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Daily Water Temperature Time Series for the Upper Caloosahatchee Estuary

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Background

The Caloosahatchee River, its estuary, and associated watershed are located on the lower west coast of Florida (**Figure 1**). The Caloosahatchee River (C-43 canal) runs 70 kilometers (km) from Lake Okeechobee (at the S-77 structure) to the Franklin Lock (the S-79 structure). Separating fresh and brackish water, the Franklin Lock demarcates the existing head of the Caloosahatchee Estuary, which extends 42 km downstream to Shell Point, where it empties into San Carlos Bay. *Vallisneria americana* (tape grass, wild celery) is the dominant submersed aquatic vegetation (SAV) in the upper estuary and has been routinely monitored along with water quality parameters on a monthly basis since 1998 at fixed sampling locations (Bortone and Turpin, 2000). This SAV serves as an indicator of estuarine condition and its salinity tolerance is used to identify minimum freshwater inflows that can maintain grass bed habitat and ensure the persistence of a low salinity region (SFWMD, 2003). A numerical model (termed here the *Vallisneria* model) was developed to estimate growth of *V. americana* in the upper estuary under varying environmental conditions that integrates many field and laboratory efforts and has been applied to meet management objectives (SFWMD, 2003; Hunt and Doering, 2005; Hunt, 2007)**.** Primary inputs to the model are time series of water temperature, measures of water clarity (e.g., Secchi depth and coefficient of light attenuation), and salinity. Evaluations span various time periods including multiple years or decades. However, input time series are often incomplete and/or do not typically span a sufficient monitoring period at *V. americana* sampling locations for necessary evaluations and must be estimated using available information. This document describes the development of daily mean water temperature data sets designed to provide input to the *Vallisneria* model.

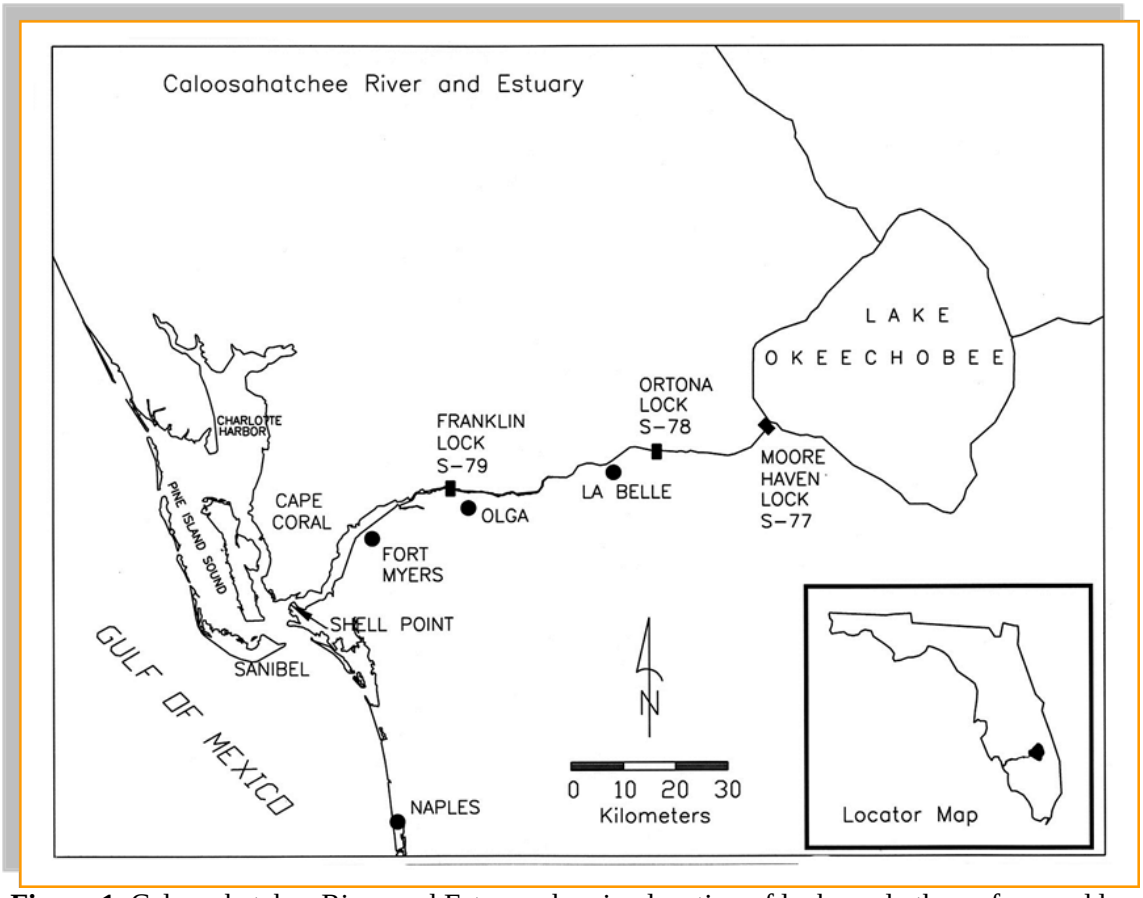

Figure 1. Caloosahatchee River and Estuary showing location of locks and other referenced locations.

Objectives

The objectives are based on specific needs for ongoing assessments and applications using the *Vallisneria* model (Hunt and Doering, 2005). There were two primary objectives of this effort:

1. Assemble a complete short-term daily mean water temperature time series at the *V. americana* monitoring sites for January 1, 1992 to January 31, 2011 based on existing water temperature measurements in the upper estuary at or near *V. americana* sampling sites. These data were used to (1) obtain estimates of daily mean water temperature for the first of each month at *V. americana* monitoring sites, which is needed as input for some modeling applications and (2) evaluate annual daily mean water temperature ranges as well as annual number of days with daily mean water temperature below specified temperatures.
2. Assemble a complete long-term daily mean water temperature time series representing upper estuarine conditions for January 1965 to January 2011 using available data from locations within the Caloosahatchee Estuary and River.

Sample Locations and Data Description

Six water temperature measurement locations, listed in **Table 1** and mapped in **Figure 2**, have been considered for the current analysis. These are two *V. americana* monitoring sites, VAL1 and VAL2, and four additional monitoring sites with water temperature measurements: Fort Myer, Marker52, S79 and S77. At the S-79 structure, monitoring is performed independently by the South Florida Water Management District (SFWMD) and United States Geological Survey (USGS) at slightly different locations. For the purposes of the current analysis these two locations have been named S79_WMD and S79_USGS. **Table 1** lists the coordinates of the water temperature measurement locations and their relative river distances to Fort Myer, which is the site with the most complete data set. The relative river distances are rough estimations based on Google Earth ruler.

Table 1. Water temperature measurement locations.

Sampling Location	Alternative Site Name	Latitude	Longitude	Approximate River Distance to Fort Myer (km)
VAL1		26°41'22.03"N	81°49'48.68"W	6.2
VAL2		26°40'20.13"N	81°51'53.51"W	2.7
Fort Myer	FMYER	26°39'07.26"N	81°52'09.30"W	reference
Marker52	02293205	26°38'29.00"N	81°52'58.00"W	1.5
S79_WMD	S79	26°43'20.72"N	81°41'35.00"W	19.0
S79_USGS	S79	26°43'26.24"N	81°41'54.28"W	19.8
S77		26°50'21.22"N	81°05'07.23"W	88.4

Figure 2. Google Earth view showing water and air temperature measurement locations.

These locations have water temperature time series for different periods of record, of various sampling frequencies and also have different reporting agencies and measuring devices. The time series used in the current analysis are described in the following paragraphs and listed in **Table 2** together with the associated data types, frequencies, start and end dates, related DBKEYs[1] for time series stored in DBHYDRO[2] and reporting agencies.

There are two main data types of water temperature time series used in the current analysis and they have been given different prefixes to ease identification: (1) the 'continuous', daily recorded (mean or instantaneous) water temperatures data sets, with the prefix '**H2OT**', and (2) the random, instantaneous water temperature measurements associated with water quality sampling events (which occur weekly, twice a month or monthly) with the prefix '**TEMP**'. The prefixes correspond to the associated DATA_TYPE defined in DBHYDRO in the table DMDBASE.DM_DATA_TYPE. To specify the sampling locations, water temperature time series names also contain the names of the sampling sites.

Table 2 lists the water temperature time series used in the analysis, their characteristics, which will also be described below, and the raw data source. 'H2OT' time series stored in DBHYDRO are kept in DMDBASE.DM_DAILY_DATA table under associated DBKEYs while 'TEMP' time series stored in DBHYDRO can be retrieved from WQDORA.SAMPLE view based on measurement locations.

The sites VAL1 and VAL2 correspond to the *V. americana* monitoring sites where water temperature measurements, **TEMP_VAL1** and **TEMP_VAL2** time series, were obtained during water quality sampling events from January 28, 1998 to December 18, 2006.

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[1]DBKEY is a 5 character string used in DBHYDRO as unique identifier of a specific time series.

[2]DBHYDRO is SFWMD's corporate environmental database for storage and retrieval of hydrologic, meteorologic, hydrogeologic, and water quality data defined at http://my.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/dbhydrobrowseruserdocumentation.pdf.

The water temperature monitoring site closest to the *V. americana* sampling locations is Fort Myer, which is positioned approximately 6 km downstream of VAL1 and less than 3 km downstream of VAL2. Daily mean water temperatures at Fort Myer, **H2OT_FtMyer** time series, are available in DBHYDRO starting from January 1992 to the current date and only 10% of the daily values are missing for the entire period of record. **H2OT_FtMyer** time series spans the *V. americana* monitoring interval (January 28, 1998 to December 18, 2006) as well as the period of most interest listed in Objective 1 (January 1, 1992 to January 31, 2011).

The proximity with the *V. americana* monitoring sites; the fact that the time series contains daily mean water temperatures rather than random, instantaneous water temperature measurements; the completeness of the data set; and its periods of record make Fort Myer the main source for daily mean water temperature estimation at the *V. americana* monitoring sites. All other data sets are basically used to complete and extend the **H2OT_FtMyer** water temperature time series.

Table 2. List of water temperature time series used in the analysis, measurement locations, data types, start and end dates, and raw data sources.

Monitoring Location	Time Series Name	Data Type	Start Date	End Date	Raw Data Source	DBKEY in DBHYDRO
VAL1	**TEMP_VAL1**	monthly random	January 28, 1998	December 18, 2006	MS Excel files	-
VAL2	**TEMP_VAL2**	monthly random	January 28, 1998	December 18, 2006	MS Excel files	-
Fort Myer	**H2O_FtMyer**	top and bottom daily mean	January 22, 1992	October 11, 2011	DBHYDRO DMDBASE.DM_DATA_TYPE table	15277, 15278, PE681, PE684
Marker52	**H2O_Marker52**	surface daily mean	October 22, 2007	current	USGS website	-
S79_WMD	**H2O_S79_WMD**	top and bottom daily mean	January 22, 1992	current	DBHYDRO DMDBASE.DM_DATA_TYPE table	15285, 15286
	TEMP_S79	random, during water quality sampling events	January 1, 1981	current	DBHYDRO WQDORA.SAMPLE view	-
S79_USGS	**H2O_S79_USGS**	daily mean	May 2, 1983	September 30, 1997	DBHYDRO DMDBASE.DM_DATA_TYPE table	00868
S77	**H2O_S77**	daily, random	October 1, 1964	September 30, 1975	DBHYDRO DMDBASE.DM_DATA_TYPE table	00854
	TEMP_S77	random, during water quality sampling events	June 18, 1973	current	DBHYDRO WQDORA.SAMPLE view	-

Water temperature time series at Marker52 (**H2OT_Marker52**) is used to estimate some of the missing water temperature values at Fort Myer. Marker52 is a USGS monitoring site and daily mean surface water temperatures values at this site, can be downloaded from the USGS ftp site[3] starting from October 22, 2007 to the current date.

Water temperature time series collected at site S79 over different periods of record are stored in DBHYDRO. At this location, the current study considered two daily mean and one instantaneous water temperature time series: **H2OT_S79_WMD** monitored by SFWMD, **H2OT_S79_USGS** monitored by USGS, and instantaneous water temperature measurements that **TEMP_S79** performed on a monthly, bi-weekly or weekly basis during water quality sampling events.

[3] USGS site: http://nwis.waterdata.usgs.gov/fl/nwis/dv?site_no=02293205.

Site S77 is also used for the current analysis, though it is located more than 88 km upstream of the VAL1 monitoring site. The water temperature measurements at S77 are stored in DBHYDRO and cover an older period of record not available through other time series. At S77 there are two available water temperature time series: the daily instantaneous water temperatures between October 1, 1964 and September 30, 1975, named **H2OT_S77**, and the instantaneous water temperature measurements performed monthly, bi-weekly or weekly during water quality sampling events, named **TEMP_S77**. Many of the random, instantaneous water temperature measurements at S77 are performed on the same dates as the measurements at S79 during SFWMD water quality sampling excursions. This fact makes the correlation between the two time series, **S77_TEMP** and **S79_TEMP**, relevant for water temperature relationships on a daily timescale.

All raw data temperature time series described above are downloaded from different data sources and are stored in Microsoft (MS) Access and Excel files that supplement the current report. Raw data files and MS Access tables names are listed in **Appendix 1**. A couple of the time series listed in **Table 2**, **H2O_FtMyer** and **H2O_S79_WMD**, are based on several distinct raw data time series and have several DBKEYs. The specific way these derived time series were built is presented in the sections below.

Water temperature values marked in DBHYDRO as "!" were considered erroneous and were omitted from analysis.[4] During data manipulation, one questionable record was found at VAL2 on January 24, 2006. On this date, water temperature at the VAL2 site was very low compared to the water temperatures at other sites in the area. This record was marked as erroneous in the original data set and was omitted from the analysis.

Raw data sets are expressed in degrees Celsius (°C) and therefore all equations between water temperature time series discussed in the current report are also expressed in ˚C.

General Approach

MS Access was used to perform data manipulation, SYSTAT and SAS were used to perform statistical tests while MS Excel and SigmaPlot were used to graph the water temperature time series.

Due to south Florida seasonality, all water temperature time series used in the current analysis have bimodal distributions. As shown in **Appendix 2**, using a significance level $\alpha = 0.05$, data sets have distributions statistically different from normality. Therefore, comparison between data sets were performed using nonparametric tests. The Wilcoxon Signed-Rank Test was used to assess if the median of the difference between paired data sets was statistically different from zero (0). Using a significance level of $\alpha = 0.05$, the paired data sets that have Wilcoxon Signed-Rank Test p-value > 0.05 are not considered statistically different, thus values from one data set may be used to fill in or "represent" the missing data in the other data set. If the Wilcoxon Signed-Rank Test p-value ≤ 0.05, the paired data sets were considered statistically different. Nevertheless, for a large number of pairs, as it is the case of our data sets, Wilcoxon Signed-Rank Test has a high power that could result in relatively small differences appearing statistically significant (p-value ≤ 0.05). Therefore, the median of the paired differences was also evaluated and compared with the accuracy of water temperature measurements. The accuracy of most water temperature probes is between 0.1 to 0.2°C and any median difference with an absolute value less than or equal to the accuracy of the measurement is meaningless. Therefore, even though Wilcoxon Signed-Rank Test p-value ≤ 0.05, and median of the paired differences is equal or less than 0.2°C, the compared data sets might be considered not significantly different.

Wilcoxon Signed-Rank Test merely assesses if the differences between the central tendencies of paired data sets are statistically different from zero, but does not evaluate similarities or dissimilarities for the entire data range. For this purpose linear regression analysis was performed to quantify the

[4] In DBHYDRO the qualifier "!" has the meaning: "Data deviates from historically established ranges."

relationship between the data sets. For the purpose of the current report, linear regression analysis supersedes the Wilcoxon Signed-Rank Test. Data sets were considered representative of each other when the Wilcoxon Signed-Rank Test shows no statistical difference between the data sets and/or linear regression between paired data is not statistically different from a 1:1 relationship.

A regression line is considered not statistically different from a 1:1 relationship when its slope and intercept are not statistically different from one (1) and zero (0), respectively. Comparisons of slopes versus one and intercepts versus zero were performed for all regressions using a significance level $\alpha = 0.05$. All linear regressions performed in the current analysis have high coefficients of determinations ($R^2 > 0.7$), which means that the relations are strongly linear and well defined. But, as the regressions are built on large number of samples and have high coefficient of determination, small deviations of the slopes or intercepts from one (1) or (0) respectively, might appear statistically significant (p-value ≤ 0.05). For these reasons, when the absolute value of an intercept is less or equal to the standard error of the regression summed with the accuracy of water temperature probes (between 0.1 to 0.2°C), this intercept is not considered practically different from zero (0), even though it might have p-value ≤ 0.05. Similarly, if the slope is statistically different from one (1), but the difference from one is less than 0.1, the slope is considered practically one. The water temperature range of the analyzed time series was between 10°C and 35°C and multiplication of such values by 0.1 would produce differences between 1°C and 3.5°C in the results, which is in the order of magnitude of the error of the analyzed linear regressions.

For the dates when none of the analyzed time series had available data, linear interpolation between water temperature values at the beginning and end of the interval was used to estimate daily values.

Objective 1

Assembly of Daily Mean Water Temperature Time Series at Fort Myer (H2OT_FtMyer) for 1992 to 2011

The monitoring location with daily average water temperature observations closest to VAL1 and VAL2 is Fort Myer (DBHYDRO site name is FMYER). The Fort Myer data sets considered for the analysis span from January 22, 1992 to January 31, 2011 and are available in DBHYDRO database under the DBKEYs 15277, 15278, PE681 and PE684. These data sets are also listed in the files that supplement the current report (see **Appendix 1**).

Water temperature at Fort Myer is measured at the surface and at the bottom using a pair of CR10 recorders. During the analyzed period of record, the initial recorders were replaced by a new pair and, for a while, both pairs measured water temperature in parallel. A summary of water temperature time series at Fort Myer is listed in **Table 3**.

Table 3. Number of daily average water temperature values at Fort Myer and the corresponding DBKEY for January 22, 1992 to January 31, 2011.

DBKEY	Minimum (Date)	Maximum (Date)	Number of Days in Interval	Number of Values in Interval	Percentage of Missing Values
15277	January 22, 1992	June 10, 2008	5,985	5,284	11.7%
15278	January 22, 1992	June 10, 2008	5,985	4,954	17.2%
PE681	May 31, 2000	January 31, 2011	3,898	3,434	11.9%
PE684	May 31, 2000	January 31, 2011	3,898	3,552	8.9%
Derived time series: **H2OT_FtMyer**	January 22, 1992	January 31, 2011	6,950	6,273	9.7%

On September 25, 1994 the water temperature values listed under DBKEY 15277 and 15278 are zero ("0") and are qualified in DBHYDRO as "!". These values were considered erroneous and have been omitted from the analyzed data set. The time series listed in **Table 3** partially overlap and in the analyzed interval there are days with one, two, three or four water temperature values, as shown in **Table 4**.

Table 4. The number of daily mean water temperature values recorded at Fort Myer for January 22, 1992 to January 31, 2011.

Number of Values	Number of Days	Percentage of Total Number of Days	Minimum (Date)	Maximum (Date)
0	677	9.7%	March 18, 1992	March 18, 2010
1	58	0.8%	October 15, 1992	August 16, 1998
2	3,612	52.0%	January, 1992	January 31, 2011
3	470	6.8%	July 25, 2001	August 18, 2004
4	2,133	30.7%	May 31, 2000	June 10, 2008
Total number of days – 6,950			January 22, 1992	January 31, 2011

Overlapping time series allow paired comparisons of water temperatures measured on the same dates. **Table 5** presents the Wilcoxon Signed-Rank Test and regression analysis results for these paired data sets. Due to the large number of pairs, Wilcoxon Signed-Rank Test has a high power and therefore small differences appear statistically significant. All Wilcoxon Signed-Rank Test p-values in **Table 5**, with the exeption of the pair 15278-PE684, are smaller than the significance level $\alpha = 0.05$, and therefore differences in compared data sets are statistically significant. On the other hand, all the medians of paired differences are under 0.1°C. Note that the accuracy of most temperature probes used to measure water temperatures is between 0.1 to 0.2°C. Therefore, any differences less than or equal to the accuracy of the measurements are practically meaningless. Along the same line of thought, linear regression analysis of the overlapping time series suggests that these data sets can be considered equivalent. The values of the intercepts are smaller than 1˚C and the slopes values are close to or equal to one.

Table 5. Wilcoxon-Signed Rank Test and linear regression analysis for paired daily mean water temperatures time series at Fort Myer.

Time Series DBKEY		N	Wilcoxon Signed-Rank Test		Regression Analysis			
Independent	Dependent		Median Difference Between Pairs	p-Value	R^2	Intercept	Intercept = 0 p-Value	Slope
15277	15278	4,796	0.08	<0.001	0.992	-0.108	0.001	0.999
15277	PE681	2,595	<0.00	0.012	1.000	-0.003	0.633	1.000
15277	PE684	2,595	0.05	<0.001	0.992	-0.081	0.067	1.002
15278	PE681	2,141	-0.05	<0.001	0.992	0.316	<0.001	0.988
15278	PE684	2,259	<0.00	0.203	1.000	-0.001	0.909	1.000
PE681	PE684	3,434	0.04	<0.001	0.994	-0.022	0.522	1.000

Basic statistics were performed for each data set. These statistics suggest strong similarities among the time series, though they might cover different time intervals. As presented in **Table 6**, the differences between minimum, maximum, median, arithmetic mean and standard deviation are less than 1°C across the different data sets. These differences are within the accuracy of water temperature measuring probes (0.1–0.2°C) and are too small to differentiate surface and bottom water temperatures.

Table 6. Statistics of the different DBKEYs time series at Fort Myer for January 22, 1992 to January 31, 2011.

Time Series DBKEY	N	Minimum	Maximum	Median	Arithmetic Mean	Standard Deviation
15277	5,284	11.7	32.8	25.6	25.2	4.6
15278	4,954	11.6	32.8	25.7	25.1	4.6
PE681	3,434	11.7	32.9	25.8	25.2	4.7
PE684	3,552	11.6	32.8	26.0	25.3	4.7

The compiled daily average water temperature **H2OT_FtMyer** time series is calculated as a mean over all recorded values available that day. For the purpose of the current analysis, the assumption is that water temperatures measured by all recorders at different water depths are generally equivalent.

The compiled Fort Myer daily average water temperature time series for January 22, 1992 to January 31, 2011 has a notable number of missing values. About 10% (676 values) of daily water temperatures were not recorded or reported. In order to supplement/complete water temperature time series at Fort Myer, other available data sets were examined. Based on the proximity to Fort Myer and their period of records, two neighboring sites, Marker52 and S79 (see **Figure 2**), were added for analysis.

Extending H2OT_FtMyer Time Series Based on Water Temperatures at Marker52

Water temperature time series at Marker52 represent daily average surface water temperatures. Measurements are performed by USGS at the monitoring site identified as 02293205 and data can be downloaded from USGS website.[5] Raw data are also listed in MS Access and MS Excel files that supplement the current report (see **Appendix 1**).

The results of paired comparison and regression analysis between **H2OT_Marker52** and **H2OT_FtMyer** time series are presented in **Table 7**. The Wilcoxon Signed-Rank Test p-value of 0.427 implies no statistically significant difference between the two time series. The regression analysis yields an intercept statistically different from zero (0) but with an absolute value lower than the standard error summed with the water temperature measurements accuracy (e.g., Abs (-0.472˚C) < (0.343 ± (0.1-0.2˚C)). Also the slope, though statistically different from one (1), differs from one by less than 0.02.

[5] http://nwis.waterdata.usgs.gov/fl/nwis/dv?site_no=02293205

Table 7. Comparison of **H2OT_Marker52** and **H2OT_FtMyer** values paired by date.

Time Series 1	Time Series 2	Number of Pairs	Wilcoxon Signed-Rank Test		Regression					
Independent	Dependent		Median Difference Between Pairs	P-value	R^2	Intercept	Intercept = 0 p-Value	Slope	Slope = 1 p-Value	Standard Error of Estimate
H2OT_ Marker52	H2OT_ FtMyer	776	<0.00	0.427	0.994	-0.472	<0.001	1.018	<0.001	0.343

Based on the results presented in **Table 7**, the values in **H2OT_Marker52** time series can be used to fill data gaps in the **H2OT_FtMyer** data set:

$$\text{H2OT\_FtMyer} \approx \text{H2OT\_Marker52} \quad (1)$$

Extending H2OT_FtMyer Time Series Based on Water Temperatures at S79

Daily average water temperature at site S79 is measured independently by SFWMD and USGS at two nearby locations. At this site, SFWMD measures water temperatures at the surface and the bottom. These data are available in DBHYDRO under DBKEY 15285 and 15286. Comparison of the two time series is presented in **Table 8**. The results of the Wilcoxon Signed-Rank Test show no statistically significant difference between the paired data sets. The regression analysis yields an intercept that is not statistically different from zero (0) and a slope equal to one (1). Since the surface and bottom data are not statistically different, the daily average water temperature time series measured by SFWMD at S79, **H2OT_S79_WMD**, is created by averaging all available values on a daily basis.

Table 8. Comparison of surface and bottom water temperatures recorded by SFWMD at S79.

Time Series 1	Time Series 2	Number of Pairs	Wilcoxon Signed-Rank Test		Regression				
Independent	Dependent		Median Difference Between Pairs	p-Value	R^2	Intercept	Intercept = 0 p-Value	Slope	Standard Error of Estimate
DBKEY = 15285	DBKEY = 15286	6,016	<0.00	0.408	0.990	-0.01	0.768	1.000	0.427

H2OT_S79_USGS represents the daily mean water temperature measurements performed by USGS at S79. Data is available in DBHYDRO under DBKEY 00868. This data set contains 109 records with values either negative or greater than 1000˚C, which are marked in the database as "!". These records have been omitted from the analysis.

A paired comparison of the compiled **H2OT_S79_WMD** time series and the **H2OT_S79_USGS** time series is presented in **Table 9** in an attempt to assess if the data sets are statistically different. Wilcoxon Signed-Rank Test reveals a statistically significant difference between data sets. Also regression analysis yields an intercept statistically different form zero (0) and a slope statistically different from one (1). Therefore the two time series have been compared individually to the **H2OT_FtMyer** time series.

Table 9. Paired comparison of the compiled **H2OT_S79_WMD** time series and the **H2OT_S79_USGS** time series.

Time Series 1	Time Series 2	Number of Pairs	Wilcoxon Signed-Rank Test		Regression					
Independent	Dependent		Median Difference Between Pairs	P-value	R^2	Intercept	Intercept = 0 p-Value	Slope	Slope = 1 p-Value	Standard Error of Estimate
H2OT_S79_USGS	H2OT_S79_WMD	1,117	0.08	<0.001	0.966	0.51	<0.001	0.978	<0.001	0.726

Paired comparison and linear regressions analysis between **H2OT_FtMyer**, **H2OT_S79_WMD** and **H2OT_S79_USGS** time series are presented in **Table 10**.

Table 10. Paired comparison of the compiled **H2OT_FtMyer** time series, the compiled **H2OT_S79_WMD** time series, and the **H2OT_S79_USGS** time series.

Time Series 1	Time Series 2	Number of Pairs	Wilcoxon Signed-Rank Test		Regression					
Independent	Dependent		Median Difference Between Pairs	P-value	R^2	Intercept	Intercept = 0 p-Value	Slope	Slope = 1 p-Value	Standard Error of Estimate
H2OT_S79_WMD	H2OT_FtMyer	5,916	-0.12	0.001	0.918	-1.822	<0.001	1.070	<0.001	1.329
H2OT_S79_USGS	H2OT_FtMyer	1,089	-0.02	0.938	0.909	-1.65	<0.001	1.065	<0.001	1.366

Wilcoxon Signed-Rank Test shows no statistically significant difference between the **H2OT_S79_USGS** and **H2OT_FtMyer** time series. Nevertheless, both regression analysis yield absolute values of the intercepts bigger than standard error of the regressions summed with water measurements accuracies. The missing values from daily mean water temperatures at Fort Myer have been estimated using equations **(2)** and **(3)** as follows:

$$\textbf{H2OT\_FtMyer} = -1.822 + 1.070 * \textbf{H2OT\_S79\_WMD} \pm 1.329 \qquad (2)$$

$$\textbf{H2OT\_FtMyer} = -1.650 + 1.065 * \textbf{H2OT\_S79\_USGS} \pm 1.366 \qquad (3)$$

A continuous daily average water temperature time series at Fort Myer for January 1, 1992 to January 31, 2011 has been assembled using linear regressions with **H2OT_Marker52**, **H2OT_S79_WMD** and **H2OT_S79_USGS** time series described above. The resulting **H2OT_FtMyer** time series make up and associated equations are summarized in **Table 13**. The time series are listed in the order of their priority. When data with higher priority is not available the next priority data set is used to estimate the daily mean water temperature at Fort Myer.

Table 11. Makeup of the assembled daily mean water temperature time series at Fort Myer for January 1, 1992 to January 31, 2011.

Time Series	Priority	Number of Days in Assembled Time Series	Percent Days in Assembled Time Series	Method Used to Fill in Missing Data
H2OT_FtMyer	1	6273	90.0%	
H2OT_Marker52	2	213	3.1%	use **H2OT_FtMyer** data
H2OT_S79_WMD	3	283	4.1%	**H2OT_FtMyer** = -1.822 + 1.070 * **H2OT_S79_WMD** ± 1.329
H2OT_S79_USGS	4	192	2.8%	**H2OT_FtMyer** = -1.650 + 1.065 * **H2OT_S79_USGS** ± 1.366
missing values		10	0.1%	linear interpolation

Comparison of Water Temperature Data Sets at VAL1, VAL2 and Fort Myer

To confirm similarities between daily mean water temperatures measured at Fort Myer and the random instantaneously monthly field water temperature measurements at VAL1 and VAL2 as part of *Vallisneria* sampling, a graphical representation of these time series is presented in **Figure 3** for January 1, 1998 to December 31, 2006 when the measurements at VAL1 and VAL2 took place.

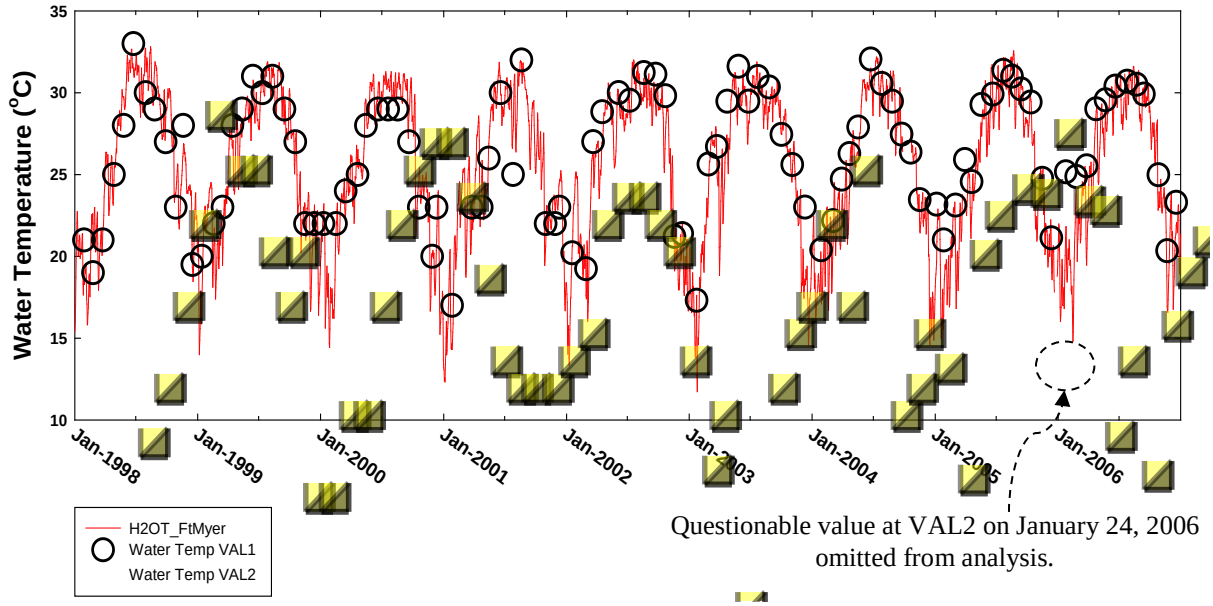


Figure 3. Daily mean water temperatures at Fort Myer and monthly water temperatures at VAL1 and VAL2 for January 1, 1998 to December 31, 2006.

Note the water temperature value of 13.2°C registered on January 24, 2006 at VAL2. This value is much lower than any other water temperatures measured at the nearby sites on the same date, as shown in **Table 12**. Therefore the value was considered questionable and was omitted from the analysis.

Table 12. Water temperature (°C) values registered on January 24, 2006.

Date	S79_H2OT _WMD	H2OT_ FtMyer	TEMP _VAL1	TEMP _VAL2
January 24, 2006	21.09	21.8	25.17	**13.2**

While the visual inspection of **Figure 3** suggests that the water temperature at Fort Myer and the *V. americana* monitoring sampling locations (VAL1 and VAL2) are similar, a quantitative relationship between the data sets is needed.

Summary statistics of water temperature **TEMP_VAL1**, **TEMP_VAL2** and **H2OT_FtMyer** time series are presented in **Table 13**. For consistency reason, statistics have been performed only for the dates when data is available for all three data sets**.** The basic statistics show strong similarity between data sets, especially between the **TEMP_VAL2** and **H2OT_FtMyer** time series.

Table 13. Summary statistics of **H2OT_FtMyer**, **TEMP_VAL1** and **TEMP_VAL2** time series values paired by date.

Water Temperature on Sampling Dates	Number of Pairs	Minimum	Maximum	Median	Arithmetic Mean	Standard Deviation
TEMP_VAL1	101	17.0	33.0	26.4	26.0	4.0
TEMP_VAL2	101	14.0	32.0	25.9	25.4	4.3
H2OT_FtMyer	101	14.3	32.7	26.3	25.4	4.5

Table 14 presents the results of Wilcoxon Signed-Rank Test and regression analysis for the three data sets. Using a significance level of $\alpha = 0.05$, the Wilcoxon Signed-Rank Test reveals a statistically significant difference between **H2OT_FtMyer** and **TEMP_VAL1** data sets, while regression analysis yelds a regression line statisticaly different from 1:1 relationship. The linear equation between these two time series is as follows:

$$\textbf{TEMP\_VAL1} = 5.368 + 0.812 * \textbf{H2OT\_FtMyer} \pm 1.420 \qquad (4)$$

Table 14. The Wilcoxon Signed-Rank Test and linear regression analysis results for **H2O_FtMyers**, **TEMP_VAL1** and **TEMP_VAL2** time series.

Water Temperature on Sampling Dates		Number of Pairs	Wilcoxon Signed-Rank Test		Regression Analysis					
Independent	Dependent		Median Difference Between Pairs	P-Value	R^2	Intercept	Intercept = 0 p-Value	Slope	Slope = 1 p-Value	Standard Error of Estimate
H2OT_FtMyer	**TEMP_VAL1**	102	-0.50	0.001	0.872	5.368	<0.001	0.812	<0.001	1.420
H2OT_FtMyer	**TEMP_VAL2**	101	-0.15	**0.937**	0.934	1.912	0.003	0.923	0.048	1.122
TEMP_VAL2	**TEMP_VAL1**	103	-0.44	<0.001	0.898	4.075	<0.001	0.864	<0.001	1.272

The Wilcoxon Signed-Rank Test does not detect any statistically significant difference between **TEMP_VAL2** and **H2OT_FtMyer** paired values. Regression analysis yields a slope statistically different from one, but the difference is at the second decimal; so practically, the slope can be considered one. The intercept is statistically different from zero and slightly larger than the regression error summed with the measurements accuracy. The positive intercept could be due to the fact that **TEMP_VAL2** values are measured during the daytime, hence are higher than **H2OT_FtMyer** values, which are averaged over the entire 24-hour day. It can be inferred:

$$\mathbf{TEMP\_VAL2 \approx H2OT\_FtMyer} \qquad \mathbf{(5)}$$

Assuming that the relationships between water temperatures at Fort Myer and random monthly water temperatures at VAL1 and VAL2 holds true for daily mean water temperatures at VAL1 and VAL2, the previous two equations become:

$$\mathbf{H2OT\_VAL1 = 5.368 + 0.812 * H2OT\_FtMyer \pm 1.420} \qquad \mathbf{(6)}$$

$$\mathbf{H2OT\_VAL2 = H2OT\_FtMyer} \qquad \mathbf{(7)}$$

Figure 4 presents the linear regression between the water temperatures measured at VAL1 and VAL2 (solid line: **TEMP_VAL1** versus **TEMP_VAL2**) and the linear relation between the water temperatures estimated at VAL1 and VAL2 based on **H2OT_FtMyer** time series (long dashed line: **H2OT_VAL1** versus **H2OT_VAL2**). Also these relationships are compared to the 1:1 line. Paired comparison of the water temperatures at VAL1 and VAL2 show statistically significant difference between the data sets, though the measurements are performed at similar depths and on the same dates (see **Table 12**). **Figure 4** reveals that at lower temperatures the regression lines are above the 1:1 line, which means that the temperatures at VAL1 are higher than at VAL2. A simple algebraic calculation indicates that for all temperatures under 28.6°C at VAL2 the estimated temperatures at VAL1 are higher. The VAL1 sampling site is located upstream of VAL2 and in closer proximity to a power plant discharge, which might be the cause of higher water temperatures relative to VAL2. Since the growth of *V. americana* is influenced by water temperature, this difference may be ecologically significant at the low tempertaure range and thus accounting for these site differences is relevant to ongoing efforts.

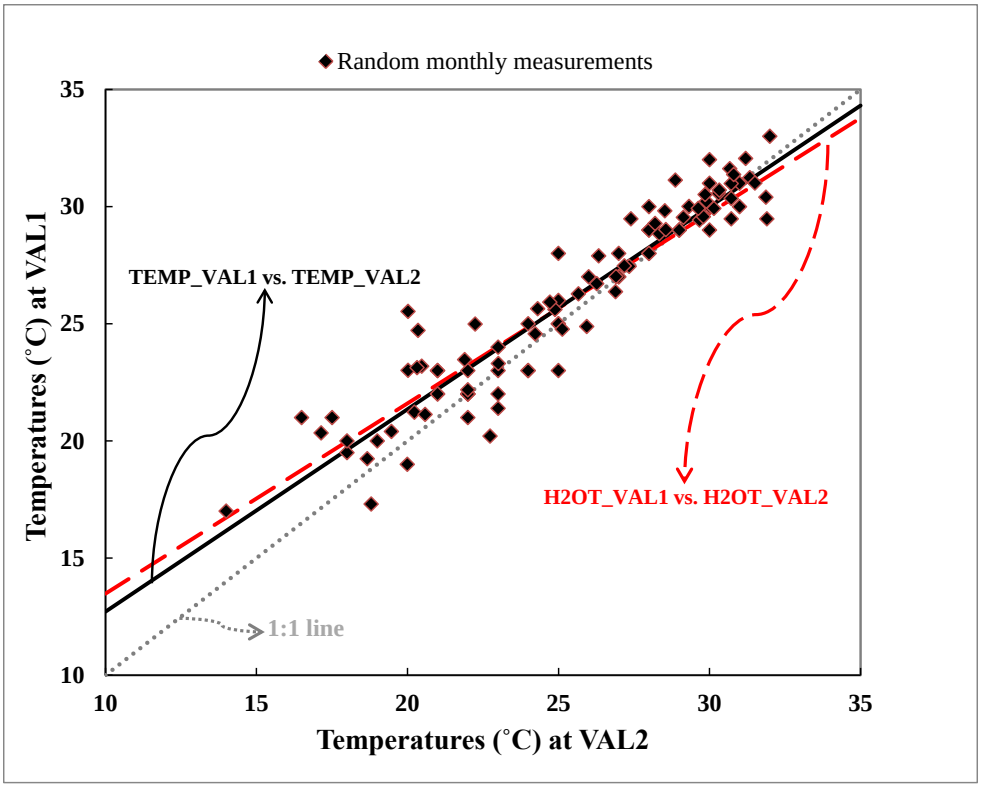


Figure 4. Linear regression between measured water temperatures and linear relation between estimated water temperatures based on **H2OT_FtMyer** time series for VAL1 and VAL2.

Estimation of Water Temperature Values at VAL1 and VAL2 for the First of the Month for 1998 to 2006

The interval of 1998–2006 corresponds to the monthly *V. americana* measurements and is a significant period used for *Vallisneria* model applications as it provides model calibration and verification. While some model applications require daily mean water temperature input values at VAL1 and VAL2, other applications require monthly input values for the first day of each month.

Time series of the measured water temperatures as well as the estimated water temperatures for the first of the month at VAL1 and VAL2 are presented in **Figure 5**.

Determination of Annual Water Temperature Ranges at Fort Myer, VAL1 and VAL2 for January 1992 to January 2011

Minimum, maximum, median, and mean water temperatures for each month using the assembled daily average water temperature at Fort Myer (equivalent to VAL2) indicate expected seasonal patterns (**Figure 6**). Most months have values that reach low temperatures that are greater than 2 standard deviations below the median (shown by asterisk on the box plot in **Figure 6**). Combined with other stressors such as high salinity or low light availability, the low temperatures may be detrimental to *V. americana* growth in some years (Bartelson et al, 2014; Hunt and Doering, in review).

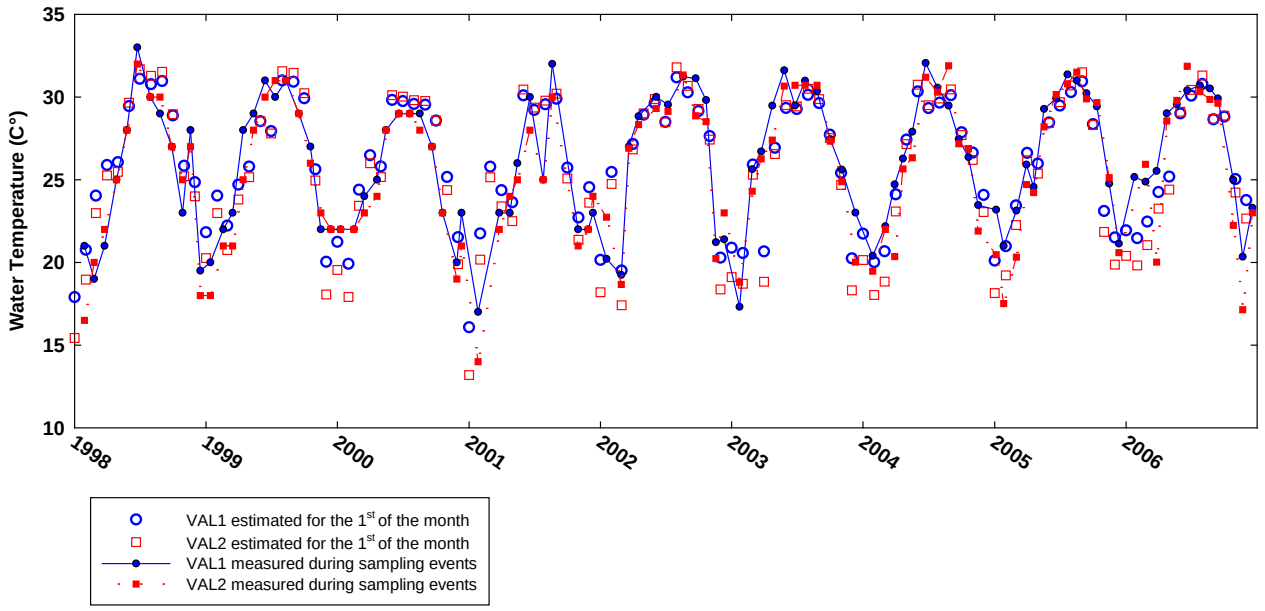
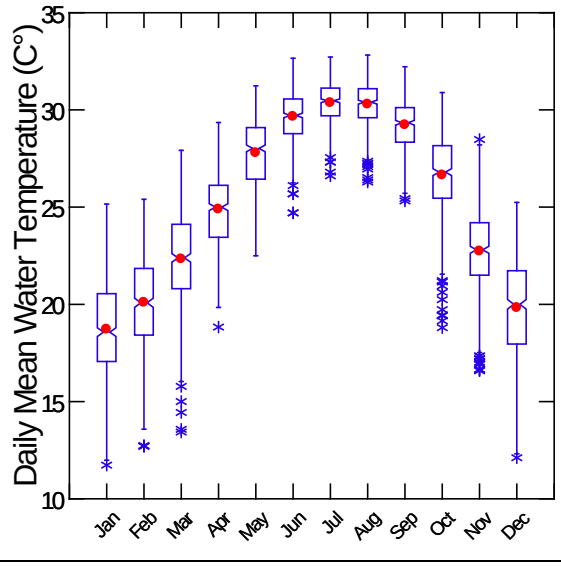


Figure 5. Graphical representation of the measured water temperatures and the estimated water temperature for the first of the month at **VAL1** and **VAL2**.

Box Plots



Basic Statistics

Month	N	Min	Max	Median	Mean	St. Dev
Jan	620	11.7	25.2	18.6	18.7	2.7
Feb	528	12.7	25.4	20.1	20.1	2.5
Mar	588	13.4	27.9	22.4	22.3	2.5
Apr	570	18.8	29.4	25.0	24.9	1.9
May	589	22.5	31.2	28.0	27.8	1.7
Jun	570	24.7	32.7	29.7	29.7	1.3
Jul	589	26.6	32.7	30.5	30.4	1.1
Aug	589	26.3	32.8	30.4	30.3	1.1
Sep	570	25.3	32.2	29.3	29.2	1.2
Oct	589	18.8	30.9	26.8	26.7	2.1
Nov	570	16.6	28.5	22.8	22.7	2.2
Dec	589	12.1	25.2	20.0	19.8	2.7

Figure 6. Box plots and basic statistics showing monthly range of assembled daily mean water temperatures at Fort Myer for January 1, 1992 to January 31, 2011.

A frequency analysis of the estimated daily average water temperature values below 17°C and 13°C was performed for January 1, 1992 to January 31, 2011. These water temperatures thresholds were chosen based on ecologically relevant temperature tolerances obtained from mesocosm experiments (Bartelson et al., 2014).

The number of days with estimated daily average water temperature at VAL1 and VAL2/Fort Myer less than or equal to 17°C/13°C by year and month for January 1, 1992 to January 31, 2011 is listed in **Table 15**. These low water temperatures occur during the dry season in the months of January, February, March, November and December. For ease of readability **Table 15** lists only these months. The blue-shaded interval corresponds to the monitoring period when *V. americana* shoot and blade density measurements were performed.

Estimated water temperatures at VAL1 are higher than at VAL2 especially during seasonal minimums. For the interval listed in **Table 15** at VAL1 there were no daily averages under 13°C and fewer daily averages under 17°C than at VAL2.

January 1, 1992 to January 31, 2011 includes 10 consecutive days with missing data when water temperature values at Fort Myer were estimated by interpolation. The missing daily values occurred between February 20, 1994 and March 1, 1994 and the months containing these dates have been highlighted in tan and marked with an "*" in **Table 15**. The number of missing daily values is written in parentheses. Based on water temperatures at the beginning and the end of this interval, as well as on the air temperatures registered during this period at the weather monitoring site BCSI (see **Figure 2** and **Appendix 3**), it is highly improbable that water temperatures at VAL2 sites dropped below 17°C during this time period.

Table 15. Number of days with estimated daily average water temperature at VAL1 and VAL2/Fort Myer less than or equal to 17°C/13°C by year and month for January 1, 1992 to January 31, 2011.
(For ease of readability the months with no values under 17˚C have been left blank and the number of days with daily averages under 13˚C are written in red. An "*" implies missing daily values during that month and the number of missing daily values are written in parentheses.)

Year	VAL1						VAL2					
	Jan	Feb	Mar		Nov	Dec	Jan	Feb	Mar		Nov	Dec
1992							5 / 0					
1993							1 / 0					7 / 0
1994		(9) *	(1) *				3 / 0	(9) *	(1) *			
1995		1 / 0				5 / 0	4 / 0	8 / 0				10 / 0
1996	2 / 0	3 / 0				3 / 0	10 / 0	10 / 2	6			5 / 1
1997	1 / 0						5 / 0					
1998							3 / 0	4 / 0				
1999	1 / 0					3 / 0	8 / 0					3 / 0
2000						1 / 0	6 / 0	5 / 0			2	10 / 0
2001	11 / 0						23 / 3					1 / 0
2002	4 / 0						9 / 0		2			3 / 0
2003	4 / 0						18 / 2					4 / 0
2004							4 / 0	1 / 0				13 / 0
2005							7 / 0	1 / 0	1 / 0			3 / 0
2006							7 / 0	4 / 0			3 / 0	1 / 0
2007							2 / 0	7				
2008	3 / 0						6 / 2					
2009	1 / 0	3 / 0					10 / 0	7 / 1	1 / 0			
2010	7 / 0					8 / 0	13 / 0	12 / 0	8 / 0			25/ 5
2011	3 / 0						8 / 0					

Objective 2

Water Temperature Time Series in Upper Caloosahatchee Estuary for January 1965 to January 2010

Water temperatures at Fort Myer are representative for the entire upper Caloosahatchee Estuary and can be used to extend water temperature time series at the monitoring sites in the area, including VAL1 and VAL2. A daily average water temperature time series at Fort Myer for January 1965 to January 2011 was assembled based on seven partially overlapping time series listed in **Table 16** in order of their priority. The basic statistics for these data sets are listed with the purpose of evaluating their similarities. Though the statistics were performed for the entire data sets, disregarding the fact that the time series have different periods of records, note that differences between the corresponding statistics are small. In addition, **Table 16** presents the basic statistics of the aggregate data set: **Agregated_H2OT_FtMyer**. This data set was created using the equations listed in **Table 17**.

Table 17 presents nonparametric paired comparison of the data sets as well as the regression analysis results. In some cases, Wilcoxon Signed-Rank Test implies different conclusions than the regression analysis.

Table 16. Basic statistics for the data sets used to construct daily average water temperature time series at Fort Myer for January 1965 to January 2011.

Statistics	TEMP_ VAL1	TEMP_ VAL2	Priority Use to Build H2OT_FtMyer							Aggregated_ H2OT_ FtMyer
			1	2	3	4	5	6	7	
			H2OT_ FtMyer	H2OT_ Marker52	H2OT_ S79_ WMD	H2OT_ S79_ USGS	Temp_ S79	Temp_ S77	H2OT_ S77	
Number of Cases	104	103	6,273	989	6,412	1,813	215	831	3,685	11,387
Minimum	17.0	14.0	11.7	12.0	14.0	15.5	14.6	9.7	9.0	11.7
Maximum	33.0	32.0	32.8	32.6	33.4	32.3	33.2	36.3	33.0	33.2
Arithmetic Mean	**26.0**	**25.4**	**25.3**	**25.4**	**25.3**	**24.9**	**26.0**	**25.3**	**24.0**	**25.0**
Standard Deviation	3.9	4.3	4.6	4.5	4.2	3.9	4.6	4.6	4.4	4.1
5%	19.9	18.0	17.2	17.6	18.0	18.4	17.4	17.0	16.5	18.0
25%	23.0	22.0	21.7	21.9	21.9	21.8	22.4	22.0	21.0	22.1
50%	**26.3**	**25.9**	**25.9**	**25.7**	**26.0**	**25.1**	**26.8**	**25.9**	**25.0**	**25.4**
75%	29.5	29.3	29.4	29.6	29.1	28.7	29.9	29.1	28.0	28.4
95%	31.3	31.2	31.2	31.1	30.5	30.1	32.0	31.6	30.0	30.9

Table 17. The Wilcoxon Signed-Rank Test and regression analysis results for the overlapping time series.
(The text in red indicates Wilcoxon Signed-Rank Test p-values > 0.05, which implies no statistically significant difference between the data sets.)

Equation Order of Priority	Dependent Variable	Independent Variable	No. Pairs	Wilcoxon Signed-Rank Test p-Value	Regression Analysis					Regression Equation
					R^2	Intercept		Slope		
						Value	p-Value for Intercept =0	Value	p-Value for Slope=1	
Temp_VAL1		**H2OT_FtMyer**	102	**0.001**	0.872	**5.368**	<0.001	**0.812**	<0.001	**H2OT_VAL1 = 5.368 + 0.812 * H2OT_FtMyer ± 1.420**
Temp_VAL2		**H2OT_FtMyer**	101	**0.933**	0.934	**1.912**	0.003	**0.923**	0.048	**H2OT_VAL2 = H2OT_FtMyer ± 1.122**
1	**H2OT_FtMyer**	**Marker52**	776	**0.421**	0.994	**-0.472**	<0.001	**1.018**	<0.001	**H2OT_FtMyer = H2OT_Marker52 ± 0.343**
2	**H2OT_FtMyer**	**H2OT_S79_WMD**	5916	**0.001**	0.918	**--1.822**	<0.001	**1.07**	<0.001	**H2OT_FtMyer = -1.822 + 1.070 * H2OT_S79_WMD ± 1.329**
3	**H2OT_FtMyer**	**H2OT_S79_USGS**	1089	**0.942**	0.909	**-1.65**	<0.001	**1.065**	<0.001	**H2OT_FtMyer = -1.650 + 1.065 * H2OT_S79_USGS ± 1.366**
4	**H2OT_FtMyer**	**Temp_S79**	132	**0.001**	0.932	**-2.111**	0.002	**1.064**	0.012	**H2OT_FtMyer = -2.111 + 1.064 * Temp_S79 ± 1.338**
5	**H2OT_FtMyer**	**Temp_S77**	449	**0.008**	0.939	**1.128**	<0.001	**0.948**	<0.001	**H2OT_FtMyer = 1.128 + 0.948 * Temp_S77 ± 1.154**
6	TEMP_S77	H2OT_S77	36	**0.466**	0.615	**8.956**	0.001	**0.659**	<0.001	**TEMP_S77 = 8.956 + 0.659 * H2OT_S77 ± 2.244**
7	**H2OT_FtMyer**	**H2OT_S77**	NA	based on Equation 6 above						**H2OT_FtMyer = 1.123 + 0.948 * Temp_S77**
										= 1.123 +0.948 * (8.956 + 0.659 * H2OT_S77)
										= 9.618 + 0.625 * H2OT_S77 ± 3.281

There are four instances with Wilcoxon Signed-Rank p-values > 0.05, highlighted in red in **Table 17**, indicating that the medians of the paired differences between compared data sets are not statistically different from zero. Regression analysis explores the similarities between data sets for the entire data range and therefore comparison of the regression lines with a 1:1 line ultimately specify the way data sets could 'fill in' for each other. All intercepts provided by the regression analysis are statistically significantly different from zero and all slopes are statistically significantly different from one, which means that regression lines are statistically different from a 1:1 line. As discussed in the *General Approach* section, the statistical significance of the slopes and intercepts could be due to the large number of samples and strong coefficient of determination ($R^2 > 0.7$), but might not be practically significant.

For example in the case of **TEMP_S77** and **H2OT_S77** time series, the Wilcoxon Signed-Rank Test indicates no statistical difference between the data sets. Nevertheless, regression analysis yields a statistically significant positive intercept, which is also practically significant because it is larger than the regression error summed with water temperature measurement accuracy. **TEMP_S77** values are measured during the daytime when water temperatures may be higher, while **H2OT_S77** values are averaged over the entire day including nighttime when water temperatures are usually lower. However, one should keep in mind that the intercept is less well defined due to the relatively small number of low temperature values in south Florida waters.

Using the equation defined in **Table 17**, a long time series of daily mean water temperature at Fort Myer was assembled and the makeup of the assembled data is listed in **Table 18**.

Table 18. The make-up of aggregate daily long-term daily mean water temperature time series at Fort Myer for January 1965 to January 2011.

Priority	Time Series	Frequency	Source	# Days	% Days
1	**H2OT_FtMyer**	Daily Mean	DBHYDRO	6273	37.27%
2	**H2OT_Marker52**	Daily Mean	USGS	213	1.27%
3	**S79_Temp**	Random	DBHYDRO	59	0.35%
4	**H2OT_S79_WMD**	Daily Mean	DBHYDRO	283	1.68%
5	**H2OT_S79T_USGS**	Daily Mean	DBHYDRO	624	3.71%
6	**S77_Temp**	Random	DBHYDRO	286	1.70%
7	**H2OT_S77**	Daily Mean	DBHYDRO	3649	21.68%
	missing values			5445	32.35%
			Total # days	16,832	

It is important to understand that the 46-year long estimated daily mean water temperatures at Fort Myer time series, between January 1, 1965 and January 31, 2011 has different uncertainties. As listed in **Table 19**, the number of missing daily values, which have been estimated using interpolation, varies in time reaching in some years more than 95%. The number of the daily missing values and their percentage by year are listed in **Table 19**. Based on the number of missing the values and the error of the estimations, the entire interval has been divided into three periods, which will be discussed below starting from the most recent to the oldest interval.

Table 19. Number of estimated and missing daily mean water temperature values at Fort Myer for January 1, 1965 to January 31, 2011 by month and year.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	# Missing values	% Missing Values
1965	31	28	31	30	31	30	31	30	27	29	28	30	9	2.5%
1966	29	27	31	5						30	29	31	183	50.1%
1967	30	28	31	28	31	29	30	31	30	31	30	28	8	2.2%
1968	31	29	31	30	30	30	31	31	30	31	30	31	1	0.3%
1969	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
1970	31	28	31	30	31	30	31		30	31	30	31	31	8.5%
1971	31	28	31	30	31	30	31	31	30	29	30	31	2	0.5%
1972	31	29	31	30	31	30	31	29	30	31	30	31	2	0.5%
1973	27	28	31	30	31	30	31	31	30	31	30	31	4	1.1%
1974	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
1975	31	28	31	30	31	30	31	31	30	4	1	3	84	23.0%
1976	1	2	2	2	2	3	2	2	2	2	3	1	342	93.4%
1977	2	2	2	2	3	2	2	2	2	3	1	2	340	93.2%
1978	3	2	2	2	2	2	3	2	2	2	1	2	340	93.2%
1979	2	2	2	3	2	2	2	2	2	3	2	2	339	92.9%
1980	1		1	3	2	2	2	2	2	3	1	2	345	94.3%
1981	2	2	2	3	2	3	2	2	2	2	1	1	341	93.4%
1982	1	2		2	2	2	1	1	2	1	1	2	348	95.3%
1983	1	3	3	2	2	2	1	1					350	95.9%
1984	1	1	2	2		2	1	1	1	2	1	1	351	95.9%
1985	2	2	1	1	2	1	2	1	1	1	1	1	349	95.6%
1986	1	1	2	2	2	1	2	1	2	1	1	2	347	95.1%
1987	2	2	2	2		2	1	1	1	1	2	1	348	95.3%
1988	2	1	3	1	2	1	2	2	1	2	1	2	346	94.5%
1989	2	2	1	2	2	1	2	2	1	20	3	1	326	89.3%
1990	1	2	2	2	3	1	2	1	2	26	30	30	263	72.1%
1991	31	28	31	30	18	22	31	31	30	31	30	16	36	9.9%
1992	31	29	31	30	31	30	31	31	30	31	30	31		0.0%
1993	31	28	31	30	31	30	31	31	30	31	30	31	10	2.7%
1994	31	19	30	30	31	30	31	31	30	31	30	31		0.0%
1995	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
1996	31	29	31	30	31	30	31	31	30	31	30	31		0.0%
1997	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
1998	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
1999	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
2000	31	29	31	30	31	30	31	31	30	31	30	31		0.0%
2001	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
2002	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
2003	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
2004	31	29	31	30	31	30	31	31	30	31	30	31		0.0%
2005	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
2006	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
2007	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
2008	31	29	31	30	31	30	31	31	30	31	30	31		0.0%
2009	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
2010	31	28	31	30	31	30	31	31	30	31	30	31		0.0%
2011	31													

The January 1, 1992–January 31, 2011 interval, studied in the Objective 1 section, is well defined. As shown in **Table 20**, 90% of the daily values are obtained directly through measurements at Fort Myer. The interval has only ten consecutive missing daily values, which have been estimated using interpolation. The rest of the values are estimated based on regression with other daily mean water temperature time series, and the errors of the estimations are also listed in the table.

Table 20. Daily values obtained from each data set for January 1, 1992 to January 31, 2011.

January 1, 1992 to January 31, 2011			
6,971 days			
Time Series Used for Estimation	# days	% days	Error of the Estimation
H2OT_FtMyer	6,273	90.0%	0
H2OT_Marker52	213	3.1%	0.343
H2OT_S79_WMD	283	4.1%	1.329
H2OT_S79_USGS	192	2.8%	1.366
Interpolation	10	0.1%	—

The October 1, 1975–December 31, 1991 interval has the most number of missing values with 87.5% of the daily values obtained through interpolation. The water temperature values at Fort Myer estimated for this interval are approximate and most likely miss the seasonal minimums and maximums. **Table 21** lists the makeup of the assembled water temperature at Fort Myer for this interval and the errors of the estimations.

Table 21. Makeup of the assembled water temperature at Fort Myer for October 1, 1975 to December 31, 1991.

October 1, 1975 to December 31, 1991			
5,936 days			
Time Series Used for Estimation	# days	% days	Error of the Estimation
H2OT_S79_USGS	432	7.3%	1.366
Temp_S79	59	1.0%	1.338
Temp_S77	250	4.2%	1.154
Interpolation	5,195	87.5%	—

The January 1, 1965–September 30, 1975 interval has only approximately 6% of missing daily values. Nevertheless, most of the values in this interval are estimated based on the daily random water temperatures at S77, which is placed more than 88 km upstream. The errors associated to the regressions used for estimations are bigger. Also the temperature values at S77 are old and might be less reliable. The makeup of the assembled water temperature time series at Fort Myer is listed in **Table 22**.

Table 22. Makeup of the assembled water temperature time series at Fort Myer for January 1, 1965 to September 30, 1975.

January 1, 1965 to September 30, 1975			
3,925 days			
Time Series Used for Estimation	# days	% days	Error of the Estimation
H2OT_S77	3,649	93.0%	**3.281**
Temp_S77	36	0.9%	1.154
Interpolation	240	6.1%	—

Automatic Excel calculations were set up in the files *Make_Inter1.xlsx* and *Make_Inter2.xlsx* in order to perform linear interpolation for the missing values. The resulting time series of the continuous daily mean water temperature values at Fort Myer, VAL1 and VAL2 are listed in the Excel file *Wtemp_ExtendTimeSereis_VAL1_VAL2_1965_2011.xlsx*, spreadsheet *DailyWtemp_FtMyer*.

The graphical representation of the total daily mean water temperature time series at Fort Myer/VAL2 derived for January 1, 1965 to January, 31 2011 is presented in **Figure 7**.

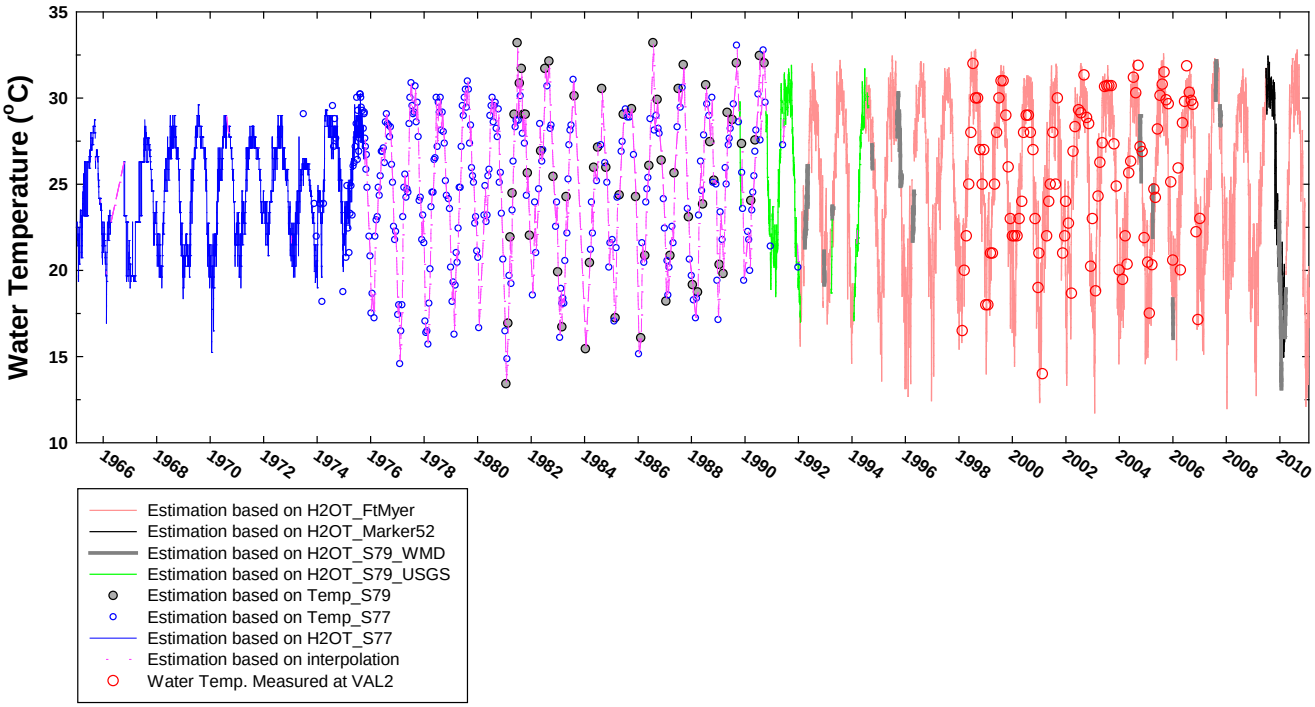


Figure 7. Assembled daily mean water temperature time series at Fort Myer/VAL2 for January 1, 1965 to January 31, 2011

Note that the water temperature time series in **Figure 7** has only values between 15°C and 30°C for the first ten years (1965–1975). Values outside of this range occur after 1976, and values under 15°C are more frequent after 1995. This feature might be a consequence of the fact that older data is assembled based on instantaneous water temperatures measured during daytime and ignore the lower nighttime water temperature values.

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Appendix 1. List of Raw Data Filenames

Table A1-1 contains a list of raw data filenames.

Table A1-1. List of raw data filenames.

Water Temperature Time Series Name	**Description of the Time Series**	**RawData_CalooEstuary_WaterTemp.accdb Access Database Table Name (**stored in the SFWMD Morpho database, filename **Daily Water Temperature Time Series for the Upper Caloosahatchee Estuary)**	**Excel Filename and Other Raw Data Sources**	**DBKEY in DBHYDRO**
TEMP_VAL1	Instantaneously measured water temperatures at VAL1 and VAL2	**Temp_VAL1_VAL2**	**Temp_VAL1_VAL2.xlsx** stored in the SFWMD Morpho database, filename **Daily Water Temperature Time Series for the Upper Caloosahatchee Estuary**	
TEMP_VAL2				
H2OT_FMYER	Daily mean water temperature at Fort Myer	**H2OT_RawData_S77_S79_FMYER**	DBHYDRO (DM_DAILY_DATA table: daily average over DBKEY)	15277, 15278, PE681, PE684
H2OT_S79_WMD	Daily mean water temperature at S79 measured by SFWMD			15285, 15286
H2OT_S79_USGS	Daily mean water temperature at S79 measured by USGS			00868
H2OT_S77	Daily instantaneously water temperature at S77			00854
H2OT_Marker52	Daily mean surface water temperature at Marker52	**H2OT_RawData_Marker52**	USGS website: site name 2293205	
TEMP_S79	Water quality sampling events instantaneously measured water temperatures at S79	**Temp_RawData_S77_S79_FlagNull**	DBHYDRO (SAMPLE view)	
TEMP_S77	Water quality sampling events instantaneously measured water temperatures at S77			
Results	**Extended H2OT at VAL1 and VAL2/Fort Myer for January 1, 1965–January 31, 2011**	**Wtemp_ExtendTimeSereis_VAL1_VAL2_1965_2011.xlsx** stored in the SFWMD Morpho database, filename **Daily Water Temperature Time Series for the Upper Caloosahatchee Estuary**		

Appendix 2. Histograms and Normality Test for Water Temperature Time Series Used in the Analysis

The histograms of water temperature time series used in the analysis show a bimodal distribution (**Figure A2-1**), which is due to south Florida seasonality.

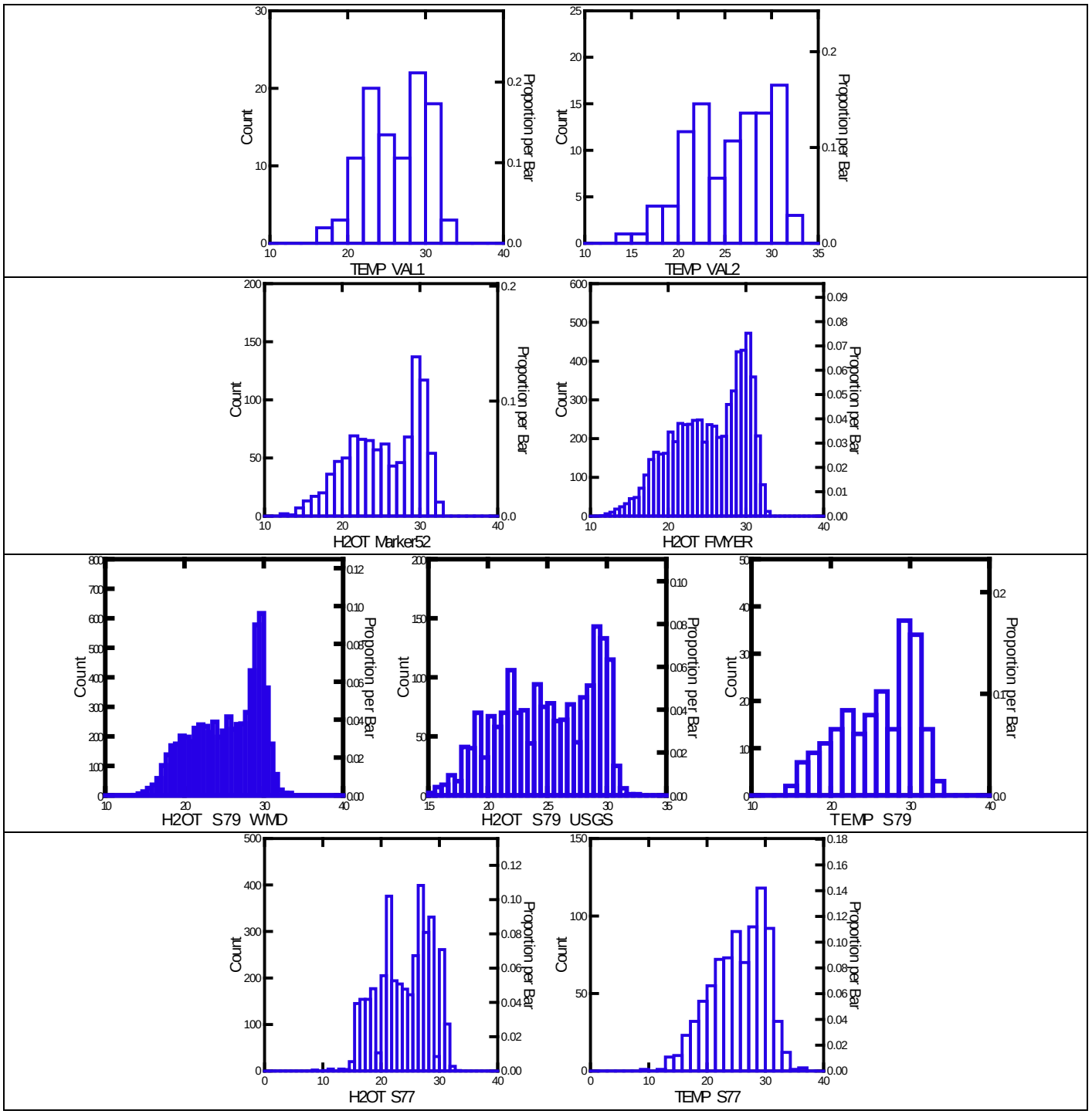

Figure A2-1. Histograms of water temperature time series used in the analysis.

The Shapiro-Wilk normality test, presented below in **Tables A2-1** and **A2-2**, can be performed for the data sets with less than 5,000 cases: **TEMP_VAL1**, **TEMP_VAL2**, **H2OT_S77**, **TEMP_S77**, **H2OT_ S79_USGS**, **TEMP_S79** and **H2OT_ Marker52**. All Shapiro-Wilk p-Values show a statistically significant difference between the distributions of water temperature time series and the normal distribution. For the two data sets with more than 5,000 elements, **H2OT_ S79_WMD** and **H2OT_FMYER**, the deviation from normality can be implied by their histograms, which are similar to the histograms of the other data sets.

Table A2-1. Shapiro-Wilk normality test for **TEMP_VAL1** and **TEMP_VAL2**.

Statistic	TEMP_VAL1	TEMP_VAL2
N of Cases	104	103
Shapiro-Wilk Statistic	0.952	0.954
Shapiro-Wilk p-Value	0.001	0.001

Table A2-2. Shapiro-Wilk normality test for remaining data sets.

Statistic	H2OT_S77	TEMP_S77	H2OT_ S79_WMD	H2OT_ S79_USGS	TEMP_S79	H2OT_ Marker52	H2OT_ FMYER
Number of Cases	3,685	831	6,412	1,813	215	989	6,273
Shapiro-Wilk Statistic	0.957	0.972	NA	0.951	0.944	0.945	NA
Shapiro-Wilk p-Value	<0.001	<0.001	NA	<0.001	<0.001	<0.001	NA

Appendix 3. Air Temperatures at Site BCSI and Water Temperatures at Fort Myer for February 20 to March 1, 1994

The February–March 1994 interval contains ten consecutive days with no available water temperature data at Fort Myer or any other location in the upper Caloosahatchee Estuary. To evaluate the water temperature values during the days with missing data, between February 20, 1994 and March 1, 1994, air temperatures registered at the site BCSI (latitude = 26˚19'17.291'', longitude = -81˚04'04.239'') were taken into consideration.

Starting in October 21, 1992 and up to the current date, the daily minimum, mean and maximum air temperatures at BCSI were monitored by SFWMD using a CR10 recorder and were stored in DBHYDRO under the DBKEYS listed in **Table A3-1**. Linear regression between the daily mean water temperature at Fort Myer and daily mean air temperature at BCSI for October 21, 1992 to January 31, 2011 were evaluated (**Figure A3-1**).

The daily mean water temperatures at Fort Myer can be estimated using the linear regression equation presented in **Figure A3-1**. **Table A3-1** lists the daily minimum, mean and maximum air temperatures at BCSI and the daily mean water temperatures at Fort Myer estimated based on the linear regression for February 20 1994 to March 1, 1994.

Note that even on the date with the lowest mean air temperature at BCSI, February 27, 1994, the linear regression does not predict daily mean water temperatures at Fort Myer lower than 17°C.

Table A3-1. Daily minimum, mean and maximum air temperatures at BCSI for each DBKEY.

DATE	Daily Air Temperature at BCSI			Daily Mean Water Temperature at Fort Myer Based on Regression
	MINIMUM	MEAN	MAXIMUM	
	DBKEY: TA619	DBKEY: 15682	DBKEY: MTA620	
February 20, 1994	17.7	24.4	31.9	27.2
February 21, 1994	18.1	24.1	31.3	26.8
February 22, 1994	16.3	22.7	30.2	25.6
February 23, 1994	14.9	23.4	32.4	26.2
February 24, 1994	20.3	24.6	30.7	27.3
February 25, 1994	19.1	22.7	31.0	25.6
February 26, 1994	19.1	23.3	28.9	26.1
February 27, 1994	14.6	19.7	26.6	22.8
February 28, 1994	16.0	21.0	27.4	24.0
March 1, 1994	19.1	22.2	26.0	25.1

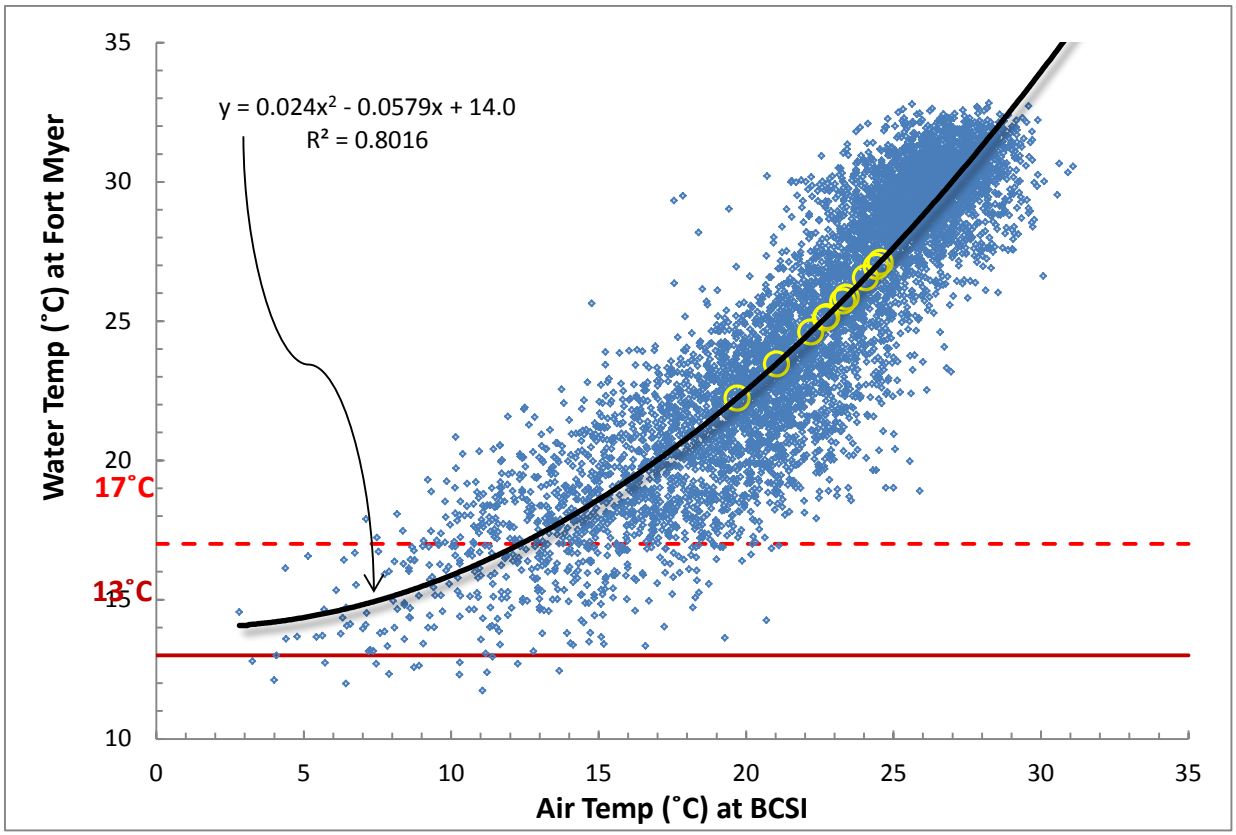

Figure A3-1. Linear regression between the daily mean water temperature at Fort Myer and daily mean air temperature at BCSI for October 21, 1992 to January 31, 2011.