ECOLOGICAL CHARACTERISTICS OF COUNTY DRAINS IN THE RIVER RAISIN, MICHIGAN

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ABSTRACT

Agricultural drainage is widely implemented throughout the U.S. to improve land drainage and increase crop productivity, affecting as much as 50% of cropland area in Midwestern states. Many of the headwater streams of this region are managed under state laws by drainage districts, county drain commissioners or similar entities. The ecological condition of these streams is sparsely documented but considered poor. I evaluated ten stream reaches, each of which contained a segment managed under the Michigan Drain Code and an unmanaged segment ("natural"), using a paired reach sampling design. Habitat quality was significantly lower for seven of nine rapid assessment metrics and for overall habitat quality. Other physical characteristics including woody debris, substrate particle size and sinuosity were all greater in natural reaches. In comparison to natural reaches, county drains were significantly incised and were nearly straight in planform. Biological assessment using macroinvertebrates indicated slightly improved scores in natural reaches but differences were not significant for most metrics. A regression of biological metrics against habitat quality that included data from a wide variety of streams within the watershed reveals poorer biological condition in both stream types than would be expected from habitat alone, suggesting that these systems are challenged by additional stressors.

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1. INTRODUCTION

Studies of fluvial geomorphology show that a river system will tend toward a state of dynamic equilibrium following disturbance (Leopold, 1994). When a state of dynamic equilibrium is achieved, the river exhibits a relatively stable dimension, pattern and profile such that, over time, channel features are maintained and the stream system neither aggrades nor degrades (Rosgen, 1996). This is not the case for county drains.

In the Midwest, county drains are systems of open channels receiving water from subsurface tiles that drain primarily agricultural lands. These systems have evolved from the small open ditches originally constructed by early settlers to drain wet areas in fields. Inevitably drainage from upland farmers affected the drainage of those farmers downstream and prompted the creation of open channel networks. To regulate these complex channel networks, Congress established Drainage Districts to meet the objective of draining excess water to allow for the public's safety and agricultural production (Atherton et al., 1999). These drainage enterprises were developed principally in 1) the prairie and level uplands of the Midwest, 2) the bottom lands of the Mississippi Valley, 3) the bottom lands of the Piedmont and hill areas of the South, 4) the coastal plains of the East and South and 5) the irrigated areas of the West (Schwab, 1993). Ohio passed its first drainage laws in 1841 (Atherton et al., 1999). Primary development occurred during 1870 – 1920 and the post WWII period from 1945 – 1960. Today's drainage networks are a common part of the Midwest landscape; the Great Lakes and Cornbelt regions have the most extensively drained states in the nation with typically 25 – 60% of the agricultural lands in each state "drained" (Zucker, 1998).

A typical county drain is a channel in which the gradient and trapezoidal cross-section have been increased so that larger amounts of water move through the watershed more quickly. The constructed channels of these low gradient trapezoidal channels have a tendency to aggrade (Schwab, 1993). As a result, drainage channel capacity and shape must be continually maintained for the designed drainage effects. Maintenance activities include sedimentation removal and clearing of blocked subsurface drain outlets (Nolte, 1972). Hydraulic backhoes sculpt uniform trapezoidal shaped channels from the natural channels. The regular maintenance does not allow natural geomorphic processes to occur. The resultant channels are highly artificial and present a challenging environment for the biota.

Channelization affects both the physical and biological components of the ecosystem. In channelized rivers, enlargement of channel size, and especially increases in channel width, enhance the fluvial power of floods, but decrease the power of low flows, resulting in substantial erosion during floods and re-deposition during low flows (Rhoads, 1990). High rates of sediment deposition result in loss of the best benthic habitat and, consequently, reduction in invertebrate population (Waters, 1995). Channelization also results in the straightening of channels, causing important microhabitats such as bends, pools and riffles to be destroyed during construction. Reduction of habitat diversity, and in particular the elimination of pools, adversely affects fish populations. In order to sufficiently drain the constructed networks, channel gradients are excavated below natural riverbed, resulting in a deeply incised and over-sized channel (Schoof, 1980, Zucker et al., 1999). Infante (2001) found that fish assemblages decreased significantly with increasing channel incision.

Drainage activities also affect the riparian vegetation, and are accompanied by the loss of trees and shrubs, which are replaced in most cases with a monoculture of grasses. In constructing and maintaining county drains, channels are stripped of their natural vegetation to allow equipment access, decrease drainage time, and provide more tillable land (Allan, 2007). Removal of riparian vegetation can cause considerable change in stream habitat conditions, altering the composition of the biological community (Sweeney, 1992) and resulting in warmer stream temperatures (Abell and Allan, 2002). Brush and tree removal deprive instream biota of important spawning habitats, food supply, cover and shelter (Schoof, 1980).

The characteristics of channelized streams have been investigated, with some of the most comprehensive studies carried out in Illinois (Landwehr and Rhoads, 2003; Rhoads and Herricks, 1996). Lakshminarayana et al. (1992), Cooper, et al. (2002) and Anderson et al. (2003) are some of the relatively few studies focused on the ecological impact of agricultural drainage. The present study evaluates the ecological structure of county drains in the River Raisin watershed and the macroinvertebrate community that inhabits them. In addition, I compare county drains with other agricultural headwaters in the River Raisin watershed for a number of ecological metrics.

2. METHODS

2.1 LOCATION AND SITE SELECTION

The study sites lie within the River Raisin Watershed, which is located in southeast Michigan with a small portion in Ohio (Figure 1). The 2,776 km^2 watershed represents three different ecoregions: the Southern Michigan and Northern Indiana Till

Plain, the Eastern Corn Belt Plain, and the Huron, Erie Lake Plain (Omernik, 1988). The last glacial retreat of the Pleistocene Epoch created two distinct geological patterns represented today. In the northwest, glacial moraines and till plains consisting of cobbles, clay, silt, sand and gravel form rolling hills referred to as the Irish Hills. The headwaters arise at 330 m in an area of inter-connected lakes and swampy channels that support the steepest portion of the River Raisin (1.1 m/km). The topography and soils of the middle sections of the Raisin are a series of glacial lake dunes traversing the basin from the southwest to the northeast. These mid-basin dunes consist of well-drained sands and sandy loams (SEMCOG, 1978). Downriver of this section and south of Adrian, Michigan, one encounters lake bed deposits from the glacial meltwaters. This resulted in abundant wetlands that were originally thought too mosquito-infested to ever be populated by man (Hager, 1997). The river gradient is low through this section (0.25 m/km) and the soils are clay and sand layered lake deposits. After the War of 1812 settlers cleared and drained much of the watershed land for farming, and this area remains in such use today.

Land use today in the River Raisin watershed is predominately agriculture, accounting for approximately 65% of total land use (Figure 1). The primary crops are soybeans, corn and wheat with some specialty crops as well as some dairy operations. The 400 km-long river has a complex drainage network of 4,800 km of man-made drainage systems that flow into the river and its tributaries. Most of the 14% forest and grassland are found in the headwaters in the northwest. Most of the 134,000 people are concentrated in small cities with populations of less than 10,000. Adrian and Monroe, Michigan are the largest urban centers. Much of the upper northwestern watershed remains forested while the dominant agricultural land use appears in the mid and lower watershed where the highly productive lakebed soils are located. The lower 4 km of the river flows through the highly urban and industrialized city of Monroe, Michigan, before it enters into Lake Erie. The River Raisin watershed basin is representative of watersheds in the southern Great Lakes region (Bright, 1995) and provides a good study site of county drains within the southern Great Lakes region.

All research sites are located near the middle of the watershed and lie within Lenawee County, Michigan (Figure 2). The county includes moraines near its northern border and lake bed deposits predominately in agricultural use in the middle and southern parts. The majority of the River Raisin watershed is in Lenawee County and the ranges of physiognomy, geology, land use and population distributions throughout the watershed are represented within Lenawee County as well.

River Raisin research sites were selected through the following criteria. Connected adjacent reaches with a natural watercourse and an open county drain were selected as a set of paired research sites. The reaches had to be located on at least a 1 km long tributary and maintain flowing water through the spring and fall. Paired sites had to be of the same stream order and at least 150 m long. Sites were located using the Lenawee County Drain Commission’s map of county drains. Fifteen possible paired sites of a natural reach and county drain existed in the county and 10 paired sites met the above criteria and were selected for study (Table 1).

2.2 <u>MACROINVERTEBRATES</u>

2.2.1 Sampling

Macroinvertebrate sampling was completed twice at each research site during August – September 2002 and again April - May 2003 to capture seasonal variation in biota. For each sampling period one composite sample from a 100 m reach was collected using a 250 μm mesh D-frame net. Habitat was sampled in proportion to its presence throughout the reach. Habitat included pools, riffles, runs, undercut banks, overhanging vegetation and woody debris. The sample was preserved with 75% ethyl alcohol and brought back to the lab. There it was diluted with tap water to four gallons. After thoroughly stirring, 2 quart volumes were dipped and placed into sorting pans for random selection. Macroinvertebrates from the classes Insecta, Annelida and Crustacea (Amphipoda only), were randomly selected and placed into a sample vial for a total 100 specimens per vial. A second vial was filled in the same manner to produce a total of 200 specimens from each sampled site per sampling season for a targeted total of 400 specimens. When the targeted 400 specimens were not present at seven sites analyses were based on the total number of specimen in the field sample.

2.2.2 Analyses

Invertebrates were identified to the lowest practical taxonomic level. Family was the lowest level identified for the Class Insecta. All other classes were not identified beyond order. Because multiple indices are available to calculate invertebrate diversity and some authors (e.g., Resh and Jackson, 1993) argue against relying on a single measure, I calculated several diversity indices and metrics. Hilsenhoff Family-level Biotic Index (FBI) scores were determined according to procedures described by Hilsenhoff (1988). The number of individuals in each family was multiplied by its tolerance value. The sum of all those products was divided by the total number of individuals to yield a weighted average tolerance score for the sample.

$$\text{FBI} = \frac{\sum t_i n_i}{N}$$

t_i = tolerance value of the i^{th} taxa, (Hilsenhoff 1988)
n_i = number of individuals of the i^{th} taxa
N = Total number of individuals in the sample

Another biotic index, the Ohio EPA Invertebrate Community Index (ICI) (Ohio EPA, 1988) was also calculated for each site (Table 2). The ICI scoring system is scaled to the drainage area for all of the metrics except percent mayfly composition and the percent tribe Tanytarsini midge composition, and assigns a score of 0 (worst condition), 2, 4, or 6 (best condition). Due to differences in taxonomic identification level, metrics for presence of tolerant species and for the presence of Tanytarsini midges were omitted (see Table 2 for complete listing of the metrics used). Three multimetric indices incorporating pollution sensitive macroinvertebrates were calculated: Sum of Ephemeroptera, Plecoptera and Trichoptera taxa (EPT); the ratio of EPT taxa to Dipteran taxa (EPT/D); and the percent of EPT taxa (% EPT richness). A fourth index, percent dominance (% Dominance), was calculated by summing the individuals of the three dominant taxa and expressing that as a percentage of the total individuals. Single metrics include total number of taxa (taxa richness), number of Dipteran taxa, number of Ephemeroptera taxa, number of Plecoptera taxa and the number of Trichoptera taxa.

Selected metrics were also calculated based on the number of individual specimens in the sample and are listed with an “individuals” qualifying term (Table 5).

2.3 RIPARIAN VEGETATION

Riparian vegetation was classified into four categories: grass, forb, shrub, and tree at twenty research sites. Transects at 5m increments were inventoried and recorded as percent representation of grasses, forbs, shrubs and trees for 100m reaches. Each transect was 0.3 m wide with the length of the transect extending past each bank twice the distance between streambanks. Visual estimations of each vegetation classification were made and only classes representing greater than 33% were considered. Riparian vegetation was analyzed by paired t-test to determine significant vegetation comparisons between natural reaches and county drains.

2.4 HABITAT

Habitat was assessed using Michigan Department of Environmental Quality Procedure 51, Habitat Assessment protocol (MDEQ, 1997) during spring 2003 at each study site. The protocol sums nine individual metrics of substrate habitat diversity and availability, degree of embeddedness, velocity and depth variability, flow stability, bottom deposition, availability of pools-riffles-runs-bends, stream bank stability, bank vegetation stability, and streamside cover (Table 3). Paired t-tests were completed to analyze habitat differences between natural reaches and county drains.

2.5 CHANNEL SUBSTRATE

Channel substrate was assessed by measuring the diameter of random substrate particles along each 150m reach to quantify substrate (Infante, 2001). Three to four substrate particles were randomly selected in the channel thalweg at 5m intervals along the reach for a total of 100 particles. Particles were measured using a US SAH-97^{TM} Hand-held Size Analyzer or gravelometer by recording the smallest opening in the gravelometer through which the particle could pass. A site D_{50} particle size was calculated from the 100 particles measured at each site. Paired t-tests were completed to analyze substrate differences between natural reaches and county drains.

2.6 WOOD

Wood within channel was measured at the 20 research sites for 150m reaches and summed to produce a total wood volume with the reach. Wood at 5 m transects 0.3 m wide were measured and summed along the reach. Average transect wood volumes were calculated for each 5 m reach, then multiplied by the length of the reach segment (5m) and summed for a total mass of wood within the channel. Wood measurements were taken for two flow types, wetted channel and bankfull flow (2.5 year storm water level or where permanent vegetation was established on the streambank). Paired t-tests were used to compare woody debris differences between natural streams and county drains.

2.7 SINUOSITY

Sinuosity was measured by surveying the channel thalweg for 100m reach at each research site, with the exception of research pair 1, during leaf-off conditions. Dense and tall vegetation in pair 1 obstructed the view from the survey tripod and could not be surveyed without major vegetation removal. Northing and easting coordinates where recorded with a total station at all points where the channel thalweg changed directions. Using ArcView^{TM} , the length of the channel thalweg and the straight line distance between the first and last survey points were digitally measured.

$$\text{Sinuosity} = \frac{\text{Length of channel thalweg}}{\text{Straight line length between first and last coordinates of channel thalweg}}$$

Paired t-tests analyzed sinuosity differences between natural streams and county drains.

2.8 CHANNEL SHAPE

Channel cross sections were surveyed at the 20 research sites. A self leveler laser and rod were used to measure elevation of principal channel points: top of bank, toe, thalweg, and at points of wetted depth change. Horizontal distance between survey points was measured using a survey tape. Hydraulic radius was calculated for low flow condition. Depth was determined by dividing the representative cross-sectional area by the width of the water surface. A measure of channel incision was calculated as the distance between bankfull and low flow depth of a representative cross-section and also the ratio of bankfull to low flow stream width as described in Infante (2001) as the fit of the low flow to the available channel.

2.9 HYDRAULICS

Velocity was measured with Marsh-McBirney 201D digital current meter using standard metering techniques (Dunne and Leopold, 1978). Slope was calculated from the difference between the first and last thalweg survey points of each 100m reach.

2.10 AGE OF CHANNELIZATION

The county drains of Lenawee County were legally established from 1899 to 1950. Original survey dates in most cases occurred two to three years after establishment. However original construction for the county drain research sites was not found in the Lenawee County Drain Commission files. Lenawee County Drain Commission administers drain maintenance as petitioned by the public and these dates of drain maintenance are recorded in the Lenawee County Drain Commission log. Detailed descriptions of Lenawee County channel maintenance procedures are not recorded. Personal communication from Joe Brezvai, Drain Commission Engineer, suggests that maintenance may follow one of two scenarios: 1) removal of vegetation either with a hydraulic backhoe and scalping the vegetation and topsoil off the streambanks or cutting vegetation by means of a mower and loppers, 2) Reshaping of the channel with the use of large equipment to remove sediment and debris from the channel bottom and to reshape channel dimension back to original design depth, toe, width, and profile slope. For this study the date of last county drain maintenance was used as the date of channelization.

3. RESULTS

3.1 MACROINVERTEBRATES

3.1.1 Assemblage Composition

Over 6,800 macroinvertebrates representing 52 families of insects and 4 classes of other macroinvertebrates were collected from 20 sites located on 10 streams. Most sites had 300 – 400 individuals with totals ranging from 208 to 411 (mean = 341.4) (Appendix 1). The number of families at each site ranged from 8 to 26 with a mean of 18.6. The greatest diversity occurred in the order Diptera, which included from 3 to 10 families per site (mean = 6.0), while EPT taxa varied from 0 to 10 per site (mean = 3.6) (Appendix 2).

Six common taxa accounted for over 75% of the total invertebrates collected, with the most abundant taxon, midges of the Chironomidae, accounting for over half of the total. Elmidae, Tipulidae, Hirudinea, Amphipoda, and Tabanidae round out the rest of the most abundant taxa. Baetidae, Heptageniidae, Caenidae, and Leptophlebiidae were the most common ephemeropteran families found. Plecoptera and Trichoptera were less common, with zero to two families of stoneflies and zero to five families of caddisflies at a site. Only three taxa of Plecoptera were collected: Perlodidae, Nemouridae, and Capniidae.

The most abundant taxa were also those occurring with the highest frequency across sites (Table 4). The Chironomidae occurred at all sites and the Elmidae, Tipulidae, Oligochaeta, Amphipoda, and Tabanidae occurred in at least 75% of the sites. Families of EPT were encountered less frequently, with Ephemeroptera families Baetidae, Heptageniidae, Caenidae, and Leptophlebiidae occurring at 25 – 40% of the sites. The Trichoptera families Phryganeidae and Psychomyiidae were found at 30% and 35% of the sites, and the Plecoptera family Perlodidae at 25% of the sites, indicating a lower frequency of occurrence consistent with lower overall abundances. Several other taxa including the Ceratopogonidae, Corixidae, Gerridae, and Simuliidae were not abundant yet occurred in over half of the sites.

3.1.2 Assemblage Comparisons: Natural Streams and County Drains

Comparison of mean values from natural streams versus county drains for each of 23 macroinvertebrate metrics (Table 5) strongly indicates that biological assemblages of drains are impaired relative to natural streams. Metrics were higher in natural streams for 16 of the 23 comparisons, significantly so in three cases. Taxa richness was similar between the two stream types, although trichopteran metrics were higher in natural reaches. Trichoptera diversity and abundance was double in natural reaches as both number of taxa and number of individuals were twice that found in county drains. Trichopteran metrics provided the strongest evidence that natural reaches have greater richness, more individuals, and higher percentage representation within the site assemblages.

The multi-metric indices were all greater in natural reaches than county drains, but none were significantly so at $p< .05$ (one-tailed test based on the expectation of poorer conditions in drains). However, if the significance level is relaxed slightly ($p< .10$), then three indicator metrics were significantly higher, including EPT taxa, percent EPT taxa, and the EPT/Diptera taxa ratio. The Hilsenhoff FBI showed the least support for the expectation that invertebrate assemblages of drains would receive lower biological quality scores. In sum, natural streams received higher scores than county drains with most metrics, and although some showed little difference or even higher values in drains, the fact that 70% of the macroinvertebrate metrics exhibited higher means in natural reaches indicates a trend in the expected direction. Overall, natural reaches tend to have more robust macroinvertebrate assemblages than do county drains.

3.2 HABITAT

3.2.1 Habitat Assessment

Within this predominantly agricultural watershed there exist reaches that provide little habitat to support aquatic life and other reaches with very desirable habitat, as evidenced by total habitat quality scores that ranged from 20 to 102 out of a possible score of 145. Mean scores for seven of the nine individual MDEQ metrics were rated poor to fair (Table 6). The velocity and depth metric ranged from 0 to 13 with a mean of 5.2, which is considered fair, due to the frequent absence of two of the four habitat categories, riffles and fast, deep runs. The bottom substrate metric had the greatest range (0 to 18) and variability (mean ± s.d.: 5.95 ± 5.88), however most sites were poor due to less than 10% rubble, gravel, or other stable habitat being present and the obvious lack of habitat for macroinvertebrates. Stream banks appeared moderately unstable, based on the observed frequency and size of erosional areas. Steep bank slopes also showed evidence of high erosion potential during extreme high flows. Only two metrics, vegetative stability and streamside cover, were rated as good. Some 50-79% of the stream bank surfaces were covered by vegetation, resulting in good bank vegetation stability.

3.2.2 Habitat comparison

Natural reaches had significantly better habitat (mean ± s.d.: 70.18 ± 19.72) than did county drains (mean ± s.d.: 35.0 ± 8.01). Seven of the nine habitat metrics had statistically higher scores in natural reaches than in county drains (Table 7). Pools, riffles, and runs were far more common in natural reaches than county drains (Figure 4). Habitat quality scores for bottom substrate, embeddedness, and velocity and depth variation all were greater in natural reaches, which were rated fair, than in county drains, which were rated as poor. The contrast between natural reaches and drains was even more pronounced for flow stability, bottom deposition, and presence of pool, riffle, run, and bend habitats, all of which were rated as good in natural reaches and poor in county drains.

Little difference was observed in bank stability between each natural reach and its paired county drain (means of 5.4 and 5.5, respectively) where streambanks were in fair condition and moderately unstable. There is high potential for erosion during extreme high flows due to moderate frequency and size of erosional areas on side slopes, which vary from gradual sloping bare earth to gully wash-outs on steep slopes. Vegetation stability was the only metric that was greater in county drains (mean ± s.d.: 7.5 ± 3.17) than in natural reaches (mean ± s.d.: 5.6 ± 2.22). Dense grass seeding provided stability to the steep side slopes of county drains, whereas the natural reaches had areas of exposed soil (Figure 3.4). Both fell into the category of good, and the two stream types were not significantly different (p-value = .088).

3.3 WOOD

The extent of wood varied widely among the 20 stream sites, as some reaches had substantial logjams whereas others were devoid of any wood. The volume of wood within the bankfull channel ranged from 0 to 14.7 m^3/150 m (mean = 3.4 m^3/150 m) and approximately half of this was available habitat under low flow conditions (mean of 2.0 m^3/150 m). Comparing the two channel types, wood in the bankfull channel was over seven times more abundant in natural streams (mean = 5.9 m^3/150 m) compared with county drains (mean = 0.8 m^3/150 m) (Figure 5). Logjams were not present in county drains but accounted for two-thirds of the total volume of wood in the bankfull channel of natural reaches (Figure 3.4). For all other sizes of wood, natural reaches and county drains were similarly proportioned however with less frequent occurrence in the county drains. Within the bankfull channel, each wood size in the county drains had less than one-half the volume of natural reaches (Appendix 3).

Wood within the wetted channel was greater in all four size categories and in total volume for natural reaches (mean = 2.4 m^3/150 m) by a factor of ten in comparison with drains (mean = 0.2 m^3/150 m). The majority of the wood present in both cases occurred in the size range of 11 – 30 cm diameter and natural reaches had six times more wood than did drains. Logjam habitat was not found in the county drains while logjams occurred in 20% of the natural reaches and accounted for one-third of the total volume of wood within the wetted channel.

3.4 RIPARIAN VEGETATION

Riparian vegetation across the 20 sites was quite diverse and ranged from a monoculture of grass to mature forest. The most frequently occurring vegetation, forbs and shrubs were present at 90% of sites and averaged 23% and 19% respectively of the vegetation at each site (Appendix 4). Trees were present at 85% of the sites and ranged from 1 to 84% of the riparian vegetation (mean ± s.d.: 29.43 ± 26.58). Grasses occurred at 70% of the sites and where present ranged from 1 to 100% (mean ± s.d.: 28.8 ± 35.88).

Riparian vegetation along county drains tended toward a monoculture of grasses whereas natural reaches provided more vegetation diversity. On average natural reaches had 3.5 of the four vegetation types present and county drains had 3.0 (p=.05). Grasses occurred at 80% of the drain sites and represented more than half of the riparian vegetation along county drains (Figure 6). In contrast, grasses represented only 6.8% of the riparian vegetation along natural reaches and occurred at only 60% of the sites. The quantity of forbs or shrubs was not significantly different between natural reaches and county drains, but were present at all natural reaches and only 80% of the county drains.

Grasses were the dominant vegetation along county drains while trees were the dominant vegetation along natural reaches (Figure 3.5). Grass cover was seven times greater in county drains (mean ± s.d.: 51.0 ± 39.0) than in natural reaches (mean ± s.d.: 6.7 ± 10.3) (p-value = .005) and trees were three times greater along natural reaches (mean ± s.d.: 47.7 ± 22.6) than county drains (mean ± s.d.: 12.4 ± 15.9) (p-value = .01).

3.5 CHANNEL DIMENSIONS

Channel dimensions were variable across the 20 research sites but were similar in having relatively small low flows in combination with much greater bankfull flows that were approximately ten times the low flow. Wetted channel cross-sectional area ranged from 0.05 to 2.8 m^2 (mean = 0.65), whereas bankfull cross-sectional area ranged from 0.8 to 35 m^2 (mean = 7.7) (Appendix 5). Wetted channel depth varied from 0.03 to 0.58 m (mean ± s.d.: 0.20 ± 0.15). Channel incision was six times the low flow depth and ranged from 0.3 to 3.2 m (mean = 1.2). Channel width ranged from 1.4 to 5.3 m (mean ± s.d.: 2.8 ± 1.1). Hydraulic radius ranged from 0.03 to 0.51 m (mean ± s.d.: 0.18 ± 0.13).

Natural channels and county drains differed in bankfull capacity and channel incision but not in most other channel dimensions. The incision depth of county drains (mean ± s.d.: 1.6 m ± 0.79) was twice that of natural reaches (mean ± s.d.: 0.8 m ± 0.37) (p = 0.003) (Figure 7). In addition, the bankfull cross-sectional area (mean ± s.d.: 11.1 m^2 ± 9.5) of county drains was almost three times that of natural reaches (mean ± s.d.: 4.3 m ± 3.3) (p = .025). Water depth, surface width, cross-sectional area, and hydraulic radius did not differ significantly.

The sinuosity of the channels differed significantly, with county drains that were nearly straight and natural reaches that on average were 12% more sinuous than county drains (p-value =.006) (Figure 8). The county drain sinuosity ranged from 1.0 to 1.1 (mean ± s.d.: 1.03 ± 0.05) whereas the sinuosity of the natural reaches was more variable, ranging from 1.0 to 1.4 (mean ± s.d.: 1.15 ± 0.12) (Figure 10).

Channel profile slopes were not significantly different between natural reaches (mean ± s.d.: 0.0034 m/m ± 0.0022) and county drains (mean ± s.d.: 0.0029 m/m ± 0.0024) (p=.69).

3.6 LOW FLOWS AND OTHER PHYSICAL FACTORS

Differences between measured low flow rates were negligible. Natural reach low flows (mean ± s.d.: 0.13 m^3 ± 0.13) were within 6% of the county drain rates (mean ± s.d.: 0.12 m^3 ± 0.13).

Substrate particle size was similar across the 20 research sites; however, the particle size range of natural reaches was more variable compared to the homogenous county drains. Median particle size (D_{50}) within natural reaches ranged from 1.1 to 30.2 mm (mean ± s.d.: 4.93 ± 8.96) and county drains ranged from 1 to 7 (mean ± s.d.: 1.77 ± 1.86). However the median D_{50} for natural reaches and county drains were relatively small, 1.65mm and 1.1 mm respectively, and not significantly different (p-value = 0.16).

3.7 CHANNEL MAINTENANCE

County drain sites had all received maintenance that included vegetation and sediment removal, with the exception of site 2d, where a road crossing culvert replaced in 1977 was the only recorded intervention (Table 1). The date of last county drain channel maintenance ranged from 1965 to 2001 (mean ± s.d.: 1991.2 ± 12.4) (Table 7). The median was 1997, which reflects the somewhat regular occurrence of channel maintenance.

Natural sites for the most part were not managed; however, three of the natural sites did receive regular maintenance from adjacent landowners that included mowing and/ or burning. An approximately 10 m reach of research site 1n experienced spring vegetation burning and regular grass mowing throughout the growing season. Site 2n receives periodic mowing of the understory and removal of logjams by the adjacent landowner (Figure 3.2). An approximately 30m section along site 8n is used as the landowners lawn (Figure 3.8), and vegetation is maintained by mowing approximately once per week throughout the growing season.

4. DISCUSSION

County drains differ from their paired natural stream reaches in multiple features of channel shape and habitat that result from the excavation and maintenance of stream sections designated under the County Drain Code and managed by Drain Commissioners and land-owners. The bankfull capacity of county drains was on average three times greater than natural reaches, and the former also were more deeply incised. During the construction of county drains, excavated material typically is placed on one or both sides of the channel, forming small levees that restrict overbank flooding. As a consequence, larger storm events are contained within the county drain channel, whereas the less incised and smaller capacity natural reaches are more likely to overflow their banks, thus dissipating energy and connecting to their floodplains with greater frequency (Figure 3.7).

In addition to an increase in overall channel size, county drains are straightened to enhance water conveyance (Ward et al. 2001). Natural stream channels were moderately sinuous, with sinuosity indices in the range of 1.1 to 1.2, whereas the county drains were relatively straight channels. Because much of the study region was historically wetland, which was drained by ditch construction beginning in the mid-nineteenth century, it is difficult to know whether natural channels have been deepened and straightened, or if the channel is completely artificial. Over time and in response to high flows, channels are expected to shift in location, develop sinuosity, and reach a stable state. However, drain maintenance occurred on average every 10 years, which would disrupt any natural tendency to develop channel features more similar to natural reaches.

Substrate conditions differed markedly between county drains and natural channels. Median particle size was smaller and visually assessed silt deposition greater in the county drains. Because country drains were located upstream of the natural reach in nine of the ten pairs, and the amount of sedimentation was expected to be similar throughout all sites, this difference indicates that different geomorphic processes are occurring, presumably reflecting greater in-stream erosion, deposition, or both. Because county drains have three times the flow capacity of natural reaches, sediments are more likely to be retained within the channel, whereas the natural reach can deposit sediments on the floodplain during times of high flows. It also is possible that more sediment is eroded from stream banks within county drains, which presumably experience higher velocities at high flows because they have less opportunity to dissipate energy with overbank flows.

Natural reaches contained substantially more wood that country drains. Because wood serves as habitat for biofilms, invertebrates, and fishes, creates channel complexity, retains organic matter, and is a food resource for some insects, its presence significantly benefits the biota. Channel and bank maintenance activities again are important contributors to these differences, through active removal of wood from the channel as well as management of riparian vegetation. Trees were absent from county drains but accounted for about half of the riparian cover along natural reaches, where they serve as a continual source for wood in the channel. Along county drains, in contrast, the dominant riparian cover was grass. However, while grasses provide the dominant cover for county drains, shrubs and small trees replaced grasses as time between maintenance is extended. Portions of both natural reaches and county drains were maintained by private landowners for the desired aesthetics. In some cases riparian vegetation became part of grassed lawns and in others the desired effect was a mowed understory with a tree canopy (Figure 3.8). Landowner education covering the ecological benefits of decreasing stream temperature and providing fish habitat and macroinvertebrate food sources may stimulate more diversity of riparian vegetation along the county drains.

As a consequence of these profound differences in channel shape, substrate, and wood between county drains and natural stream channels, it is not surprising that habitat quality differed markedly between the two channel types. Overall habitat quality was assessed using the visual scoring system of the Michigan DEQ, and seven of the nine individual metrics received significantly lower scores in country drains. However, county drains received higher (but not significantly so) scores than did natural reaches for the stability of the streambanks and the presence of streambank vegetation. This can be attributed to the dense grasses planted along county drains, which provide structural stability for the streambank, and the tendency for the grasses of county drains to result in little bare ground, whereas streambank shading by the wooded riparian of natural reaches resulted in greater exposure of bare soil (Figure 3.4).

In contrast to the pronounced differences between natural reaches and county drains in channel shape and habitat quality, evidence supporting the hypothesis that natural reaches supported a more diverse and less tolerant macroinvertebrate assemblage was less dramatic but still convincing. Of the twenty-three macroinvertebrate metrics that were evaluated, sixteen gave higher scores to natural reaches, as expected, although only three were statistically significant at $p< .05$. However all five of the indicator metrics were lower in drains and three of the five were statistically significant at $p < .10$.

Only the FBI showed no support for the hypothesis. Fitzpatrick et al. (2001) found nutrient concentration and flow variability to have more influence on the FBI than other factors. In this study it is possible that the quality of physical habitat may be compromised by stressful nutrient levels that flow through both the natural and county drains on the same reach, resulting in similar FBI scores.

Trichoptera metrics were significantly greater in natural streams than in county drains, but other pollution-sensitive metrics were not statistically significant. The Ephemeroptera, Plecoptera, and Trichoptera groups usually inhabit the surface of stones and the interstitial spaces between and beneath large substrate particles such as pebbles and cobbles (Merritt and Cummins, 2008), and are also associated with wood (Johnson et al. 2003). Because county drains had more fine sediments, poorer habitat and less wood, they would be expected to harbor fewer invertebrates, particularly of sensitive taxa. Thus it is surprising that the differences in invertebrate assemblages between the two channel types are not more pronounced.

Geographic location of drains relative to natural reaches suggests that spatial dependence may help to explain the lack of strong differences in the biota between paired sites. With one exception, all natural reaches were downstream of the county drains, separated by a distance ranging from the length of a road culvert to 1000 m. Adverse conditions, particularly associated with flow, may be transmitted downstream from county drains to natural reaches. However, a similar study of agricultural drainage in which county drains and natural reaches were not located on the same tributaries resulted in the similar finding that the biota was very similar in the two cases (Stammler, 2007, Ward-Campbell, 2007) even though the spatial dependence was not a factor in the study.

Despite the lack of strong biological differences in my study, when each metric is considered as part of an overall pattern, it appears clear that natural reaches tend to have more diverse macroinvertebrate communities than do county drains. Macroinvertebrate sampling in county drains during low flow conditions often was difficult, and this may be a limitation of the present study. Culvert outlets often were locations of erosion, creating pools where various invertebrates, especially dipterans, could be collected during low flow conditions. Although not prime habitat, these pools may serve as a refuge for some pollution-sensitive families during low flow, allowing these families to repopulate the entire reach of the county drain when water levels are higher. Nonetheless, culvert outlets and road crossings are inherently a part of the agricultural county drain and their influence needs to be considered.

Key geomorphic processes affecting the lack of macroinvertebrates in both the natural reach and county drains may be flashy flow regimes. Although flow stability in natural reaches was rated significantly higher than in county drains, based on greater mid-summer flows in the former, the downstream location of natural reaches meant that high flows from county drains with their three times greater capacity likely created a strong erosional stress in natural reaches during storm events. The shape characteristics of incision and bankfull capacity indicate systems in the headwaters that are flashy, even in comparison other River Raisin sites (Infante, 2001). The bankfull cross-sectional areas measured in this study, ranging from .84 m^2 to 35 m^2, are similar to Infante's River Raisin sites, which ranged from .28 m^2 to 29 m^2 (mean = 6.58 m^2). However, Kelley's sites have considerably smaller low flows. Poff and Ward (1989); Poff and Allan (1995);

and Riseng et al. (2004) found that flow plays a central role in stream ecology and my findings suggest this to be the case in these headwaters studied, natural and county drains.

Sedimentation in confined drainage channels is critical to macroinvertebrate habitat, as the effects of sedimentation on macroinvertebrates are well documented (Waters, 1995). County drain channel bottoms have a variable layer of sediment on the substrate. Schroeder (1994) and Nerbonne (2001) suggest that most of the variation of invertebrate metrics is caused by fine sediment and embeddedness. When a gravel-cobble substrate is changed to silt-sand, a taxonomic alteration occurs. The classic change due to sediment is from a community of EPT to one mainly of oligochaetes and burrowing chironomids. A sedimentation threshold at which even the natural reaches are unable to support diverse EPT communities may be crossed in these agricultural headwaters.

The physical habitat of natural reaches is similar to other natural reaches in the watershed, however the macroinvertebrates communities are not. When compared with other streams in the River Raisin, habitat quality of natural reaches in this study (median = 68.8) were similar to those reported by Wood in 2002 (median = 71.5) and slightly higher than Lammert in 1999 (median = 58.5). As expected, the habitat scores of the county drains (median = 34) were well below these other sites. However, macroinvertebrate assemblages of natural reaches in this study score lower than those from Wood's (2002) study despite the similarity in habitat scores, as can be seen in the regression of taxon richness versus habitat quality for my study sites and those from Wood (2002) (Figure 9). The number of taxa from Lammert's sites (14 – 39, mean = 26.2) and Wood's sites (13 – 61) are considerably greater than I observed at natural reaches (mean = 18.7) and county drains (mean = 18.5) in the present study. This strongly suggests that these headwater sites in the River Raisin's agricultural landscape, including both natural and county drain sites, are particularly stressful environments for macroinvertebrates.

The extent of drainage on an agricultural landscape may not be easily assessed by studying only current-day conditions. The typical mode of erosional adjustment by the natural process of re-establishment of channel sinuosity following straightening of meanders may require many decades or even centuries of post channelization recovery (Barnard and Melhorn, 1982; Rhoads and Urban, 1997; Urban, 2000). Mattingly (1993) reported that channelization had occurred in all first-order streams in some watersheds of East Central Illinois. The legacy of past anthropogenic activities of channelization might best be studied by comparing headwaters in predominately agricultural watersheds with and without drainage and headwaters with less agriculture land use.

I have applied many traditional ecological measurements in quantifying the structure of these headwater streams. Geological, topographical and hydrological attributes may be the critical factors to more completely explain the effects of agricultural drainage that need further clarification. By emphasizing restoration of riparian zones, land managers assume that stream conditions across the whole catchments can be mitigated by attention only to land adjacent to the stream. Although riparian zones have been used effectively to mitigate the adverse effects of many land-use practices, understanding the linkages among ecological processes that shape biodiversity, biotic communities is far from complete (Harding, 1998). In this study where in-stream habitat and riparian conditions provided good habitat, the macroinvertebrate community was quite stressed. This suggests that watershed-wide land use of sustained disturbance such as agriculture may be a critically important influence on biology. Conservation of these huge drainage networks may require preservation of the entire watershed – not just fragments of it as many current policies requiring BMPs in the riparian zone assume.

In summary, county drains are physically very different from the natural reaches that occur in the same stream segment of the agricultural headwaters of the River Raisin. Whereas the macroinvertebrate community is somewhat more diverse in natural reaches, its biota is none the less very similar to county drains. A homogeneous macroinvertebrate community may demonstrate the effects of excessive sedimentation and flashy flow regimes in predominately agricultural headwaters. Because artificial drainage is an accepted necessity for the propagation of Midwest crops, best management practices that integrate measures for sediment control and moderation of flow regimes may provide the greatest benefit to these challenged ecosystems.

Figure 1. Land use/ land cover of River Raisin Watershed. The principal land use is agriculture, represented by pink and salmon shades. Forested areas are represented by green and urban areas are black (Michigan Department of Information Technology, Center for Geographic Information, Michigan Landsat Thematic Mapper 1997-2001).

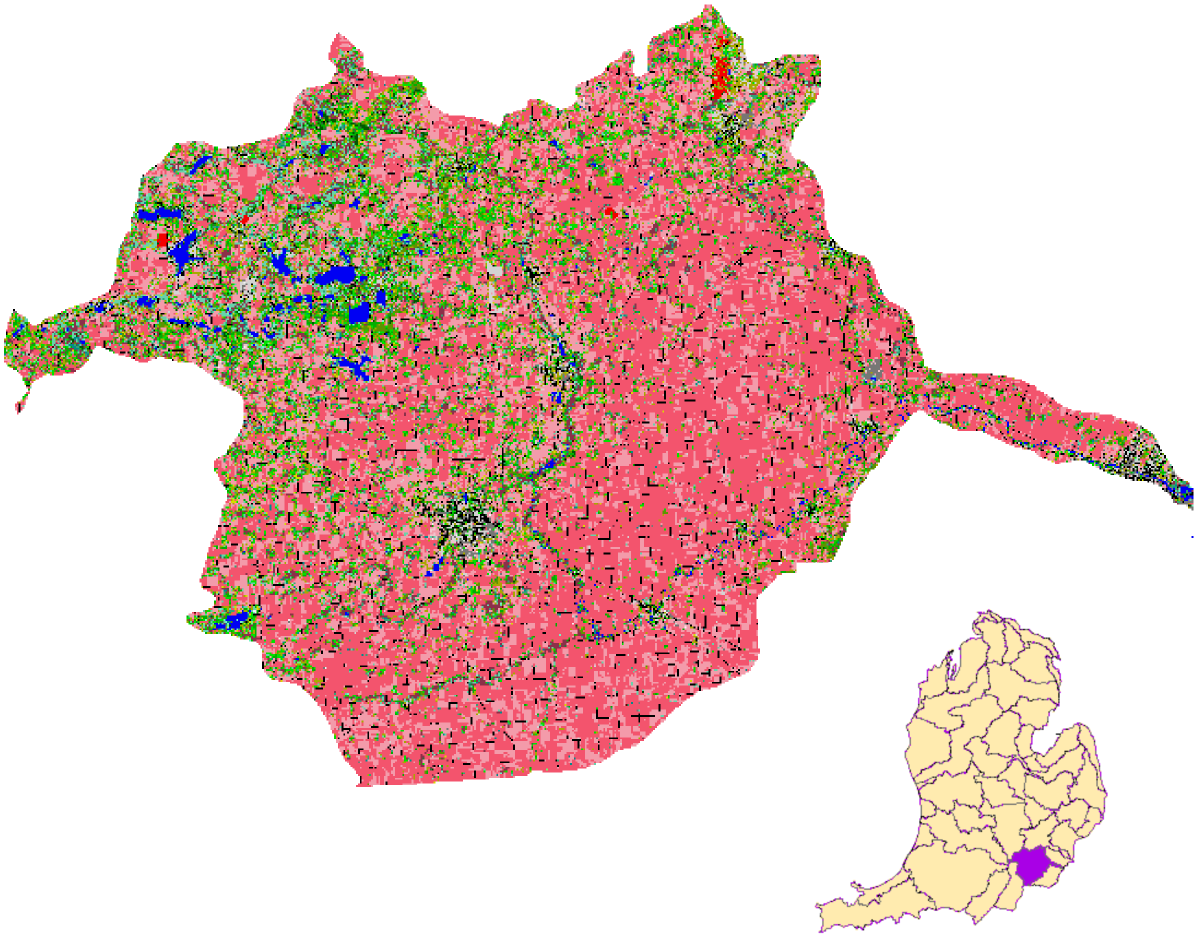

Figure 2. Location of study sites in Lenawee County, Michigan.

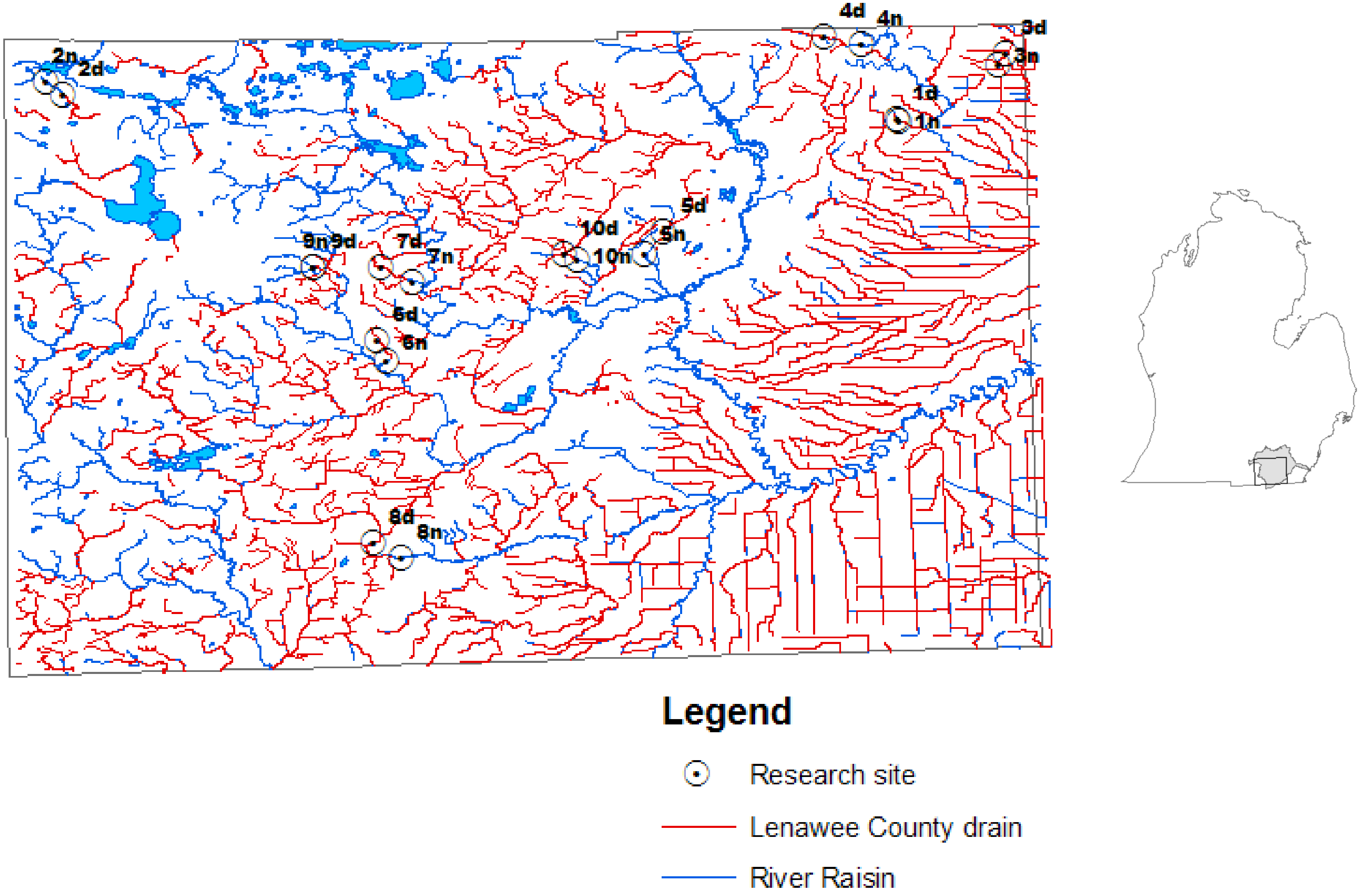

Figure 3. Photos of paired research sites taken during spring 2003. The natural channel is top photo and the county drain is the bottom photo.

3.1 Paired sites 1n and 1d note the shade provided by the dense canopy cover of shrub riparian vegetation and bare soil along the natural reach in top photo. The county drain vegetation is primarily grasses (bottom photo).

3.2 Paired sites 2n and 2d. The county drain below (bottom) has not had riparian maintenance within the last 50 years. While the sites look similar note the absence of woody debris in the county drain and the abundance of grasses. The landowner adjacent to the drain maintains the riparian vegetation by periodically mowing the understory.

05/12/2003

05/12/2003

3.3 Paired sites 3n and 3d.

3.4 Paired sites 4n and 4d. Note the absence of wood in the channel and in the riparian zone throughout the county drain (bottom). However streambanks along the county drain were stable with dense vegetation. Whereas the natural channel has many exposed soil surface areas with potential for erosion (top).

3.5 Paired sites 5n and 5d.

3.6 Paired sites 6n and 6d. The county drain has not had maintenance since 1980. Brush and trees are re-vegetated the steep stream banks.

3.7 Paired sites 7n and 7d. The stream channel is hard to discern from the floodplain vegetation in the natural channel (above). While the county drain channel is deeply incised and easily contains the entire storm flow (bottom).

3.8 Paired sites 8n and 8d. The natural reach (top photo) shows the left bank of the channel is maintained by the adjacent landowner. This streambank demonstrates an unstable side slope as earth is exposed indicating active erosion as channel shape changes preventing vegetation from establishing. The county drain (bottom photo) demonstrates the classic dense grass cover protecting the streambank. Yet along the inside of the channel bend, the longer non-uniform channel bend is sloughed stream bank that has been re-stabilized by grasses.

3.9 Paired sites 9n and 9d.

3.10 Paired sites 10n and 10d

Figure 4. Comparison of individual MDEQ habitat metrics and their sum for ten natural reaches and ten county drains. Box plots depict minimum, maximum, median and quartile values. Outliers defined as observations > 1.5 x interquartile range are shown as points. Note that natural reaches clearly had higher scores in all but 2 metrics, bank stability and bank vegetation stability.

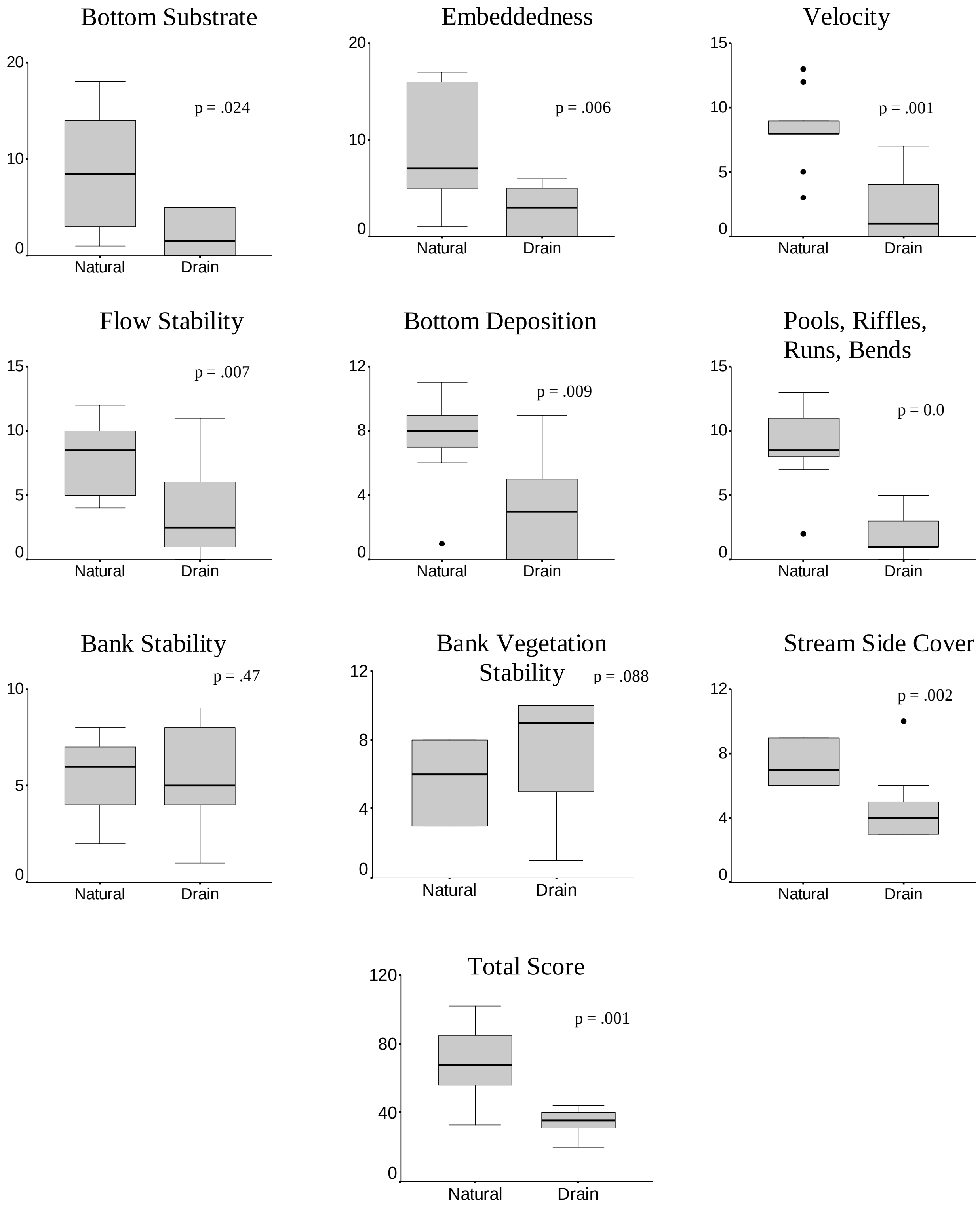

Figure 5. Comparison of wood volume in ten natural reaches and ten county drains. Box plots depict minimum, maximum, median and quartile values. Outliers defined as observations > 1.5 x interquartile range are shown as points. Categories of wood are described as small where d < 4 cm; medium where 4cm < d < 10 cm; large where 10 cm < d < 30 cm; and logjam where d > 30 cm. Note the total volume of wood is greater in both the wetted channel and bankfull channel of natural reaches. Wood throughout the range of sizes is significantly more abundant in natural reaches for all wetted channel measures except for logjams.

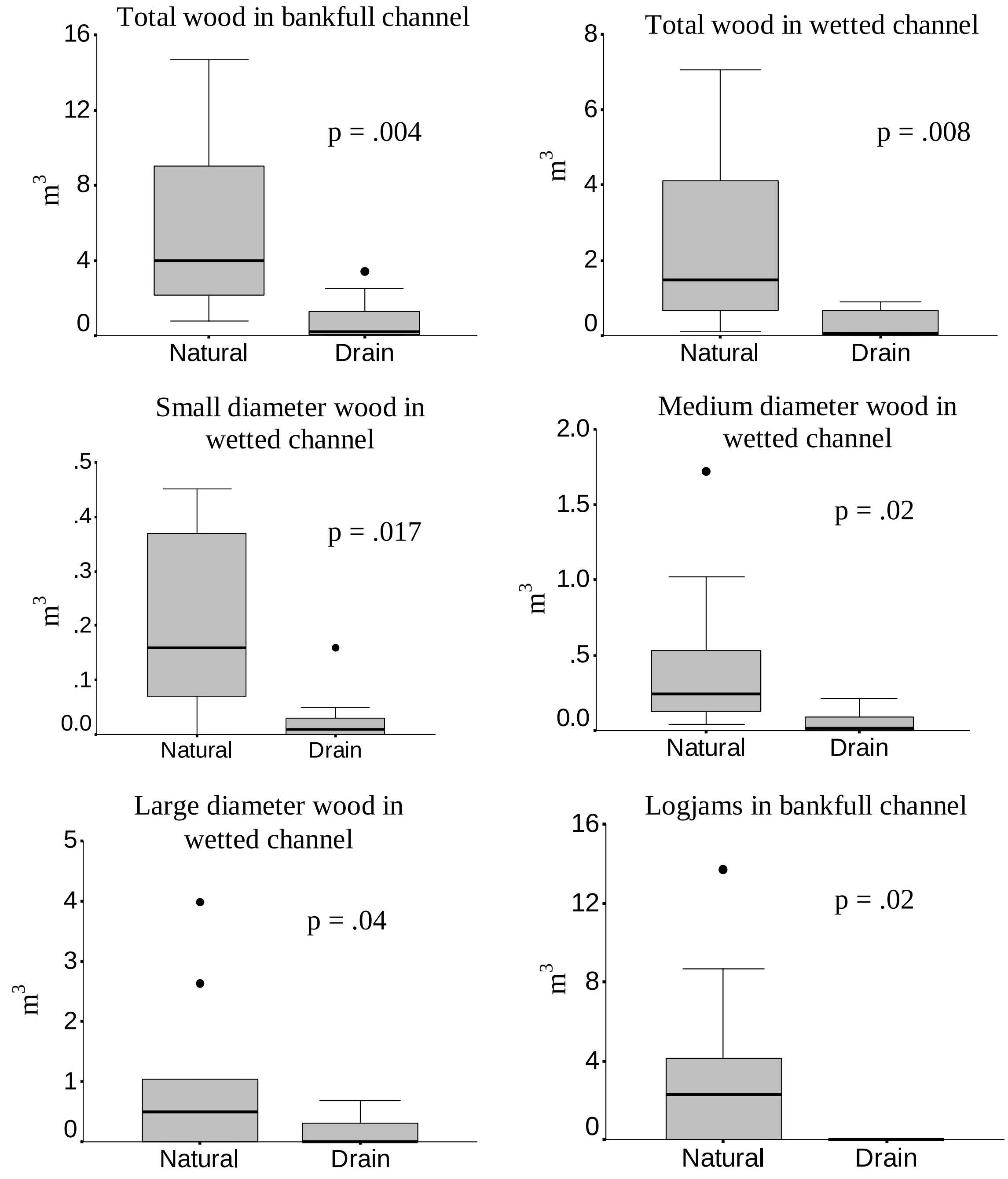

Figure 6. Comparison of riparian vegetation for ten natural reaches and ten county drains. Box plots depict minimum, maximum, median and quartile values. Outliers defined as observations > 1.5 x interquartile range are shown as points. Significant differences between natural channels and county drains were found for riparian grass (p = .005) and riparian tree (p = .003)

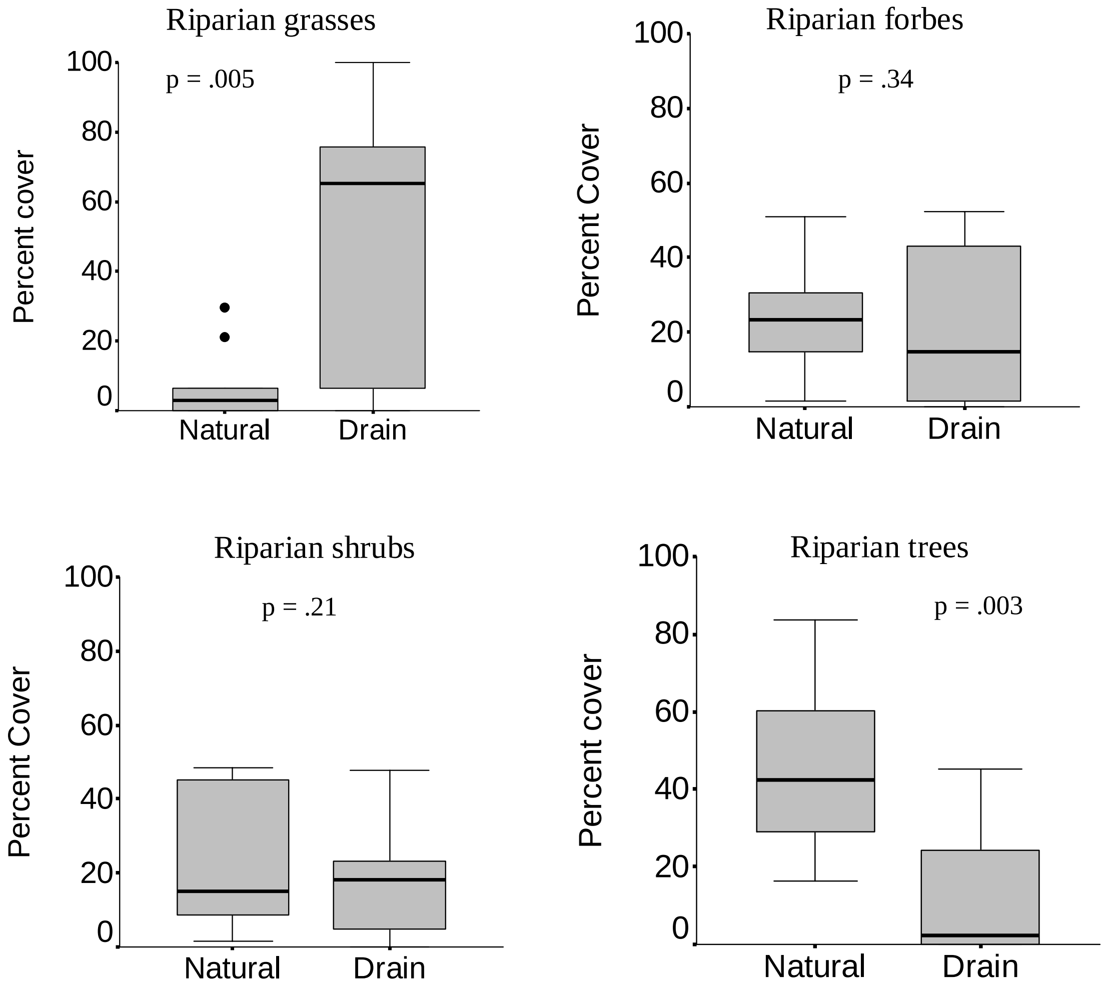

Figure 7. Comparison of channel shape variables for ten natural reaches and ten county drains. Box plots depict minimum, maximum, median and quartile values. Outliers defined as observations > 1.5 x interquartile range are shown as points. Significant differences between natural channels and county drains were found for channel incision (p = .002) and bankfull cross section (p = .013).

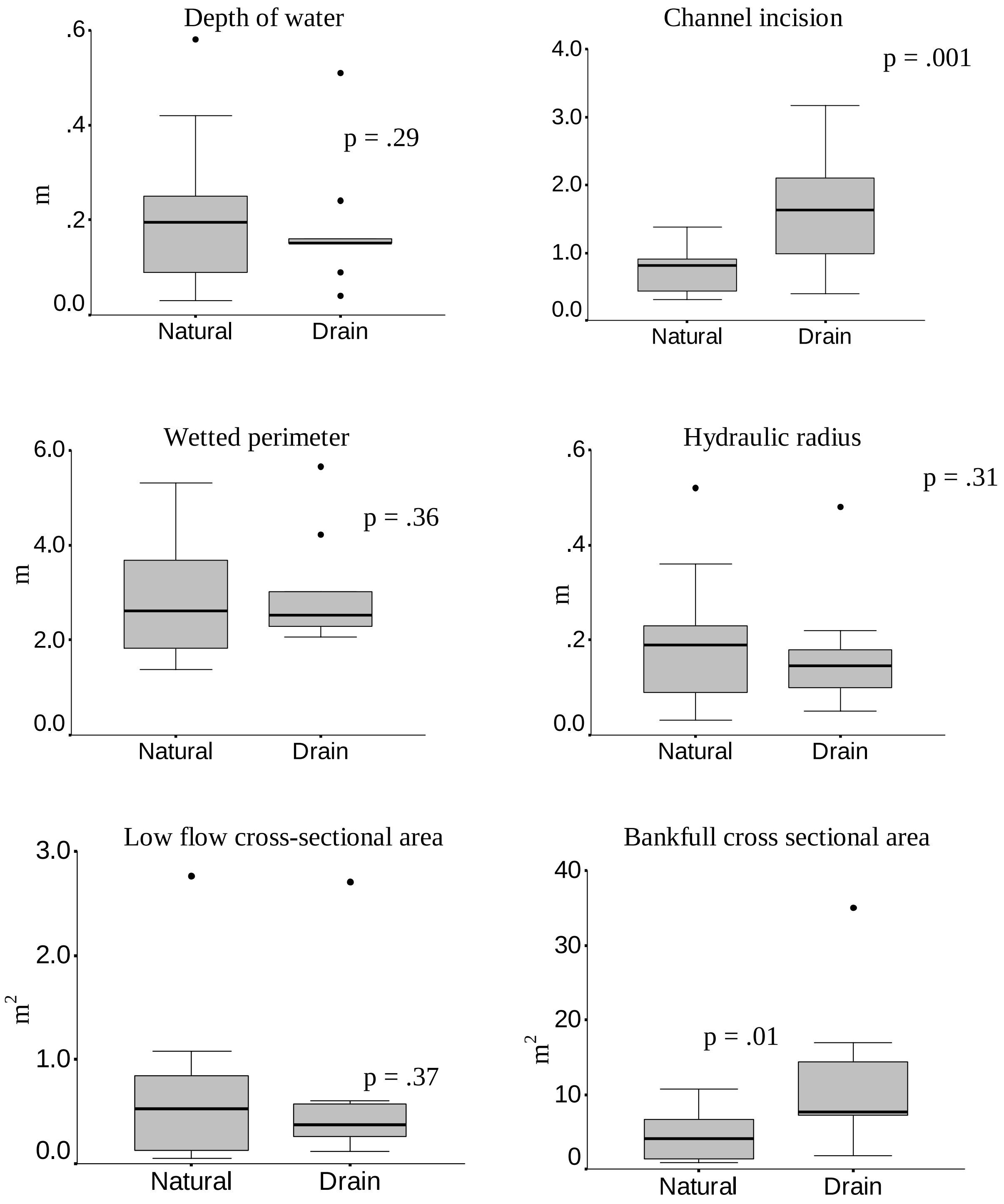

Figure 8. Comparison of sinuosity for nine natural reaches and nine county drains. Sites 1n and 1d were omitted due to dense brush blocking survey equipment line of sight. Each box plot shows the min, max, median and quartile values. Outliers defined as observations > 1.5 x interquartile range are identified as points. Natural reaches are significantly more sinuous than county drains.

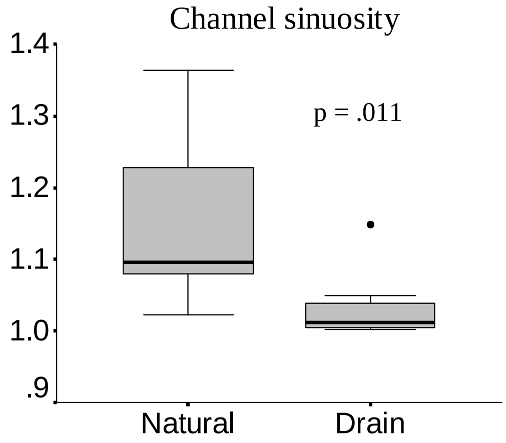

Figure 9. Relationship between number of taxa collected and habitat quality for small streams in the River Raisin watershed. The regression line is derived from 22 sites reported in Wood (2002). County drains from this study appear consistent with the trend line from Wood, with lower habitat quality and fewer taxa. Natural reaches in this study show a wider range in habitat quality but the number of taxa was lower than expected based on Wood's sites and similar to country drain sites.

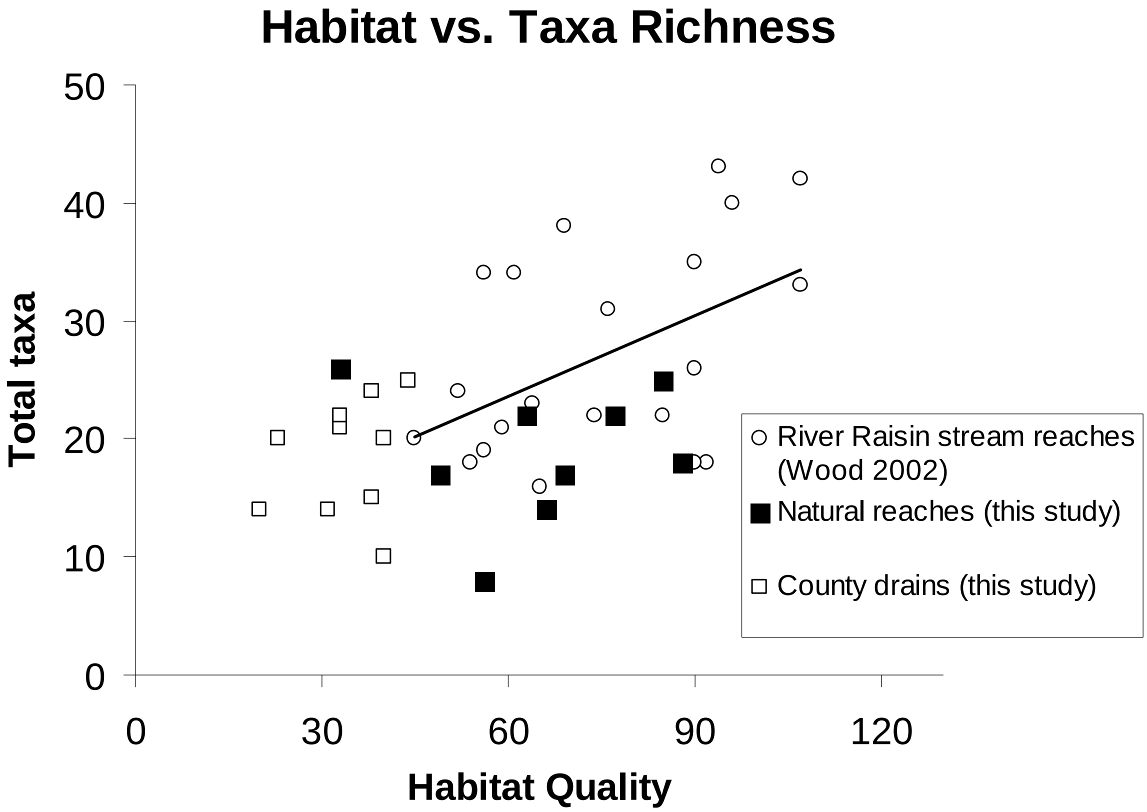

Table 1. Location and history of Lenawee County Drain research sites. Blank entries indicate data was not available.

Site No.	Township	Sec-tion	Drain Name	Date legally established	Date Surveyed	Length of open channel (ft)	Acres drained	Date of maintenance	Maintenance
1d	Macon	20	Macon #21	7/27/1950	7/12/1948	7077		1977	cleaned (brush and tree removal)
2d	Woodstock	17	Burk Drain	6/21/1905	4/28/1905	13930	630	1966	culvert replaced
3d	Macon	12	Macon New #8 & Extension	6/8/1936	6/6/1949	7854		2001	
4d	Macon	6	Macon + Clinton Ext. Joint County	5/15/1899	6/12/1947			2001	cleaned (brush and tree removal)
5d	Raisin	18	Cook	7/20/1903	5/5/1961	10480	2300	1994	cleaned (brush and tree removal)
6d	Dover	11	Lowery Drain	2/8/1900	5/23/1947			1980	sediment removal
7d	Rome	24	Hunt Creek	3/30/1901	3/25/1901		370	1995	cleaned(brush, tree, sediment removal)
8d	Seneca	14	Bear Creek Drain	5/5/1915	7/1/1961	54000	12800	1998	cleaned (brush & tree removal)
9d	Rome	22	Wallace Drain	2/18/1908	11/16/1908	3828		2001	cleaned (brush & tree removal)
10d	Adrian	15	Case Drain					1999	brush & veg. sprayed and then removed

Table 2. Metrics of the Ohio Invertebrate Community Index (ICI), with scoring criteria based on a watershed of 10 mi^2 or less. Metric scores were interpolated from Table 5-1 of Biological Criteria for the Protection of Aquatic Life: Volume II: Users Manual for Biological Field Assessment of Ohio Surface Waters (Ohio EPA 1988). Metrics marked with an asterisk were not used in this study.

Metric	Score			
	0	2	4	6
Total number of taxa	0 - 19	20 - 29	30 - 39	≥ 40
Number of mayfly taxa	0 - 1.8	1.9 - 3.7	3.8 - 5.7	≥ 5.8
Number of caddisfly taxa	0 - 0.1	0.2 - 1.7	1.8 - 2.9	≥ 3
Number of dipteran Taxa	0 - 5.9	6 - 11.9	12 - 17.9	≥ 18
Percent mayfly	0	0.1 - 9.9	10 - 24.9	≥ 25
Percent caddisfly	0	0.1 - 1.2	1.3 - 2.2	≥ 2.3
*Percent tanytarsini midges	0	0.1 - 9.9	10 - 24.9	≥ 25
Percent other dipteran and non-insect	≥ 63	62.9 - 46.1	46 - 30.1	≤ 30
*Percent tolerant organisms	≥ 27.4	27.5 - 18.1	18 - 9.6	≤ 9.5
Number of qualitative EPT taxa	0 - 2.4	2.5 - 5	5.1 - 7.9	≥ 8

Table 3. Habitat Quality Evaluation Index protocol (MDEQ 1997)

Habitat Parameter	Excellent	Good	Fair	Poor
1 Bottom substrate available cover	Greater than 50% rubble, gravel, submerged logs, undercut banks, or other stable habitat. 16 – 20	30-50% rubble, gravel or other stable habitat. Adequate habitat 11 – 15	10-30% rubble, gravel or other stable habitat. Habitat availability less than desirable. 6 – 10	Less than 10% rubble, gravel or other stable habitat. Lack of habitat is obvious. 0 - 5
2 Embeddedness	Gravel, cobble and boulder particles have between 1 and 25% of their surfaces covered by fine sediment. 16 – 20	Gravel, cobble and boulder particles have between 25 and 50% of their surface covered by fine sediment. 11 – 15	Gravel, cobble and boulder particles have between 50 and 75% of their surface covered by fine sediment. 6 – 10	Gravel, cobble and boulder particles have over 75% of their surface covered by fine sediment. 0 – 5
3 Velocity:depth slow:deep <1 ft/s >1.5 ft slow:shallow <1 ft/s < 1.5 ft fast:deep >1 ft/s >1.5 ft fast:shallow >1 ft/s <1.5 ft	Shallow habitats all present plus runs and pools. 16 – 20	Only 3 of the 4 habitat categories present (missing ruffles or runs receive lower score than missing pools). 11 - 15	Only 2 of the 4 habitat categories present (missing riffles/runs receive lower score). 6 – 10	Dominated by one velocity/depth category (usually pool). 0 – 5
4 Flow stability	Continual flow all year. Natural water supply substantial. 12 – 15	Seasonal high flows. Low flow constant or nearly so. Some point discharge contributes to flow. 8 – 11	Periodic high and low flows. Irregular flow pattern. Discharges contribute substantially to low flow. 4 – 7	Ephemeral stream. Usually no mid-summer flow. If it flows year-round discharges form major contribution. 0 – 3
5 Bottom deposition	Less than 5% of the bottom affected by deposition. 12 - 15	5-30% affected. Some deposition in pools. 8 – 11	30-50% affected. Deposits, obstructions, constrictions and bends. Some filling of pools. 4-7	More than 50% of the bottom changing nearly year long. Pools almost absent due to deposition. only large rocks in riffle exposed. 0 – 3
6 Pools-riffles-runs-bends	Variety of habitats. Deep riffles and pools. 12 – 15	Adequate depths in pools and riffles. Bends provide habitat. 8 – 11	Occasional riffle or bend. Bottom contours provide some habitat. 4 – 7	Essentially a straight stream. Generally all flat water or shallow riffle. Poor habitat. 0 - 3
7 Bank stability	Stable. No evidence of erosion or bank failure. Side slopes generally < 30%. Little potential for future problem. 9 – 10	Moderately stable. Infrequent, small areas of erosion mostly healed over. Side slopes up to 40% on one bank. Slight potential in extreme floods. 6 – 8	Moderately unstable. Moderate frequency and size of erosional areas. Side slopes up to 60% on some banks. High erosion potential during extreme high flow. 3 – 5	Unstable. Many eroded areas. Side slopes > 60% common. "Raw" areas frequent along straight sections and bends. 0 - 2
8 Bank vegetation stability	Over 80% of the streambank surfaces covered by vegetation or boulders and cobble. 9 – 10	50-79% of the streambank surfaces covered by vegetation, gravel or larger material. 6 – 8	25-49% of the streambank surfaces covered by vegetation, gravel or larger material. 3 – 5	Less than 25% of the streambank surfaces covered by vegetation, gravel, or larger material. 0 - 2
9 Streamside cover	Dominant vegetation is shrub. 9 – 10	Dominant vegetation is of tree form. 6 – 8	Dominant vegetation is grass or forbes. 3-5	Over 50% of the streambank has no vegetation and dominant material is soil, rock, bridge materials, culverts, or mine tailings. 0 - 2

Table 4. Frequency of occurrence of taxa across 20 sites for taxa found at five or more sites, expressed as a percent.

Class	**Order**	**Family**	**Natural Sites**	**Drain Sites**	**Total Sites**
Insecta	Odonata	Aeshnidae	70	40	55
	Amphipoda		70	100	85
Insecta	Ephemeroptera	Baetidae	40	40	40
Insecta	Ephemeroptera	Caenidae	20	30	25
Insecta	Odonata	Calopterygidae	60	40	50
Insecta	Diptera	Ceratopogonidae	70	70	70
Insecta	Diptera	Chironomidae	100	100	100
Insecta	Odonata	Coenagrionidae	20	60	40
Insecta	Heteroptera	Corixidae	40	70	55
Insecta	Diptera	Culicidae	50	40	45
Insecta	Diptera	Dixidae	40	30	35
Insecta	Coleoptera	Elmidae	100	90	95
Insecta	Heteroptera	Gerridae	70	40	55
Insecta	Coleoptera	Haliplidae	0	50	25
Insecta	Ephemeroptera	Heptageniidae	50	20	35
Hirudinea			50	70	60
Insecta	Coleoptera	Hydrophilidae	50	50	50
Insecta	Trichoptera	Hydropsychidae	70	50	60
	Isopoda		30	20	25
Insecta	Ephemeroptera	Leptophlebiidae	30	20	25
Oligochaeta			90	90	90
Insecta	Plecoptera	Perlodidae	20	30	25
Insecta	Trichoptera	Phryganeidae	40	20	30
Insecta	Trichoptera	Psychomyiidae	40	10	25
Insecta	Coleoptera	Scirtidae	50	40	45
Insecta	Diptera	Simuliidae	70	40	55
Insecta	Diptera	Stratiomyidae	30	70	65
Insecta	Diptera	Tabanidae	70	80	75
Insecta	Diptera	Tipulidae	90	100	95
Insecta	Heteroptera	Veliidae	40	40	40

Table 5. Macroinvertebrate metric comparison of ten natural reaches and ten county drains. Note that natural reach means exceed county drains in 16 metrics, with three statistically significant. Values in bold are significant with p-value ≤ .05.

Measure	**Natural**	**Drain**	**p-value**	**Nat > Drain**
Individuals	341.3	341.5	0.50	no
Ephemeroptera individuals	8.70	11.80	0.16	no
Plecoptera individuals	4.30	4.70	0.47	no
Trichoptera individuals	14.40	6.50	**0.04**	**yes**
Diptera individuals	219.80	197.60	0.22	yes
(Ephemeroptera, Plecoptera, Trichoptera individuals) ÷ Diptera individuals	0.15	0.14	0.46	yes
Ephemeroptera, Plecoptera, Trichoptera individuals	27.30	23.00	0.31	yes
% Ephemeroptera individuals	2.29	3.19	0.16	no
% Plecoptera individuals	1.09	1.25	0.45	no
% Trichoptera individuals	3.90	1.89	**0.04**	**yes**
% Diptera individuals	68.82	60.14	0.21	yes
% Ephemeroptera, Plecoptera, Trichoptera individuals	0.07	0.06	0.34	yes
% Dominant	78.44	82.24	0.29	no
Taxa richness	18.7	18.5	0.45	yes
Ephemeroptera taxa	1.40	1.20	0.32	yes
Plecoptera taxa	0.60	0.40	0.28	yes
Trichoptera taxa	2.40	1.20	**0.05**	**yes**
Diptera taxa	5.50	6.10	0.31	no
Ephemeroptera, Plecoptera, Trichoptera taxa	4.40	2.80	0.10	yes
(Ephemeroptera, Plecoptera, Trichoptera taxa) ÷ Diptera taxa	0.77	0.44	0.07	yes
% Ephemeroptera, Plecoptera, Trichoptera taxa	21.40	13.60	0.08	yes
Field Biotic Index	6.12	5.92	0.25	yes
Ohio Invertebrate Community Index	16.20	12.40	0.11	yes

Table 6. Habitat quality for 20 reaches (10 natural and 10 county drains) in the River Raisin, assessed using MDEQ Procedure 51, summer 2003. Mean and medians are shown, along with category ratings. The majority of site metrics were rated as fair.

Habitat Parameter	Mean	Rating	Median	Rating	Standard deviation	Min	Max
Bottom substrate	5.95	Poor	4	Poor	5.88	0	18
Embeddedness	5.85	Fair	5	Poor	5.47	0	17
Velocity:depth	5.2	Fair	5.5	Fair	4.25	0	13
Flow stability	5.8	Fair	5	Fair	3.93	0	12
Bottom deposition	5.4	Fair	6	Fair	3.66	0	11
Pools-riffles-runs	5.25	Fair	4	Fair	4.22	0	13
Bank stability	5.45	Fair	5	Fair	2.54	1	9
Bank vegetation	6.55	Good	7	Good	2.84	1	10
Streamside cover	5.95	Good	6	Good	2.14	3	10
Sum	51.4		42		23.24	20	102

Table 7. Comparison of habitat quality for 20 reaches of River Raisin (10 natural and 10 county drains). Shown are mean values for each habitat metric for each stream type and statistical significance based on a paired t-test. A ">" sign indicates that habitat quality score was higher in natural reaches; a "<" sign indicates higher habitat scores in county drains. Scores for natural reaches are statistically significant for seven of nine metrics and for overall habitat quality.

Parameter	Natural	Drain	p-value	Nat.vs.drain	Significance
Bottom substrate	8.9	3.0	0.024	>	yes
Embeddedness	8.9	2.8	0.006	>	yes
Velocity:depth	8.3	2.1	0.001	>	yes
Flow stability	8.1	3.5	0.007	>	yes
Deposition	7.7	3.1	0.009	>	yes
Pools, riffles, runs	8.7	1.8	0.000	>	yes
Bank stability	5.4	5.5	0.470	<	no
Bank vegetation	5.6	7.5	0.088	<	no
Streamside cover	7.2	4.7	0.002	>	yes
Sum	68.8	34	0.001	>	yes

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APPENDIX 1

List of macroinvertebrates from 20 research sites in River Raisin. Only the order Insecta is identified at the family level.

		Site Number	1n	1d	2n	2d	3n	3d	4n	4d	5n	5d	6n	6d	7n	7d	8n	8d	9n	9d	10n	10d
Insecta	**Coleoptera**	Curculionidae						1													2	
		Dytiscidae (L&A)			1							7				1						
		Elmidae (L&A)	13	9	28	11	64	7	52		8	8	2	2	1	2	110	150	181	49	23	42
		Gyrinidae	4	5												1		1				
		Haliplidae		9				5				1						3		2		
		Hydrophilidae (L&A)	1					2		1	2	3	3		1			4		2	1	
		Lampyridae	1																		19	
		Psephenidae									1											
		Scirtidae (L)					3		1			3					1	3	1	7	1	19
	Diptera	Ceratopogonidae	5		1	1	3	3	3	7				1	1			1	1	2	6	1
		Chaoboridae					2	2				1					1					
		Chironomidae	173	253	156	164	201	136	146	10	262	214	181	228	143	190	176	105	69	182	241	215
		Culicidae	1				7	14			5			1					1	2	4	3
		Dixidae			2		3	3		1									1		4	4
		Dolichopodidae												3							1	
		Empididae					2		6									1			1	
		Psychodidae												2								
		Sciomyzidae										1		3								
		Simuliidae	3		103				11	3	4		9		1		8	6		1		2
		Stratiomyidae	2	1			3		1	2		1		10		1		1				1
		Syrphidae												4								
		Tabanidae	5	7	13	50	3	8			20	6		5			3	23	35	2	12	4
		Tipulidae	10	1	5	25	26	5	49	1	18	1	8	18		2	10	3	18	16	9	12
	Ephemeroptera	Baetidae	1					3			2							3	40	18	2	1
		Baetiscidae																2				
		Caenidae							5			4		1					1	60		
		Heptageniidae							2		1						4		7	2	9	22
		Leptophlebiidae									4							1	7	1	1	
	Heteroptera	Belostomatidae										1								2		
		Corixidae		26			2	112		1		2		1	1		1	10			2	1
		Gerridae		1	1	1	2		1		1			4	1		2				1	1
		Mesoveliidae										2										
		Notonectidae		2				1						1							6	
		Veliidae				2	1										6	1	1	3	2	1
	Lepidoptera	Pyralidae												1								
	Megaloptera	Sialidae									4	1							1			
	Odonata	Aeshnidae		6	2	1	2				4	2			6		1	5	2		2	
		Calopterygidae	3			3	4	5	3		12							1	3		5	1
		Coenagrionidae	2				2	3		4		24				3		3		3		
		Corduliidae																				1
		Gomphidae															1		1			
		Libellulidae																		1		

APPENDIX 1 (continued)

	Site Number	1n	1d	2n	2d	3n	3d	4n	4d	5n	5d	6n	6d	7n	7d	8n	8d	9n	9d	10n	10d
Plecoptera	Capniidae													1				4			6
	Nemouridae			1						21											
	Perlodidae			15	1		38			1							2				
Trichoptera	Hydropsychidae			10	7	5		11		24			1			28	7	27	19	6	17
	Hydroptilidae							1													
	Lepidostomatidae																	4			
	Limnephilidae	3		2						4									1		
	Philopotamidae																1	1			
	Phryganeidae		1	1					6	2				4						2	
	Polycentropodidae							1	1												3
	Psychomyiidae			1		1				5								1			1
Amphipoda		5	11	27	42	4	34		7		56		15	229	1	1	46	3	3	3	1
Hirudinae		1	74		4		3	2	238		4	3	14	5		1					2
Isopoda						2						2		1	1						1
Oligochaeta		1	2	5	2	9	4	2	8		6	1	3	10	6	3		1	10	5	7
Total Indiv.		234	408	374	314	351	389	297	290	405	348	209	318	405	208	357	383	411	388	370	369
Total Taxa		18	15	18	14	22	20	17	14	22	21	8	20	14	10	17	24	25	22	26	25

APPENDIX 2

List of macroinvertebrate sums of individuals, groups of individuals and groups of families collected at 10 paired research sites of natural reaches (n) and county drains (d). Taxa were enumerated at the family for the class Insecta and class for all others.

Paired site no.	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10
type case	n	d	n	d	n	d	n	d	n	d	n	d	n	d	n	d	n	d	n	d
No. of Individuals	234	408	374	314	351	389	297	290	405	348	209	318	405	208	357	383	411	388	370	369
No. of Diptera individuals	199	262	280	240	250	171	216	24	309	224	198	275	145	193	198	140	125	205	278	242
No. of Ephemeroptera individuals	1	0	0	0	0	3	7	0	7	4	0	1	0	0	4	6	55	81	12	23
No. of Plecoptera individuals	0	0	16	1	0	38	0	0	22	0	0	0	1	0	0	2	4	0	0	6
No. of Trichoptera individuals	3	1	14	7	6	0	13	7	35	0	0	1	4	0	28	8	33	20	8	21
No. of Taxa	18	15	18	14	22	20	17	14	22	21	8	20	14	10	17	24	25	22	26	25
No. of Diptera taxa	7	4	6	4	9	7	6	6	5	6	3	10	3	3	5	7	6	6	8	8
No. of Ephemeroptera taxa	1	0	0	0	0	1	2	0	3	1	0	1	0	0	1	3	4	4	3	2
No. of Plecoptera taxa	0	0	2	1	0	1	0	0	2	0	0	0	1	0	0	1	1	0	0	1
No of Trichoptera taxa	1	1	4	1	2	0	3	2	5	0	0	1	1	0	1	2	5	2	2	3

APPENDIX 3

Metrics of habitat quality for 20 research sites, 10 natural reaches and 10 county drains. Means and standard deviations are given for both cases.

Site	Substrate	Embeddedness	Velocity:depth	Flow stability	Deposition	Pools,riffes, runs, bends	Bank stability	Veg stability	Cover	Total
1n	11	16	8	9	11	8	8	8	9	88
1d	0	0	0	7	1	1	9	10	10	38
2n	16	17	13	12	8	13	8	8	7	102
2d	2	6	1	1	4	3	4	4	6	31
3n	11	5	9	10	7	8	2	5	6	63
3d	5	3	1	3	5	1	8	9	5	40
4n	18	1	8	8	9	11	5	3	6	69
4d	0	0	0	0	0	1	5	10	4	20
5n	1	16	12	8	10	10	4	7	9	77
5d	2	1	2	11	0	1	5	7	4	33
6n	6	5	5	4	8	7	7	8	6	56
6d	0	0	0	1	0	0	8	10	4	23
7n	6	7	8	12	8	9	4	3	9	66
7d	1	5	1	1	9	1	9	10	3	40
8n	3	7	9	5	6	8	2	3	6	49
8d	1	5	4	6	3	3	4	9	3	38
9n	14	13	8	9	9	11	7	7	7	85
9d	5	5	5	3	3	2	2	5	3	33
10n	3	2	3	4	1	2	7	4	7	33
10d	14	3	7	2	6	5	1	1	5	44
n mean	8.9	8.9	8.3	8.1	7.7	8.7	5.4	5.6	7.2	68.8
n std dev	5.93	6.06	2.91	2.96	2.75	2.98	2.32	2.22	1.32	20.22
d mean	3	2.8	2.1	3.5	3.1	1.8	5.5	7.5	4.7	34
d std dev	4.3	2.39	2.42	3.47	3	1.48	2.88	3.17	2.11	7.69

APPENDIX 4

List of wood volumes in 20 research sites for wetted channels and bankfull channels. Wood is grouped by diameter (d) size.

	Wetted Channel					Bankfull Channel				
	d < 4 cm	4 cm < d < 10 cm	10 cm < d < 30 cm	30 cm < d	Total volume of wood	d < 4 cm	4 cm < d < 10 cm	10 cm < d < 30 cm	30 cm < d	Total volume of wood
Site	m^3/150 m	m^3/150 m	m^3/150 m	m^3/150 m	m^3/150 m	m^3/150 m	m^3/150 m	m^3/150 m	m^3/150 m	m^3/150 m
1n	0.07	0.04	0.00	0.00	0.11	0.24	0.45	0.11	0.00	0.80
1d	0.02	0.00	0.00	0.00	0.02	0.13	0.07	0.00	0.00	0.20
2n	0.19	0.25	0.90	0.00	1.34	0.46	1.68	2.96	0.00	5.10
2d	0.05	0.15	0.68	0.00	0.88	0.25	0.53	1.73	0.00	2.50
3n	0.45	1.02	2.62	0.00	4.09	0.00	0.18	0.18	8.64	9.00
3d	0.03	0.09	0.55	0.00	0.67	0.10	0.52	0.68	0.00	1.30
4n	0.27	0.23	1.02	0.00	1.52	0.05	0.14	0.38	4.14	4.70
4d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5n	0.09	0.36	1.04	0.00	1.49	0.06	0.13	0.26	2.75	3.20
5d	0.01	0.02	0.00	0.00	0.03	0.04	0.06	0.00	0.00	0.10
6n	0.37	0.23	0.00	0.00	0.60	0.04	0.06	0.15	1.85	2.10
6d	0.01	0.01	0.00	0.00	0.02	0.07	0.13	0.00	0.00	0.20
7n	0.04	0.13	0.10	1.17	1.45	0.10	0.19	0.13	2.78	3.20
7d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8n	0.43	1.72	3.98	0.00	6.13	0.88	2.79	11.03	0.00	14.70
8d	0.01	0.04	0.00	0.00	0.05	0.02	0.08	0.00	0.00	0.10
9n	0.13	0.53	0.00	0.00	0.66	0.49	0.99	0.22	0.00	1.70
9d	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.20
10n	0.00	0.07	0.07	6.93	7.07	0.15	0.44	0.29	13.72	14.60
10d	0.16	0.21	0.31	0.00	0.68	0.51	1.44	1.25	0.00	3.20

APPENDIX 5

Percentages of riparian vegetation for all sites, 10 natural reaches and 10 county drains in River Raisin. The mean and standard deviation are given for both cases and for the total data set.

Site No.	grasses	forbs	shrubs	trees
1n	4.8	30.7	48.4	16.1
1d	6.4	43	47.9	2.7
2n	6.4	46.8	17.8	29
2d	0	50	4.8	45.2
3n	29.6	1.6	8.6	60.2
3d	28	36.6	23.6	11.8
4n	0	14.5	1.6	83.9
4d	75.8	4.8	19.4	0
5n	1.1	4.4	46.5	48
5d	73.7	3.2	22	1.1
6n	21	25.8	17.7	35.5
6d	57	1.7	17.2	24.1
7n	4.8	21	45.2	29
7d	75.8	24.2	0	0
8n	0	16.1	4.9	79
8d	100	0	0	0
9n	0	28	11.8	60.2
9d	93.6	0	4.8	1.6
10n	0	51.1	12.5	36.4
10d	0	52.2	23.1	24.7
nat mean	6.8	24.0	21.5	47.7
nat stdev	10.3	16.1	18.1	22.6
drain mean	51	21.6	16.3	11.1
drain stdev	39	22.1	14.7	15.4
all mean	28.9	22.8	18.9	29.4
all stdev	35.9	18.9	16.3	26.6

APPENDIX 6

List of channel dimensions, flow and substrate particle size for all sites, 10 natural and 10 county drains. The mean and standard deviation are given for each case. Sites 1n and 1d could not be surveyed due to obstructing vegetation.

Site	Sinuosity	% Slope	depth m	Width m	Low flow Area m^2	Incision	Bankfull area m^2	Flow m^3/s	Substrate D_{50} mm
1n			0.29	1.372	0.12	0.82	0.85	0.004	5
1d			0.48	2.743	0.40	0.82	4.59	0.006	1
2n	1.080	.71	0.40	2.073	0.25	0.43	1.52	0.067	1.5
2d	1.050	.31	0.30	2.438	0.22	0.40	1.84	0.023	1.1
3n	1.023	.11	0.69	3.505	0.73	0.91	5.03	0.029	1.7
3d	1.007	.52	0.51	1.676	0.26	1.83	7.64	0.032	1.7
4n	1.207	.51	0.81	3.383	0.84	1.25	6.61	0.329	30.2
4d	1.148	.07	1.68	5.273	2.70	3.17	35.03	0.280	1
5n	1.090	.46	0.64	1.676	0.33	0.34	3.21	0.081	1.1
5d	1.002	.02	0.54	2.896	0.47	1.68	7.24	0.053	1
6n	1.096	.19	0.11	1.372	0.05	0.30	1.36	0.003	1.8
6d	1.003	.62	0.15	2.499	0.11	1.58	8.08	0.009	1
7n	1.228	.03	1.36	2.591	1.08	0.49	1.08	0.259	1.6
7d	1.012	.39	0.51	1.920	0.30	1.55	7.48	0.291	1.2
8n	1.246	.22	0.65	4.115	0.82	1.37	10.74	0.197	1.4
8d	1.039	.04	0.78	2.377	0.57	2.10	16.89	0.157	1.1
9n	1.364	.39	0.18	2.164	0.12	0.82	7.28	0.011	3.6
9d	1.032	.06	0.51	2.225	0.34	2.26	14.44	0.029	1.6
10n	1.033	.43	1.92	4.724	2.76	0.88	5.79	0.282	1.4
10d	1.005	.55	0.48	4.115	0.60	0.98	7.62	0.305	7
nat mean	1.152	.34	0.215	2.696	.71	.76	4.35	0.126	4.93
nat std dev	.114	.22	0.170	1.177	.81	.37	3.30	.040	2.83
drain mean	1.002	.287	.180	2.817	.60	1.64	11.09	.119	1.77
drain std dev	.047	.244	.127	1.084	.75	.79	9.47	.040	0.58