Irrigation District Water Quality Program

Addendum to water quality trends in irrigation water of southern Alberta

VOLUME 8-ADDENDUM

Addendum to Volume 8: Water Quality Trends in Irrigation Water of Southern Alberta (2021)

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Executive Summary

Nearly 75% of Canada's irrigation occurs in southern Alberta's irrigation districts. The associated irrigation conveyance network supplies water for crops and livestock production, rural communities and many rural homes. Irrigation water provides wildlife habitat and recreational activities such as fishing, boating, and camping on irrigation reservoirs. Good quality irrigation water is important for all these uses. The quality of irrigation water in Alberta has been monitored by several researchers, including a 10-year project (now a continuing program) conducted by the Government of Alberta, Agriculture and Agri-Food Canada, and the Alberta Irrigation Districts Association. The objective of this project was to assess the quality of irrigation water within Alberta's irrigation districts using a long-term, consistent approach. This addendum adds five additional years of data from 2019 to 2023 to the original analysis of temporal irrigation water quality trends completed using data from 2006 to 2007 and 2011 to 2018. The additional data resulted in a 15-year dataset of 74 sites and 19 water quality parameters. Sites in eleven irrigation districts were included, with evaluation of nutrient, salinity and physical parameters. *Escherichia coli* and pesticide residues in water were also included. Data was evaluated regionally (all sites combined) and also on a site-by-site basis.

Of the 19 parameters included in the regional trend analysis, 12 had decreasing trends, two had increasing trends and five had no trends. The increasing trends were for the pesticides atrazine and EPTC and may be related to increased production of potatoes and corn in the area. For the site-by-parameter analysis, many sites exhibited increasing, decreasing and no trends depending on the parameter. In total, 335 trends were detected out of 902 datasets; 327 (36%) of which were decreasing and eight (1%) of which were increasing. The other datasets showed no trends (63%). Primary sites (district source water) showed mostly decreasing or no trends. Two primary sites showed increasing trends of total suspended solids. Secondary sites (mid-district irrigation supply water) also showed mostly decreasing or no trends. One increasing trend in *Escherichia coli* was observed. Return sites (unused irrigation water returning to rivers) showed increasing or decreasing trends depending on the site, with some sites demonstrating no trend. When compared overall, there were no significant differences in trend direction based on site type which indicates that the drivers of the trends are similar for all site types.

While these results indicate mostly stable or improving irrigation water quality (decreasing trends), this data is critical for managing and protecting Alberta’s high quality irrigation water. Interpretation of temporal trends are important for identifying and prioritizing potential water quality concerns. Sites and parameters that indicate degrading water quality (increasing trends) should have potential causes investigated and, if necessary, mitigation strategies developed to prevent further degradation. Ongoing monitoring is valuable to determine whether observed trends continue and how they relate to land use or climate changes for the protection of Alberta’s excellent quality irrigation water for all users in the future.

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1 Introduction

Nearly 75% of Canada's irrigation occurs in Alberta (Agricultural Water Survey 2022), with much of this irrigation occurring in Alberta's irrigation districts. These districts encompass approximately 8,000 km of district- and government-owned irrigation infrastructure and 56 reservoirs that together serve nearly 580,000 ha of irrigated agricultural land (AGI 2023). Irrigation is essential for high agricultural production and crop diversity in southern Alberta. The irrigation conveyance network supplies water to many rural homes and more than 30 communities for household potable water, municipal purposes, parks, and industrial uses including commercial food processing. The conveyance network also supplies water for other important uses such as livestock production, wildlife habitat, and recreational activities such as fishing, boating, and camping on irrigation reservoirs. High yielding and safe food production requires low concentration of pesticide residues and pathogens in irrigation water. Low nutrient concentrations in water help prevent the growth of aquatic weeds and algae that can impede water conveyance. Good quality irrigation water also minimizes treatment costs for rural communities.

The quality of irrigation water in Alberta has been previously monitored by researchers including Bolseng (1991), Cross (1997), Greenlee et al. (2000), Saffran (2005), Little et al. (2010), and Palliser Environmental Services Ltd. (2011); however, variations in design, parameters, and methodology used among these studies made the data difficult to compare. In response to a need for a long-term, consistent database of irrigation water quality, Alberta's irrigation districts partnered with the Government of Alberta and Agriculture and Agri-Food Canada to conduct the Irrigation District Water Quality project (now a continuing program; www.idwq.ca). The water quality information gathered for this program enables irrigation managers to be proactive in recognizing potential water quality concerns and to make science-based decisions to maintain and improve irrigation water quality.

The first 10-year dataset (2006 to 2007, 2011 to 2018) was evaluated by Kobryn and Villeneuve (2021). Trends were evaluated for parameters including nutrients, salinity, temperature, pH, *Escherichia coli (E. coli),* and pesticide residues. This report indicated some temporal trends (consistent upward or downward shifts in data with time) in water quality within irrigation districts, with generally stable water quality and improving overall regional trends. The report recommended continued monitoring to strengthen the database and enable more robust trend analysis. At the end of 2023, five additional years of irrigation water quality data were available from the Irrigation Districts Water Quality program. These five years of data were added to the original dataset of the initial report (Kobryn and Villeneuve 2021), creating a comprehensive 15-year dataset (2006-2007, 2011-2023). The purpose of this addendum is to perform trend analyses on the comprehensive dataset and report the results.

2 Methods

2.1 Site and parameter selection

As with the initial analyses (Kobryn and Villeneuve 2021), water sampling sites were defined as primary, secondary, and return site types (Charest et al. 2015). Primary sites were where source water entered an irrigation district, such as from a reservoir, river diversion, or main canal (Figure 1). Secondary sites were on lateral canals that branch off a main canal or were immediately downstream of a mid-district reservoir. Return sites were located at the ends of the irrigation district conveyance network where unused irrigation water is returned to a river. Return sites are divided into watershed returns, where water returns to a river via a coulee or natural drainage, and infrastructure returns, where water returns through a constructed irrigation canal (Table 1).

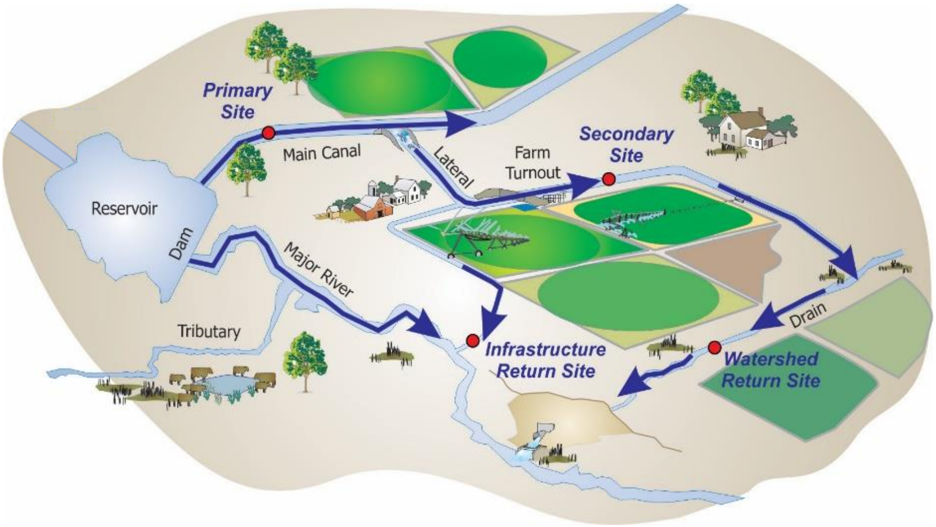


Figure 1. Schematic diagram of southern Alberta’s irrigation conveyance network and Irrigation District Water Quality program site types.

Irrigation water was sampled at sites in 11 districts from 2006 to 2023 (Figure 2). The irrigation districts sampled were Aetna (AID), Bow River (BRID), Eastern (EID), Lethbridge Northern (LNID), Magrath (MID), Mountain View (MVID), Raymond (RID), Taber (TID), St. Mary River (SMRID), United (UID), and Western (WID). In 2023, TID was amalgamated with SMRID, but TID data was kept separate for the purposes of this analysis and addendum. Also in 2023, AID amalgamated with Leavitt Irrigation District and was renamed Southwest Irrigation District. Leavitt Irrigation District did not have any IDWQ sites due to its proximity to AID, so AID’s single site maintained its AID classification for the purpose of this addendum. Each site type (i.e., primary, secondary, or return) was not represented in each irrigation district (Table 1).

A threshold of 10 years of data was chosen as a requirement for the proposed trend analysis and 74 sites met this threshold. Although the data had a 15-year range, as the study progressed, some sites were discontinued due to logistics or conversion of open canals to pipelines in which surface water samples could no longer be collected. As well, a parameter review at the end of 2015 resulted in some parameters (i.e., metals) being discontinued. These parameters were not re-evaluated as they did not meet the 10-year data threshold. Nineteen parameters met the threshold including: nutrients, specifically nitrate-nitrogen (NO_3-N), total nitrogen (TN), orthophosphate (PO_4-P), and total phosphorus (TP); total dissolved solids (TDS), an indicator of salinity; physical parameters of temperature, total suspended solids (TSS), and pH; *E. coli*– the only bacteriological parameter consistently measured throughout the study; and ten pesticide residues (Table 2).

Table 1. Sites from which data were used in trend analyses.

District	Type	Site
AID	Return	A-R1[y]
BRID	Primary	BR-P1
	Secondary	BR-S1
		BR-S3
		BR-S4a
		BR-S5
	Return	BR-R1[z]
		BR-R2[y]
		BR-R3[y]
		BR-R4[y]
		BR-R5[z]
EID	Primary	E-P1
	Secondary	E-S1
		E-S2
		E-S3
		E-S4
		E-S5
		E-S6
		E-S8
	Return	E-R1[z]
		E-R2[z]
		E-R2a[y]
		E-R3[z]
		E-R4a[z]
		E-R5[z]
		E-R8a[y]
LNID	Primary	LN-P1
	Secondary	LN-S1
		LN-S2
		LN-S3
		LN-S4
		LN-S5
	Return	LN-R1[y]
		LN-R2[y]
		LN-R4[z]
MID	Primary	M-P1
	Secondary	M-S1
	Return	M-R1[y]
MVID	Primary	MV-P1
	Return	MV-R1[z]
RID	Primary	R-P1
	Return	R-R1[y]
		R-R2[y]
SMRID	Primary	SMW-P1
	Secondary	SMW-S2
	Return	SMW-R1[y]
		SMW-R2[z]
	Primary	SMC-P1
	Secondary	SMC-S1
		SMC-S2
		SMC-S3
	Return	SMC-R1[z]
		SMC-R3[z]
		SMC-R4[z]
	Primary	SME-P1
	Secondary	SME-S1
	Return	SME-R1a[z]
		SME-R2[y]
TID	Primary	T-P2
	Secondary	T-S2
		T-S3
	Return	T-R1[z]
		T-R2[z]
UID	Primary	U-P1
	Secondary	U-S1
	Return	U-R2[z]
WID	Primary	W-P1
		W-P2
	Secondary	W-S1
		W-S2
		W-S3
		W-S4
	Return	W-R1a[z]
		W-R2[y]

[z] Infrastructure return

[y] Watershed return

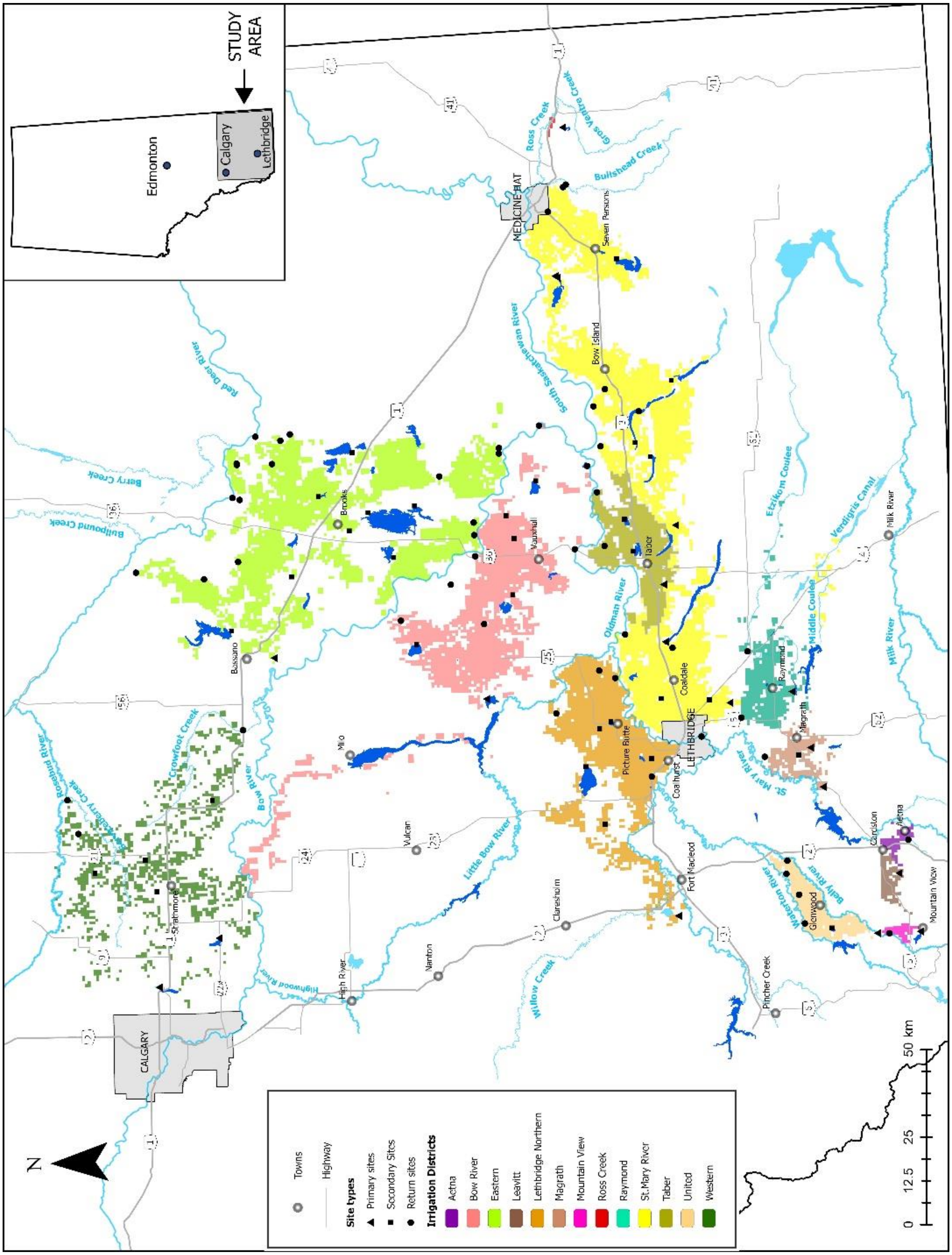


Figure 2. Sampling site location within Alberta's irrigation districts.

Table 2. Water quality parameters analyzed for the presence of trends in this study.

Variable Type	Variable	Abbreviation	Units	Years of data
Nutrients	Nitrate-nitrogen	NO_3-N	mg/L	15
	Total nitrogen	TN		13
	Total phosphorus	TP		15
	Orthophosphate phosphorus	PO_4-P		14
Salinity	Total dissolved solids	TDS	mg/L	
Physical	pH	pH	unitless	15
	Temperature	Temp	deg C	15
	Total suspended solids	TSS	mg/L	15
Bacteriological	*Escherichia coli*	*E. coli*	CFU/100 ml	15
Pesticides	2,4-Dichlorophenoxyacetic acid	2,4-D	mg/L	14
	Atrazine	Atra		12
	Bromoxynil	Brox		14
	Clopyralid	Clop		12
	Dicamba	Dicm		14
	Dichlorprop	Dcpr		10
	S-ethyl dipropylthiocarbamate	EPTC		10
	2-methyl-4-chlorophenoxyacetic acid	MCPA		14
	Mecoprop	MCPP		14
	Simazine	Sima		12

2.2 Sample Collection

Water sampling occurred from late May to the beginning of September, with two to five weeks separating four sampling events (Kobryn and Villeneuve 2021). Collection times were optimized to occur during active irrigation demand. Two to three days were required to sample all sites during each sampling event. Samples were collected using a 1-L polyethylene bottle, attached to a telescopic pole with an extension range of four meters. A new sampling bottle was used at each site to fill laboratory bottles for the analysis of different parameters. Samples were placed in coolers with ice while in the field, and delivered to analytical laboratories at the end of each day.

2.3 Data Analysis

2.3.1 Testing for the Presence of Seasonality

The evaluation of water quality trends of the 15-year dataset was conducted using the same statistical tests used in the initial analyses (Kobryn and Villeneuve 2021). The presence of seasonality (i.e., differences in concentrations that are related to the timing of sampling) were assessed before testing for the presence of trends. Seasonality was tested using a version of the generalized Wilcoxon score test using the ‘cendiff’ routine in the package NADA (Lee 2013) of the statistical software R (R Development Core Team 2022).

2.3.2 Parameter-by-site Trend Analysis

Two different Mann-Kendall tests were used for the analysis of temporal trends of each parameter at each site (herein referred to as the ‘parameter-by-site’ analysis), depending on whether seasonality was present or not. For datasets that displayed seasonality, the Seasonal Kendall test was used (Hirsch et al. 1982). Before performing Seasonal Kendall tests, data were re-censored at the highest method detection limit (MDL), as the Seasonal Kendall test cannot accommodate multiple detection limits. In this process, all censored (less than MDL) values and values less than the maximum MDL for a given parameter were set at the same (arbitrary) value less than the greatest MDL. These analyses were performed in the statistical software R, using the function ‘kendallSeasonalTrendTest’ with a continuity correction, in the package ‘EnvSats’ (Millard 2013). For data that were not seasonal, a version of a Mann-Kendall test that can accommodate multiple detection limits, the Censored Mann-Kendall test, was used. Because this test allows the presence of multiple MDLs (unlike the Seasonal Kendall), it did not require data to be re-censored below the highest MDL. Censored data were set at the detection limit, as described in Helsel (2012). These tests were implemented using the ‘cenken’ routine in the package NADA in R (Lee 2013).

In addition to requiring at least 10 years of data, the parameter-by-site trend analyses were not performed if parameter data for a site had less than two values that were greater than the MDL, as statistical power would have been too low to detect a trend. Because many individual trend tests were performed in the parameter-by-site analysis, the false discovery rate (FDR) method (Benjamini and Hochberg 1995) for P-value adjustment (P_{adj}) was used to adjust the P-values of individual trend tests to maintain the expected rate of false positives for the entire analysis (rather than individual tests) at 0.05.

2.3.3 Regional Trend Analysis

Regional trend analyses were conducted by parameter (considering all sites) using the Regional Kendall test. This test is the same as the Seasonal Kendall test and was performed using the ‘kendallSeasonalTrendTest’ function in R, with sites instead of seasons used to block the data (Helsel and Frans 2006). Like the Seasonal Kendall test, the Regional Kendall test cannot accommodate multiple MDLs, so the data for the test were re-censored at an arbitrary value less than the highest MDL, as described previously. Additionally, the Regional Kendall test can only accommodate one observation per site per year, so for each parameter at each site, the third largest concentration of four values per year, after censoring, was used (i.e., the 75th percentile). The FDR method of P-value correction was used for the Regional Kendell tests performed to maintain the expected rate of false positives for the regional trend analysis at 0.05.

All three of the tests used for this trend analysis (i.e., the Seasonal Kendall, Censored Mann Kendall, and Regional Kendall) have test statistics based on Kendall’s tau correlation coefficient. This coefficient measures the strength of the monotonic (i.e., consistently increasing or decreasing) association between two variables

All three of the tests used for this trend analysis (i.e., the Seasonal Kendall, Censored Mann Kendall, and Regional Kendall) have test statistics based on Kendall’s tau (τ) correlation coefficient. This coefficient measures the strength of the monotonic (i.e., consistently increasing or decreasing) association between two variables, for example, a given water quality parameter and time. It makes no assumption about the shape of the trend (e.g., linear, exponential, logarithmic) if it is monotonic. Kendall’s tau varies between 1 and -1, with positive values indicating a positive correlation (increasing trend), negative values indicating a negative correlation (decreasing trend), and 0 indicating no association (no trend). The absolute value of the magnitude of tau reflects the strength of the correlation (i.e., values close to 1 and -1 represent strong correlations) (Helsel and Hirsch 2002). The shape of trends was not assessed or reported in this study, and because the P-values of the tests used were not affected by transformations that do not change the ranks of the data, the data were not transformed before performing trend tests (Helsel and Hirsch 2002)**.**

Trend analysis results are summarized in terms of trend direction (increasing or decreasing). With regard to water quality, decreasing trends are usually associated with improving water quality because decreased concentrations of contaminants such as pesticide residues, pathogens or excess nutrients can make water suitable for more water uses based on water use guidelines (GOA 2018). Similarly, increasing trends usually indicate degrading water quality due to greater concentrations of contaminants. The exceptions are the parameters of temperature and pH as they are not measured as concentrations and decreases or increases outside of optimal ranges may be problematic.

3 Results and Discussion

3.1 Seasonality

The presence of seasonality, or in this case, differences in values related to the timing of sampling (i.e., late May to early July, July, late July to early August, late August to mid-September) were explored. Of the 1,406 parameter-by-site datasets (i.e., 19 parameters by 74 sites), 290 displayed seasonal patterns. Certain parameters tended to display seasonality more often than others, but only temperature (73 out of 74 sites) and TDS (60 of 74 sites) displayed seasonality in more than half of the parameter's datasets (i.e., sites). Of the remaining parameters, only TSS (28 of 74 sites) and *E. coli* (26 of 74 sites) demonstrated seasonality in more than one quarter of the datasets. As it is related to trend analysis, seasonality was assessed only to decide whether to perform Seasonal Kendall or Censored Mann-Kendall tests.

3.2 Trend Analysis

3.2.1 Regional Trend Analyses

Of the 19 parameters included in regional trend analysis (i.e., all sites combined by parameter), 12 had decreasing trends, two had increasing trends, and five had no trends (Table 3). Moderate decreasing (improving water quality) trends (τ correlation coefficient = -0.5 to -0.3) were observed for concentrations of NO_3-N, TN, TP, TDS, and 2,4- D. Weak decreasing trends (τ = -0.3 to -0.1) were observed for concentrations of dicamba, and MCPA. Weak decreasing trends (τ correlation coefficient = 0.27 to -0.28) also occurred for pH and temperature. Very weak decreasing trends (τ = -0.10 to 0) were observed for concentrations of TSS, dichlorprop, and mecoprop. The two very weak increasing (degrading water quality) trends were observed in atrazine (τ = 0.01) and EPTC (τ = 0.03). Atrazine is commonly used on corn while EPTC is used on corn, beans and potatoes and the acreage producing these crops has increased 26% for corn and 35% for potatoes between 2015 and 2022 in the irrigation districts (AGI 2016, AGI 2023).

The environmental quality guidelines for Alberta surface water for atrazine are 10 µg/L for irrigation, 5 µg/L for livestock water, and 1.8 µg/L for the protection of aquatic life (GOA 2018). The concentrations of atrazine detected during this program had a range of 0.02 to 0.53 µg/L and were below these guidelines. In absence of environmental quality guidelines, EPTC concentrations of 0.03 to 1.00 µg/L detected during this program were compared to a Canadian drinking water guideline of 74 µg/L, for chronic exposure for infants; the population most at risk for adverse effects (PMRA 2007) and concentrations were below this guideline. Although raw irrigation water (as measured) should not be consumed without treatment, this comparison of untreated water to the (treated) drinking water guideline illustrates the low risk that EPTC concentrations in irrigation water poses. Drinking water guidelines are typically the most stringent of guidelines due to the direct link to human health. EPTC has since been removed from Canadian drinking water guidelines due to its low risk to human health (PMRA 2007).

3.2.2 Parameter-by-Site Trend Analyses

For parameter-by-site analyses, 902 datasets were tested out of 1,406 potential datasets. Tests were not performed in 504 instances when datasets (i.e., sites) had fewer than two values above the MDL or were missing whole years of data for a certain parameter and the 10-year threshold was not met for that parameter. In total, 335 trends ($P_{adj} \leq 0.05$) were detected (37% of tests): 327 of which were decreasing (usually considered improving water quality, except for pH and temperature) and eight of which were increasing (degrading water quality) (Table 3). The other tests showed no trends.

Many sites exhibited increasing, decreasing and no trend depending on the parameter. The parameter with the most (sites with) decreasing trends was 2,4-D with over 60 sites. Other parameters such as TN, TP, TDS, pH, and temperature had decreasing trends occurring at 25 to 50 sites depending on the parameter. Decreasing trends were also detected for NO_3-N, PO_4-P, TSS, *E. coli* and for pesticides; Dichloroprop, Dicamba, MCPA and MCPP. Increasing trends were observed for TN, NO_3-N, TDS, TSS and *E. coli* at 1 to 2 sites depending on the parameter, and were not detected for any pesticide. It is important to consider that although a minimum of ten years of data were included for each test, particularly in datasets (such as pesticide parameters) with high proportions of below-MDL data, the absence of a trend may reflect low power to detect a trend rather than the absence of a true trend (Helsel et al. 2020).

Table 3 Summarized results of regional and parameter-by-site trend analysis of nutrient, salinity, physical, bacteriological, and pesticide parameters. Tests that did not indicate the presence of a statistically significant trend are labelled as "ns"; "NA" indicates that no test was run because there were less than 10 years of collected data, or because there was less than two values that were greater than the MDL. Trends that were statistically significant after FDR P-value correction are represented by - for decreasing trends and + for increasing trends. Trends that were significant before correction for multiple tests but not afterwards are represented by (-) and (+).

		Regional																		
		NO$_3$-N	**TN**	**PO$_4$-P**	**TP**	**TDS**	**pH**	**Temp**	**TSS**	***E. coli***	**2,4-D**	**Atra**	**Brox**	**Clop**	**Dcpr**	**Dicm**	**EPTC**	**MCPA**	**MCPP**	**Sima**
		-	-	ns	-	-	-	-	-	ns	-	+	(+)	ns	-	-	+	-	-	(-)
		Parameter-by-site																		
Total decreasing trends:		10	49	1	33	46	30	33	7	3	61	0	0	0	9	19	0	18	8	0
Total increasing trends:		1	1	0	0	1	0	0	3	2	0	0	0	0	0	0	0	0	0	0
District	**Site**	**NO$_3$-N**	**TN**	**PO$_4$-P**	**TP**	**TDS**	**pH**	**Temp**	**TSS**	***E. coli***	**2,4-D**	**Atra**	**Brox**	**Clop**	**Dcpr**	**Dicm**	**EPTC**	**MCPA**	**MCPP**	**Sima**
AID	A-R1	ns	NA	NA	ns	ns	-	ns	ns	ns	ns	NA	NA	NA	NA	(-)	NA	ns	NA	NA
BRID	BR-P1	ns	-	NA	-	-	-	-	ns	ns	-	NA	ns	ns	NA	NA	NA	ns	NA	NA
	BR-R1	ns	-	NA	-	-	(-)	ns	ns	ns	-	NA	NA	NA	NA	NA	NA	(-)	NA	ns
	BR-R2	(-)	-	NA	-	-	-	-	ns	ns	-	NA	ns	NA	-	-	NA	ns	NA	ns
	BR-R3	ns	ns	NA	ns	ns	ns	ns	ns	-	-	NA	NA	NA	-	(-)	ns	ns	NA	ns
	BR-R4	ns	-	NA	(-)	-	(-)	ns	ns	(+)	-	ns	ns	ns	-	(-)	NA	ns	NA	ns
	BR-R5	ns	-	NA	ns	-	-	-	ns	ns	-	NA	NA	NA	NA	ns	NA	ns	NA	ns
	BR-S1	ns	-	NA	(-)	-	(-)	(-)	ns	ns	-	NA	NA	ns	NA	ns	NA	ns	NA	NA
	BR-S3	ns	-	NA	ns	-	-	-	ns	+	-	NA	NA	NA	NA	NA	NA	-	ns	ns
	BR-S4a	-	-	NA	-	-	-	-	ns	ns	-	NA	NA	NA	NA	ns	NA	ns	NA	ns
	BR-S5	ns	-	NA	ns	-	(-)	(-)	ns	(-)	-	NA	NA	NA	NA	(-)	ns	ns	NA	ns
EID	E-P1	ns	ns	NA	ns	ns	ns	ns	ns	ns	-	NA	NA	NA	NA	ns	NA	ns	ns	NA
	E-R1	ns	-	NA	ns	ns	-	(-)	ns	ns	-	NA	NA	NA	NA	-	NA	ns	NA	NA
	E-R2	(+)	-	NA	-	(-)	ns	ns	ns	(-)	-	(+)	NA	NA	NA	-	NA	ns	NA	NA
	E-R2a	ns	-	NA	ns	ns	-	-	-	ns	-	NA	ns	ns	NA	(-)	NA	ns	NA	NA
	E-R3	ns	(-)	NA	ns	ns	ns	ns	ns	ns	-	NA	NA	NA	NA	ns	NA	ns	ns	NA
	E-R4a	(-)	ns	NA	-	-	ns	ns	ns	ns	-	NA	NA	NA	NA	(-)	NA	ns	NA	NA
	E-R5	ns	ns	NA	ns	ns	-	ns	ns	ns	-	NA	NA	NA	NA	ns	NA	NA	NA	NA
	E-R8a	-	-	NA	-	-	-	ns	ns	ns	-	NA	ns	ns	NA	-	NA	ns	NA	NA
	E-S1	ns	-	NA	-	ns	ns	(-)	-	ns	-	NA	NA	NA	NA	-	NA	NA	ns	NA
	E-S2	ns	ns	NA	ns	ns	ns	ns	ns	ns	-	NA	NA	NA	NA	ns	NA	ns	ns	NA
	E-S3	ns	ns	NA	-	ns	ns	ns	ns	ns	-	NA	ns	NA	NA	ns	NA	ns	ns	NA
	E-S4	ns	ns	NA	ns	(-)	ns	-	ns	ns	-	NA	NA	NA	NA	ns	NA	NA	NA	NA
	E-S5	ns	ns	NA	ns	ns	ns	ns	ns	ns	-	NA	NA	NA	NA	ns	NA	ns	NA	NA
	E-S6	ns	ns	NA	-	ns	ns	ns	ns	ns	-	NA	NA	NA	NA	ns	NA	ns	NA	NA
	E-S8	ns	-	NA	-	-	-	(-)	ns	ns	-	NA	NA	NA	NA	-	NA	ns	ns	NA
LNID	LN-P1	-	-	NA	ns	ns	ns	-	ns	ns	ns	NA	NA	NA	NA	NA	NA	ns	NA	NA
	LN-R1	ns	-	NA	ns	-	(-)	-	-	ns	-	NA	NA	NA	NA	ns	NA	ns	NA	NA
	LN-R2	+	+	NA	ns	+	(-)	-	ns	ns	ns	(+)	ns	NA	NA	ns	NA	(-)	NA	NA
	LN-R4	ns	-	NA	-	-	-	-	ns	ns	-	NA	NA	NA	NA	-	NA	-	-	NA
	LN-S1	-	-	NA	-	ns	ns	-	ns	ns	ns	NA	NA	ns	NA	ns	NA	ns	NA	NA
	LN-S2	NA	-	NA	ns	-	(-)	(-)	ns	ns	-	NA	NA	NA	NA	NA	NA	ns	NA	NA
	LN-S3	ns	-	NA	-	-	-	ns	ns	ns	ns	NA	ns	NA	NA	ns	NA	ns	NA	NA
	LN-S4	ns	-	NA	(-)	-	(-)	-	ns	ns	-	NA	NA	ns	NA	ns	NA	ns	NA	NA
	LN-S5	ns	-	NA	ns	-	ns	ns	ns	ns	-	NA	NA	NA	NA	ns	NA	ns	ns	NA

Table 3 *continued*.

District	Site	NO_3-N	TN	PO_4-P	TP	TDS	pH	Temp	TSS	*E. coli*	2,4-D	Atra	Brox	Clop	Dcpr	Dicm	EPTC	MCPA	MCPP	Sima
MID	M-P1	(-)	ns	NA	ns	ns	ns	-	+	ns	-	NA	NA	NA	NA	ns	NA	ns	NA	NA
	M-R1			NA	ns	-	ns	-	(+)	ns	-	NA	NA	ns	NA	ns	NA	(-)	NA	NA
	M-S1	-	-	NA	-	-	ns	-	(-)	ns	-	NA	NA	ns	NA	ns	NA	ns	NA	NA
MVID	MV-P1	ns	-	NA	-	ns	-	-	+	ns	-	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MV-R1	ns	ns	NA	ns	ns	-	-	ns	ns	(-)	NA	NA	NA	NA	NA	NA	ns	NA	NA
RID	R-P1	-	-	NA	ns	(-)	ns	-	ns	ns	-	NA	NA	NA	NA	ns	NA	ns	NA	NA
	R-R1	-	-	NA	-	-	ns	-	ns	(-)	-	ns	NA	NA	NA	ns	NA	ns	ns	NA
	R-R2	ns	ns	NA	(-)	-	ns	-	-	ns	-	NA	NA	ns	NA	ns	NA	ns	NA	NA
SMRID	SMC-P1	ns	-	NA	ns	-	-	ns	ns	-	-	NA	NA	ns	NA	ns	NA	-	NA	NA
	SMC-R1	ns	-	NA	-	-	-	-	ns	ns	-	ns	NA	NA	NA	NA	ns	-	NA	NA
	SMC-R3	(-)	-	NA	-	-	-	-	ns	ns	ns	ns	NA	NA	NA	ns	ns	-	ns	NA
	SMC-R4	ns	-	NA	ns	-	-	-	+	ns	-	ns	NA	NA	NA	ns	NA	-	NA	NA
	SMC-S1	ns	-	NA	ns	-	ns	ns	ns	ns	(-)	ns	NA	NA	NA	NA	ns	-	ns	NA
	SMC-S2	ns	-	NA	-	-	ns	ns	ns	ns	ns	ns	NA	ns	NA	NA	ns	-	NA	NA
	SMC-S3	ns	-	NA	ns	-	-	-	ns	ns	-	NA	NA	NA	NA	ns	ns	-	NA	NA
	SME-P1	ns	-	NA	-	-	-	-	ns	ns	-	ns	NA	NA	-	ns	NA	-	NA	NA
	SME-R1a	ns	ns	NA	ns	-	ns	ns	ns	ns	(-)	NA	NA	NA	NA	NA	NA	ns	ns	NA
	SME-R2	(+)	-	NA	ns	-	-	(-)	-	ns	(-)	ns	NA	NA	NA	ns	NA	ns	NA	NA
	SME-S1	ns	ns	NA	ns	-	-	ns	ns	ns	ns	ns	NA	NA	NA	NA	NA	-	NA	NA
	SMW-P1	ns	(-)	NA	(-)	-	ns	-	ns	ns	-	NA	NA	NA	NA	NA	NA	ns	NA	NA
	SMW-R1	(-)	-	NA	-	-	ns	ns	ns	ns	-	NA	NA	ns	NA	-	NA	-	ns	NA
	SMW-R2	ns	ns	NA	-	(-)	(-)	-	-	+	-	NA	NA	NA	NA	-	ns	-	NA	NA
	SMW-S2	ns	-	NA	-	(-)	ns	-	ns	ns	-	NA	NA	NA	NA	NA	NA	(-)	NA	NA
TID	T-P2	ns	-	ns	ns	-	(-)	ns	ns	ns	-	ns	ns	ns	NA	ns	NA	(-)	NA	NA
	T-R1	-	-	(-)	-	-	ns	ns	ns	ns	-	NA	NA	ns	-	(-)	ns	-	NA	NA
	T-R2	ns	ns	(+)	ns	-	-	(-)	ns	ns	-	ns	ns	NA	-	-	ns	-	ns	NA
	T-S2	ns	-	-	-	-	-	-	ns	(-)	-	ns	NA	ns	-	-	(+)	-	ns	NA
	T-S3	ns	(-)	ns	-	-	-	ns	ns	ns	-	ns	NA	NA	-	-	ns	-	ns	NA
UID	U-P1	ns	ns	NA	ns	ns	ns	-	ns	(+)	ns	NA	NA	NA	NA	ns	NA	ns	NA	NA
	U-R2	ns	(-)	NA	-	ns	ns	-	-	-	-	NA	NA	NA	NA	ns	NA	ns	NA	NA
	U-S1	ns	-	NA	-	ns	-	-	ns	(-)	-	NA	NA	NA	NA	ns	NA	ns	NA	NA
WID	W-P1	ns	ns	NA	ns	-	ns	ns	(-)	ns	-	NA	NA	NA	NA	-	NA	ns	-	NA
	W-P2	ns	-	NA	-	-	ns	ns	ns	ns	-	NA	NA	NA	NA	-	NA	ns	-	NA
	W-R1a	ns	-	NA	-	ns	-	ns	ns	ns	-	NA	NA	NA	NA	ns	NA	ns	-	NA
	W-R2	ns	-	NA	-	-	(-)	ns	ns	ns	-	NA	ns	ns	NA	-	NA	ns	-	NA
	W-S1	ns	(-)	NA	ns	-	-	ns	ns	ns	-	NA	ns	NA	-	-	NA	-	-	NA
	W-S2	ns	-	NA	ns	-	(-)	ns	ns	(-)	-	NA	NA	ns	NA	-	NA	ns	(-)	NA
	W-S3	ns	-	NA	-	-	-	ns	ns	ns	-	NA	ns	ns	NA	-	NA	ns	-	NA
	W-S4	-	-	NA	(-)	ns	(-)	ns	ns	ns	-	NA	NA	ns	NA	-	NA	ns	-	NA

3.2.3 Site type and district comparison

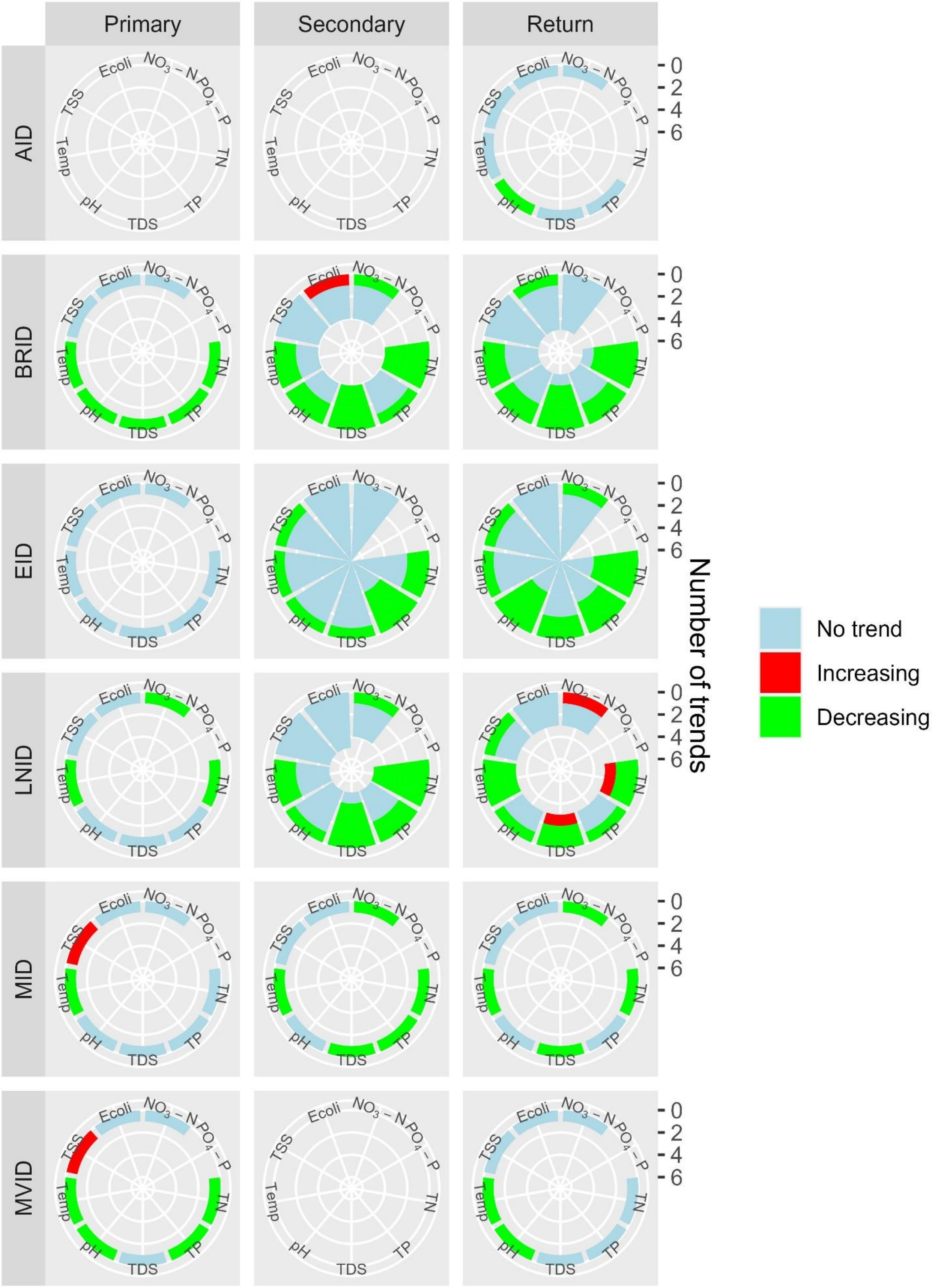
Primary sites showed mostly decreasing or no trends, with two increasing trends (Figure 3 and Figure 4). This indicates that water quality is largely stable or improving. The two increasing trends were for TSS at MV-P1 and M-P1, which are interpreted as a degradation in water quality due to increased particulates and the associated nutrient and pesticide residue that may be attached to the suspended solids (Commelin et al. 2022). Since these increases occurred at sites with generally low TSS values (median values of 3 mg/L at both sites), continued monitoring and preparedness for mitigation is warranted at these sites if TSS continues to increase.

Secondary sites also showed mostly decreasing or no trends with one increasing trend in *E. coli* at BR-S3 (Figure 3 and Figure 4). An increasing trend in *E. coli* is considered a degradation in water quality, as it indicates an increased risk of the presence of fecal pathogens. Although this site shows an increasing trend in *E. coli*, the majority of values (i.e., median 14 CFU/100 ml) were below the irrigation water quality guideline for *E. coli*, which is 100 CFU/100 ml (GOA 2018). Similar to the increasing trends of TSS at MV-P1 and M-P1, BR-S3 warrants continued monitoring and preparedness for mitigation if required.

Return sites showed increasing and decreasing trends depending on the site, with some demonstrating no trends (Figure 3 and Figure 4). Increasing trends were observed at LN-R2 for NO_3-N, TN, and TDS. Although increasing trends for these parameters would usually be interpreted as a degradation of water quality, this site is located on an open canal that had its upstream portions converted to pipeline over the last five years of the 15-year dataset. Many irrigation districts are converting open canals to pipelines and the on-demand nature of pipeline delivery reduces the amount of unused (return) water in the system. This means that LN-R2 experienced less (irrigation) water present and a subsequent increase of groundwater seepage. Groundwater seepage occurs when the surrounding water table is higher than the canal water level (Winter et al. 1998). Prior to conversion to pipeline delivery, Zikey (2001) reported that the irrigation canal which includes LN-R2, experienced an annual groundwater seepage gradient related to the irrigation season. Periods of low groundwater seepage into the canal occurred during the summer months of May to October (i.e., irrigation season) and corresponded to when canal water levels were near capacity. Conversely, the groundwater seepage rate into the canal increased when the canal was dewatered from November to April. The reduced volume of return water in the canal after conversion to pipeline delivery mimics the previous dewatered period and groundwater seepage into the canal is now occurring during the irrigation season This canal is located in an area of intensive livestock operations (Serecon 2023) and groundwater in this area has elevated nitrogen (NO_3-N and TN) and salt (TDS) concentrations (Kohn et al. 2016). Because of the reduction in irrigation water volume at this site, and the groundwater influence, these increasing trends should not be interpreted as a degradation of irrigation water quality. It is also not considered a representation of increased risk to the receiving environment as, in terms of load, the decreased volume of water compensates for the increased concentrations (data not shown).

Increasing trends in TSS and *E. coli* were observed at two other return sites: SMC-R4 for TSS and SMW-R2 for *E. coli*. Values for TSS at SMC-R4 were low (median value of 10 mg/L) and values for *E. coli* at SMW-R2 were generally below the environmental quality guideline of 100 CFU/100 ml for irrigation water (median value of 70 CFU/100 ml). While both sites with increasing trends warrant continued monitoring, the *E. coli* trend at SMC-R4 warrants investigation into potential causes and development of mitigation strategies to prevent further degradation of water quality and guideline exceedances.

As discussed previously, deviation outside of optimal ranges for temperature and pH may indicate degrading water quality, so comparison of values to guidelines must be done to assess the risk of the decreasing trends observed for these parameters. The environmental quality guideline for Alberta's surface waters (GOA 2018) indicates a pH range of 6.5 to 9 for the protection of freshwater aquatic life. The range of pH for primary sites was 6.9 to 9.3, secondary sites was 6.9 to 9.9 and return sites was 7.0 to 9.9. These values are generally within the recommended guidelines, with some exceedances of the upper range. Because pH is showing a decreasing trend, exceedances of the upper range may be reduced but values should continue to be monitored for exceedances of the lower guideline range. The environmental guideline for temperature is narrative and depends upon weekly site-specific averages so the monthly temperature values collected for this program cannot be compared.



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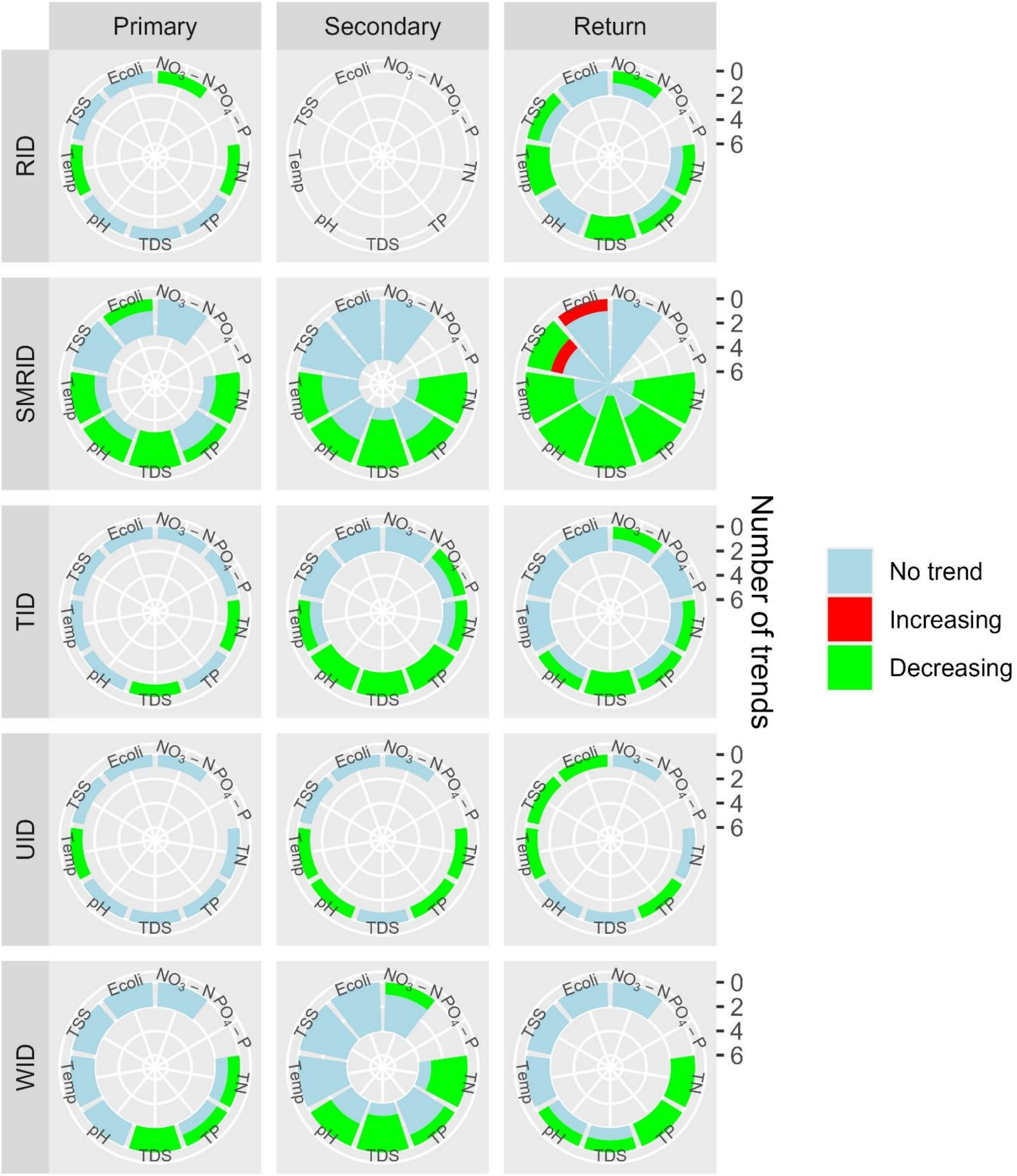
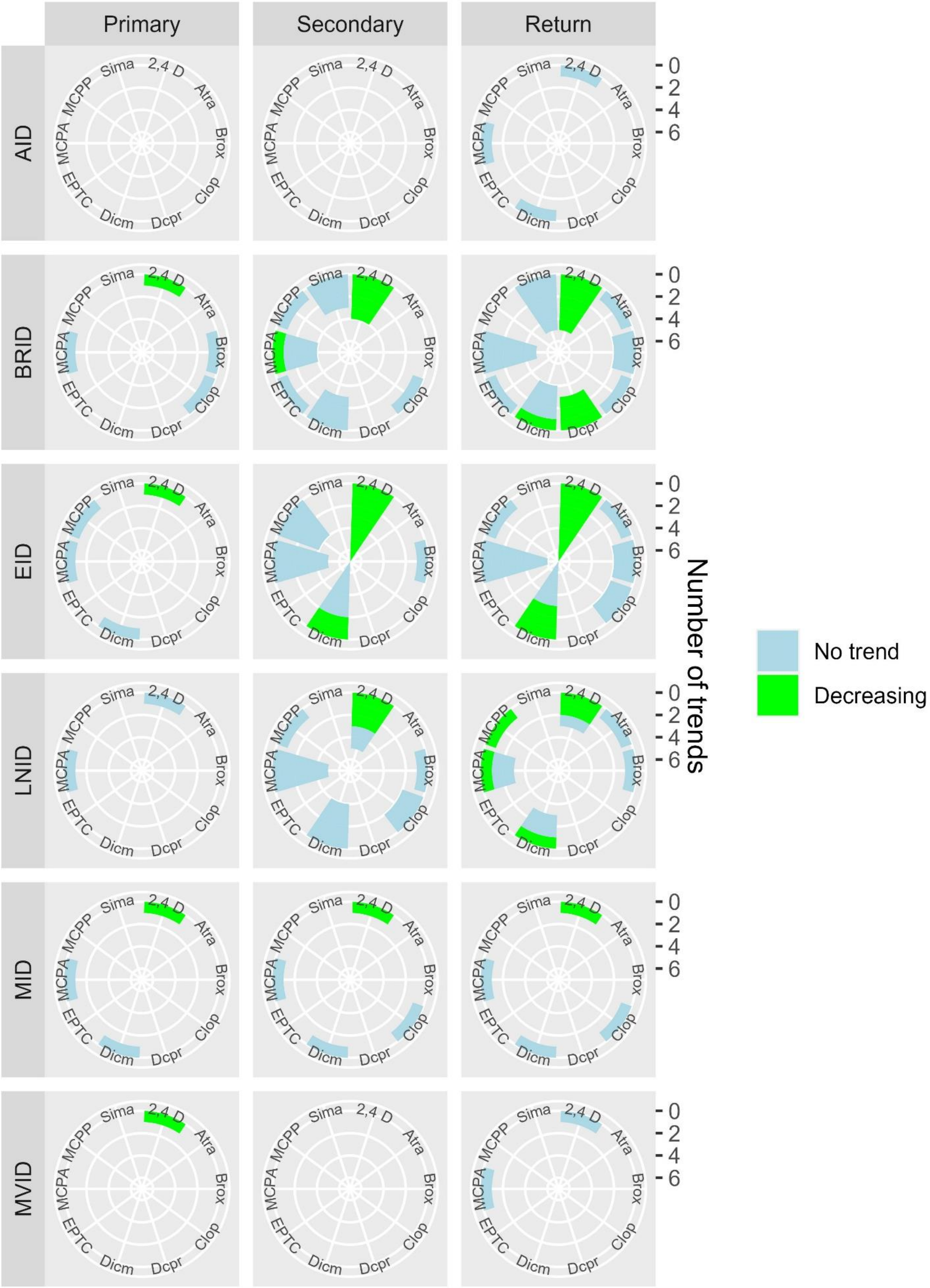


Figure 3. Wheel graphs showing number of increasing, decreasing or no trends for nutrient, salinity, bacteriological, and physical parameters by site type by irrigation district.



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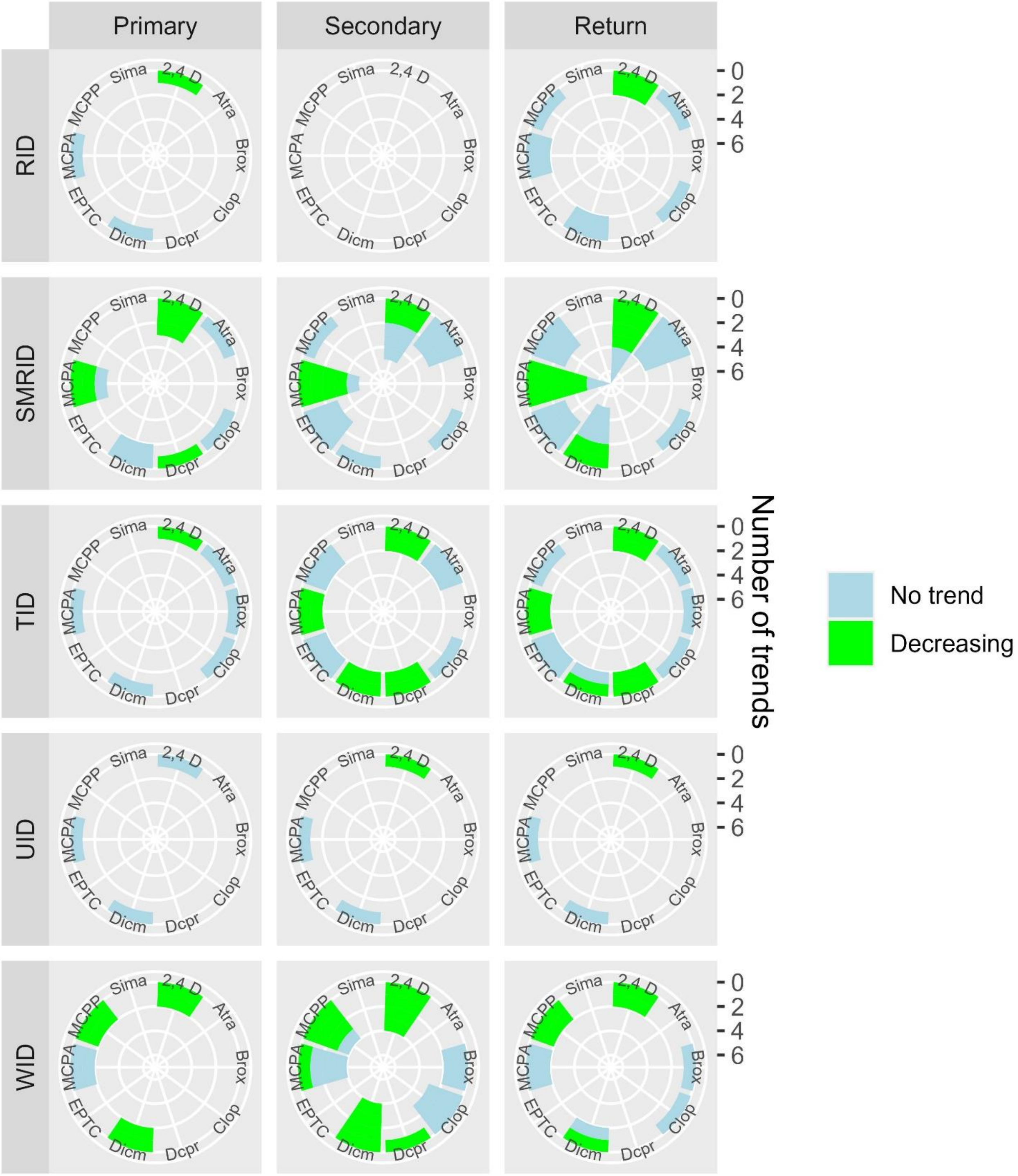

Figure 4. Wheel graphs showing number of decreasing or no trends for pesticide parameters by site type by irrigation district. There were no increasing trends for pesticide parameters.

Infrastructure and watershed return site types showed similar proportions of trend direction (Figure 5). Percentages were used for comparison due to differing numbers of sites (i.e., 18 infrastructure returns and 14 watershed returns). Infrastructure returns had 38.3% (83) decreasing trends, while watershed returns had 36.1% (65) decreasing trends. These percentages of decreasing trends were not significantly different (p>0.05) between the return site types. Infrastructure returns had 0.9% (2) increasing trends and watershed returns had 1.7% (3) increasing trends. These percentages of increasing trends also were not significantly different (p>0.05) between return site types. These similarities were unexpected as watershed returns have been shown to have poorer water quality than infrastructure returns due to opportunity for irrigation water to mix with surface water in watershed returns (Kerr and Villeneuve 2021). In contrast, constructed irrigation canal banks, such as infrastructure return canals, are often bermed (i.e., designed at a higher grade than the surrounding landscape) to act as a buffer against surface runoff from the surrounding landscape. It was assumed that this design would offer an advantage to infrastructure returns not available to watershed returns that would result in more decreasing or fewer increasing trends for infrastructure returns. Conversely, the similarity of percentages of trend directions between return site types suggest that although there is an overall difference in the water quality of these return types, the forces driving trends in the water quality were similar.

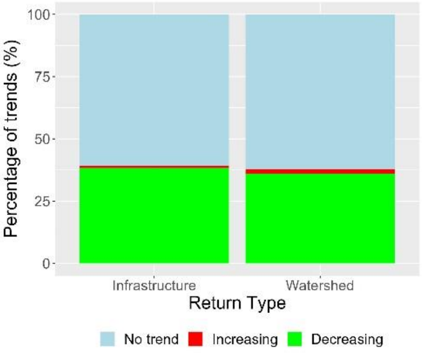

Figure 5. Bar graph of percentage of trend types by return site type

Overall, when site types were compared, primary, secondary, and return site types showed decreasing trends for 34.7%, 35.8%, and 37.3% of the total trend tests, respectively (Figure 6). Site types also showed increasing trends for 1.3%, 0.30%, and 1.3% of trend tests for primary, secondary, and return sites, respectively. Although water quality tends to degrade as water moves through the irrigation infrastructure (Little et al. 2010; Charest et al. 2015; Kerr and Villeneuve 2021), the slight incremental shifts between primary, secondary and return sites should not be interpreted as water quality changes through the irrigation infrastructure. These trends exist for different parameters, often at non-connected sites, and were not statistically significant (p>0.05). Aside from previously discussed localized factors, identifying the cause of decreasing or increasing trends at specific sites was outside the scope of this study.

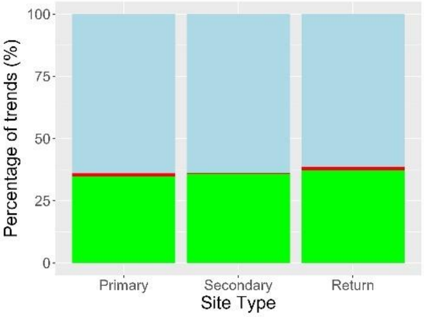

Figure 6. Bar graph of percentage of trend types by site type

3.2.4 Interpreting Trends for Water Management

The results of these analyses show that there were some temporal trends in water quality parameters from 2006 to 2023 in Alberta's irrigation districts. Parameter-by-site analysis generally agreed with the regional analysis. Parameters with regional trends usually showed trends of the same direction at individual sites (i.e., TP, pH, temperature, 2,4-D, dicamba, dichloroprop, MCPA, and mecoprop). An exception was for atrazine and EPTC, for which very weak increasing (degrading water quality) regional trends were detected and no individual sites showed increasing trends for these parameters.

For those parameters for which no regional trend was found, there were three scenarios in which this result may not be interpreted as definitive proof that regional trends were absent. The first was when there was little power to detect trends because although two or more values were above the MDL, most values of the dataset were below the maximum MDL. For these parameters, it is possible that trends were present in concentrations below detection limits. That said, from a management perspective, it is likely acceptable to interpret these instances as having no meaningful trend. This point also applies to datasets in the parameter-by-site analyses. The second scenario occurs when both decreasing (improving) and increasing (degrading) trends occur at individual sites (i.e., *E. coli*; Table 3). When there are similar numbers of trends in opposing directions for the same parameter, the absence of an overall regional trend may be because negative and positive trends from different sites neutralize any detectable trend at the regional scale (Helsel and Frans 2006). For these parameters, the parameter-by-site analysis is more important than the regional analysis in determining whether trends were present. However, in the case of *E. coli,* with 69 sites showing no trend and five showing opposing trends, it is probable that a regional trend was legitimately absent. Finally, a lack of overall trend as detected by analysis could also occur if a trend was present but was non-monotonic (e.g., humped or u-shaped). This phenomenon was not assessed in the parameter-by-site analysis, and was not formally tested in the regional analysis, but visual inspection of regional results (Figure A.1) did not show the presence of humped or u-shaped trends in the parameters for which regional trends were not found. Although, as discussed previously, potential multi-year oscillations may be superimposed and negating each other.

Information on the presence of water quality trends in the irrigation districts of Alberta can advise water management decisions by identifying and prioritizing parameters that represent water quality concerns. For example, if a parameter consistently exceeds water quality guidelines (regionally or site-specifically) and exhibits an increasing (degrading) trend, it may be considered a higher management priority than a parameter that exceeds guidelines but has a decreasing (improving) trend. Similarly, if a parameter is below guidelines but its concentration is increasing (degrading) with time, proactive management actions may prevent it from becoming problematic. Based on the results of this study, particular attention should be given to the (albeit very weak) increasing (degrading) regional trends observed for atrazine and EPTC and to individual sites where increasing (degrading) trends occurred despite the absence of a regional trend (i.e., E. *coli* at BR-S3 and SMW-R2). Also, individual sites that show an increasing (degrading) trend while regional trends are improving (e.g., TSS at MV-P1, M-P1 and SMC-R4) are of interest as this may indicate localized water quality concerns.

These results should not be used to conclude that any particular management practices during the period of the study caused the observed trends as information on changes in land use and practices was not available nor included in the temporal trend analysis. Charest et al. (2015) examined the complexities of relationships between land use and water quality within the former TID, which was used as a case study, but did not include a temporal component. Further research would be needed to connect changes in water quality to changes in land use. When water quality concerns are identified by trend analyses, it is recommended that further work be done to investigate the causes of these identified trends; particularly if values are approaching environmental quality guidelines for intended water uses.

It is unknown whether trends in water quality at any given site are driven by trends in the source water for that site or by phenomena occurring between sites (e.g., land practices between a return site and its respective secondary or primary site). To address this question at a regional scale, spatio-temporal analysis that considers the network connectivity of sites and the magnitude of concentrations or loads would be necessary. However, clues can be gathered from the patterns of trends on a site-by-site basis for connected sites. For example, if decreasing (or increasing) trends are observed at primary sites through secondary sites and related return sites, this could indicate that the trends are driven by the quality of the source water without influence from other factors. In contrast, if a trend is observed at a return site but not in its source water, it may be speculated that factors between the sampling sites may be affecting the change. In cases where there is interest in understanding the causes of trends, such patterns can be used to generate hypotheses and ideas for further investigation.

The nonparametric trend analysis conducted did not provide information on the magnitude or rate of change in parameters with time, only whether values typically increased or decreased with time. If the presence of a trend is concerning, further analysis to estimate the magnitude and rate of change can be performed to better understand the nature of the trend.

The results of the trend analyses within this report indicate that irrigation water in Alberta is generally stable or improving within the irrigation districts. Results are also consistent with the results of the water quality index assessment (Little et al. 2010; Kerr and Villeneuve 2021) which qualified Alberta irrigation water as ’good’ or ’excellent’ as per the Canadian Council of Ministers of the Environment (CCME) water quality index categories.

5 Conclusion

Temporal trend analyses were performed on 19 water quality parameters measured in 2006 to 2007 and 2011 to 2023 in Alberta’s irrigation districts. Overall, parameter-by-site analysis indicated relative stability in water quality during the study with decreasing trends (generally improving water quality) or no trends detected at the resolution of individual sites. The few parameter-by-site analysis that showed increasing trends were due to changes in localized conveyance methods or were associated with low concentration that warrant continued monitoring and preparedness for mitigation. Regional trend analysis, which combined all sites, also showed mostly stable or decreasing trends. Two very weak increasing regional trends (degrading water quality) occurred for pesticides atrazine and EPTC. While concentrations are well below published water quality guidelines, continued monitoring is necessary to determine whether the observed trends are consistent with time.

Information on the presence of water quality trends in the irrigation districts of Alberta can inform management decisions by identifying and prioritizing parameters and locations of water quality concerns to enable mitigation. Continued monitoring is valuable to determine whether observed trends and interpretation continue and how they relate to land use or climate changes. The results of these trend analysis indicate stable or improving water quality within the irrigation districts of Alberta and identify areas for proactive management to ensure excellent quality irrigation water for all users in the future.

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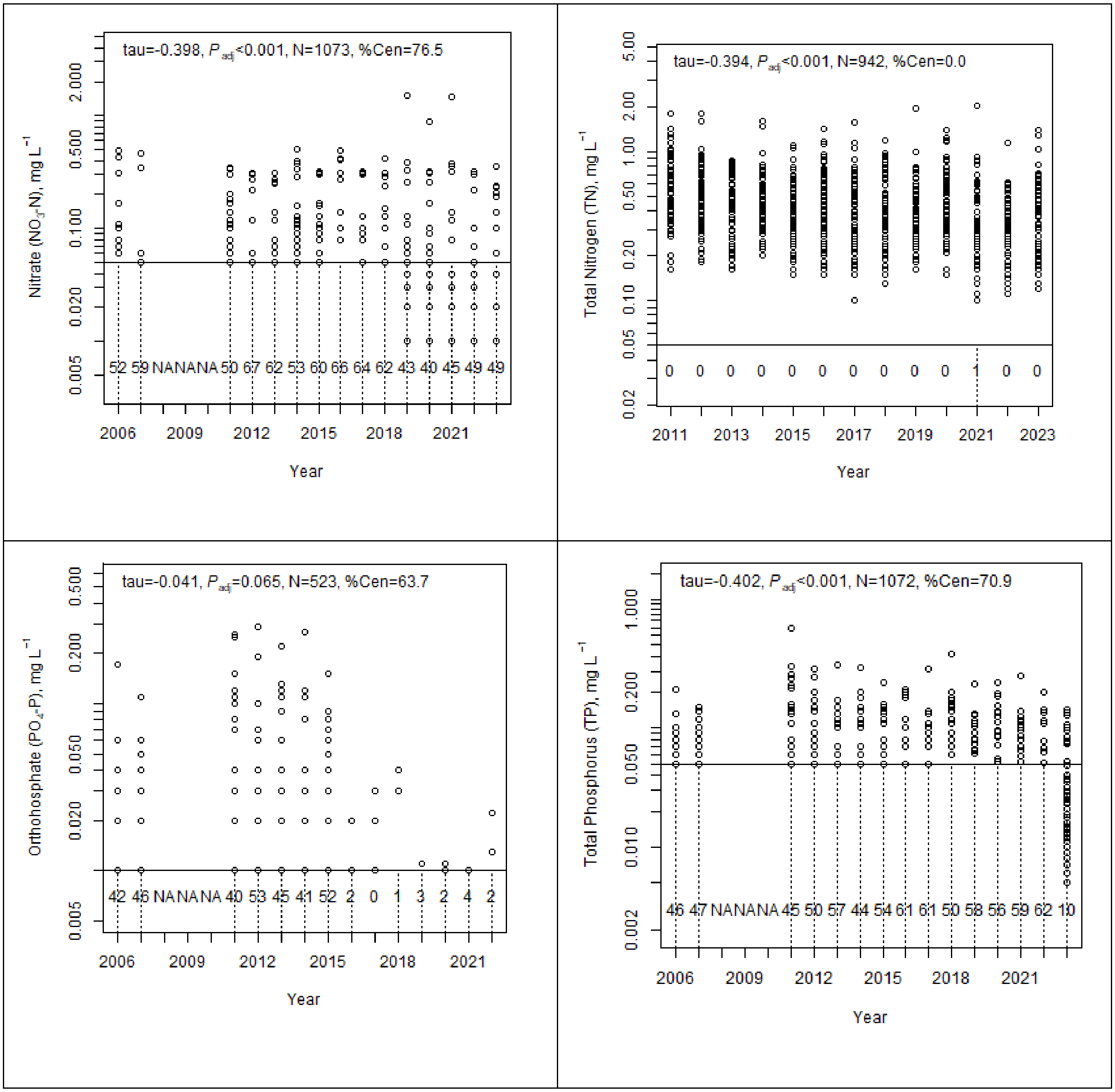
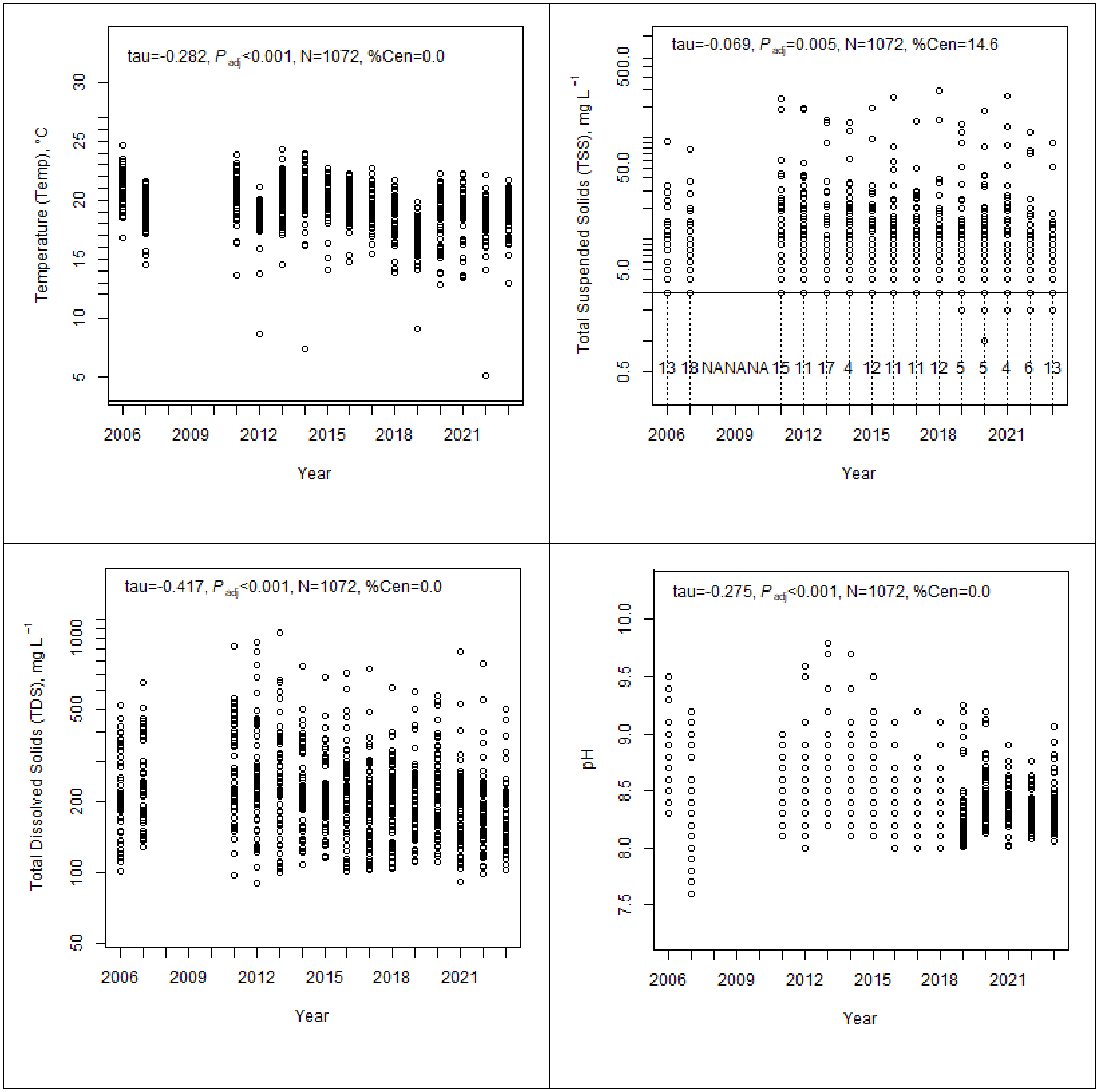
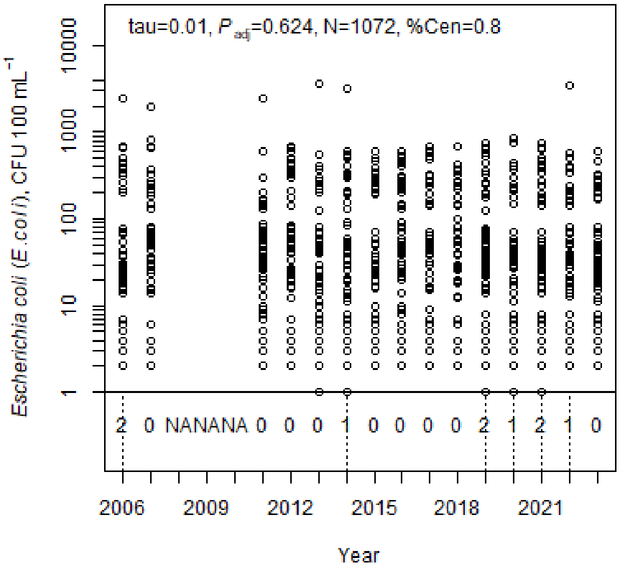
Appendix A.1

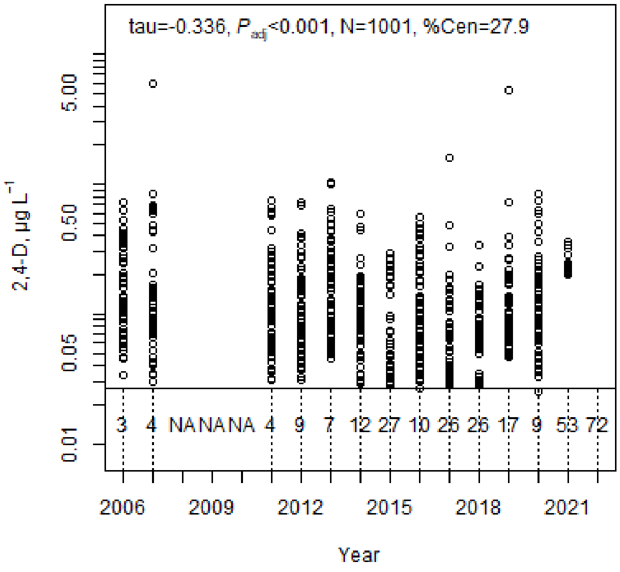
Regional trends in water quality data in Alberta's irrigation districts from 2006 to 2023. Results of the Regional Kendall trend tests are displayed at the top of plots, with tau representing Kendall's correlation coefficient, P_{adj} representing the P-value of the test after applying a FDR P-value adjustment of 19 tests, N representing the number of measurements used in the analysis, and %Cen representing the percentage of censored data. If data below MDLs were present, the number of below-MDL values per year are reported below a horizontal line representing the MDL. For graphical clarity, the y-axis is presented in log scale for most parameters.

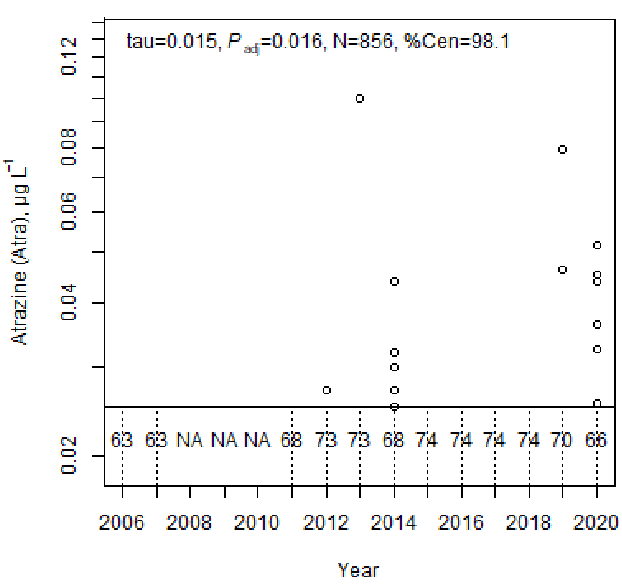


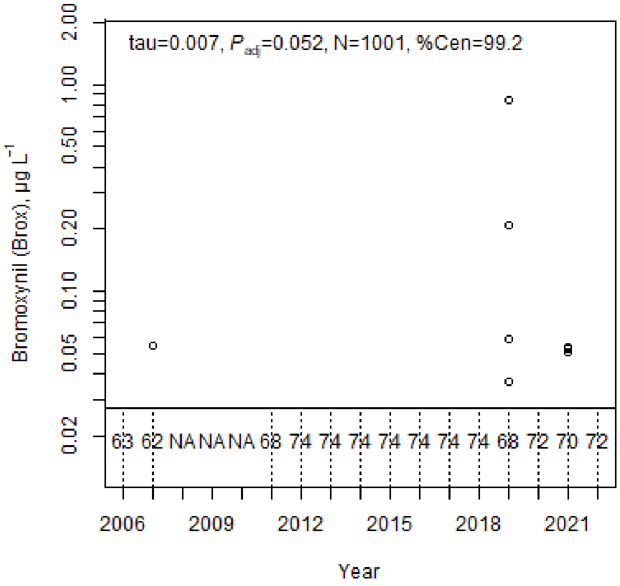


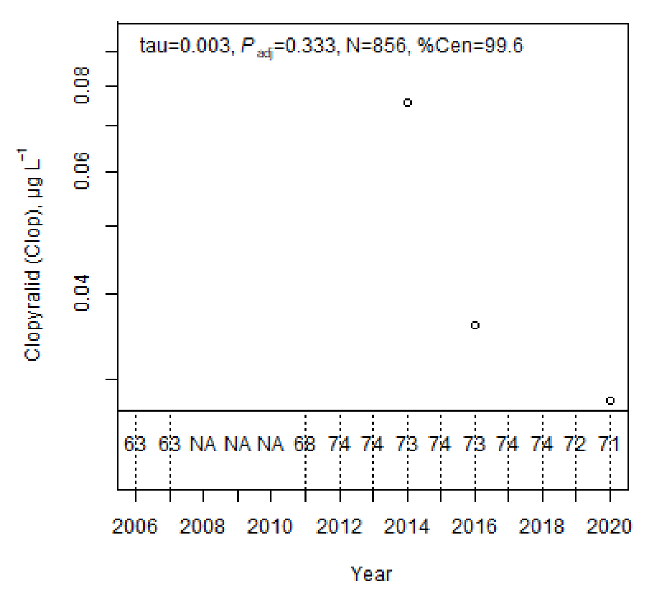
tau=-0.282, P adj<0.001, N=1072, %Cen=0.0
Temperature (Temp), °C
5
10
15
20
25
30
2006
2009
2012
2015
2018
2021
Year
tau=-0.069, P adj=0.005, N=1072, %Cen=14.6
Total Suspended Solids (TSS), mg L⁻¹
0.5
5.0
50.0
500.0
13 18 NA NA NA 15 11 17 4 12 11 11 12 5 5 4 6 13
2006
2009
2012
2015
2018
2021
Year
tau=-0.417, P adj<0.001, N=1072, %Cen=0.0
Total Dissolved Solids (TDS), mg L⁻¹
50
100
200
500
1000
2006
2009
2012
2015
2018
2021
Year
tau=-0.275, P adj<0.001, N=1072, %Cen=0.0
pH
7.5
8.0
8.5
9.0
9.5
10.0
2006
2009
2012
2015
2018
2021
Year

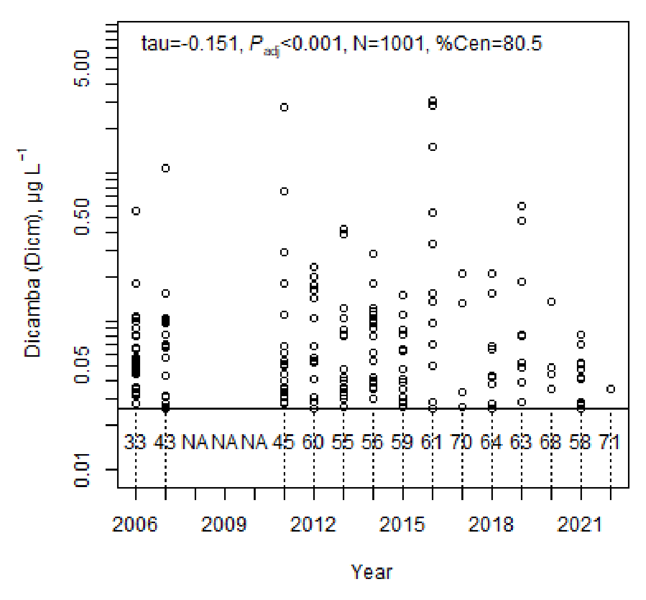

tau=0.01, P_{adj}=0.624, N=1072, %Cen=0.8
Escherichia coli (E.coli), CFU 100 mL^{-1}
1
10
100
1000
10000
2 0 NA NA NA 0 0 0 1 0 0 0 0 2 1 2 1 0
2006
2009
2012
2015
2018
2021
Year

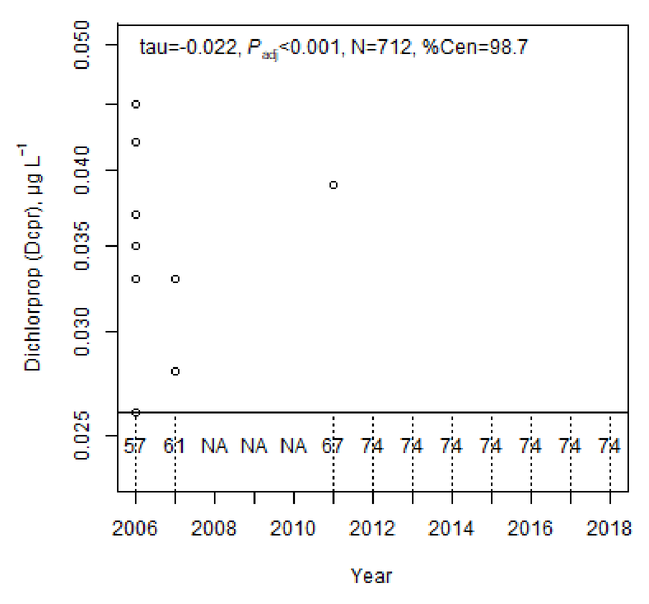

tau=-0.336, P_{adj}<0.001, N=1001, %Cen=27.9
2,4-D, µg L^{-1}
0.01
0.05
0.50
5.00
3 4 NA NA NA 4 9 7 12 27 10 26 26 17 9 53 72
2006
2009
2012
2015
2018
2021
Year

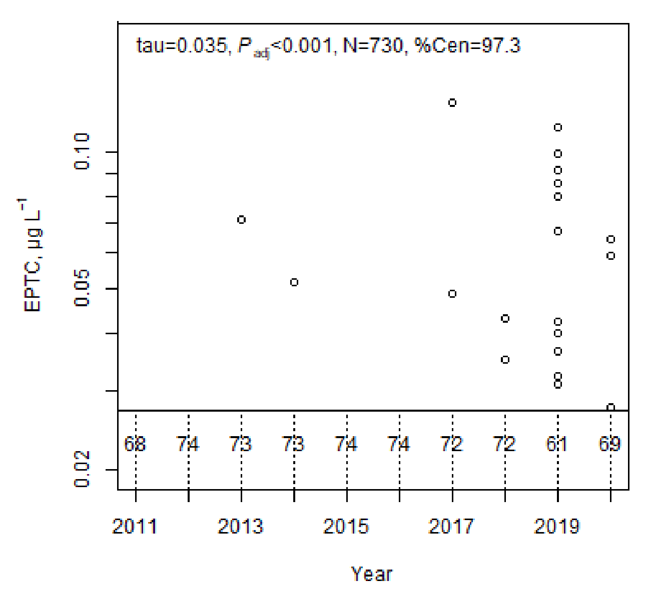

tau=0.015, P_{adj}=0.016, N=856, %Cen=98.1
Atrazine (Atra), µg L^{-1}
0.02
0.04
0.06
0.08
0.12
63 63 NA NA NA 68 73 73 68 74 74 74 74 70 66
2006
2008
2010
2012
2014
2016
2018
2020
Year

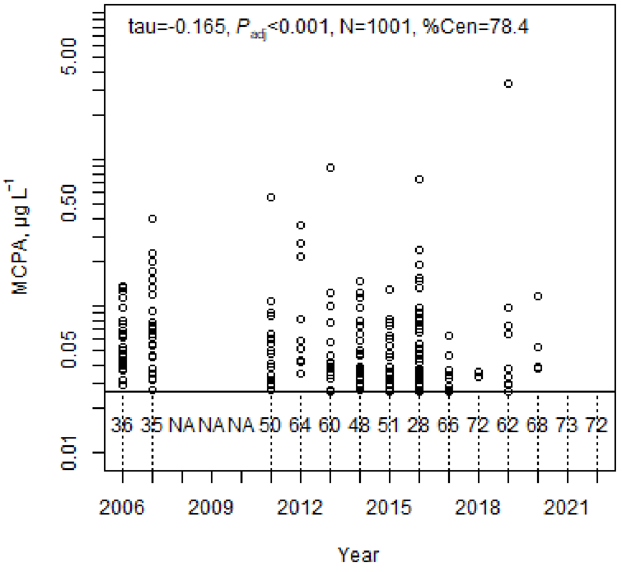

tau=0.007, P_{adj}=0.052, N=1001, %Cen=99.2
Bromoxynil (Brox), µg L^{-1}
0.02
0.05
0.10
0.20
0.50
1.00
2.00
63 62 NA NA NA 68 74 74 74 74 74 74 74 68 72 70 72
2006
2009
2012
2015
2018
2021
Year

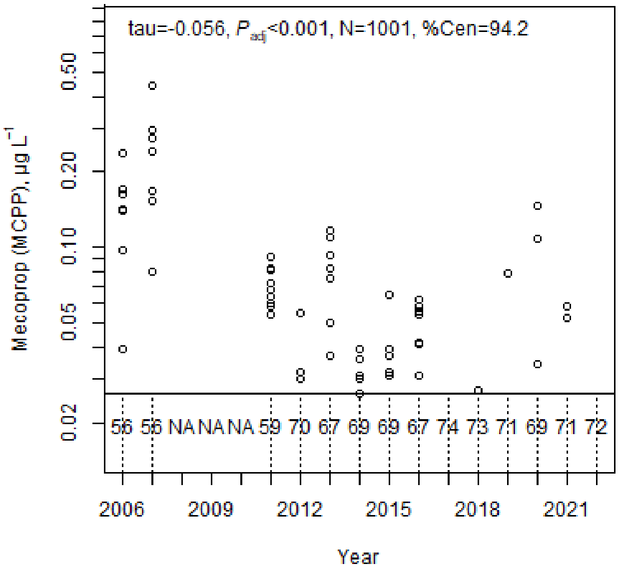

tau=0.003, P_{adj}=0.333, N=856, %Cen=99.6
Clopyralid (Clop), µg L^{-1}
0.04
0.06
0.08
63 63 NA NA NA 68 74 74 73 74 73 74 74 72 71
2006
2008
2010
2012
2014
2016
2018
2020
Year

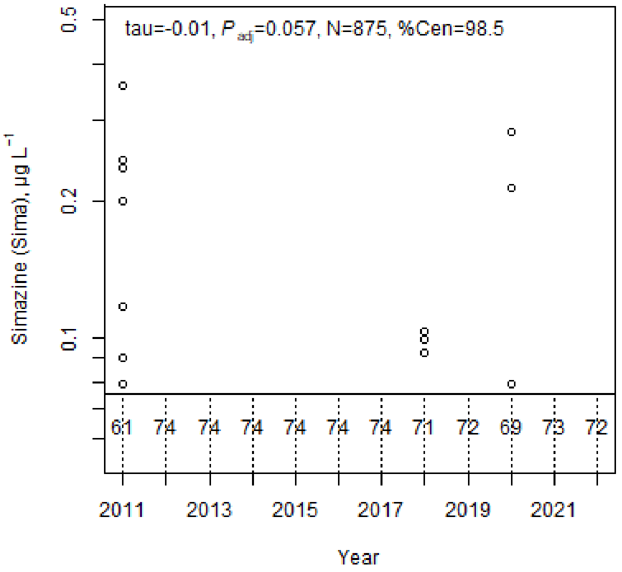

tau=-0.151, P_{adj}<0.001, N=1001, %Cen=80.5
Dicamba (Dicm), µg L^{-1}
0.01
0.05
0.50
5.00
33 43 NA NA NA 45 60 55 56 59 61 70 64 63 68 58 71
2006
2009
2012
2015
2018
2021
Year


tau=-0.022, P_{adj}<0.001, N=712, %Cen=98.7
Dichlorprop (Dcpr), µg L^{-1}
0.025
0.030
0.035
0.040
0.050
57 61 NA NA NA 67 74 74 74 74 74 74 74
2006
2008
2010
2012
2014
2016
2018
Year


tau=0.035, P_{adj}<0.001, N=730, %Cen=97.3
EPTC, µg L^{-1}
0.02
0.05
0.10
68 74 73 73 74 74 72 72 61 69
2011
2013
2015
2017
2019
Year


tau=-0.165, P_{adj}<0.001, N=1001, %Cen=78.4
MCPA, µg L^{-1}
5.00
0.50
0.05
0.01
36 35 NA NA NA 50 64 60 48 51 28 66 72 62 68 73 72
2006
2009
2012
2015
2018
2021
Year


tau=-0.056, P_{adj}<0.001, N=1001, %Cen=94.2
Mecoprop (MCPP), µg L^{-1}
0.50
0.20
0.10
0.05
0.02
56 56 NA NA NA 59 70 67 69 69 67 74 73 71 69 71 72
2006
2009
2012
2015
2018
2021
Year


tau=-0.01, P_{adj}=0.057, N=875, %Cen=98.5
Simazine (Sima), µg L^{-1}
0.5
0.2
0.1
61 74 74 74 74 74 74 71 72 69 73 72
2011
2013
2015
2017
2019
2021
Year