Air-Water Temperature Correlation

New Mexico Environment Department
Surface Water Quality Bureau
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Summary

This document provides a tool for identifying appropriate stream classifications and attainable aquatic life use subcategories. The investigation described here demonstrates that, based on data for approximately 300 New Mexico streams, air temperature is highly correlated with stream water temperature and subsequently with the attainable aquatic life use subcategory.

The key results presented in this document are these, which are applicable unless there are significant groundwater inputs or microclimate effects:

(1) maximum weekly average (water) temperature is equal to July average air temperature; and
(2) attainable aquatic life use subcategories can be related to July average air temperature, as follows:

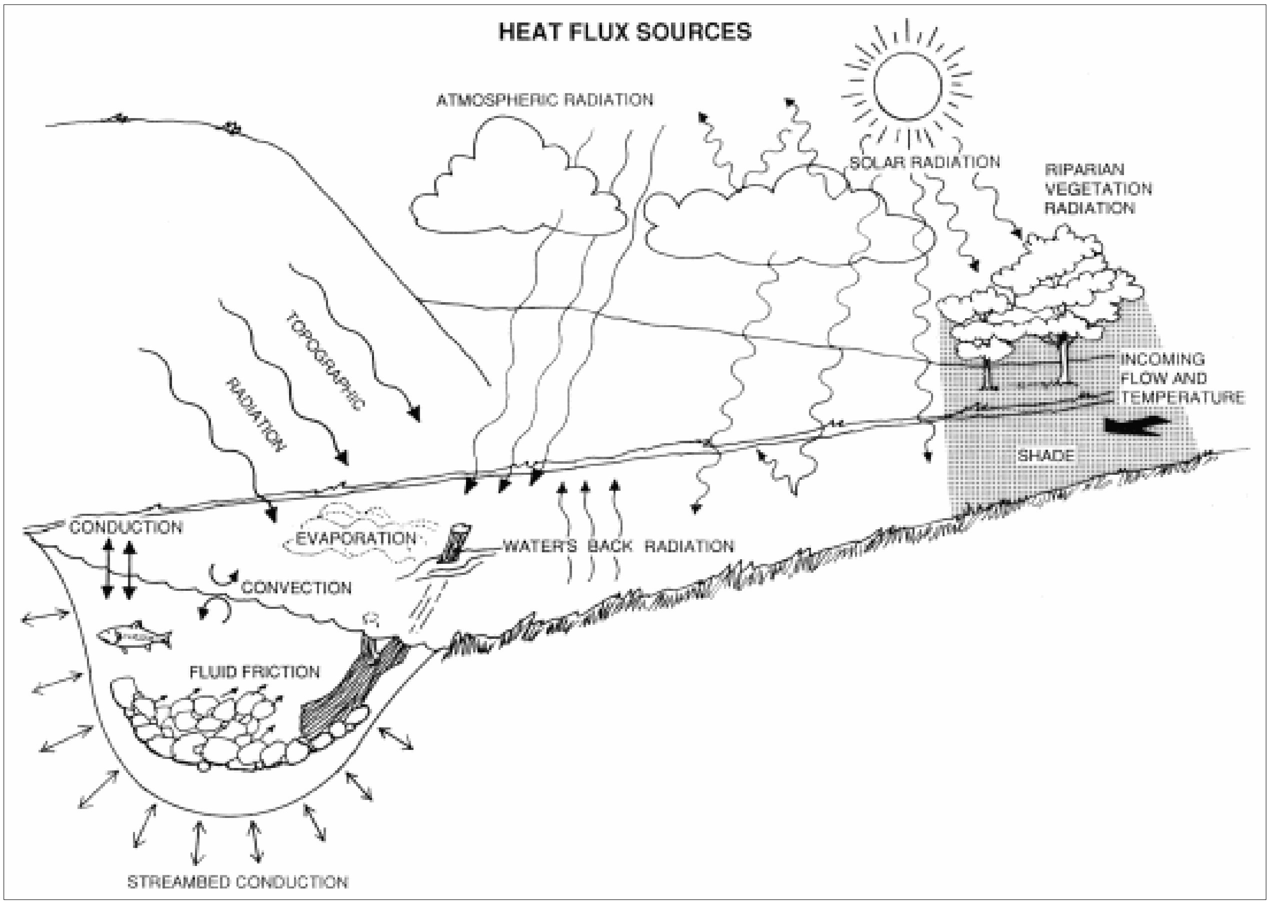
- high quality and coldwater uses may be attainable if July average air temperature is ≤18°C;
- marginal coldwater and coolwater uses may be attainable if July average air temperature is ≤23°C;
- uses more restrictive than warmwater are generally not attainable if July average air temperature is >23°C.

Introduction

Temperature has been identified as a leading cause of impairment in rivers and streams in New Mexico (NMED/SWQB 2009). However, the Surface Water Quality Bureau (SWQB) suspects that many of these waters are misclassified; that is, the designated aquatic life use or associated criteria cannot be attained because of naturally limiting conditions.

In the absence of significant groundwater input, stream water temperature is the result of the relationship of eight heat flux components: convection, conduction, fluid friction, evaporation, water back radiation, atmospheric (long wave) radiation, vegetative and topographic (long wave) radiation and solar (short wave) radiation, as illustrated in following figure from the SSTEMP water temperature model (Bartholow, 2002).

Figure 1



Five of the components (evaporation, water back radiation, atmospheric radiation, solar radiation and vegetative-topographic radiation) generally account for more than 90% of the stream heat flux. The significant positive heat fluxes are atmospheric and vegetative-topographic long wave radiation, and short-wave solar radiation.

With the exception of solar radiation, the heat flux components cannot be measured directly, but a number of related factors (and solar radiation) can be. These factors include:

Meteorological Factors

- air temperature
- solar radiation
- relative humidity
- wind speed
- possible sun
- ground temperature

Water or Streamcourse Factors

- inflow temperature
- accretion (groundwater inflow) temperature
- segment inflow (water flow at the top of the segment)
- segment outflow (water flow at the bottom of the segment)
- thermal gradient

Geographical Factors

- latitude
- segment length
- upstream elevation
- downstream elevation

Insolation Factors

- shading
- width-to-depth ratio

Air temperature is highly correlated with the significant positive heat flux components including solar radiation, and consequently with stream water temperature. The correlation is supported by the SSTEMP water temperature model documentation, which asserts: "Air temperature will usually be the single most important factor in determining mean daily water temperature."

The factors of relative humidity and wind speed are not directly associated with positive heat flux, although they have some influence on water temperature. The remaining meteorological and geographical factors have less influence on water temperature. None of the meteorological or geographical factors are amenable to human intervention.

The water or streamcourse factors are inflow temperature, groundwater inflow, stream segment inflow and outflow, and thermal gradient. With few exceptions, the inflow temperature is correlated to meteorological factors, chiefly air temperature. Although most New Mexico streams are shallow and are not "gaining streams" (not fed by groundwater) for most of their length, there are specific instances where groundwater inflow influences water temperature. Stream flow may influence water temperature, although it may not be amenable to modification. The insolation factors of shading and width-to-depth ratio have some influence on water temperature and are amenable to human intervention through stream restoration activities.

Correlation between Air Temperature and Water Temperature

The SWQB has developed a statewide correlation between July average air temperature and MWAT water temperature (MWAT - maximum weekly average temperature). The MWAT is defined as the seven-day mean of consecutive daily mean temperatures, where daily means are calculated from multiple, equally spaced values per day (Todd et al., 2008). Water quality criteria documents such as EPA (1972) recommend aquatic life temperature limits for prolonged exposure based on the MWAT. Chronic water temperature criteria based on the MWAT have recently been developed in Colorado (Todd et al., 2008).

The analysis provided here verifies a strong correlation between weekly and monthly averages of stream and air temperature. The relationship can be used to estimate the naturally attainable water temperature at any location in the state, absent site-specific mitigating conditions.

Water Temperature Data

Water temperatures were obtained from SWQB water thermograph data. Since 1999, SWQB has deployed long-term temperature data recorders (thermographs) at approximately 300 monitoring stations on New Mexico streams. During the summer season of June through August the thermographs record hourly temperatures, providing approximately 3,000 data points at each station. We reduced the data to summary statistics: the reference date (date of the first maximum temperature); the maximum temperature; the maximum weekly average temperature (MWAT); the 4-hour maximum temperature that occurs for 3 consecutive days (4T3); and the 6-hour maximum temperature that occurs for 3 consecutive days (6T3).

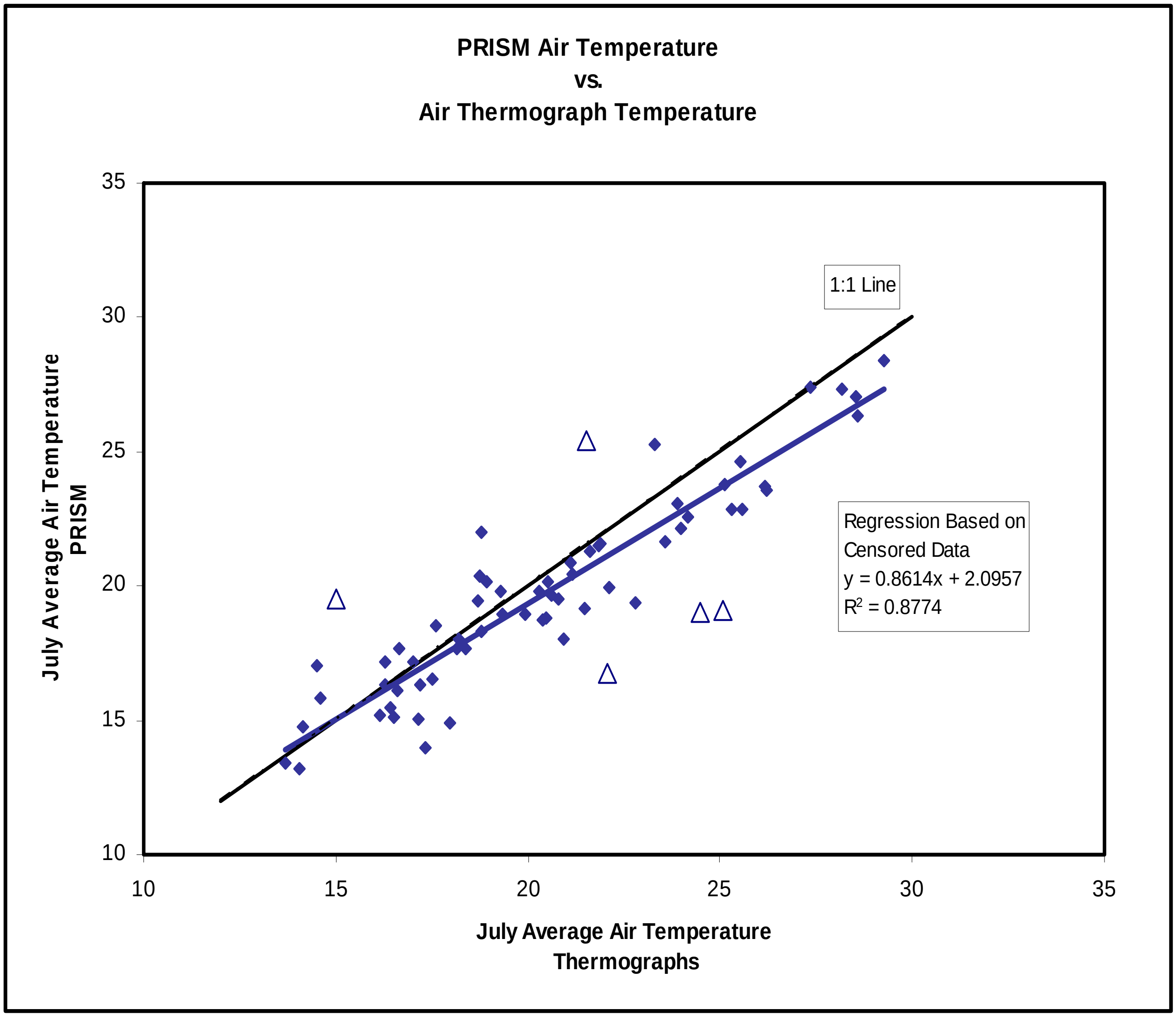
Air Temperature Data

Air temperatures were obtained from two sources: a publically available temperature model known as PRISM (Parameter-elevation Regressions on Independent Slopes Model) and SWQB air thermographs. PRISM, available at http://www.prism.oregonstate.edu/, provides gridded data that can be used to find representative July temperatures for any location in the United States. PRISM can be used to provide July average temperatures that can be associated with any SWQB water monitoring location. The SWQB co-deployed ambient air thermographs at approximately 70 water thermograph stations. Data provided by these thermographs was also used to calculate July average air temperatures.

PRISM Data Evaluation

Because the PRISM data is potentially more useful than the limited number of SWQB air thermographs, we evaluated the suitability of PRISM data by comparing the SWQB air thermograph data to the PRISM data. The comparison is shown in Figure 2.

Figure 2



The figure shows July average PRISM air temperatures plotted against July average temperatures measured using SWQB air thermographs. If the PRISM model correlated exactly with the air thermographs, the PRISM data would plot on the 1:1 line. The PRISM data may not plot precisely on the line for a number of reasons such as microclimate effects and imprecision of the PRISM model. To adjust for some of this variation, five data points where the thermograph and PRISM values were more than 3.8°C different were not used to develop the regression line. The points that were not used are plotted as triangles in the figure. The cutoff of 3.8°C was chosen because it is two standard deviations from the mean difference between the two datasets.

The regression indicates strong correlation and a slope of nearly 1. Based on this evaluation, we concluded that the PRISM dataset was suitable for use in providing July average temperatures at SWQB water monitoring locations.

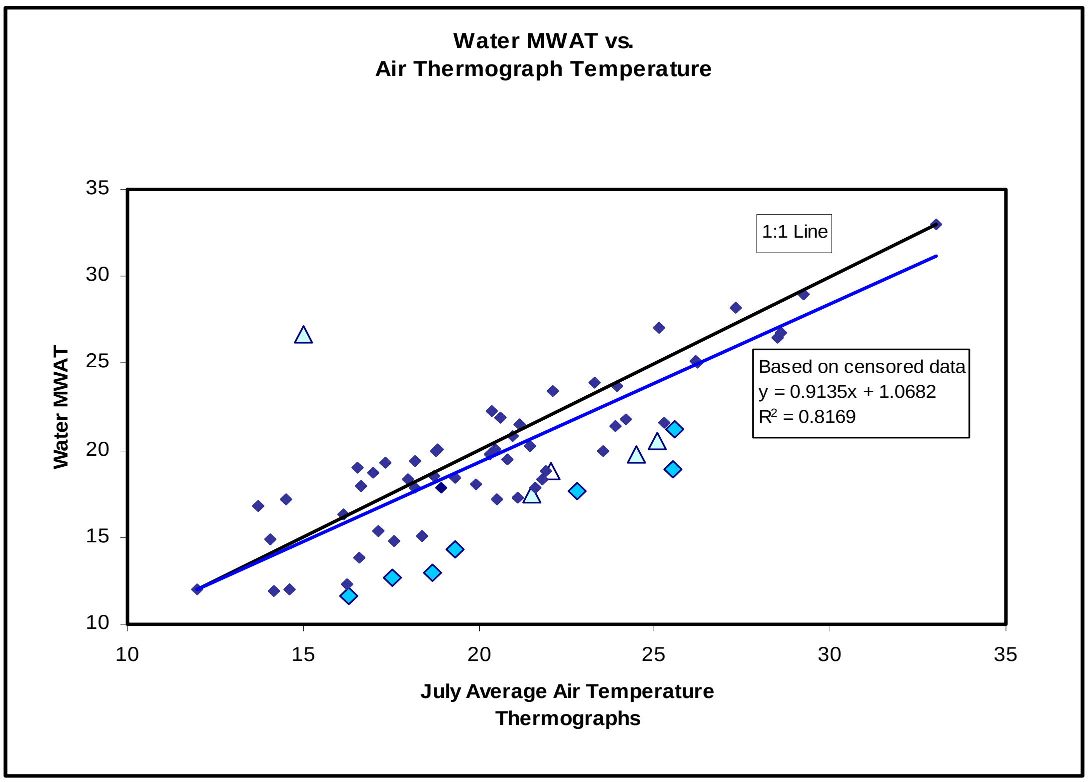
Outlier Analysis

Although other investigators have reported an almost 1:1 relationship between weekly average stream temperature and monthly average air temperature (Morrill et al. 2005), there are a number of reasons why the SWQB dataset may not correlate precisely with the July average air temperatures. These reasons include local conditions that cause the water temperature to be unusually high or low, unrepresentative thermograph locations, inconsistent periods of record and other causes.

To develop a basis for removing data points not well-correlated with July air temperature, particularly where the water temperature is influenced by groundwater, we considered the locations where we had both air and water thermograph data. Based on visual examination of the thermographs, it appeared that at locations where the air – water difference was greater than 4°C, the temperatures were either outliers, influenced by microclimate effects or moderated by groundwater.

To test this, we plotted air thermograph and water MWAT data (Figure 3). Locations identified as outliers in the *PRISM Data Evaluation* (Figure 2) are shown as triangles. Of the five points identified in the *PRISM Data Evaluation*, four also have an air-water difference greater than 4°C. One (15.00°C air, 26.62°C water) appears to be an outlier due to unusually low air thermograph readings, with an air – water difference of negative 11.6°C. The unshaded triangle, identified in the *PRISM Data Evaluation*, had a difference of 3.3°C which is less than the 4-degree cutoff.

Figure 3



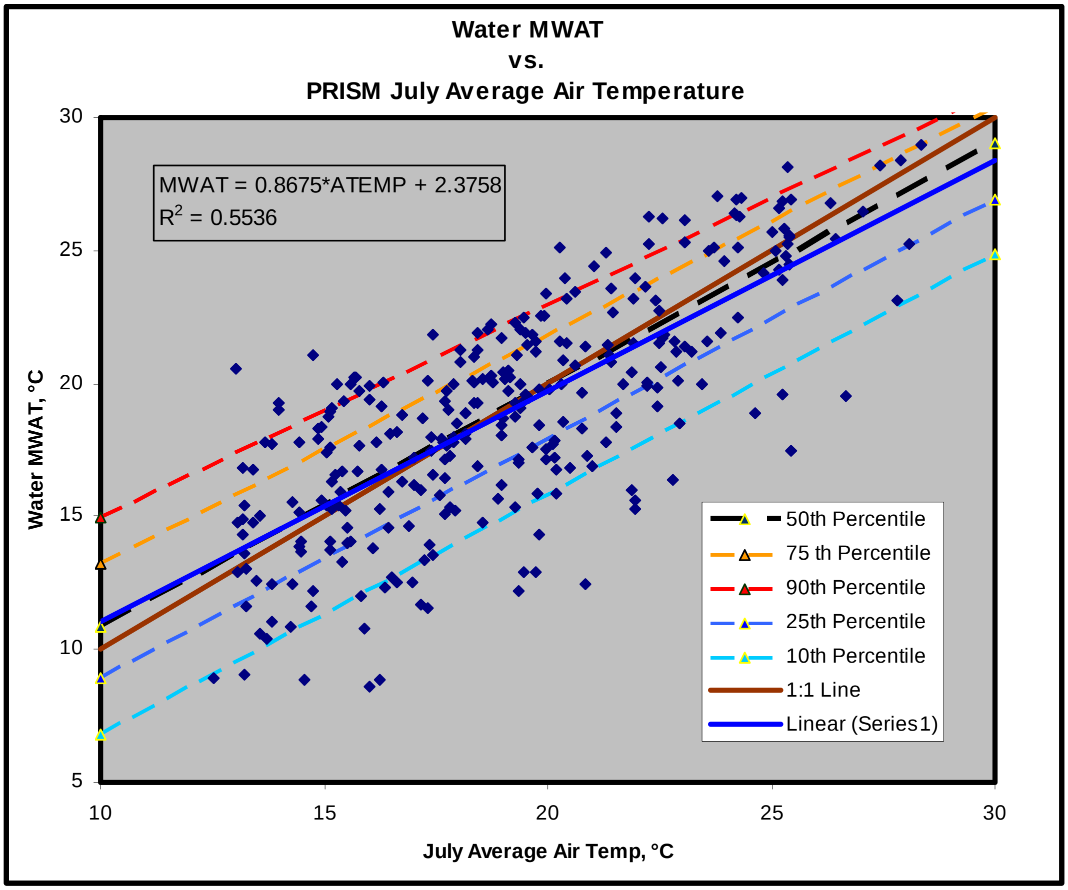
We identified seven additional points (the larger shaded diamonds) based on a positive air – water difference greater than 4°C. At five of the locations, the daily water temperature variation was low (a reference date diel water temperature difference less than 6°C), indicating groundwater influence. Two had a diel difference greater than 12°C. For these, however, the thermograph temperature was about 3°C greater than predicted by PRISM. If the PRISM temperature had been used these points would have been within the 4°C cutoff and would not be shown as shaded diamonds. All seven points, as well as four of those identified by the *PRISM Data Evaluation,* plot in the lower range of the relationship.

Based on this evaluation, we concluded that a July average air – water MWAT difference of 4°C was a reasonable value for use in removing data from locations significantly influenced by groundwater or microclimate effects.

Statewide Correlation

We compared thermograph data from 293 monitoring locations to July average air temperatures from PRISM and plotted the results in Figure 4. No data points were removed. The figure includes the linear least squares regression, the 1:1 line and percentile regression lines.

Figure 4



Regression Coefficients

	m	b
10th percentile	0.9033	-2.2126
25th percentile	0.9015	-0.1133
50th percentile	0.9097	1.7368
75th percentile	0.8571	4.6514
90th percentile	0.8005	6.9644
Linear regression	0.8675	2.3758

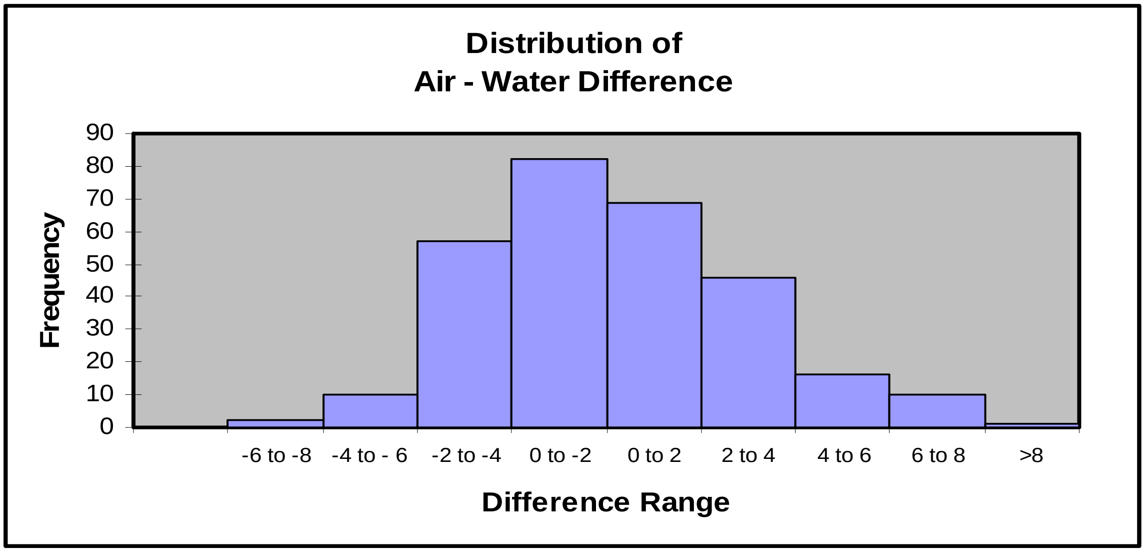
Representative results from the regressions are shown below:

Table 1

July Average Air Temp, °C	Water MWAT based on Regression, °C	Water MWAT 50th Percentile, °C	Water MWAT 25th Percentile, °C	Water MWAT 10th Percentile, °C
15	15.39	15.38	13.41	11.34
20	19.73	19.93	17.92	15.85
25	24.06	24.48	22.43	20.37

Consistent with the *Outlier Analysis*, we calculated the air – water difference. There are 27 locations with an air – water difference greater than 4°C, and 12 with a difference less than 4°C. The distribution is shown in Figure 5.

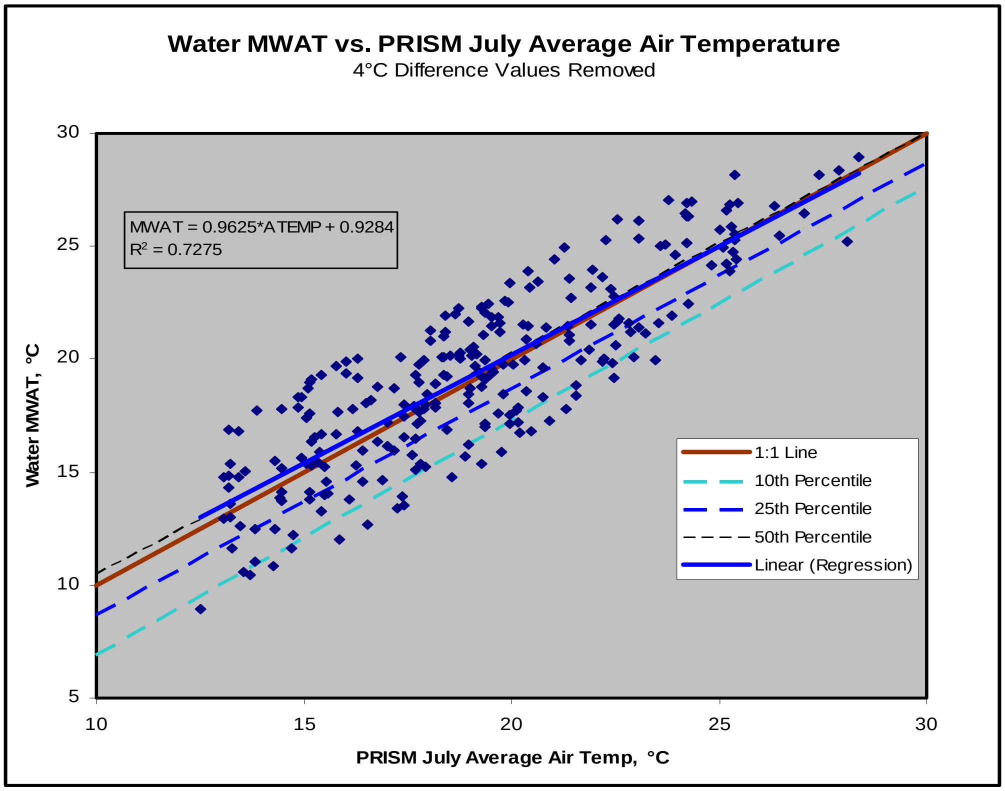
Figure 5



Difference	-6 to -8	-4 to - 6	-2 to -4	0 to -2	0 to 2	2 to 4	4 to 6	6 to 8	>8
Frequency	2	10	57	82	69	46	16	10	1

After removing points with a greater than 4°C difference, we plotted the remaining 254 data points as water MWAT vs. PRISM July average air temperature in Figure 6.

Figure 6



Regression Coefficients

	m	b
10th percentile	1.0353	-3.4280
25th percentile	1.0000	-1.3400
50th percentile	0.9768	0.6900
Linear regression	0.9625	0.9284

Representative results from the regressions are shown below:

Table 2

July Average Air Temp, °C	Water MWAT based on Regression 4°C Δ Removed, °C	Water MWAT 50th Percentile, 4°C Δ Removed, °C	Water MWAT 25th Percentile, 4°C Δ Removed, °C	Water MWAT 10th Percentile, 4°C Δ Removed, °C
15	15.37	15.34	13.66	12.10
20	20.18	20.23	18.66	17.28
25	24.99	25.11	23.66	22.45

Tables 1 and 2 show that in the 15 to 25°C air temperature range, both the 4°C Δ removed and all data regressions predict a temperature within 1°C of the 1:1 line (MWAT = July Average Air Temperature).

Reference Site Evaluation

A list of New Mexico locations considered to be reference sites has recently been developed. *Sediment in New Mexico Streams: Existing Conditions and Potential Benchmarks* (Jessup et al. 2010) includes a file, AppF_NM Datasets2.xlsx, that lists 45 New Mexico locations considered to be reference sites based on characteristics other than temperature. The 45 locations are listed in the file *Bedded Sediment Reference Sites*. SWQB has collected thermograph data at only 13 of these sites. The sites are listed in Table 3.

At the first three sites (Rito Resumidero blw Resumidero Spring, Rio Puerco de Chama @ FR 103 and Bear blw Dorsey Spring), the July average air temperature (PRISM) minus the water MWAT was more than 4°C, and the thermographs did not exhibit the usual diel variation. As with the previous statewide analysis, these characteristics suggest that groundwater inflow are moderating the air temperature influence, so these sites were not used for this analysis.

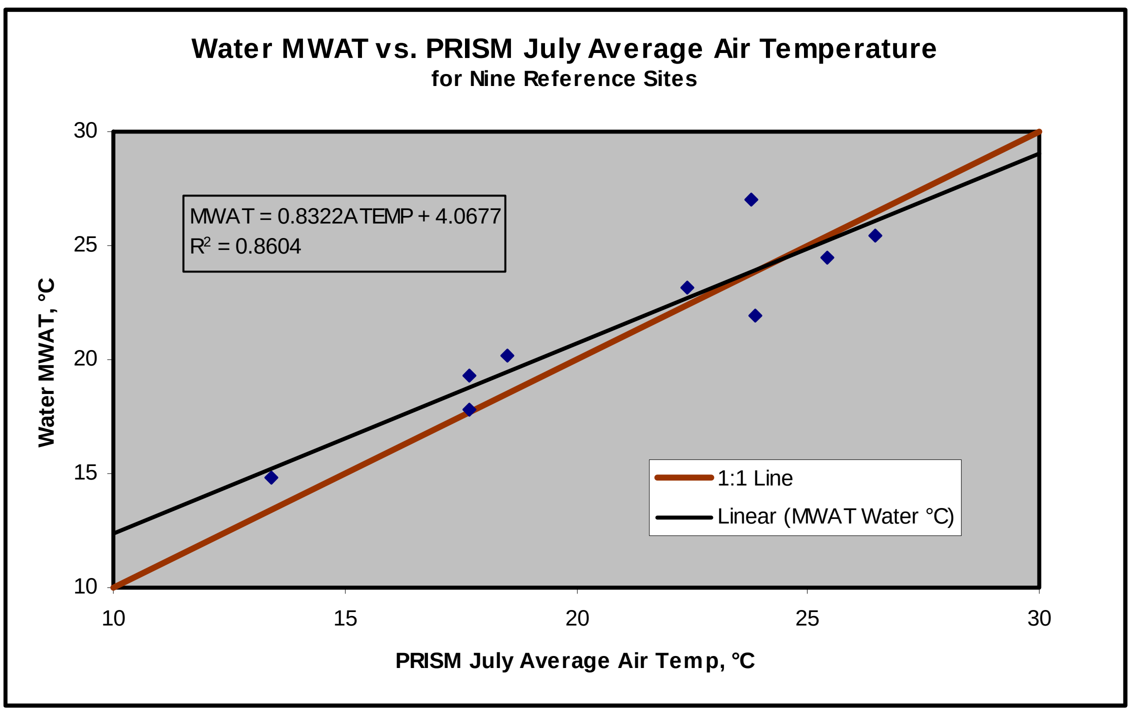
The Dry Cimarron River @ Jesus Mesa site had an air – water difference slightly greater than 4°C, and the air temperature was lower than the water temperature. Although the water temperature exhibited diel variation, the difference between the daily maximum and minimum was less than expected, indicating that factors other than air temperature may be influencing water temperature. The stream at this site is surrounded by exposed bedrock that may elevate the water temperature. Because of this potential microclimate effect, and in order to be consistent with the 4°C cutoff, the Jesus Mesa site was also not used for the reference site correlation.

Table 3

STORET ID	Station	July Average Air Temp (PRISM) °C	MWAT Water °C	Air-Water Difference °C
29RResum001.9	~~Rito Resumidero blw Resumidero Spg~~	~~16.26~~	~~8.87~~	7.39
78BearCr027.0	~~Bear blw Dorsey Spg~~	~~23.45~~	~~18.01~~	5.44
29RPuerc037.5	~~Rio Puerco de Chama @ FR 103~~	~~16.97~~	~~12.54~~	4.43
77Turkey001.8	Turkey Creek	23.87	21.92	1.95
78GilaRi025.5	Gila blw Blue	26.44	25.44	0.99
78GilaRi069.2	Gila blw Mangas	25.41	24.45	0.96
28RGRanc013.1	RG del Rancho @ Talpa-1305269	17.68	17.82	-0.14
77EFkGil000.2	E Fk Gila	22.40	23.14	-0.74
28RCosti032.5	Costilla abv Comanche (blw impoundment)	13.41	14.79	-1.39
05MPonil000.1	M Ponil abv S Ponil	17.70	19.30	-1.60
05NPonil000.1	N Ponil abv S Ponil	18.53	20.19	-1.66
10UteCre104.3	Ute nr Bueyeros	23.79	27.04	-3.26
02DryCim047.2	~~Dry Cim @ Jesus Mesa~~	~~22.27~~	~~26.28~~	-4.02

Figure 7 is a graph of the data from the remaining nine sites.

Figure 7



Representative results are shown below:

Table 4

July Average Air Temp, °C	Water MWAT based on Regression using Reference Data °C
15	16.55
20	20.71
25	24.87

At 15 and 20°C, the predicted MWAT using the reference data is 0.7 to 1.6°C *greater* than the 1:1 line. At 25°C, the reference data regression predicts a water temperature within 0.2°C of the 1:1 line. Despite the limited number of data points, it is clear that the reference sites fall along the same 1:1 air-water temperature relationship found for all sites.

MWAT Prediction Equation

Representative results from the previously discussed regressions are shown below:

Table 5

July Average Air Temp, °C	Water MWAT based on Regression 4°C Δ Removed, °C	Water MWAT based on Regression using All Data, °C	Water MWAT based on Regression using Reference Data °C	Water MWAT 25^{th} Percentile, All Data °C
15	15.37	15.39	16.55	13.41
20	20.18	19.73	20.71	17.92
25	24.99	24.06	24.87	22.43

In the15 to 25°C air temperature range, the 4°C Δ removed and all data regressions predict a temperature within 1°C of the 1:1 line (MWAT = July Average Air Temperature). The reference data regression predicts a water MWAT slightly *greater* than the 1:1 line at 15 and 20°C.

The 1:1 relationship holds for the regression based on all data and also holds when sites expected to be influenced by groundwater are removed. Because of this, and significantly because it also is consistent with the regression based on reference sites, the 1:1 relationship represents the *attainable* water MWAT for locations where water temperature is controlled by ambient air temperature.

We conclude that for New Mexico streams not significantly influenced by groundwater, the *attainable* water MWAT equals the July average air temperature from the PRISM dataset. That is,

MWAT = ATEMP (PRISM July Average Air Temperature)

The regressions based on all of the data, on data without locations suspected of being groundwater dominated, and on reference sites all follow the 1:1 line. Based on this, the 1:1 line appears to represent the physical relationship that exists where the attainable water temperature is correlated to air temperature.

Points that plot below the 1:1 line may represent sites where the water temperature is somewhat influenced by groundwater, or may result from microclimate effects or data collection problems including unrepresentative thermograph locations or inconsistent periods of record. For these reasons, the 25^{th} percentile does not appear to be useful in estimating the naturally attainable water temperature unless there is specific local information to suggest otherwise.

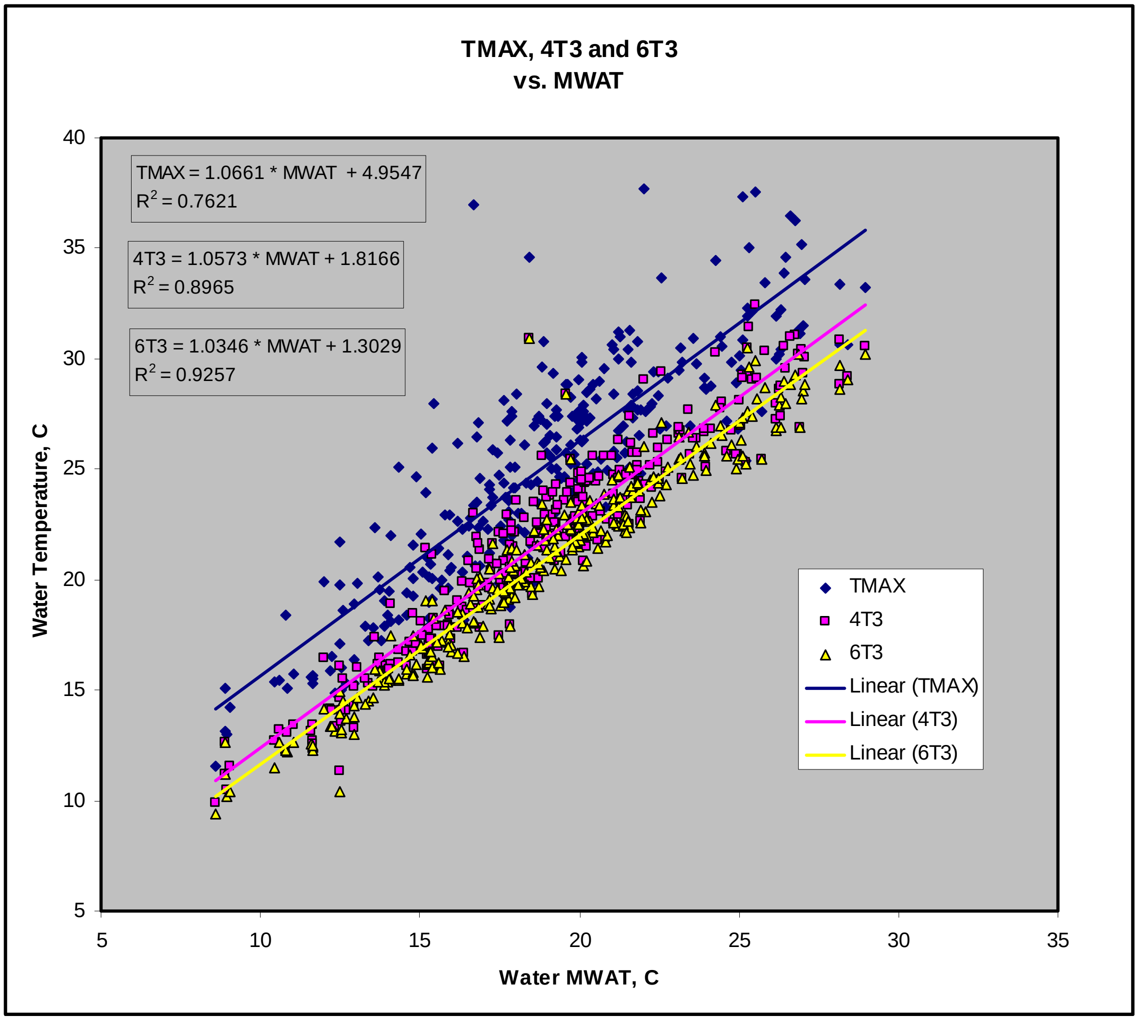
Relationship of MWAT and Air Temperature to NM Criteria

New Mexico aquatic life temperature criteria are not based on the MWAT. As reflected in 2010 amendments to New Mexico's *Standards for Interstate and Intrastate Waters* (20.6.4 NMAC), the criteria are based on maximum, 4T3 and 6T3 temperatures defined as follows: maximum temperature means the instantaneous temperature not to be exceeded at any time; 4T3 temperature means the temperature not to be exceeded for four or more consecutive hours in a 24-hour period on more than three consecutive days; and 6T3 temperature is means the temperature not to be exceeded for six or more consecutive hours in a 24-hour period on more than three consecutive days.

The air-water temperature correlation was developed to predict water MWAT values based on July average temperatures. Because New Mexico criteria are not based on MWAT, predicted MWATs need to be related to New Mexico criteria statistics.

To do this, the dataset that includes the statistics from 293 sites was used to develop a relationship between maximum (TMAX), 4T3 and 6T3 temperature and MWAT. Four TMAX values that were greater than 38°C (100 °F) were removed before doing the correlation, because water temperatures greater than 100°F are usually the result of the thermograph being out of the water. Correlations are in Figure 8.

Figure 8



The air – water temperature correlation indicated that MWAT = ATEMP (PRISM July Average Air Temp). Substituting ATEMP for MWAT yields the following:

6T3 = 1.03 * ATEMP + 1.30
4T3 = 1.06 * ATEMP + 1.82
TMAX = 1.07 * ATEMP + 4.95

Based on these relationships, if the water temperature is not reduced by groundwater input or microclimate effects, the designated use based on water temperature is related to July average air temperature as follows:

- If the air temperature is ≤18, high quality coldwater or coldwater may be attainable;
- If the air temperature is between 18 and 23, marginal coldwater or coolwater may be attainable;
- If the air temperature is >23, uses more restrictive than warmwater are generally not attainable.

Table 7

Temp, °C	High Quality Coldwater	Coldwater	Marginal Coldwater	Coolwater	Warmwater	Marginal Warmwater
Maximum Criterion	23	24	29	29	32.2	32.2
4T3 Criterion	20	-	-	-	-	-
6T3 Criterion	-	20	25	-	-	-
ATEMP (July Average Air Temperature)	≤17	≤18	≤23	≤23	>23	>23
Water Stats @ ATEMP	TMAX 23.1 4T3 19.8	TMAX 24.2 6T3 19.8	TMAX 29.6 6T3 25.0	TMAX 29.6		

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