions in mortality between the inputs and outputs of each pond were also assessed by t-test. Pyrethroid concentrations of each sample were compared to toxicity data, using a linear regression, to determine if pyrethroids were the source of toxicity. To account for the relative differences in toxicity among members of the pyrethroid pesticides, a toxicity unit approach was employed. Pyrethroid toxicity units (TUs) were calculated by dividing the concentration of each pyrethroid by the H. azteca 96-hr median lethal concentration (LC50) of each compound. With this method it is possible to determine the contribution of each compound to the overall toxicity as one TU should cause 50% mortality to *H. azteca* in a standard 96-hr toxicity test, regardless of which pyrethroid is present. Population numbers of *H. azteca* were not subject to statistical analysis because of the limited samples. Population numbers for each pond were simply evaluated semi-quantitatively.

Results

Water Toxicity Survival in the controls was good for all tests. Mortality in the controls was between 4%-8% for all three rounds of sampling. The majority of samples caused acute mortality to *H. azteca* especially in the first two rounds of sampling (Fig. 2). Overall 66% of the 18 total samples were toxic. Heron Bay was the most toxic of any location, with the inlet and outlet both showing more than 50% mortality during the first two rounds of sampling. Tule Ponds was the second most toxic location followed closely by Tysons Pond. Scottsdale Pond in Novato did not show nearly as much toxicity as the other two locations, but the inlet did have nearly 50% mortality on 2/15/09. The two most toxic samples were collected from the Heron Bay inlet and the Tysons Pond Inlet on 11/1/08, with both having 98% mortality.

TIEs confirmed that pyrethroids were the cause of mortality in every toxic sample. Statistically significant increases in mortality were observed in every sample that contained PBO. For the first round of sampling the following increases in mortality were seen in the replicates that contained PBO: Tule Ponds inlet-88.5% increase, p-value=.0002; Tysons Pond inlet-64.3% increase, p-value=.001; Heron Bay inlet-53.8% increase, p-value=.02. The second round of sampling for the replicates containing PBO also showed increases in mortality, and were as follows: Tule Ponds inlet-97.3% increase, p-value=.0000; Heron Bay inlet-92.9% increase, p-value=.0001; Scottsdale Pond inlet-53.1% increase, p-value=.02.

There was a significant difference in toxicity between inlet water and outlet water at each location. Tysons Pond was the largest detention pond and had the highest average reduction in mortality, with an 87.5% difference between the inlet and the outlet water (p-value=.00001, d.f.=18). Tule Ponds exhibited an average reduction in mortality of 58.9% (p-value=.0007, d.f.=18). The other two ponds showed reductions in mortality between the inlets and the outlets but the results were not significant. Scottsdale Pond showed a reduction of 43.5% (p-value=.07, d.f.=8) and Heron Bay, the smallest detention pond, showed a difference in mortality of only 14.1% (p-value=.15, d.f.=18).

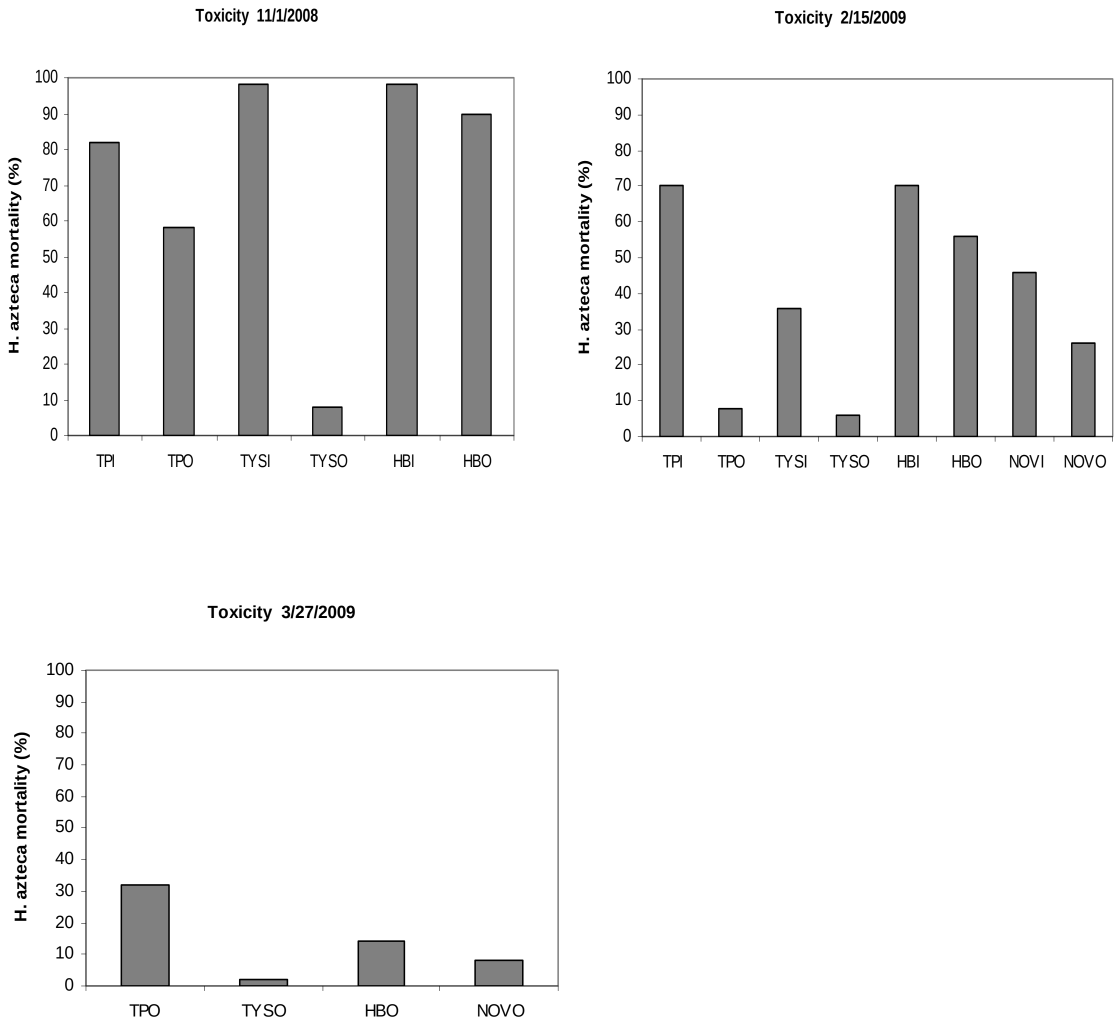
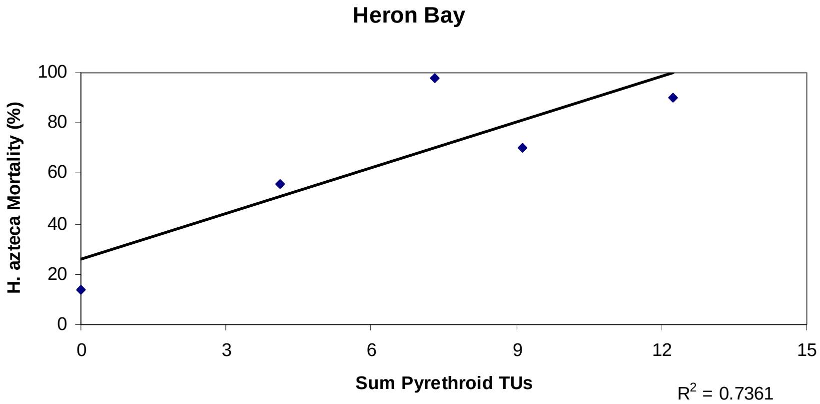
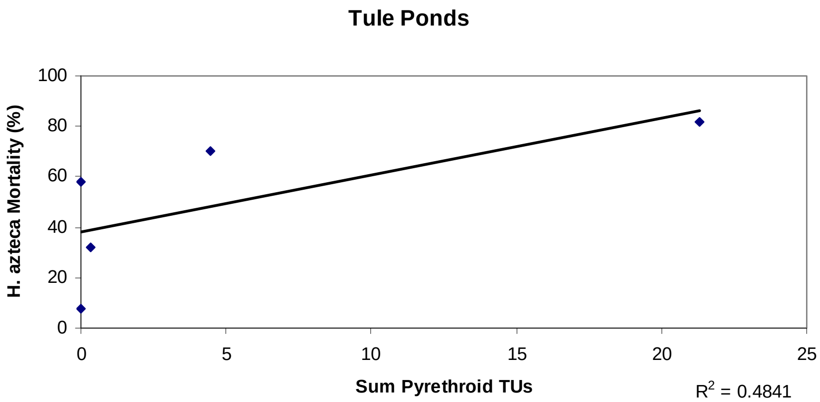


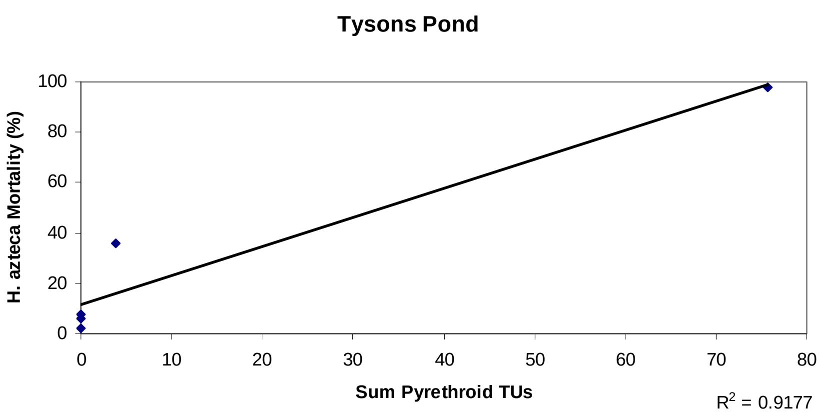
Figure 2: Toxicity of detention pond water samples to H. azteca in a 96-hr toxicity test. Different graphs represent three separate sampling events on 11/1/2008, 2/15/2009 and 3/27/2009. (TPI=Tule Pond Inlet, TPO=Tule Pond Outlet, TYSI=Tysons Pond Inlet, TYSO=Tysons Pond Outlet, HBI=Heron Bay Inlet, HBO=Heron Bay Outlet, NOVI=Scottsdale Pond Inlet, NOVO=Scottsdale Pond Outlet)

Water Chemistry Complete water chemistry results are available in the appendix. Five of the eight commonly used pyrethroids were observed in the Alameda County detention ponds. 72% of all the samples had at least one detectable pyrethroid (appendix). At the Marin County location, only one pyrethroid, bifenthrin, was present. Bifenthrin was by far the most common pyrethroid present in the stormwater, typically concentrated in the 10-40 ng/L range, with one concentration greater than 95 ng/L. Cyfluthrin and lambda-cyhalothrin were the second most common pyrethroids, with typical concentrations less than 12 ng/L. Permethrin and cypermethrin were also observed but in small concentrations typically less than 3 ng/L. The first round of sampling contained the highest concentrations of pyrethroids with an overall average of 75.77 ng/L at each location. As was expected, the second round of sampling had lower concentrations of pyrethroids (average=17.79 ng/L) than the first round but contained higher concentrations of pyrethroids than the third round (average=0.64 ng/L). The highest concentrations were found at the Tysons Pond Inlet, the Tule Ponds Inlet, and the Heron Bay Outlet during the first round of sampling. Tysons Pond Inlet, the site with the highest toxicity, had the highest concentrations of pyrethroids observed at any location. During the first round of sampling Tysons Pond contained 95.85 ng/L bifenthrin, the highest concentration observed in this study and nearly thirteen times the concentration it takes to cause 50% mortality in standard toxicity tests with *H. azteca*. The same sample also contained 81.28 ng/L cyfluthrin, 35 times greater than the concentration it takes to cause 50% mortality in standard toxicity tests with *H. azteca*. Seven of the 18 samples contained no pyrethroids in a concentration higher than the reporting limit of 1 ng/L. All seven of these samples were taken from outlets. Tysons Pond Outlet did not contain any pyrethroids during the three rounds of sampling, and Tule Ponds Outlet contained a detectable concentration of pyrethroids only in the third round of sampling. Three other samples had only one pyrethroid present in each sample while all other samples contained multiple pyrethroids.

It is not possible to determine if other unanalyzed substances are contributing to water toxicity but it is clear that in nearly all of the samples the pyrethroid concentration alone is enough to account for the observed toxicity to *H. azteca* (Fig. 3). The pyrethroid TUs were summed for each location to obtain an overall cumulative effect from exposure to all of the pyrethroids at that location. Samples with less than one TU were generally non-toxic, while samples with greater than two TUs were consistently toxic to H. azteca. No significant differences in suspended sediment load between the ponds were found during any of the sampling events. Significant contributions to bioavailability of the pyrethroids were thus not affected by the suspended sediment loads in the water.


Heron Bay
H. azteca Mortality (%)
100
80
60
40
20
0
0
3
6
9
12
15
Sum Pyrethroid TUs
R2 = 0.7361


Tule Ponds
H. azteca Mortality (%)
100
80
60
40
20
0
0
5
10
15
20
25
Sum Pyrethroid TUs
R2 = 0.4841


Tysons Pond
H. azteca Mortality (%)
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
Sum Pyrethroid TUs
R2 = 0.9177

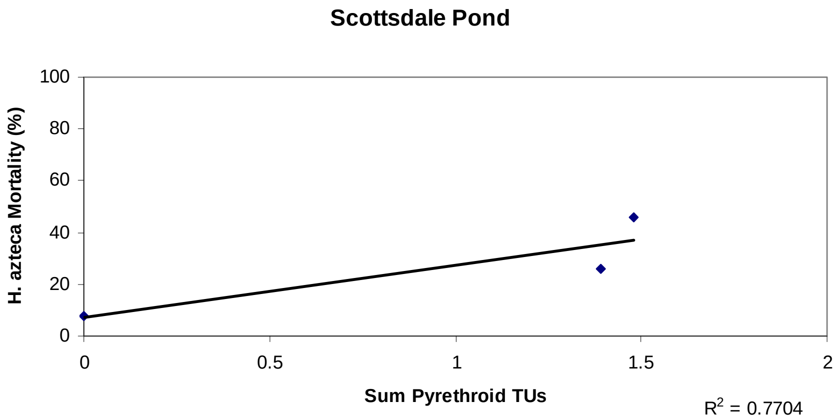
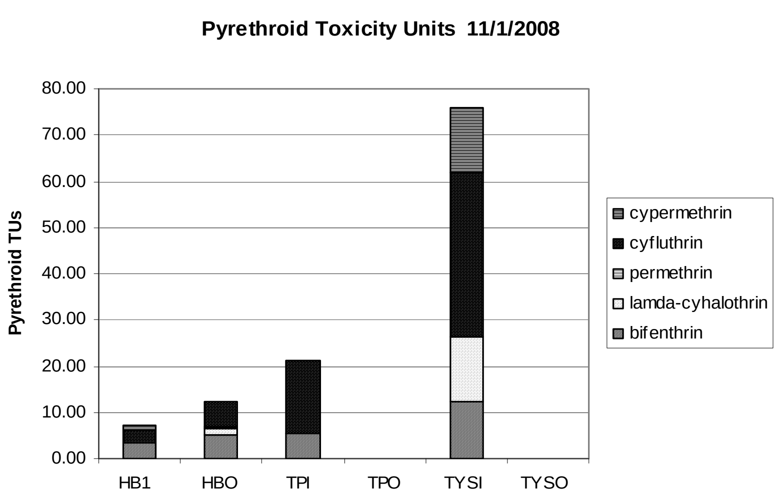
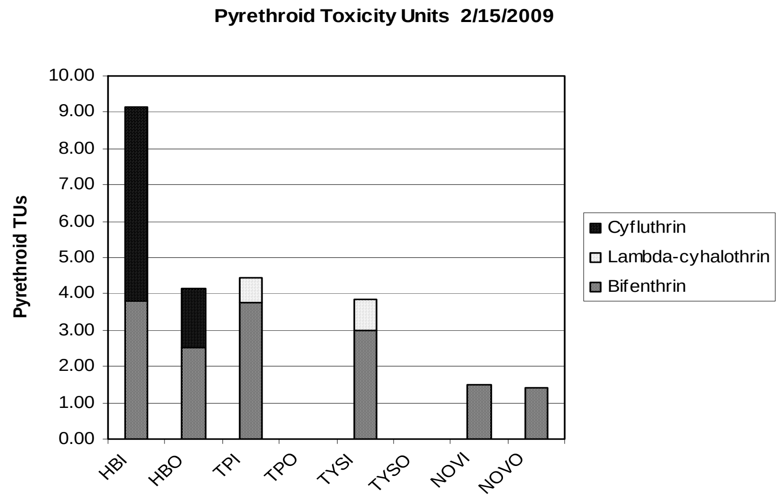


Figure 3: Correlations between the sum of pyrethroid TUs and the mortality to H. azteca found in the laboratory for each location

Ten of 18 samples contained greater than one TU of pyrethroids, while eight of 18 samples could be considered toxic (Fig. 4). Seven of the 18 samples contained no TUs and one sample contained less than one TU. The first round of sampling contained the greatest number of TUs for each location except for Heron Bay inlet, which contained more TUs during the second round of sampling. The first round of sampling produced three locations with greater than 10 TUs; with Tysons Pond Inlet containing a project high 75.85 TUs. The third round of sampling did not have a single location with over one TU. Bifenthrin and cyfluthrin were the biggest contributors to the pyrethroid TUs while permethrin, although present in high concentrations, contributed very little to the overall TUs because of its high LC50.





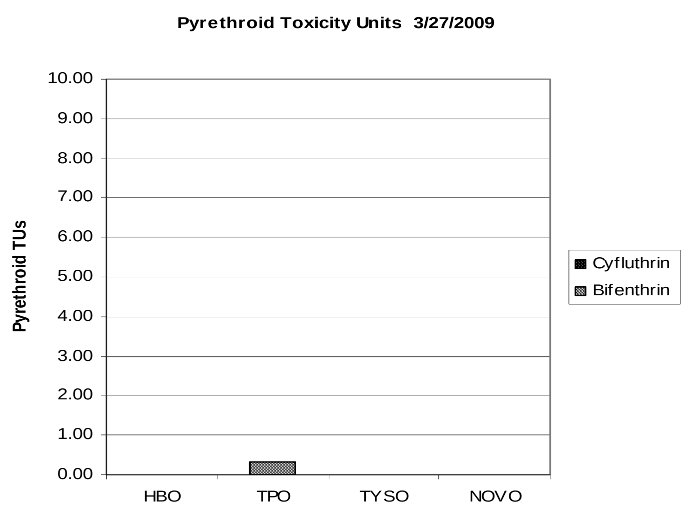


Figure 4: Sum of pyrethroid TUs at each location. Different graphs represent three separate sampling events on 11/1/2008, 2/15/2009 and 3/27/2009. (TPI=Tule Pond Inlet, TPO=Tule Pond Outlet, TYSI=Tysons Pond Inlet, TYSO=Tysons Pond Outlet, HBI=Heron Bay Inlet, HBO=Heron Bay Outlet, NOVI=Scottsdale Pond Inlet, NOVO=Scottsdale Pond Outlet)

H. azteca Abundance Species sampling for H. azteca showed the presence of the amphipod at all four of the study sites on at least one location (Table 2). At three of the locations, H. azteca was found during both the fall and spring. The amphipods were only found during the fall sampling at Tule Ponds. Overall the fall sampling contained a much higher number of H. azteca than the spring sampling with over 80% reductions in population size at each location. The twelve H. azteca found at Tule Ponds during the fall sampling event were unexpected. The Ponds had been dry for weeks and the entire H. azteca community was destroyed. The ponds filled up with stormwater from the rain event one week earlier and the water sampled from the pond's only inlet pipe contained 21.3 TUs of pyrethroids. Interestingly, there were more H. azteca during this sampling event than there were at the end of the rainy season when the water contained only 0.33 TUs of pyrethroids.

Table 2: The numbers of H. azteca counted from species samples obtained one week after the first significant rain (> 0.5 in) of the season and one week after the last significant rain of the season

Location	**11/5/2008**	**3/27/2009**	**% reduction**
Heron Bay	102	3	97.1
Tule Ponds	12	0	NA
Tysons Pond	103	18	82.5
Scottsdale Pond	446	81	81.8

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Discussion

Twelve of the eighteen samples caused significant mortality to the test species *H. azteca* in laboratory tests. Detectable concentrations of pesticides were found over the three sampling events in 72% of the samples. Ten samples contained high enough concentrations of pyrethroids to explain the toxicity to *H. azteca*. Correlations between pyrethroid concentrations and H. azteca were significant at three of the four locations (R^2 values: HB=.74, TP=.48, TYS=.92, SP=.77). The ponds showed effectiveness in reducing toxicity in runoff water. Two of the ponds, Tule Ponds and Tysons Pond, showed statistically significant reductions in toxicity between the inlet water and the outlet water while a third pond, Scottsdale Pond, showed a large reduction in toxicity but did not have enough data points to be statistically significant. In general, ponds with a larger size showed a greater reduction in pyrethroid concentrations due to the longer residence time of the water in the ponds (Marsalek *et al*. 2002). The first round of sampling produced concentrations of pyrethroid pesticides that are among the highest that have ever been recorded in urban runoff (Weston *et al.* 2009). The sampling sites with the highest concentrations of pyrethroids were, as predicted, the ponds which were located in newer residential neighborhoods such as Tysons Pond (Sum TUs= 79.62), Heron Bay (Sum TUs=32.82) and Tule Ponds (Sum TUs=25.74). These ponds repeatedly showed some of the highest toxicity among any of the samples at the inlets. Scottsdale Pond consistently contained much lower concentrations of pyrethroids (Sum TUs=2.87)

The effects of pesticide concentrations on resident communities of *H. azteca* was less clearly defined. All of the ponds showed reductions in the populations of *H. azteca* but there are many factors that potentially contributed to this population reduction. *H. azteca* normally breed from February to October, so the amphipods could have suffered from a lack of breeding (Maxted and Shaver 1997). Other factors that potentially contributed to the population decline are an increase in predation, or a lack of food resources during the winter. *H. azteca* populations were healthy in the fall sampling at every location except for Tule Ponds, although they were still found in that sample. Though these healthy communities were expected at large ponds with abundant vegetation (food source) and healthy habitat, I did not expect to see the presence of amphipods at Tule Ponds because of its relatively small size and poor water quality. These results were very surprising and can be explained by two scenarios. One possible explanation is that laboratory conditions are not a good representation of the conditions which *H. azteca* experience in a natural setting. In a laboratory water test the pyrethroids that are present in the water have no organic carbon to bind to and causing them to stay in the water for longer, and consequently increasing toxicity. Another possible explanation is that the *H. azteca* living in the wild have evolved a resistance to pyrethroid pesticides which the laboratory cultured *H. azteca* do not have. This plausible assertion would indicate why the animals in a natural setting are able to survive much better than lab-cultured representatives of the same species held under the same conditions in the laboratory. When Tule Ponds were first sampled for water they had been completely dry beforehand due to an arid summer. When the community samples were taken, only toxic water from the first major storm event was present in the Ponds. However, there was still a community of *H. azteca* living in the water. These results indicate that there must have been some population which was able to survive in the storm drain system. This population either tolerated much higher concentrations of pyrethroids than previously thought possible, or lived in some portion of the storm sewer network that did not receive pyrethroids. It is apparent that the populations at some ponds were thriving despite the toxic water flowing in from the storm drains. This finding did not match my hypothesis and suggests that there might be some other factors that can mediate the effects of the toxic water and alleviate some of the harmful toxic agents.

The effect of the ponds on the pyrethroid concentrations was generally consistent with my hypotheses. All of the outlets showed reduced toxicity from the inlets, although the results were only statistically significant for two ponds (TYS 87.5% reduction, p-value=.00001, TP 58.9% reduction, p-value=.0007, SP 43.5% reduction p-value=.07, HB 14.1% reduction p-value=.15). At Tyson's Pond for example the inlet showed toxicity to 100% of the amphipods in the laboratory while the outlet only showed toxicity to 10% of the amphipods. The long residence time of the water in the ponds as well as multiple abiotic factors, cause the ponds to be successful in sequestering most of the pyrethroids which are flowing out of the storm drains. The abiotic factors which influence a ponds ability to sequester pesticides include the amount of organic carbon in the water, the sediment load of the water and the vegetation present in the pond (Marsalek *et al*. 2002). While some of the pond outlets still showed slight toxicity, it is clear that these ponds are invaluable in reducing pesticide loads between the point source of the storm drains and the creeks where the water eventually flows to. Pesticide concentrations at each pond did not indicate a strong relationship with population levels of amphipods. Numbers of amphipods seemed to be influenced by many factors and could not be positively correlated, solitarily, with pesticide concentrations in the water. These results were consistent with other studies which indicate that pesticides alone can not be the only consideration when assessing toxicity in urban waterways (Maxted and Shaver 1997).

The results of my study are consistent with other studies conducted on pyrethroids in an urban environment and with studies that measured the effects of storm water ponds on reducing water toxicity (Marsalek *et al*. 2002, Weston *et al.* 2009). Weston *et al*. found toxic concentrations of pyrethroids coming from storm drains in residential neighborhoods, with professional use as the dominant source. The most common pyrethroid found was bifenthrin, followed by cyfluthrin and cypermethrin. My study also found bifenthrin to be the pyrethroid of the greatest toxicological concern. The highest reported concentration of bifenthrin found by Weston *et al.* was 73 ng/L while the highest concentration of bifenthrin reported in this study was 95 ng/L. Marsalek *et al*. found severe toxicity in detention pond sediments but found no acute toxicity in the creek directly below the detention pond. Sediments and toxicants were found to be sequestered by the pond and benthic communities below the pond were found to be healthy. This study produced similar results with water coming out of the ponds found to be non-toxic in 89% of the samples. This study focused on a much more polluted system than the one that was studied by Marsalek *et al*. and still found similar results with respect to the relative water quality of pond outflow.

This study raises interesting questions that could lead to some important future research. One of the major issues necessitating consideration is the ability of wild populations of amphipods to withstand much greater concentrations of pesticides than the same populations could in a laboratory setting. In a natural setting there are many more biotic and abiotic factors which contribute to water toxicity, but it seems that in some cases *H. azteca* must be building a resistance to the pyrethroids. It could be insightful to sample some of these amphipods from the toxic locations and culture them in the laboratory. A wild population could be raised and used to test water toxicity in the lab. I believe that there might be a large difference between the lab cultured amphipods and the wild amphipod's ability to withstand pyrethroid pesticides.

Since pesticide use is unlikely to be curtailed in coming years, it is important to consider the usefulness of stormwater detention ponds. Pyrethroid pesticide use continues to rise every year as the population of California grows and urban development continues to expand. The ability of stormwater detention ponds to mediate this growing pesticide use must be considered to protect the health of our waterways and the communities of organisms that live there. This study, and others, demonstrates the ability of these ponds to reduce runoff toxicity. This study, however, was limited in its scope and could have benefited from more sampling events throughout the course of the rainy season. In the future, taking multiple samples per storm event would facilitate a better idea of the overall pesticide load entering the ponds during each storm. This study however, should provide excellent preliminary data for a more in depth study of the role of pesticides in the stormwater detention pond ecosystems.

This study helped illuminate some of the water quality issues surrounding storm water detention ponds. It also highlighted their ability to mediate the toxicity of water before it connects to surface waters, and eventually to the San Francisco Bay. Stormwater detention ponds are an important tool in reducing toxicity of contaminated water as well as supporting populations of benthic organisms which survive despite the sometimes treacherous state of their habitat. This study has also reinforced the fact that dangerous levels of pesticides are being used everyday in urban neighborhoods. The concentrations of pesticides exiting these storm drains during rain events are extremely toxic and may point to a general overuse of pesticides around the home. It is important that the public is informed about the consequences of pesticide use with respect to both wildlife and humans. If the overuse of pesticides persists, however, it might be wise to incorporate storm water detention ponds into every new subdivision and commercial building complex as they greatly reduce the toxicity of stormwater runoff. These stormwater detention ponds are an easy and efficient way to protect the state water systems and promote healthy and vibrant communities within the entire aquatic ecosystem.

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Appendix

	HB1	HBO	TPI	TPO	TYSI	TYSO
	11/1/2008	11/1/2008	11/1/2008	11/1/2008	11/1/2008	11/1/2008
chloropyrifos	0.00	1.97	5.49	3.81	0.00	0.00
bifenthrin	26.41	40.64	42.18	0.00	95.85	0.00
fenpropathrin	0.00	0.00	0.00	0.00	0.00	0.00
lamda-cyhalothrin	<RL	2.88	0.00	0.00	32.03	0.00
permethrin	17.53	25.85	0.00	0.00	0.00	0.00
cyfluthrin	5.78	12.65	36.40	0.00	81.28	0.00
cypermethrin	2.82	0.00	0.00	0.00	32.30	0.00
esfenvalerate	0.00	0.00	0.00	0.00	0.00	0.00
deltamethrin	0.00	0.00	0.00	0.00	0.00	0.00

	HBI	HBO	TPI	TPO	TYSI	TYSO	SPI	SPO
	2/15/2009	2/15/2009	2/15/2009	2/15/2009	2/15/2009	2/15/2009	2/15/2009	2/15/2009
Chloropyrifos	9.15	5.59	3.75	4.88	15.75	0.00	9.63	7.74
Bifenthrin	29.13	19.51	28.97	0.00	23.13	0.00	11.41	10.70
Fenpropathrin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lambda (total)	0.00	0.00	1.55	0.00	1.96	0.00	0.00	0.00
Permethrin (total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cyfluthrin (total)	12.29	3.66	0.00	0.00	0.00	0.00	0.00	0.00
Cypermethrin(total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Esfenvalerate (total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deltamethrin (total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	HBO	TPO	TYSO	SPO
	3/27/2009	3/27/2009	3/27/2009	3/27/2009
Chloropyrifos	1.62	5.88	0.00	5.23
Bifenthrin	9.08	3.45	0.00	7.91
Fenpropathrin	0.00	0.00	0.00	0.00
Lambda (total)	0.00	0.00	0.00	0.00
Permethrin (total)	0.00	0.00	0.00	0.00
Cyfluthrin (total)	2.79	3.12	0.00	0.00
Cypermethrin(total)	0.00	0.00	0.00	0.00
Esfenvalerate (total)	0.00	0.00	0.00	0.00
Deltamethrin (total)	0.00	0.00	0.00	0.00

Appendix: complete pesticide concentration data for all three sampling rounds. (TPI=Tule Pond Inlet, TPO=Tule Pond Outlet, TYSI=Tysons Pond Inlet, TYSO=Tysons Pond Outlet, HBI=Heron Bay Inlet, HBO=Heron Bay Outlet, SPI=Scottsdale Pond Inlet, SPO=Scottsdale Pond Outlet)