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Nine Decades of Salinity Observations in the San Francisco Bay and Delta: Modeling and Trend Evaluations

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Supplemental Data

The supplemental data contains the following:

Figure S1. X2 Position by Month on the San Joaquin River Branch (1922-2012) Grouped by Water Year Classification

Table S1. DWR Document Sources

Table S2. Bulletin 23 Summary of Data Used

Table S3. CDEC Summary of Data Used

Table S4. Trend Analysis on X2 for the San Joaquin River Branch over 1922-1967, 1968-2012, and 1922-2012

Table S5. X2 on San Joaquin River Branch Wilcoxon Rank Sum Test Results (Comparison of 1968–2012 Values Against 1922–1967 Values)

Appendix A: Statistical Analysis Methodology

Electronic data files of salinity and interpolated X2 value (*Microsoft Excel* files: Supplemental_Data_WR.1943-5452.0000617_Hutton2 and Supplemental_Data_WR.1943-5452.0000617_Hutton3)

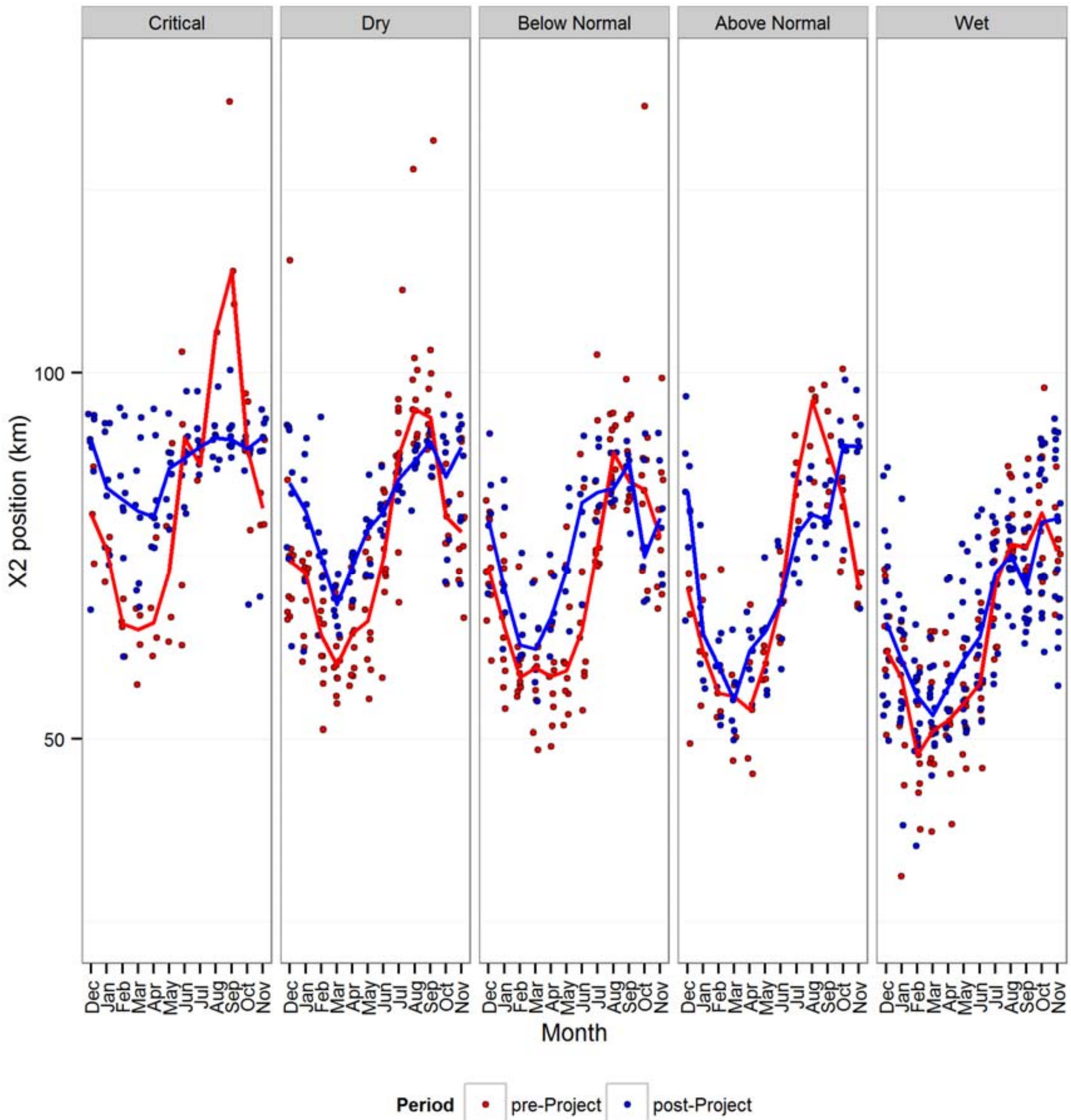

Figure S1. Average monthly X2 position is shown by water year class on the San Joaquin River branch under pre-project (Water Years 1922-1967) and post-project (Water Years 1968-2012) conditions, with lines connecting the seasonal medians. Symbols show individual year values (red = pre-Project; blue = post-Project), with lines connecting the seasonal medians. In all but wet years, post-project X2 position tends to be further downstream (i.e. lower) in summer months and further upstream (i.e. higher) in other months. X2 position in October and November is generally more closely associated with the previous water year; thus the x-axis spans the months December through November.

Table S1. DPW or DWR Bulletin Site Information

Report	Years
DPW/DWR Bulletin 23	1929–1961
DPW Bulletin 27	1921–1931
DWR Bulletin 65	1962
DWR Bulletin 130	1963– 1971

References:

Department of Public Works, Division of Water Resources (1930 to 1955) Bulletin 23 Report of the Sacramento–San Joaquin Water Supervisor For the Period 1924–1954.

Department of Public Works, Division of Water Resources (1931) Bulletin 27 Variation and Control of Salinity in the Sacramento–San Joaquin Delta and Upper San Francisco Bay.

Department of Water Resources (DWR) (1956 to 1962) Bulletin 23 Report of the Sacramento–San Joaquin Water Supervisor For 1955–1961.

Department of Water Resources (DWR) (1957) Joint Hydrology Study: Sacramento River and Sacramento–San Joaquin River Delta, Division of Planning, July.

Department of Water Resources (DWR) (1962) Bulletin 65 Hydrologic Data 1962.

Department of Water Resources (DWR) (1963 to 1971) Bulletin 130 Hydrologic Data 1963–1971.

Table S2. Bulletin 23 Data Summary of Data Used

Station	Code	Start	End	Number of Grab Sample Observations	Distance from Golden Gate (km)
Suisun and San Pablo Bays					
Point Orient	PTO	2/10/1926	8/30/1957	2,427	19.8
Point Davis	PTD	2/6/1926	8/14/1957	1,907	40.6
Crockett	CRK	9/26/1946	6/30/1971	1,729	44.6
Benicia	BEN	1/15/1943	6/30/1963	1,616	52.3
Martinez	MRZ	1/2/1946	6/30/1971	1,773	52.6
Bulls Head Point	BHP	2/2/1926	7/14/1941	1,325	54.7
West Suisun	WSN	9/2/1946	6/30/1963	1,924	59.5
Bay Point	BPT	2/2/1926	10/22/1944	922	64.2
Port Chicago	PCT	9/2/1946	6/10/1971	2,385	66
O and A Ferry	OAF	6/2/1920	3/30/1957	2,904	74.8
Pittsburg[1]	PTS	1/6/1942	5/6/1971	1,541	77.2
Lower Sacramento River					
Collinsville	CLL	6/2/1920	9/30/1969	3,564	81.8
Emmaton	EMM	6/4/1920	6/30/1971	2,067	92.9
Threemile Slough Bridge	TSB	9/4/1926	8/30/1969	2,377	96.6
Rio Vista	RVB	8/4/1920	5/26/1971	3,068	102.2
Isleton Bridge	ITB	7/2/1924	6/26/1971	2,008	110.6
Walnut Grove	WNG	8/14/1920	10/30/1939	250	124.6
Lower San Joaquin River					
Antioch	ANH	6/14/1920	6/26/1971	4,532	88.4
Antioch Bridge	ANB	10/2/1956	5/22/1971	804	93.7
Jersey Island	JER	6/2/1920	6/18/1971	1,376	98.8
False River	FRV	4/10/1965	6/30/1971	277	101.2
Oulton Point	OPT	9/2/1952	6/26/1963	779	108.1
San Andreas Landing	SAL	9/2/1952	6/2/1971	1,339	113.1
Webb Pump	WBP	7/28/1920	10/18/1952	1,151	115.9
Medford Island Pump	MIP	7/18/1924	11/6/1925	51	128.6
Kings Island Pump	KIP	6/18/1931	10/26/1939	94	135.5
Stockton Country Club	SCC	8/18/1926	11/6/1934	184	146.1
Stockton	SCT	9/2/1948	7/30/1952	250	152.6

[1] Anomalies found during the tidal adjustment of Bulletin 23 Pittsburg data prevented it from being used in the calculation of isohaline positions

Table S3. CDEC Summary of Data Used

Station	DWR Distance from Golden Gate (km)	RKI	Agency	Source	Data Type and Units	Frequency	Period of Record
Suisun & San Pablo Bays							
Martinez	54/55[2]	RSAC054	DWR	CDEC	EC (uS/cm)	Hourly	06/1994 – 07/2012
			DWR	CDEC	EC (uS/cm)	Daily	01/2006- 01/2012
			USBR	USBR-CVO	EC (uS/cm)	Daily	01/1965 – 01/1996
			USBR	STORET	EC (uS/cm)	Daily	10/1967- 04/1992
Port Chicago	64	RSAC064	USBR	CDEC	EC (uS/cm)	Daily	01/1999 – 01/2012
			USBR	CDEC	EC (uS/cm)	Hourly	12/1996 – 07/2012
			USBR	USBR-CVO	EC (uS/cm)	Daily	01/1966 – 01/1998
			USBR	USBR-CVO	EC (uS/cm)	Hourly	04/1996 – 05/2005
			USBR	STORET	EC (uS/cm)	Daily	10/1967- 04/1992
Mallard Island	75	RSAC075	DWR	CDEC	EC (uS/cm)	Daily	01/1995 – 07/2012
			DWR	CDEC	EC (uS/cm)	Hourly	12/1983 – 07/2012
			DWR	DWR-ESO	EC (uS/cm)	Event	09/1982 – 10/1985
			DWR	DWR-ESO	EC (uS/cm)	Hourly	01/1984 – 09/2002
			DWR	STORET	EC (uS/cm)	Daily	1/1981 – 12/1987
Chipps Island	75	RSAC075	DWR	STORET	EC (uS/cm)	Daily	05/1976 – 09/1992

[2] The stations named Martinez are in slightly different locations for the USBR and CDEC data sources. The CDEC station is located at RKI RSAC054. The USBR station is at the Shell refinery pier, about 900 meters upstream of the CDEC station (Eli Ateljevich, personal communication). We treat the data as coming from one station for calculations not explicitly involving distance from Golden Gate (e.g., data cleaning and filling), but calculation of isohaline positions uses the distance corresponding to the relevant station location.

Table (continued) CDEC Summary of Data Used

Station	DWR Distance from Golden Gate (km)	RKI	Agency	Source	Data Type and Units	Frequency	Period of Record
Lower Sacramento River							
Collinsville	81	RSAC081	USBR	CDEC	EC (uS/cm)	Daily	01/1999 – 07/2012
			USBR	CDEC	EC (uS/cm)	Hourly	03/1988 – 07/2012
			USBR	USBR-CVO	EC (uS/cm)	Daily	01/1966 – 01/1998
			USBR	USBR-CVO	EC (uS/cm)	Hourly	04/1996 – 05/2005
			USBR	STORET	EC (uS/cm)	Daily	10/1967 – 11/1992
Emmaton	92	RSAC092	USBR	CDEC	EC (uS/cm)	Hourly	01/1988 – 07/2012
			DWR	DWR-BDO	EC (uS/cm)	15MIN	07/1988 – 02/2000
			USBR	USBR-CVO	EC (uS/cm)	Daily	01/1964 – 01/1996
			USBR	USBR-CVO	EC (uS/cm)	Hourly	04/1996 – 05/2005
			USBR	STORET	EC (uS/cm)	Daily	10/1967 – 11/1992
Rio Vista	101	RSAC101	USBR	CDEC	EC (uS/cm)	Daily	08/1999 – 07/2012
			DWR	CDEC	EC (uS/cm)	Daily	12/1995 – 10/2003
			DWR	CDEC	EC (uS/cm)	Hourly	01/1984 – 07/2012
			DWR	DWR-ESO	EC (uS/cm)	Hourly	05/1983- 09/2002
			USBR	USBR-CVO	EC (uS/cm)	Daily	01/1966 – 01/1998
			USBR	USBR-CVO	EC (uS/cm)	Hourly	04/1996 – 05/2005
			USBR	STORET	EC (uS/cm)	Daily	10/1967 – 11/1992

Table (continued) CDEC Summary of Data Used

Station	DWR Distance from Golden Gate (km)	RKI	Agency	Source	Data Type and Units	Frequency	Period of Record
Lower San Joaquin River							
Pittsburg	77	RSAC077	USBR	CDEC	EC (uS/cm)	Daily	01/1999 – 07/2012
			USBR	CDEC	EC (uS/cm)	Hourly	03/1988 – 07/2012
			USBR	USBR-CVO	EC (uS/cm)	Hourly	04/1996 – 05/2005
			USBR	USBR-CVO	EC (uS/cm)	Daily	01/1965 – 01/1998
			USBR	STORET	EC (uS/cm)	Daily	10/1967 – 11/1992
Antioch	85.75	RSAN007	USBR	CDEC	EC (uS/cm)	Daily	08/1999 – 07/2012
			DWR	CDEC	EC (uS/cm)	Daily	01/1995 – 07/2012
			DWR	CDEC	EC (uS/cm)	Hourly	02/1984 – 07/2012
			DWR	DWR-ESO	EC (uS/cm)	Hourly	05/1983- 09/2002
			USBR	STORET	EC (uS/cm)	Daily	10/1967 – 11/1992
Blind Point	92.85	RSAN014	DWR	CDEC	EC (uS/cm)	Daily	12/1995 – 08/1999
			DWR	CDEC	EC (uS/cm)	Daily	03/2010 – 07/2012
			DWR	CDEC	EC (uS/cm)	Hourly	01/1984 – 09/1999
			DWR	DWR-CD	EC (uS/cm)	Event	09/1982 – 09/1997
			DWR	STORET	EC (uS/cm)	Daily	08/1971 – 10/1979
Jersey Point	95.75	RSAN018	USBR	CDEC	EC (uS/cm)	Daily	08/1999 – 07/2012
			USBR	CDEC	EC (uS/cm)	Hourly	03/1988 – 07/2012
			USBR	USBR-CVO	EC (uS/cm)	Daily	01/1964 – 01/1998
			USBR	USBR-CVO	EC (uS/cm)	Hourly	04/1996 – 05/2005
			USBR	STORET	EC (uS/cm)	Daily	10/1967 – 11/1992
Three Mile Slough at San Joaquin River	100.4	SLTRM004	USGS	CDEC	EC (uS/cm)	Daily	06/2008 – 07/2012
			DWR	DWR-CD	EC (uS/cm)	15MIN	10/1987 – 02/1998
San Andreas Landing	109.2	RSAN032	USBR	CDEC	EC (uS/cm)	Daily	08/1999 – 07/2012
			USBR	CDEC	EC (uS/cm)	Hourly	03/1988 – 07/2012
			USBR	USBR-CVO	EC (uS/cm)	Daily	01/1964 – 01/1998
			USBR	USBR-CVO	EC (uS/cm)	Hourly	04/1996 – 05/2005
			USBR	STORET	EC (uS/cm)	Daily	10/1967 – 05/1988

Table S4. San Joaquin X2 Mann-Kendall Test Results, WY

Years	Month	Sample Size	Sen's Trend Slope Median	Test Decision
1922–1967	Jan	39	-0.1	↔
	Feb	39	-0.03	↔
	Mar	40	0.09	↔
	Apr	39	0.19	↔
	May	39	0.08	↔
	Jun	40	0.01	↔
	Jul	39	0.09	↔
	Aug	37	-0.19	↔
	Sep	39	-0.51	↓
	Oct	41	-0.36	↓
	Nov	40	-0.27	↓
	Dec	40	-0.21	↓
1968–2012	Jan	44	0.25	↔
	Feb	43	0.10	↔
	Mar	43	0.02	↔
	Apr	43	0.02	↔
	May	45	-0.20	↔
	Jun	45	-0.11	↔
	Jul	45	-0.12	↔
	Aug	45	0.05	↔
	Sep	45	0.22	↑
	Oct	45	0.25	↑
	Nov	45	0.40	↑
	Dec	45	0.42	↑
1922–2012	Jan	83	0.11	↑
	Feb	82	0.09	↑
	Mar	83	0.08	↑
	Apr	82	0.15	↑
	May	84	0.13	↑
	Jun	85	0.10	↔
	Jul	84	-0.02	↔
	Aug	82	-0.14	↓
	Sep	84	-0.13	↓
	Oct	86	-0.01	↔
	Nov	85	0.11	↑
	Dec	85	0.15	↑

Table S5. San Joaquin X2 Wilcoxon Rank Sum Test Results (comparison of 1968–2012 values against 1922–1967 values)

Month	Year Type				
	Critical	Dry	Below Normal	Above Normal	Wet
Jan	8.9 (↔)	10.1 (↑)	7.5 (↔)	-1.0 (↔)	4.1 (↔)
Feb	17.6 (↑)	10.8 (↑)	4.4 (↑)	0.8 (↔)	5.7 (↑)
Mar	17.3 (↑)	7.6 (↑)	3.1 (↔)	0.9 (↔)	1.7 (↔)
Apr	14.9 (↑)	9.2 (↑)	9.1 (↑)	7.2 (↔)	4.5 (↔)
May	13.2 (↔)	10.8 (↑)	13.3 (↑)	2.4 (↔)	6.3 (↑)
Jun	-1.7 (↔)	5.5 (↔)	16.4 (↑)	0.7 (↔)	6.8 (↑)
Jul	2.5 (↔)	-4.4 (↓)	6.0 (↔)	-7.9 (↓)	2.3 (↔)
Aug	-14.4 (↔)	-7.9 (↓)	-3.6 (↔)	-12.1 (↓)	-3.5 (↓)
Sep	-22.9 (↓)	-4.1 (↔)	0.9 (↔)	-8.6 (↓)	-6.0 (↓)
Oct	-2.8 (↔)	2.7 (↔)	-7.4 (↔)	6.7 (↔)	-2.2 (↔)
Nov	9.9 (↔)	8.6 (↔)	1.8 (↔)	18.0 (↔)	3.6 (↔)
Dec	9.7 (↔)	9.0 (↔)	4.8 (↔)	14.7 (↑)	2.7 (↔)

Appendix A. Statistical Procedures Used

MANN-KENDALL TEST FOR SEN SLOPE SIGNIFICANCE

The Mann-Kendall test for trend is insensitive to the presence or absence of seasonality. It is a nonparametric test since it does not assume any type of data distribution. Nonetheless, two forms of the test are provided: one that ignores data seasonality (even if it is present) and one that considers data seasonality. In either test, the null hypothesis (H_0) assumes that the trend is zero, and the alternate hypothesis (H_a) is that the trend is either upward or downward. Details of the Mann-Kendall trend test for slope and the seasonal Kendall trend test are shown below.

In general, the Mann-Kendall trend test considering seasonality indicates a larger range for an allowable estimate of trend when seasonality is actually present than the range indicated by the test performed ignoring seasonality.

In the Mann-Kendall trend analysis and Kendall seasonal analysis, the "Sen" slopes are first calculated, ranked, and then assigned the indicator value of +1, -1, or 0 according to the sign of the calculated differences of all possible time-ranked pairs. The Mann-Kendall S statistic is then computed as the number of positive differences minus the number of negative differences. The Kendal test statistic Ts is computed using the S value and its variance $VAR(S)$, such that a positive Ts value means an upward trend and a negative Ts value means a negative trend. Significance of the Kendal test statistic Ts is determined by comparing it against the cumulative normal distribution function $Z_{1-\alpha}$. The median value of the Sen slope is calculated with and without seasonality. Since slopes are calculated over all possible time intervals, it is possible that the test indicates a "non-zero" trend, yet the median slope value equal zero.

MANN-KENDALL TREND TEST FOR SLOPE

Mann-Kendall Trend Test for Sen Slope Significance – for number of data as small as 10, unless there are many tied (e.g., equal, NDs are treated as tied) values (Gilbert, 1987; p. 208)	
Indicator Function $\operatorname{sgn}(x_j - x_k)$	= 1 if $(x_j - x_k) > 0$ = 0 if $(x_j - x_k) = 0$ = -1 if $(x_j - x_k) < 0$ where $x_1, x_2, ..., x_n$ are the time ordered data (n is the total of data).
Mann-Kendall Statistic, S	$= \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k)$
Variance of S : $VAR(S)$	$= \frac{1}{18}\Big[n(n-1)(2n+5)$ $- \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5)$ $- \sum_{q=1}^{h} u_q(u_q - 1)(2u_q + 5)\Big]$ $+ \frac{\sum_{p=1}^{g_i} t_{ip}(t_{ip}-1)(t_{ip}-2) \sum_{q=1}^{h_i} u_{iq}(u_{iq}-1)(u_{iq}-2)}{9n_i(n_i-1)(n_i-2)}$ $+ \frac{\sum_{p=1}^{g_i} t_{ip}(t_{ip}-1) \sum_{q=1}^{h_i} u_{iq}(u_{iq}-1)}{2n_i(n_i-1)}$ where g is the number of tied groups (equal-valued) in the data set; t_p is the number of tied data in the p-th group; h is the number of sampling times (or time periods) in the data set that contain multiple data; u_q is the number of multiple data in the q-th time period; and n is the number of data values.
Test Statistic, Ts	The Kendal statistic Ts is defined as $= \frac{S - 1}{[VAR(S)]^{1/2}}$ if $S > 0$ $= 0$ if $S = 0$ Ts $= \frac{S + 1}{[VAR(S)]^{1/2}}$ if $S < 0$ where a positive Ts value means an upward trend and a negative Ts value means a negative trend.

Hypothesis Test: H_0 = no trend H_{a1} = upward trend present H_{a2} = downward trend present This is a one-sided test at the α significance level.	The null hypothesis H_0 assumes that there is no trend in the data as a function of time. However, we will check for two alternative hypotheses. These are determined as follows: A1) Reject the null hypothesis H_0 and accept the alternative hypothesis Ha1 for an upward trend if $T_s > 0 \quad and \quad T_s > Z_{1-\alpha}$; A2) Reject the null hypothesis H_0 and accept the alternative hypothesis Ha2 of a downward trend if $T_s < 0 \quad and \quad \lvert T_s \rvert > Z_{1-\alpha}$. The term $Z_{1-\alpha}$ is the cumulative normal distribution function, which can be obtained from Table A1 in Gilbert (1987; p. 254).
Sen's Slope Estimator: Q	Slopes are initially calculated over each possible time period: $Q_{lk} = \frac{X_l - X_k}{t_l - t_k}$, l > k where Xl and Xk are the concentrations measured at time tl and tk. These Qlk individual slopes are ranked, and the median value is used to represent the slope estimator of trend (Gilbert, 1987; p. 227).

WILCOXON RANK SUM TEST

Assumptions in the Wilcoxon Rank-Sum test are generally more reasonable than those in the Student t-test. The Wilcoxon Rank-Sum test assumes that: (1) both data sets contain random values from their respective populations, and (2) in addition to independence within each data set, there is mutual independence between the two sample sets. No assumptions are made about data distribution. The null hypothesis is that the two location means are equal, and the alternative hypothesis is that the two location means are different.

Wilcoxon Rank-Sum Test for Comparison of Means – a one-sided, non-parametric test for comparing the means of two data sets (Gilbert, 1987; p. 247). In this application the two data sets are concentration data from pooled background and a single compliance location.	
Sum of Ranks: W_A, W_B	First pool all of the data from samples A and B, then rank the values from smallest to largest. Sum all of the ranks associated with samples A and B from the pooled sample set, respectively.
n_A, n_B	Number of observations in samples A and B, respectively.
Test Statistic: Z_A	$Z_A = \dfrac{[W_A - n_A \frac{(m+1)}{2}]}{\left\{ \frac{n_A n_B}{12} \left[(m+1) - \frac{\sum_{j=1}^{g} t_j (t_j^2 - 1)}{m(m-1)} \right] \right\}^{1/2}}$ where $m = (n_A + n_B)$, g is the number of tied groups, and t_j is the number of tied data in the j-th group.
Hypothesis Test: H_0 = means are the same H_{a1} = Compliance location has a higher concentration than the Background. H_{a2} = Background location has a higher concentration than the Compliance. This is a one-sided test at the α significance level.	Accept the null hypothesis H_0 of equal means if $Abs[Z_A] < Z_{1-\alpha}$ $accept\ H_0$. Reject the null hypothesis H_0 of equal means if $Z_A \geq Z_{1-\alpha}$ $reject\ H_0\ and\ accept\ H_{a1}$, if $Z_A \leq -Z_{1-\alpha}$ $reject\ H_0\ and\ accept\ H_{a2}$, where $Z_{1-\alpha}$ is the critical Z value given in Table A1 of Gilbert (1987; p. 254).

REFERENCE

Gilbert, R. 1987. Statistical Methods For Environmental Pollution Monitoring. Van Nostrand Reinhold Co., NY. 320 pp.