St. Olaf College

Local Ecology Research Papers

An Investigative Study of Water Quality and Macroinvertebrate Populations in Rice Creek

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Biology 371: Field Ecology

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Abstract

Agriculture and the environment are both centerpieces of Minnesota but may be at odds with one another. Dangerous chemicals used for agricultural practices can enter aquatic ecosystems via runoff, harming organisms. The purpose of this study was to assess water quality in a Stream and Ditch site in Rice Creek. Water chemistry was monitored by measuring temperature, pH, dissolved oxygen, and conductivity. Using D-nets, samples of aquatic macroinvertebrate populations were collected. Although there were no significant differences in water chemistry between sites, the stream exhibited higher conductivity and dissolved oxygen levels, and higher species richness. Increased levels of nitrates, phosphorous, and total suspended solids were detected in the Ditch, which also had an increased pH. The highest Shannon (0.62) and Simpson (0.76) indexes were found in the Stream. Macroinvertebrates with low pollution tolerance were found in the Stream, while species with higher pollution tolerance were found in the Ditch, which, in conjunction with water chemistry data, may indicate healthier water quality in the Stream. This study is important because the macroinvertebrate populations present in Rice Creek act as bioindicators. By turning to the smaller members of the ecological community, we can gain insight into chemical properties, pollution levels, and overall water quality.

Introduction

Southern Minnesota resides in the Driftless Region, which consists of streams fed from cold groundwater that travels through limestone. These streams provide perfect conditions for trout to live in: cool summer waters that are warmer than the air temperatures in the winter, so trout can continuously grow throughout the year (MN DNR, 2021). Minnesota is abundant in both bodies of water and farmland, so the cool streams that make up the Driftless region are being threatened by another powerhouse—Minnesota agriculture. Runoff from agricultural fields and tile contributes to levels of excess nutrients and sediment within Rice Creek (Shea, 2020). Through the addition of extra sediment deposits, trout eggs may be smothered. Overall, runoff can compromise stream flows and temperatures that are ideal for trout to live in (MN DNR, 2021). Rice Creek is the only trout stream in Rice County and the most western trout stream in all of Minnesota (Kraus and McKittrick (A), 2021). The biodiversity supported by Rice Creek is a rarity, especially in Rice County, and risks severe degradation from agricultural runoff.

Agricultural ditches are in place to facilitate drainage, irrigate crops, and prevent floods on local farmlands. These ditches are typically considered artificial bodies of water, and therefore are not routinely monitored. However, due to the runoff and the connectivity of agricultural ditches and drainage systems, water can travel far and wide (Hill, 2016). If these waters are polluted by fertilizer, pesticide, and road salts, aquatic populations may be irreparably damaged.

Water Quality Indicators

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Many different factors can be monitored to provide insight into overall water quality and stream health. First, conductivity is the ability of water to conduct electricity. An increased level of conductivity may indicate polluted waters, as many different salts or chemicals can conduct electric currents. Fluctuating conductivity levels may indicate the presence of runoff in an aquatic ecosystem. Next, dissolved oxygen levels illustrate the overall amount of oxygen present. Overall, running water has higher levels of dissolved oxygen than lentic systems which have little to no flow. Lower dissolved oxygen levels may lead to eutrophication which typically presents itself as algae blooms and nutrient overloading. Nitrogen and phosphorus are both common ingredients in most agricultural fertilizers, and are both present in agricultural runoff. Phosphorus is considered the limiting nutrient in aquatic ecosystems as it controls the pace at which algae and other plants are produced. Increased levels of nitrogen and phosphorus create an environment where eutrophication occurs. Eutrophication decreases oxygen levels in water, species abundance, and species diversity, and in turn decreases overall environmental health (EPA, 2021).

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Benthic macroinvertebrates are also considered to be valuable water quality indicators. These organisms lack backbones and are visible to the eye without a microscope, but are still too small to noticeably stir the water's surface (EPA 2021; Castillo-Figueroa, 2018; Kohl, 2011). They reside in the bottom sediments within a body of water and are often found under rocks, logs, and plant vegetation. Macroinvertebrates are ideal organisms to study, especially in regards to water quality because they spend most of their lives in the water, have a short life cycle, are easy to collect, and have differing levels of pollution tolerance, as well as a rapid response to anthropogenic influences (EPA 2021; Kohl, 2011). Aquatic insects such as mayflies, stoneflies, and caddisflies are particularly sensitive to changes in water chemistry characteristics such as dissolved oxygen, total suspended solids, and overall nutrients that come with increased pollution (Moolna, 2019). Due to their increased sensitivity, *Ephemeroptera* (Mayflies), *Plecoptera* (Stoneflies), and *Trichoptera* (Caddisflies) are used as strong biological indicators and are at the center of the EPT index. The EPT index tallies the number of different species in these different groups as a bioindicator of water quality: the more species, the healthier the perceived water quality (NRCS, n.d). An overall indicator of healthy water is increased species richness, as well as macroinvertebrate species that are intolerant of pollution. Indicators of poor water quality are decreased levels of macroinvertebrate diversity and abundance. It is important to remember that although macroinvertebrates are valuable bioindicators, other data such as water chemistry can be used in conjunction with species distributions to determine overall water quality.

Longitudinal Studies–Clean Water Partners

Clean River Partners, previously the Cannon River Watershed Partnership, are the principal investigators for a local ecological study of Rice Creek to study water quality. Currently, 85% of the land within the Rice Creek Watershed is under agricultural use. With so much farmland, the waterways of this watershed are more susceptible to fertilizer runoff from nearby fields, which can harm aquatic ecosystems. The main goals of this project include increasing local use of cover crops and improving overall water quality in Rice Creek through reducing nitrate contamination levels. As farmers reduce fertilizer use and tilling practices, less chemical runoff will enter local waterways, in turn improving overall ecological health.

The first steps of the project included recruiting a dozen local farmers to implement cover crops onto their agricultural fields. Between the dozen farmers, cover crops were added to 1,000 acres of farmlands in the area. For the past few years, water quality such as conductivity and dissolved oxygen have been measured at tile drainage areas and other locations throughout Rice

Creek. Macroinvertebrate populations, as well as fish populations, are monitored to assess how water chemistry impacts local ecological populations. Since this longitudinal study has collected data over the years, I will be comparing water chemistry data readings that I collect to the trends exhibited over the past few years, specifically from 2019 to 2021. Longitudinal studies such as this hold critical value in ecology, as water pollution levels and their impacts can be monitored over time, and the relative success of the integration of cover crops can be analyzed.

Purpose

The purpose of my study is to investigate variation in local aquatic macroinvertebrate communities as a bioindicator of water quality. This will be done by 1) sampling local streams and ditches to determine aquatic macroinvertebrate community structure, 2) comparing local stream and ditch aquatic macroinvertebrate populations and diversity, 3) assessing aquatic macroinvertebrate populations over time to determine any community shifts that may occur, and 4) assessing stream and ditch water quality (temperature, pH, dissolved oxygen, and conductivity) and its impacts on the aquatic macroinvertebrate community structure.

Methods

This study took place near the end of October through November. Two sites, a Stream, and a Ditch site in Rice Creek were sampled three times over the sample period for aquatic macroinvertebrates. These sites were located at the intersection of Cates Avenue and 100th Street East. County Ditch 22 runs under Cates Avenue, and into a forested area, while the stream site was at the back corner of the cornfield (Figure 1). Data from a summer collection date was also used for comparisons between seasonal populations. Abiotic factors such as temperature, pH, dissolved oxygen, and conductivity were collected using probes. All of these factors were measured with different probes: temperature and conductivity were recorded using a YSI Model 30 Handheld Salinity, Conductivity, and Temperature System, pH was measured with an EcoSense pH10A Pen

Tester from YSI, and finally, dissolved oxygen was measured using a YSI ProODO Handheld Dissolved Oxygen Meter. Using a Secchi tube, I measured water clarity at all sites. It was important to start off sampling by taking these measurements in the middle of the creek before I had walked through the creek and disturbed the bottom and stirred up mud and other organic matter. Observational data such as water level, litter, and organic matter levels were also noted.

Additionally, longitudinal data from the past three years of the Clean River Partners Rice Creek project was also organized and analyzed using analysis of variance, or ANOVA statistical tests to determine significant differences in data between the Stream and Ditch sites. Water chemistry data including nitrate, phosphorus, total suspended solids, and conductivity, as well as water temperature were recorded April through November since the 2019 field season.

Macroinvertebrate collection was done via D-nets and kicking and stirring up mud and water for thirty seconds before scooping up aquatic macroinvertebrates, adopted from studies done by Bond and Hinther in previous years (Bond, 2017 and Hinther, 2018). After kicking up the bottom of the creek, I took 5 swipes, each 1 meter long with the D-net, that had successful yields of macroinvertebrates. At the Ditch site, I overturned five rocks to collect macroinvertebrates from the bottom of the creek. After collection, macroinvertebrates were placed in 70% ethanol to put them to sleep and prevent egg sacs from dropping during transport.

In the lab, macroinvertebrate identification took place using a dissection microscope. Taxon name, common name, pollution tolerance, and the specific species abundance in the Stream and Ditch sites were recorded. Pollution tolerance of each species was determined, and special attention was given to the location where each species was found, and the pollution tolerances associated with them. Data were collected and recorded into an Excel spreadsheet, and later imported into R to create tables and graphs. First, pH needs to be adjusted. To average pH, I back-calculated the H+ value by solving the following equation for each pH value: H+ = 10-pH. Then, the average of these values was used to then take the log10 of this value to get the true average pH. Next, the statistical program R (version 3.4.1) was used to perform analysis of variance, or ANOVA tests, for the abiotic, water chemistry data between the Stream and Ditch sites. Significance was determined using p-values for each of these tests. Shannon and Simpson diversity indices were calculated using the Field Ecology spreadsheet with equations to determine species diversity in both locations.

Results

Water Chemistry

Across both sites, there were no significant differences among basic water chemistry readings. Although there were no significant differences between the Stream and Ditch data, some notable trends appeared. First, the Stream had higher average conductivity (712.67 uS/cm), dissolved oxygen (11.56 mg/L), and temperature (5.9 °C) readings. The Ditch site had a higher, more basic pH of 8.2 (Table 1).

As for the longitudinal data collected by Clean River Partners (CRP) over the past three years, similar trends have been observed. First, it is important to note that similar to my data collection, there were no significant differences in any of the water chemistry data. Within nutrient analyses, it has been found that the Ditch site had higher levels of nitrate, phosphorus, and total suspended solids present, as well as a slightly higher water temperature. The Stream site had higher conductivity readings (Table 2).

Macroinvertebrates

When assessing the macroinvertebrate data, there were more species collected during summer sampling and richer species diversity (Tables 3,4). In the summer, there were 16 different species collected in the Stream, and 13 from the Ditch site. In the fall, there were 5 and 3 different species collected respectively. When comparing data collected in the fall, to data collected this summer, we can see similar species were collected. Scuds were collected across all dates. Any flies and larvae decreased in abundance as summer led into fall (Table 3).

The top three taxa that species were collected from this fall were *Amphipoda* (Amphipods), *Hemiptera* (True Bugs), and the *Diptera* (Fly) taxa (Table 4). Throughout the summer and fall sampling dates, the most common taxa collected, followed by the common species name of the organisms collected were in the *Diptera* (Midges), *Amphipoda* (Scuds), and the *Hemiptera* (Water Boatmen) taxa which all had moderate to high pollution tolerances (referred to in Tables 3 and 4). Lower pollution tolerant species were found in the Stream, while species highly tolerant to pollution were found in the Ditch (Table 3). During the fall sampling period, since there was higher species richness in the Stream site, there were higher Shannon (maximum of 0.62) and Simpson Indices (maximum of 0.76) in the Stream (Table 5). When making pairwise comparisons of Ds values via the Simpson Index, there were significant differences using a p-value of $p<0.05$ in Stream 1:Ditch 3 (t-value of 2.018672), and Stream 3:Ditch 3 comparisons (t-value of 2.24147) (Table 6).

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Discussion

Water Chemistry Data

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Le Viol et. al (2009) emphasized that landscapes with more woodland composition may have lower pHs due to litter decomposition. As litter decomposes, it discharges amounts of humic acid, lowering the pH of the water it is lying in. The Stream was more heavily wooded that the Ditch, which had larger buffer zones between the forest. This could be one reason why a smaller pH of 7.9 was exhibited in the Stream site, compared to the Ditch site. Claire Hinther conducted a study at the same Stream and Ditch sites at Rice Creek in 2018. Through her study, she also concluded that there were no significant differences in water chemistry between these sites. The stream had higher conductivity levels, but lower dissolved oxygen and pH (Hinther, 2018). The increased

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conductivity and low dissolved oxygen levels could be due to an increase in agricultural runoff in the area (EPA, 2021). The Ditch site also had increased levels of nitrate, similar to my study.

This year, nitrate levels were the lowest they have been since the study began. This severe decrease may be correlated with a lack of rainfall this year, as rain influences runoff patterns. While total nitrogen levels have been increasing, or have remained the same over the past twenty years, the opposite is true for Rice Creek (Kraus and McKittrick (A), 2021). At the Stream site, there was a 34% decrease from the 2020 nitrate levels (8.0 mg/L), for a concentration of 5.26 mg/L in 2021 (Kraus and McKittrick (B), 2021). Based on these results, the project has been able to conclude that planting cover crops result in a reduction of nitrate discharge in tile drainage systems.

Macroinvertebrates

Previously, macroinvertebrate collections in Rice Creek indicated that there were moderate levels of species diversity (9-13 different species), and most species were moderately tolerant to pollution in both the Stream and Ditch sites. In Hinther's 2018 study, there was higher species richness in the Ditch site (8), which has since changed (Hinther, 2018). More recently, although numbers were similar, species diversity was higher in the Stream site. Additionally, species highly tolerant to pollution were found in the Ditch site, which suggests there may be more pollution present (Shea, 2020). If smaller or more short-lived species are found in abundance, the species present could be more pollutant tolerant species, or since they have a short life cycle, populations may be little impacted by the presence of contaminants in the water (Le Viol et. al, 2009). Additionally, streams that are continuously altered by disturbances such as increased agricultural runoff have been shown to have decreased macroinvertebrate community diversity. When organisms come from a few taxa, this also indicates poor health within the stream community (McPherson, 2005). For example, the NRCS EPT index indicates that if waters have less than 6 EPT species present, overall water quality is poor (NRCS, n.d.). In this study, in 2021, only two

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EPT species were found and 4 were identified in 2018 (refer to full raw data spreadsheet in the Google shared folder). As for overall richness, a maximum of 6 species were found in the Stream, and 5 in the Ditch. Overall, there were 9 different species collected this fall, and there was a Shannon Index (H') value of 0.55, and a Simpson Index (Ds) value of 0.70 (Table 5). All of these numbers indicate poor water quality. It is important to remember that although macroinvertebrates are valuable bioindicators, other data such as water chemistry can be used in conjunction with species distributions to determine overall water quality.

Since agricultural runoff often goes directly into ditches that are parallel to the agricultural fields, I expect that less runoff would directly enter the streams. In a previous study, Hill et. al (2016) found lower macroinvertebrate taxonomic richness in agricultural ditches but emphasized that these ditches still act as reservoirs for flora and fauna. Richness values also decreased during the winter (Hill et. al, 2016). With the possibility of fewer pollutants present, I expected, like Hill, that the aquatic macroinvertebrate population could be more diverse and abundant in the Stream site compared to the Ditch site. In the summer, the Ditch site had thirteen different species, and during fall sampling five different species were collected, while the Stream site had sixteen and six respectively. The Stream site had overall increased levels of species richness compared to the Ditch site, although more organisms were found in the Ditch every sampling period (Table 3). Further previous studies found that species with lower pollution tolerances are found in clean streams, while those with high pollution tolerances are found in polluted streams (Hilsenhoff, 1988). In Rice Creek, the higher pollution tolerant species were found in the Ditch Site, which is closer to agricultural fields and in turn, runoff (Table 4).

Limitations

A vital gap in data collection between my research project and Clean River Partners' (CRP's) is that they had the ability to run nutrient analyses. St. Olaf does have a nutrient analyzer, however, it has not been up and running recently, which meant I could not personally collect nutrient data, but rather was able to reference longitudinal data for current conclusions. Additionally, there were some weeks where I could not complete sampling because it was deer hunting season, so there is a few-week gap in between some of my sampling days. Temperatures quickly began to fall in between these dates, which may have altered the results of the communities present in the macroinvertebrate sampling.

Future Management Strategies and Studies

One possible solution to protect agricultural ditches, and local bodies of water from runoff and pollution lies in reconciliation ecology. The concept of reconciliation ecology is one that acknowledges the significant influence humans have on different ecosystems, especially agricultural landscapes (Hill, 2016). The basic premises of this specific type of ecology lie in small modifications to management practices in order to improve overall ecosystem function and health. By implementing this practice, it allows us to still utilize the ecosystems as we have, but with less negative environmental impacts.

From this longitudinal study, we can conclude that aquatic ecosystems in the Rice Creek Watershed have benefited from local farmers transitioning to the usage and rotation of cover crops. Nitrate, phosphorous, and total suspended solid levels have decreased over the years since the transition but can still impact local fish and wildlife. Although macroinvertebrate populations become sparser during the fall and winter months in these aquatic ecosystems, they remain as key insight into the overall health of the stream and ditch sites. Currently, species with moderate to high pollution tolerances are found in high abundances in these sites, indicating that water quality is currently fair, or poor. In the future, we want to be seeing higher species abundances of those species with poor pollution tolerances, because this would indicate a healthy stream, and overall water quality. Although pollution and runoff levels within Rice Creek have been decreasing over the past few years, we want to see continuous improvement. This area will need to be routinely monitored to assess the continued impact of the implementation of cover crops.

Future studies should assess how other types of runoff are impacting local waterways within the Rice Creek Watershed such as road salt runoff or stormwater pollution. Moving forward, collaboration with Clean River Partners and the longitudinal study of Rice Creek should continue. Efforts to increase cover crop usage and decrease fertilizer use and runoff should keep growing. Water chemistry data and macroinvertebrate samples have proved to be valuable in assessing water quality in the past and will continue to provide insight into local waterways and their pollution levels. Water pollution is not something that will be fixed overnight, so routine monitoring of these bodies of water is a strong way to continue meeting benchmarks and decreasing overall pollution levels.

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Acknowledgments

I would like to thank Professor Shea for her guidance and assistance throughout this project. Thank you to the St. Olaf College Biology and Environmental Studies Departments for allowing me to use specific equipment to collect data. Special thanks go out to Professor Paul Jackson, Dane McKittrick, and Alan Kraus from the Clean River Partners for providing me with the longitudinal data sets from the Rice Creek project. Additionally, I would like to express gratitude for using the land for ecological study. Without previous stewards, this land would not be available for us to study.

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Tables and Figures:

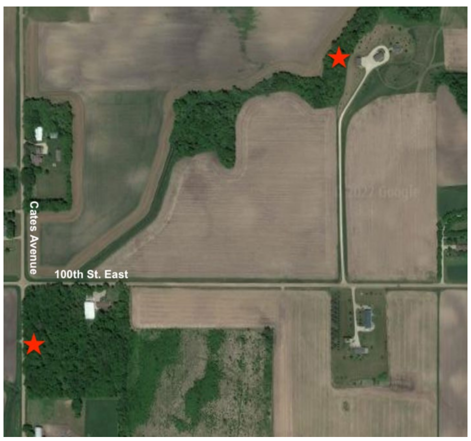

Figure 1: Google Earth satellite image of the two Rice Creek sampling sites. The Stream site is on the upper right star, at the edge of a cornfield at the intersection of Cates Avenue and 100th Street East, and the Ditch site is marked by the lower left red star. County Ditch 22 ran under the road (Cates Avenue), and into the forested area on the map.

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Table 1: Analysis of variance (ANOVA) tests, shown through a p-value which determines the significance between results for each water quality measurement, by Site.

	Stream	**Ditch**	**Pr(>F)**
Conductivity (uS/cm)	712.67	630.86	0.42
DO (mg/L)	11.56	11.22	0.64
pH	7.9	8.2	0.686
Temperature (°C)	5.9	5.2	0.86

Table 2: Analysis of variance (ANOVA) tests, shown through a p-value which determines the significance between results for each water quality measurement, by Site. This data was collected by Clean River Partners over the span of three years, and averages are shown below.

	Stream	**Ditch**	**Pr(>F)**
Nitrate (mg/L)	7.27	7.465	0.778
Phosphorous (mg/L)	0.098	0.102	0.821
TSS (mg/L)	8.10	9.24	0.627
Conductivity (uS/cm)	628.29	626.03	0.911
Temperature (C)	11.9	12.0	0.892

Table 3: A table illustrating species pollution tolerances and abundances from this summer and fall for the Stream and Ditch sites. Species richness and totals were calculated for all dates.

Common Name	Pollution Tolerance	6/29 Stream	6/29 Ditch	10/22 Stream	10/22 Ditch	11/3 Stream	11/3 Ditch	11/17 Stream	11/17 Ditch	Total
Darner Dragonfly	3 (low)	1		1						2
Broad-Wing Damselfly	5 (moderate)	4	2	13		11		7		37
Flathead Mayfly	4 (moderate)	3	1	7	1			3		15
Common Net-Spinner Caddisflies	4 (moderate	9	6							15
Black Fly Midges	6 (moderate)			5	17	4	33	3	10	72
Crane Fly Larva	3 (low)					4				4
Giant Water Bug (Toe-Biter)	10 (high)		1							1
Water Boatmen	9 (high)	2	47		26		32		3	110
Water Striders	Undetermined	8	11							19
Crawling Water Beetle	Undetermined		1							1
Long toed Water Beetle	Undetermined	1								1
Riffle Beetles (larvae)	5 (moderate)		5							5
Crayfish	6 (moderate)	3	5							8
Scuds	4 (moderate)	6	23	18	9	18	26	8	12	120
Snails	7 (high)	23								23
Backswimmer	Undetermined	1								1
Lake Limpit	Undetermined	1								1
Pouch Snail	Undetermined	20	19		4	1	2	1		47
Gilled Snail	Undetermined	1	1							2
Orb Snail	Undetermined	1	2							3
Slugs	Undetermined	1								1
Water Penny	Undetermined			1						1
Total		85	124	45	57	38	93	22	25	489
Species Richness		16	13	6	5	5	4	5	3	

Table 4: Fall data broken down by taxa and pollution tolerance for eight different taxa in the Stream and Ditch.

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Taxon Name	Pollution Tolerance	Stream 10/22	Ditch 10/22	Stream 11/3	Ditch 11/3	Stream 11/17	Ditch 11/17	Totals
Amphipoda	4 (moderate)	18	9	18	26	8	12	91
Diptera	6 (moderate)	5	17	4	33	3	10	72
Odonata	5 (moderate)	13		11		7		31
Odonata	5 (moderate)	1			1			1
Ephemeroptera	4 (moderate)	7	1			3		11
Acroloxus lacustris	7 (high)		4	1	2	1		8
Hemiptera	9 (high)		26		32		3	61
Diptera	3 (low)			4				4
Coleoptera	unknown	1						1
Total		45	57	38	94	22	25	281

Table 5: Shannon and Simpson Indices by site (Stream and Ditch). Species richness, Shannon Index (H'), Simpson Index (Ds), and the variation of the Simpson Index are recorded.

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	Stream 1	Ditch 1	Stream 2	Ditch 2	Stream 3	Ditch 3	All
Richness	6	5	5	5	5	3	9
Shannon (H')	0.62	0.55	0.56	0.53	0.62	0.42	0.55
Simpson (Ds)	0.74	0.68	0.69	0.69	0.76	0.62	0.70
Variance of Ds	0.001272	0.001311	0.002454	0.000166	0.002015	0.001993	0.001535

Table 6: Pairwise comparisons of Ds values. Calculated t values are shown. The numbers in yellow indicate significant differences in Ds values at $P<0.05$: between Stream 1 and Ditch 3, and Stream 3 and Ditch 3.

Site	Stream 1	Ditch 1	Stream 2	Ditch 2	Stream 3	Ditch 3
Stream 1						
Ditch 1	0.99396					
Stream 2	0.791201	-0.036155				
Ditch 2	1.165596	-0.164172	-0.079916			
Stream 3	-0.463097	-1.336401	-1.119657	-1.515125		
Ditch 3	2.018672	1.128014	1.005523	1.531087	2.24147	

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