Lower Dry Cimarron River
Use Attainability Analysis
New Mexico Environment Department
August 2011

Summary

The purpose of this Use Attainability Analysis (UAA) is to identify the highest attainable aquatic life use in 20.6.4 NMAC Segment 702 (referred to here as the lower Dry Cimarron, Segment 702 or 20.6.4.702 NMAC).

The US Environmental Protection Agency's (US EPA) Water Quality Standards Handbook (US EPA, 1994) recommends that a UAA should answer the following questions:

- What are the aquatic life uses currently being achieved in the water body?
- What are the causes of any impairment of the aquatic uses?
- What are the aquatic uses that can be attained based on the physical, chemical and biological characteristics of the water body?

In response to these questions, this UAA finds:

- Warmwater and coolwater aquatic life uses are currently being achieved throughout the segment, despite slight exceedences of the coolwater criteria at the lowermost monitoring stations;
- The coldwater aquatic life use with a 25°C segment-specific temperature criterion is impaired by temperature; and
- The highest aquatic life use that can be attained based on the physical, chemical and biological characteristics of the water body is coolwater aquatic life.

The coolwater aquatic life use is the highest attainable use in the lower Dry Cimarron because (1) the attainable water temperature is in the range of 28 – 30°C and (2) the native fish species have water temperature tolerances that are either warm or are intermediate between warm and cold. The combination of these factors best matches the coolwater aquatic life use.

According to federal regulations and state water quality standards, an aquatic life use may be removed or changed to a use with less stringent criteria if the use is unattainable due to one or more of six factors listed in 40 CFR 131.10(g). This UAA demonstrates that the current coldwater aquatic life use is unattainable because of factor 131.10(g)(1): Naturally occurring pollutant concentrations prevent the attainment of the use. In particular, the pollutant of heat resulting from naturally occurring ambient air temperatures prevents the attainment of the coldwater aquatic life use.

This UAA is organized into five parts. There is a brief segment description and background, then information about the ecoregion, native fishery and water quality. Next, naturally attainable water temperatures are estimated based on a statewide relationship between air and water temperatures, and then the Stream Segment Temperature Model (Bartholow, 2002) is used to evaluate the reasonable potential for reducing existing temperatures through stream restoration efforts. Finally, the attainable

temperature along with information about the native fish species is used to identify the appropriate aquatic life use subcategory.

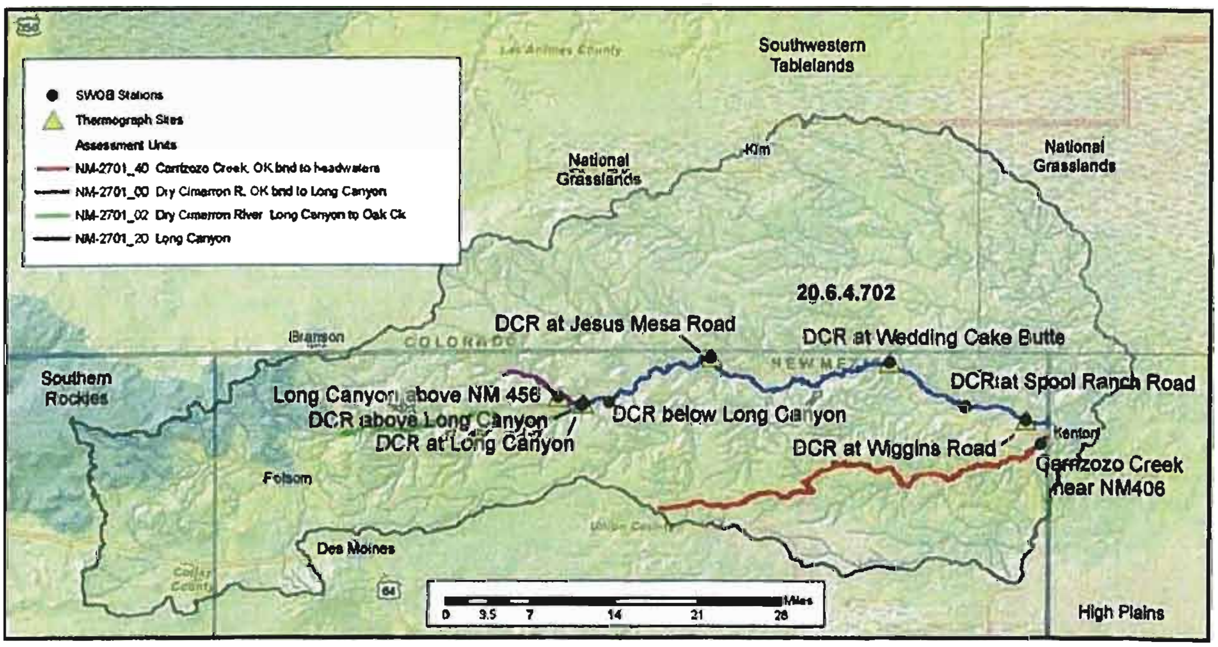
Segment Description and Background

The segment is described in New Mexico's *Standards for Interstate and Intrastate Surface Waters*, 20.6.4 NMAC (1/14/11), as:

> Perennial portions of the Dry Cimarron River below Oak Creek, and perennial portions of Long Canyon and Carrizozo Creeks (20.6.4.702 NMAC).

The segment is located in Union County in northeastern New Mexico. Total stream length is approximately 130 miles; elevations range from 4,300 feet at the eastern New Mexico border to 6,000 feet at the Dry Cimarron and Oak Creek confluence. Figure 1 indicates the four assessment units (AUs) into which the segment is divided for monitoring purposes. The AUs encompass all of the steam reaches listed in the segment description. A larger map is included as Attachment 1.

Figure 1.



A New Mexico Environment Department Surface Water Quality Bureau (SWQB) water quality survey report concluded that the Dry Cimarron River from the Oklahoma border to Oak Creek and Long Canyon were impaired due to temperature. However, the report also noted that the designated coldwater aquatic life use was not likely existing or attainable. (NMED/SWQB, 2004).

Partly as a result of the survey conclusions, in 2005 the New Mexico Water Quality Control Commission separated the upper portion of the Dry Cimarron from the lower, creating Segment 20.6.4.702 for the lower Dry Cimarron River, Long Canyon and Carrizozo Creek. For the new segment, the Commission also changed the aquatic life use to warmwater with a 32.2°C temperature criterion. However, the US EPA in its

Record of Decision on the 2005 changes said that it "did not find adequate supporting documentation justifying the less protective warmwater aquatic life designations and associated criteria" and that "the State must provide a UAA as required by 40 CFR 131.10(j)(2)." In response to US EPA's action, the Commission in 2010 returned the segment to the pre-2005 coldwater designated use and a 25°C temperature criterion, with the understanding that a use attainability analysis would be undertaken to review the appropriateness of the standard.

Ecoregion, Aquatic Life and Water Quality

Ecoregion

The lower Dry Cimarron is in Level III Ecoregion 26 (Southwestern Tablelands), which stretches from Colorado south to Artesia, New Mexico and Midland, Texas; and from the Rio Grande valley near Socorro, New Mexico east to south-central Kansas. At a finer level of detail, the majority of the lower Dry Cimarron is in Level IV Ecoregion 26f (Mesa de Maya/Black Mesa), and a small portion in Level IV Ecoregion 26l (Upper Canadian Plateau). The land cover is mostly woodland and grassland; maximum July daily mean temperatures are in the middle to upper 80°F (30°C) range (Griffith et al., 2006).

Aquatic Life

Propst (1999) discusses the native fish of the Dry Cimarron:

> "A short reach of the Dry Cimarron River, which is tributary to the Arkansas River, drains a small portion of extreme northeastern New Mexico. The Dry Cimarron River flows east from its origins on Johnson Mesa through a broken mesa and low hill landscape and exits New Mexico to Oklahoma north of Clayton. The native fish fauna of the Dry Cimarron River in New Mexico likely consisted of eight and perhaps nine species. Of these, only suckermouth minnow is protected and this species has probably been extirpated from the Dry Cimarron River in New Mexico."

The nine species are listed below. According to BISON-M (NMDGF, 2002), none of the native species are considered coldwater fish. According to Halliwell et al. (1999) and NMDGF (2002), two species have thermal tolerances between warm and coldwater (i.e., intermediate). In 2000, the SWQB collected fish in the lower Dry Cimarron. The collection included five of the native species listed below, including the two species with intermediate thermal tolerances (central stoneroller and flathead chub). A summary of University of New Mexico Museum of Southwestern Biology fish collection records is included in Attachment 2.

Table 1. Dry Cimarron River Native Fish Species

Species Name	Common Name	Thermal Tolerance	Reference
Ameiurus melas	black bullhead	Warm	NMDGF, 2002
Campostoma anomalum	central stoneroller	Intermediate	Halliwell et al., 1999
Cyprinella lutrensis	red shiner	Warm	NMDGF, 2002
Fundulus zebrinus	plains killifish	Warm	NMDGF, 2002
Hybognathus placitus	plains minnow	Warm	NMDGF, 2002
Ictalurus punctatus	channel catfish	Warm	NMDGF, 2002; Zaroban et al., 1999; Halliwell et al., 1999
Phenacobius mirabilis	suckermouth minnow	Warm	NMDGF, 2002
Pimephales promelas	fathead minnow	Warm	NMDGF, 2002; Zaroban et al., 1999; Halliwell et al., 1999
Platygobio gracilis	flathead chub	Intermediate	NMDGF, 2002

Water quality

As indicated in Figure 1 and in Table 3 below, Segment 702 is divided into four AUs. Each AU has at least one monitoring station. Temperatures have been measured at each station, although not every station includes a water thermograph.

Table 3. Segment 702 Monitoring Stations and Associated Assessment Units

Station ID	Station Description	Water Tgraph ?	Max Tgraph Temp °C	Associated AU Description
02Carriz002.7	Carrizozo Creek near NM 406	No		Carrizozo Creek, OK bnd to headwaters
02DryCim003.2	Dry Cimarron River at Wiggins Road	**Yes**	29.5	Dry Cimarron River, OK bnd to Long Canyon
02DryCim011.4	Dry Cimarron River at Spool Ranch Road	No		
02DryCim024.6	Dry Cimarron River at Wedding Cake Butte	**Yes**	30.0	
02DryCim047.2	Dry Cimarron River at Jesus Mesa Road	**Yes**	30.2	
02DryCim070.3	Dry Cimarron River below Long Canyon	No		
02DryCim074.5	Dry Cimarron River at Long Canyon	**Yes**	28.6	Dry Cimarron River, Long Canyon to Oak Creek
02DryCim075.0	Dry Cimarron River above Long Canyon	No		
02LongCa004.1	Long Canyon Creek 2 miles above NM 456	**Yes**	30.5	Long Canyon

The Dry Cimarron and Long Canyon AUs are listed as impaired for the coldwater aquatic life use due to temperature. The Dry Cimarron, OK bnd to Long Canyon AU is also listed as impaired due to low dissolved oxygen. Insufficient data were available to list the Carrizozo Creek AU, but a water temperature measurement in August 2000 exceeded the 25°C criterion.

Relationship of Water Temperature to Air Temperature

Attached to this UAA is a statewide Air-Water Temperature Correlation (NMED/SWQB, 2011) that correlates water thermograph data from 293 New Mexico locations and ambient air temperature from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) dataset. The correlation can be used at any New Mexico location to estimate naturally attainable water temperature statistics such as the MWAT and 6T3. As described in the correlation document, the MWAT is the maximum seven-day running average temperature and the 6T3 is the 6-hour maximum temperature that occurs for 3 consecutive days.

Attainable water temperature statistics at six representative locations are shown in Table 4. Figure 2 is a plot of the five stations where thermographs are located, and compares the predicted attainable temperatures with coldwater and coolwater criteria.

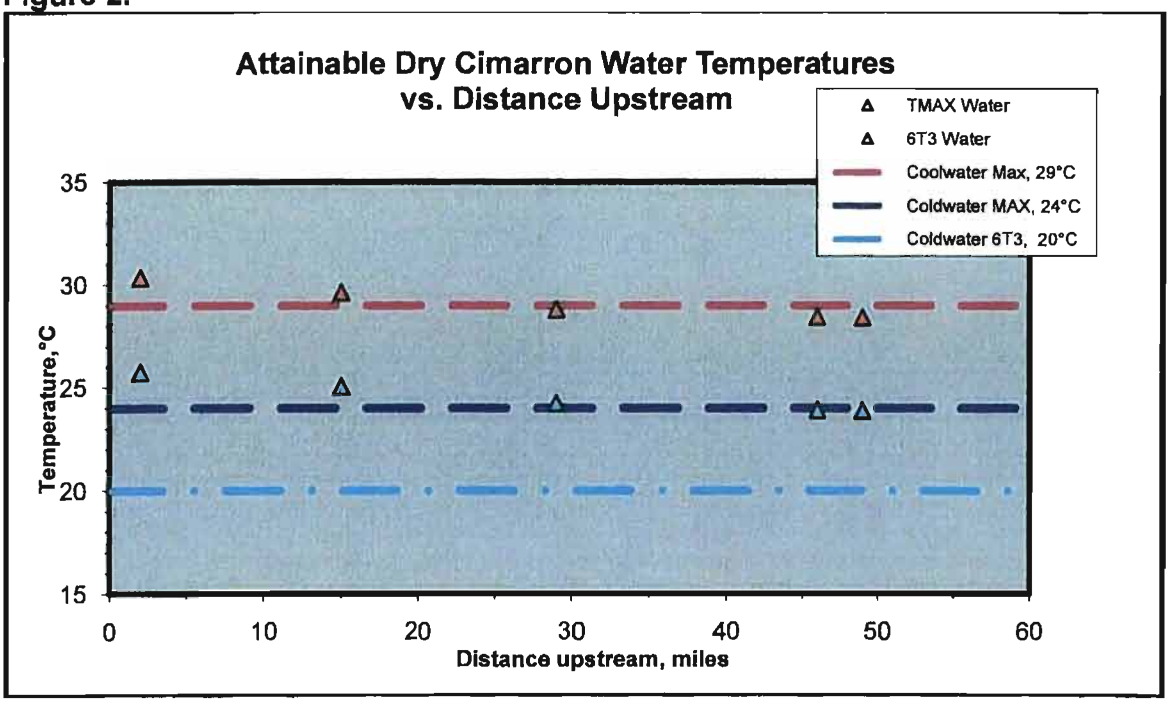
Table 4. Segment 702 Attainable Temperature Statistics

Station ID	Station	Distance from bottom of segment, mi.	July Average Air Temp,°C (PRISM)	TMAX	6T3	MWAT
	Midway up Carrizozo Creek[1]	20	22.20	28.70	24.17	22.20
02LongCa004.1	Long Canyon Creek above NM 456	49[2]	21.91	28.39	23.87	21.91
02DryCim074.5	Dry Cimarron River at Long Canyon	46	21.94	28.43	23.90	21.94
02DryCim047.2	Dry Cimarron River at Jesus Mesa Road	29	22.27	28.78	24.24	22.27
02DryCim024.6	Dry Cimarron River at Wedding Cake Butte	15	23.05	29.61	25.04	23.05
02DryCim003.2	Dry Cimarron River at Wiggins Road	2	23.72	30.33	25.73	23.72

[1] This location is not a monitoring station, but was chosen to be representative of the AU.
[2] Distance on the Dry Cimarron from the Oklahoma border plus distance on Long Canyon Creek.

The water temperature statistics indicate that the coldwater 20°C 6T3 criterion and 24°C maximum criterion are not achievable anywhere along the segment, and that the attainable maximum temperatures are in the range of 28 – 30°C.

Figure 2.



Modeling

The attainable temperatures presented in the previous section are based on a statewide correlation. Stream restoration activities can influence stream temperature by modifying flow, width-to-depth ratio and stream shading. In order to confirm the conclusion that coldwater criteria are not attainable, site-specific modeling was done using SSTEMP (Bartholow, 2002) to evaluate the effect that changes in these variables would have on water temperature.

For modeling, the stream was divided into four reaches from upstream to downstream: the first from Folsom Falls (the nearest upstream monitoring station to the segment break at Oak Creek) to Long Canyon; the second from Long Canyon to Jesus Mesa Road; the third from Jesus Mesa Road to Wedding Cake Butte; and the fourth from Wedding Cake Butte to Wiggins Road. The entire length from Folsom Falls to Wiggins Road was also modeled.

Table 5. Modeled Dry Cimarron Reaches

Station	Distance from bottom of segment, mi.	Elevation, ft.	Reach	Reach Length, mi.
Dry Cimarron at Folsom Falls	67	6140		
Dry Cimarron at Long Canyon	46	5130	Folsom Falls to Long Canyon	21
Dry Cimarron at Jesus Mesa Road	29	4850	Long Canyon to Jesus Mesa Road	23
Dry Cimarron at Wedding Cake Butte	15	4540	Jesus Mesa Road to Wedding Cake Butte	14
Dry Cimarron at Wiggins Road	2	4355	Wedding Cake Butte to Wiggins Road	13
Dry Cimarron at Wiggins Road	2	4355	Folsom Falls to Wiggins Road	65

Baseline conditions for the model runs were as follows:

Modeled date 7/15; Inflow 3 cfs; Inflow temperature 20°C; Outflow 3 cfs; Accretion temperature 10°C; Latitude 36.9 °; Width's A term 12.5 s/ft^2; Width's B term 0.2; Manning's n 0.035; Air temperature 20°C; Relative humidity 50%; Wind speed 8 mph; Ground temperature 10°C; Thermal gradient 1.65 j/m^2/s/°C; Possible sun 90%; Solar radiation 550 Langleys/d; Total shade: variable, 25 to 75%.

To investigate the variables of flow and width-to-depth ratio, larger changes than could actually be implemented were modeled. In both cases, the temperature response was minimal. Changes in flow did not reduce temperature – increasing flow from 3 cfs to 100 cfs raised the water temperature approximately 1°C probably because of increased water surface area exposed to solar insolation. Reducing the width-to depth ratio from 80:1 (baseline condition) to 8:1 reduced the mean daily water temperature by less than 0.1°C.

Stream shading was investigated at levels of 25 and 75%. The existing levels of shade along this segment have not been characterized, nor is it clear what the naturally occurring shade levels would have been in this ecoregion, where the land cover is mostly woodland and grassland (Griffith et al., 2006). A 50% increase was chosen to represent an upper limit on the increase that could be achieved with any reasonable human intervention.

As reported in the water quality section, with thermographs the SWQB has measured maximum water temperatures ranging from 28.6 to 30.5°C at five stations in the segment. For all reaches, at the baseline temperature of 20°C the model indicates that increasing shade from 25% to 75% decreases the maximum temperature by 3.2°C. Subtracting 3.2°C from the maximum measured temperatures indicates that with an upper-lirnit increase in shading, maximum water temperatures would be greater than 25°C.

Attainable Designated Use

The designated aquatic life use could be guided by all of the aquatic life, including plants, insects, macro and microinvertebrates, and vertebrates that would naturally occur in the stream. However, data to describe the distribution of all forms of aquatic life are often not available. Alternatively, the distribution of fish species is fairly well known and fish species integrate many of the variables that control the distribution aquatic life. Therefore, the fish species that can be supported or propagated are generally used to guide the selection of the aquatic life designated use.

The Dry Cimarron native fish species listed in Table 1 are representatives of the Mississippian-Missourian fish fauna. All of the native fish are either warm or warm/cold water intermediate species. There is no evidence that the native fauna included coldwater fish, particularly cutthroat trout (*Oncorhynchus clarkii*), which is the only coldwater species native to neighboring watersheds.

The attainable temperature can also be used to guide the selection of the attainable aquatic life use from the six designated aquatic life use subcategories that are nominally identified by temperature. The six aquatic life use subcategories and associated temperature criteria are listed below:

Table 6. Aquatic Life Temperature Criteria

Temp, °C	High Quality Coldwater[1]	Coldwater	Marginal Coldwater	Coolwater	Warmwater	Marginal Warmwater
Maximum	23	24	29	29	32.2	32.2
6T3	-	20	25	-	-	-

[1]High quality coldwater has a 4T3 (4-hour maximum temperature that occurs for 3 consecutive days) criterion of 20°C.

Comparing the criteria to the temperatures in Table 4, for even the most upstream reach in Segment 702, the maximum temperatures and the 6T3 temperatures are higher than coldwater criteria. For the entire segment, the attainable temperatures are in the marginal coldwater to warmwater range.

Definitions of marginal coldwater and coolwater from New Mexico Water Quality Standards are:

> "Marginal coldwater" in reference to an aquatic life use means that natural intermittent or low flows, or other natural habitat conditions severely limit maintenance of a coldwater aquatic life population or historical data indicate that the temperature in the surface water of the state may exceed 25°C (77°F).

> "Coolwater" in reference to an aquatic life use means the water temperature and other characteristics are suitable for the support or propagation of aquatic life whose physiological tolerances are intermediate between and may overlap those of warm and coldwater aquatic life.

Regarding the marginal coldwater use, the analysis presented in this UAA indicates that it is natural conditions of ambient air temperature that limit the use. Although at some locations intermittent or low flows may also limit the use, low flows are not necessary to limit a use that is already limited by air temperature. Also, coldwater species are not native to the segment. Therefore, "marginal coldwater" is not the best description of the attainable use.

The coolwater use best describes the highest attainable use because of the native fish requirements and the attainable water temperatures. Of the nine native fish species that have been found in the Dry Cimarron, seven are considered warmwater and two are considered warm/cold intermediate fish. The attainable water temperature is estimated to be in the range of 28 – 30°C. Measured temperatures have exceeded the coolwater maximum criterion of 29°C in the lower portion of the segment, but only slightly. With modest stream restoration efforts, the coolwater criterion is likely achievable.

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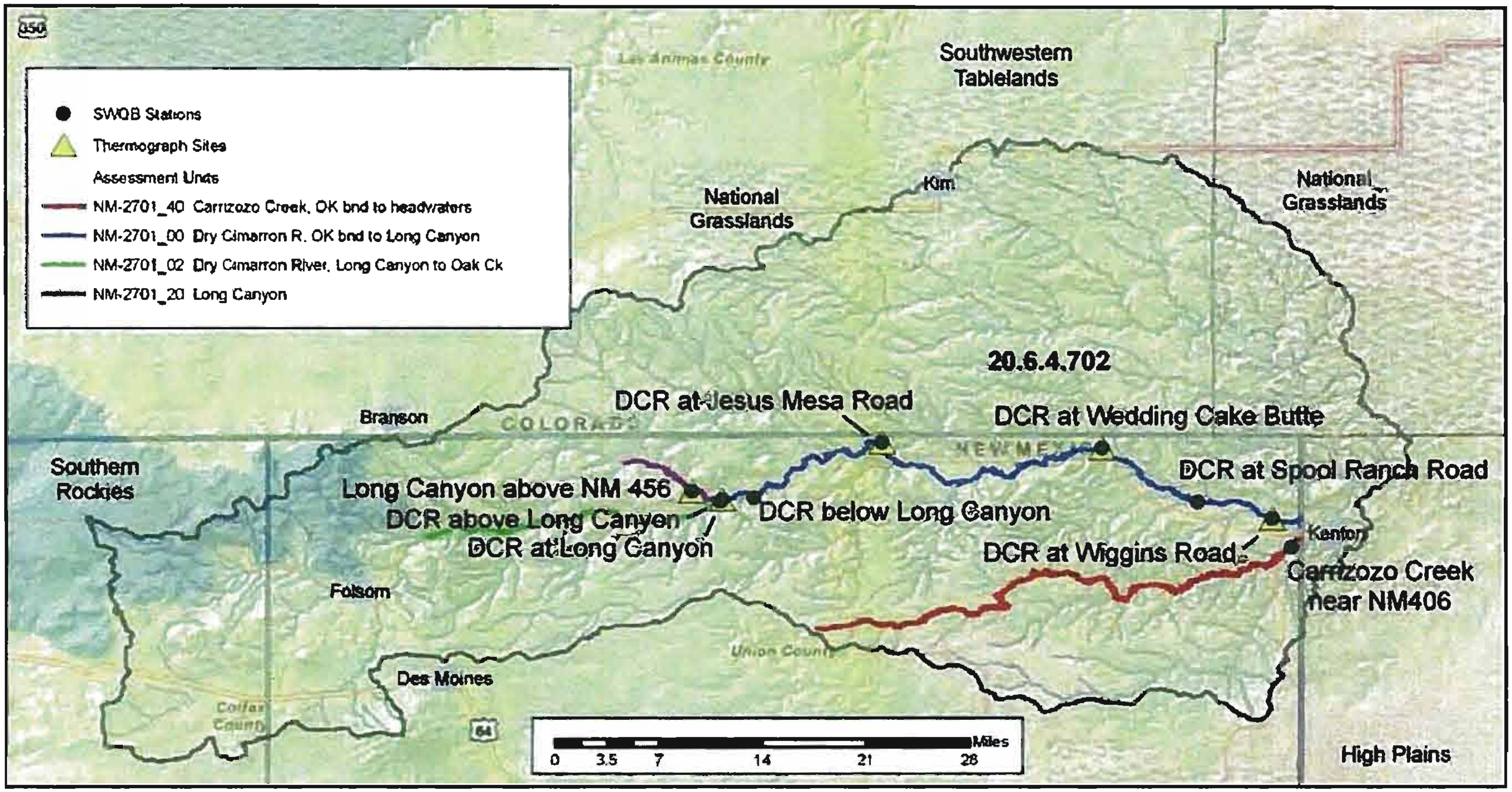
Attachment 1

Segment 20.6.4.702



Attachment 2

Museum of Southwestern Biology Records

Elevation, ft	Location	Date	bullhead (*Ameiurus*)	central stoneroller	red shiner	plains killifish	green sunfish	sand shiner	suckermouth minnow	fathead minnow	flathead chub	plains minnow
4370	Carrizozo Creek .5 mi E of SR 406	9/20/2000	X	X		X	X			X		
4500	Carrizozo Creek @ SR 406	8/15/1939		X		X		X		X		
4500	Carrizozo Creek @ SR 406	8/16/1939				X						
4520	Carrizozo Creek N of Atencio	4/1/1986	X	X		X		X		X		
4800	Carrizozo Creek 6 mi N of Atencio	4/1/1986		X						X		
4300	Dry Cimarron River .5 km upstream NM/OK border	8/15/1939	X	X	X	X		X	X	X		X
4300	Dry Cimarron River .5 km upstream NM/OK border	8/16/1980		X	X	X		X		X		
4300	Dry Cimarron River .5 km upstream NM/OK border	5/28/1949		X	X	X		X		X		
4300	Dry Cimarron River .5 km upstream NM/OK border	4/1/1986		X	X	X		X	X	X		
4300	Dry Cimarron River .5 km upstream NM/OK border	4/1/1961				X				X		
4300	Dry Cimarron River 2 mi upstream NM/OK border	6/25/1992	X	X	X	X	X	X	X	X		
4300	Dry Cimarron River 2 mi upstream NM/OK border	5/29/1975			X	X		X		X		X
4300	Dry Cimarron River 2 mi upstream NM/OK border	8/16/1939				X						
4300	Dry Cimarron River 2 mi upstream NM/OK border	8/16/1939						X				
4300	Dry Cimarron River 2 mi upstream NM/OK border	8/16/1939								X		
4300	Dry Cimarron River 2 mi upstream NM/OK border	8/16/1939		X								
4300	Dry Cimarron River 2 mi upstream NM/OK border	8/16/1980			X	X		X	X			
4300	Dry Cimarron River 2 mi upstream NM/OK border	8/16/1980								X		
4500	Dry Cimarron River 10 mi upstream NM/OK border	6/23/1968		X	X			X		X	X	
4500	Dry Cimarron River 10 mi upstream NM/OK border	12/8/1977	X	X	X	X		X	X	X	X	
4500	Dry Cimarron River 10 mi W of NM/OK border	4/2/1986				X				X	X	
4400	Dry Cimarron River 8 mi W of NM/OK border	9/20/2000	X	X		X				X	X	
4600	Dry Cimarron River 25 mi W of NM/OK border	8/15/1939	X	X						X	X	
4600	Dry Cimarron River 25 mi W of NM/OK border	8/15/1939		X								
4600	Dry Cimarron River 25 mi W of NM/OK border	4/2/1986	X	X			X			X	X	
4700	Dry Cimarron River 35 mi W of NM/OK border	8/15/1939								X		
4800	Dry Cimarron River 45 mi upstream NM/OK border S of Jesus Canyon	5/29/1975		X								
4800	Dry Cimarron River 45 mi upstream NM/OK border S of Jesus Canyon	12/8/1977			X						X	
4800	Dry Cimarron River 45 mi upstream NM/OK border S of Jesus Canyon	8/15/1939		X						X		
4800	Dry Cimarron River 45 mi upstream NM/OK border S of Jesus Canyon	4/2/1986	X	X						X	X	
4800	Dry Cimarron River 45 mi upstream NM/OK border S of Jesus Canyon	9/20/2000	X	X			X			X	X	
5000	Dry Cimarron River 2 mi downstream Long Canyon	4/2/1986		X						X	X	
5000	Dry Cimarron River at Long Canyon	9/17/1986	X	X						X	X	
5100	Long Canyon .5 mi upstream Dry Cimarron	9/17/1986	X	X						X		
5200	Long Canyon 5.5 mi upstream Dry Cimarron River	9/17/1986	X	X						X		
5300	Dry Cimarron River along SR 456, 5 mi S of Island Mesa	9/18/1986		X						X		
5500	Dry Cimarron River on SR 456 10 mi E of SR 551 intersection	6/23/1968		X						X	X	
5500	Dry Cimarron River on SR 456 10 mi E of SR 551 intersection	9/17/1986		X						X		
5600	Dry Cimarron River 1 mi downstream of Oak Creek	8/16/1980		X						X		

Attachment 3

Public Comments

In an April 2004 letter to Scott Hopkins (SWQB), Fred Like, who identified himself as someone who has "...fished the (Dry Cimarron) River all my life" says that "...this river would be better suited for Chanel Cat and Bass because the water gets too warm for trout."

Henry Brown, who says that he has lived and ranched near Long Canyon all of his life, in a February 2009 email to Heidi Henderson (SWQB) says that "Long Canyon needs to be classified as a warm water body, or at the very least cool water. During the summer the daily temperatures can exceed 100 °F for most of July and August." He goes on to say, "It seems in Long Canyon that the exceedences come from natural sources as no point source pollution is observed."

On a Public Comment Card completed in response to a February 2009 public meeting, Donald Berg, who has lived and ranched along the Dry Cimarron since 1969, says that "...the only portion capable of supporting cold water fish is a reach of about 3 miles in the Folsom Falls area." (This location is upstream from Segment 702). Similar comments were provided by Fred Daniel, who says the he has "...lived on this river all of my life." Brett Bannon makes the following statement: "Historically no salmonids were indigenous to the Dry Cimarron, and though they have been introduced by the NM Game and Fish, they do not reproduce. Green sunfish (*Lepomis cyanellus*) are found 5 miles west of and upriver from Folsom. I feel that there should be more emphasis on Warm Water Aquatic life and even more emphasis on the 'marginal' in Marginal Coldwater Aquatic life." Shari Morrow has similar comments: "I disagree that the classification for the water is cold. Trout are unable to propagate in (the) waters. Additionally the NM Game and Fish have trouble with the viability of trout they stock in the Dry Cimarron River especially in the summer months. Mainly because of the warm temperature of the water. The classification of the Dry Cimarron River needs a hard look and in my opinion would have a warm classification."

Again, Henry Brown, in response to an August 12, 2010 public meeting had the following comments: "After viewing your Folsom presentation, it is evident to me there is quite a bit of difference in the water temperature of the Dry Cimarron from the head waters on down to the Oklahoma border. I am somewhat familiar with the lower portion as I have lived in Long Canyon all my life. The lower portion of the Dry Cimarron is definitely intermittent as most of Long Canyon is. As one leaves Folsom and travels toward Oklahoma, two things become evident. The first is the altitude is decreasing and secondly the air temperature is increasing. While growing up we sometimes fished and swam in the 'river' near our home. We always enjoyed the cool water and the occasional 'mud catfish'."

Attachment 4

Air-Water Temperature Correlation

New Mexico Environment Department
Surface Water Quality Bureau
August 2011

Air-Water Temperature Correlation

New Mexico Environment Department
Surface Water Quality Bureau
August 2011

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:

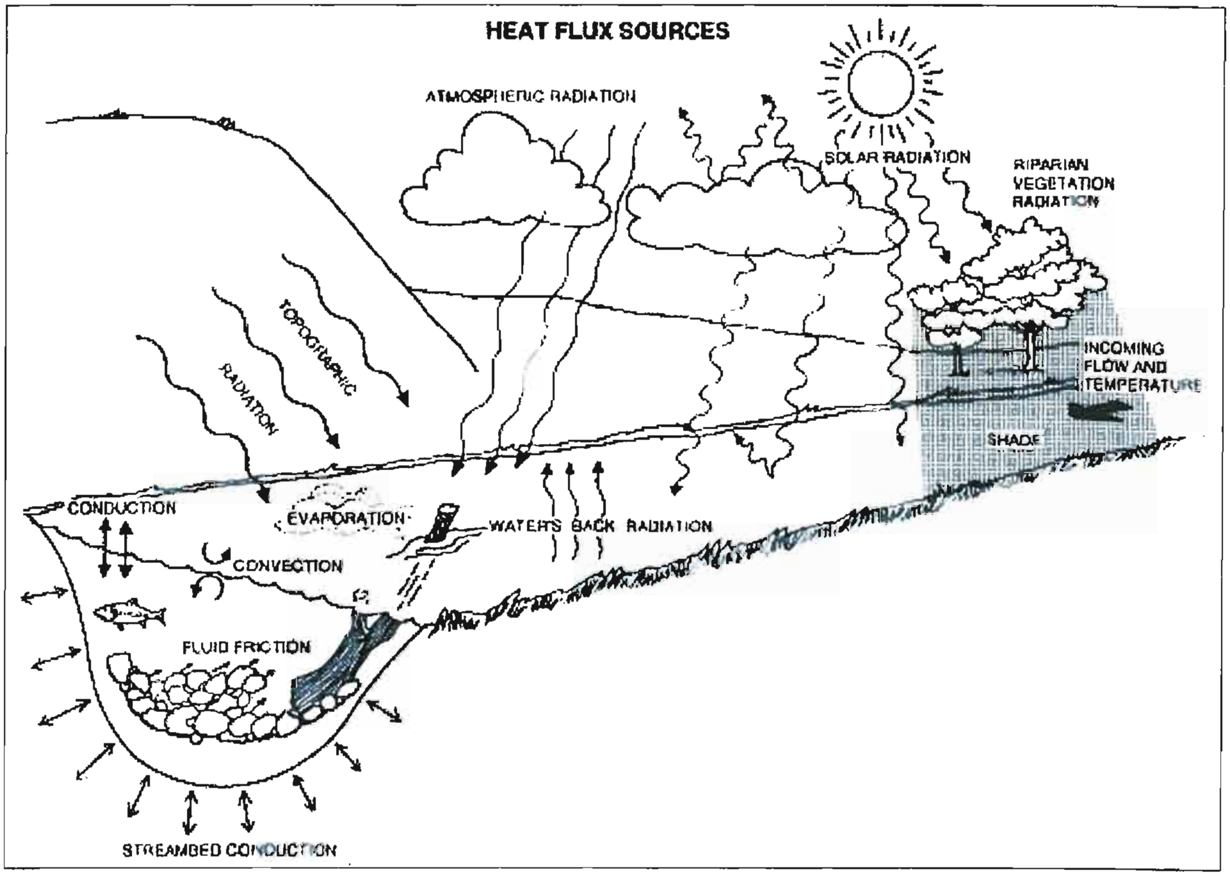
- high quality and coldwater uses may be attainable if July average air temperature is ≤18°C;
- marginal coldwater and coolwater uses may be attainable if July average air temperature is ≤23°C;
- uses more restrictive than warmwater are generally not attainable if July average air temperature is >23°C.

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).

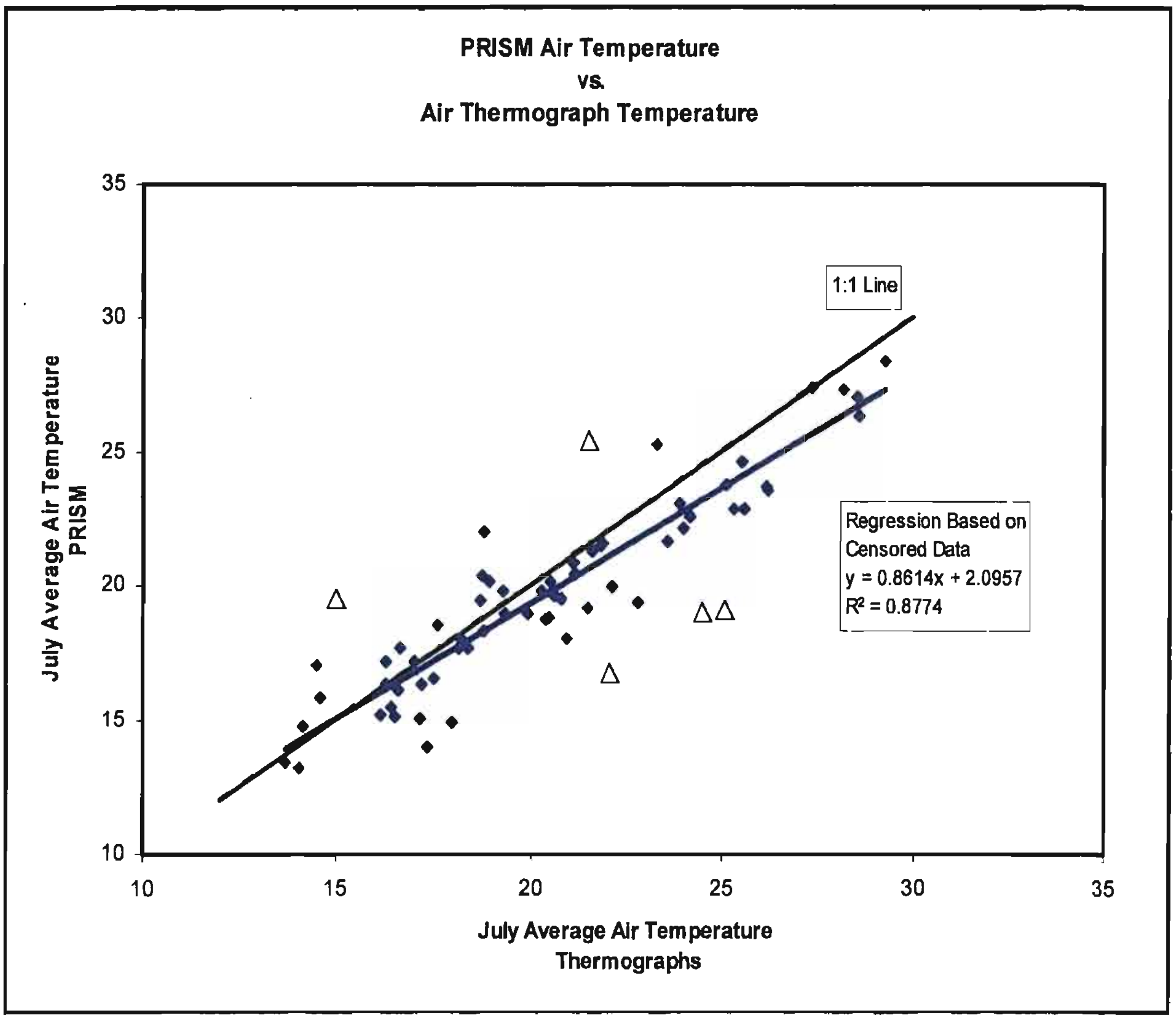
Air Temperature Data

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.

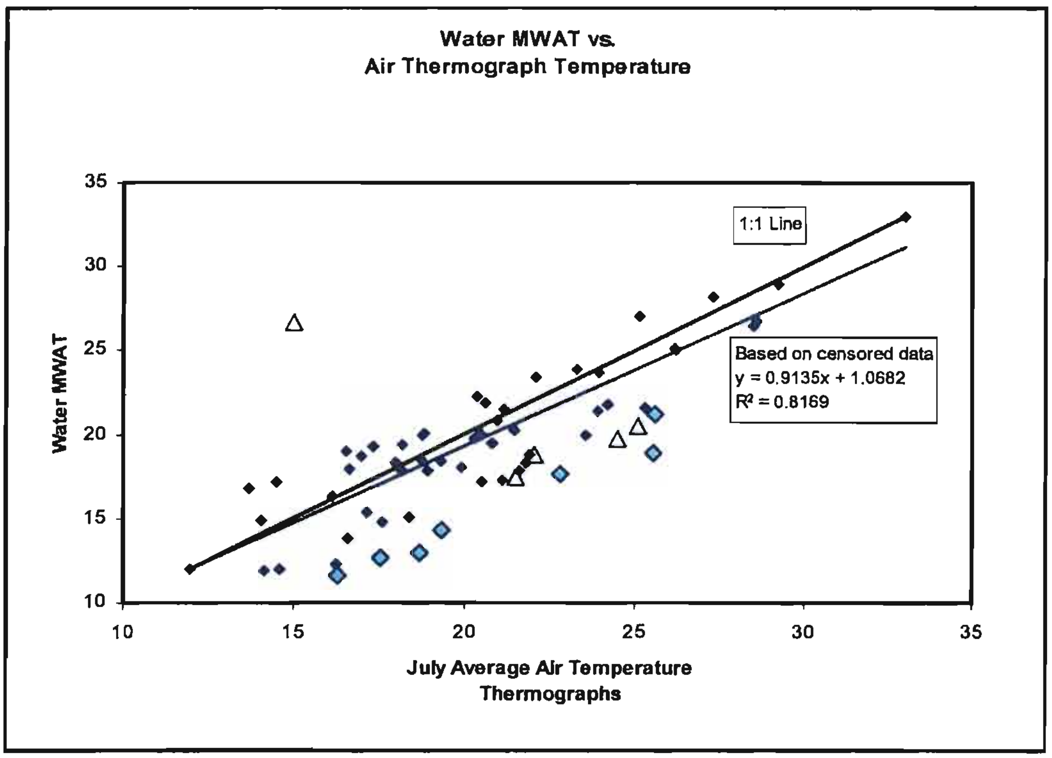
Outlier Analysis

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



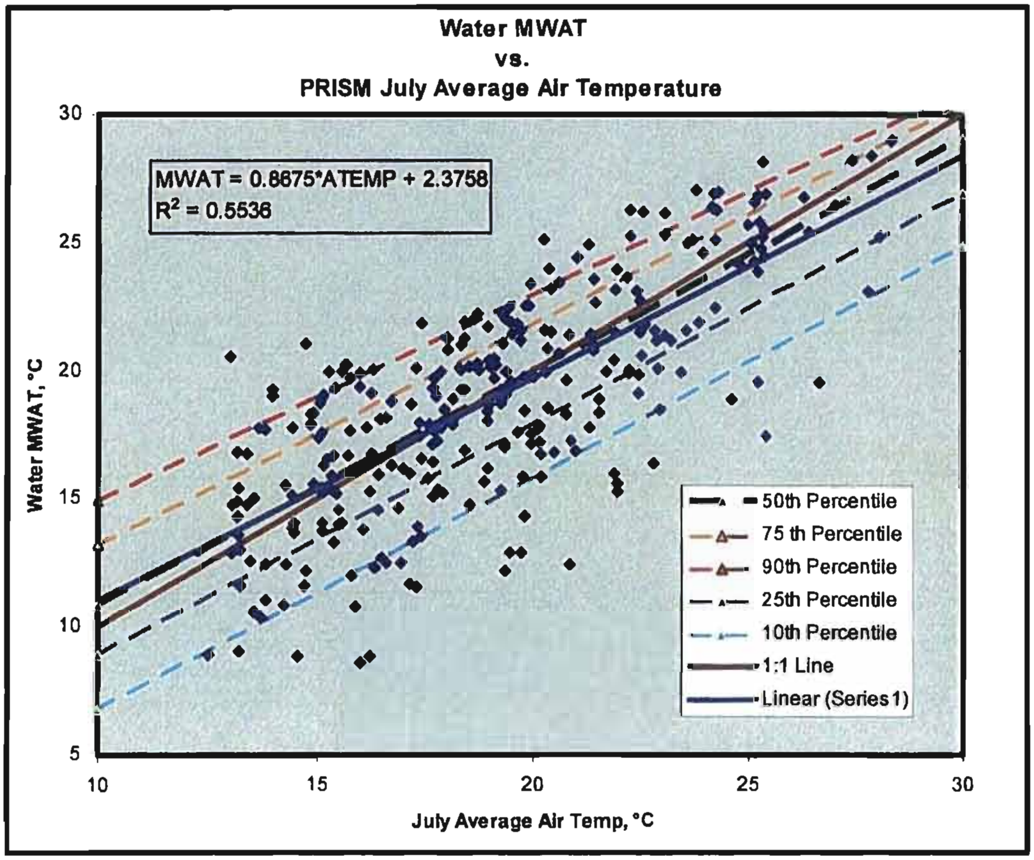
We identified seven additional points (the larger shaded diamonds) based on a positive air – water difference greater than 4°C. At five of the locations, the daily water temperature variation was low (a reference date diel water temperature difference less than 6°C), indicating groundwater influence. 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

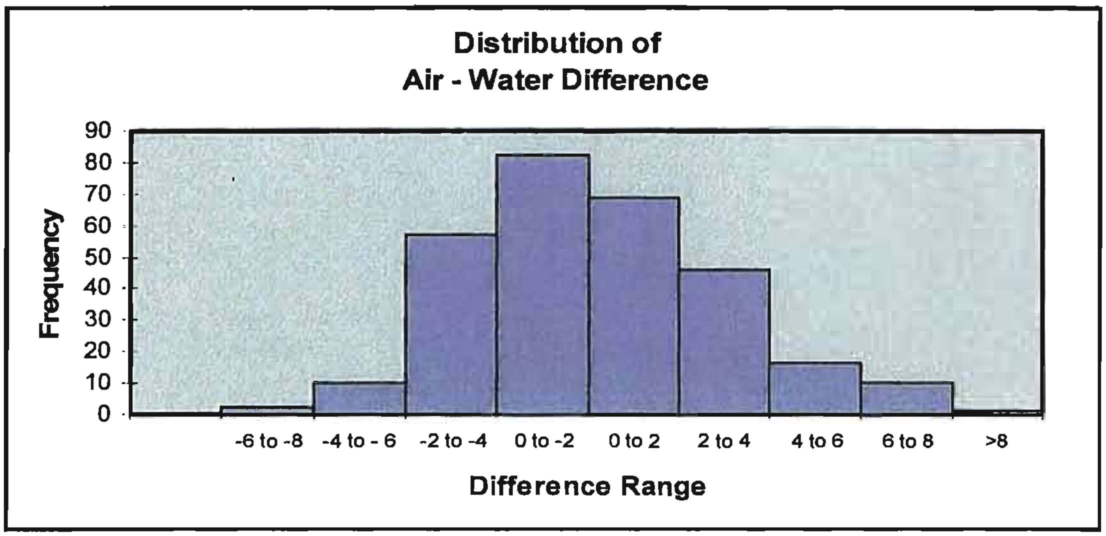
Representative results from the regressions are shown below:

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.

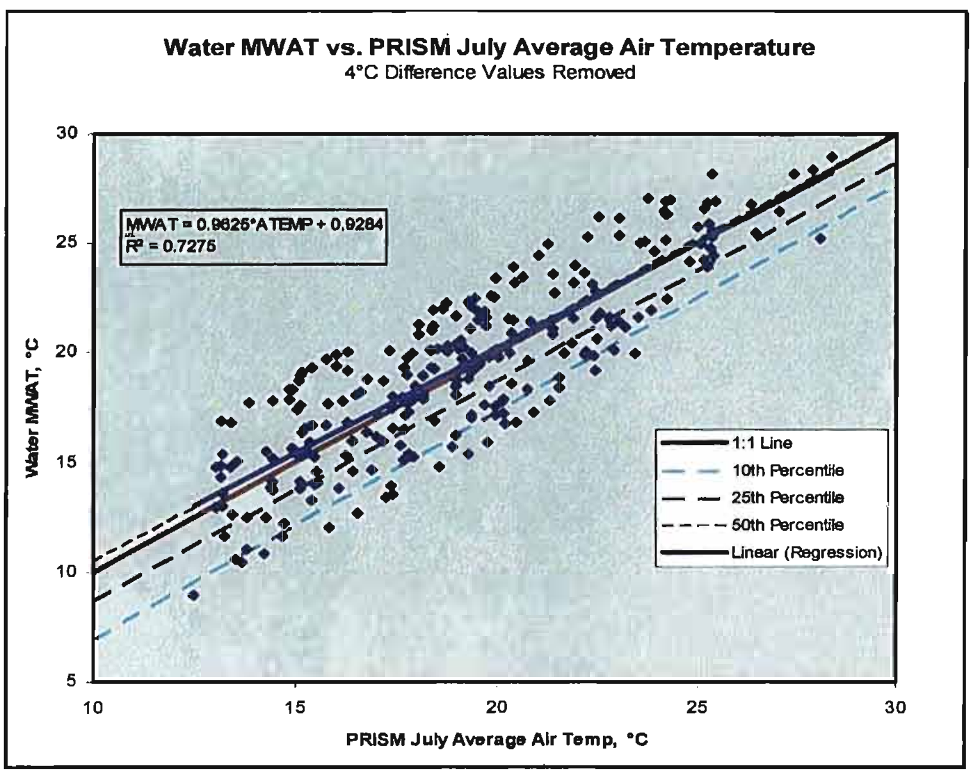
Figure 5



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.

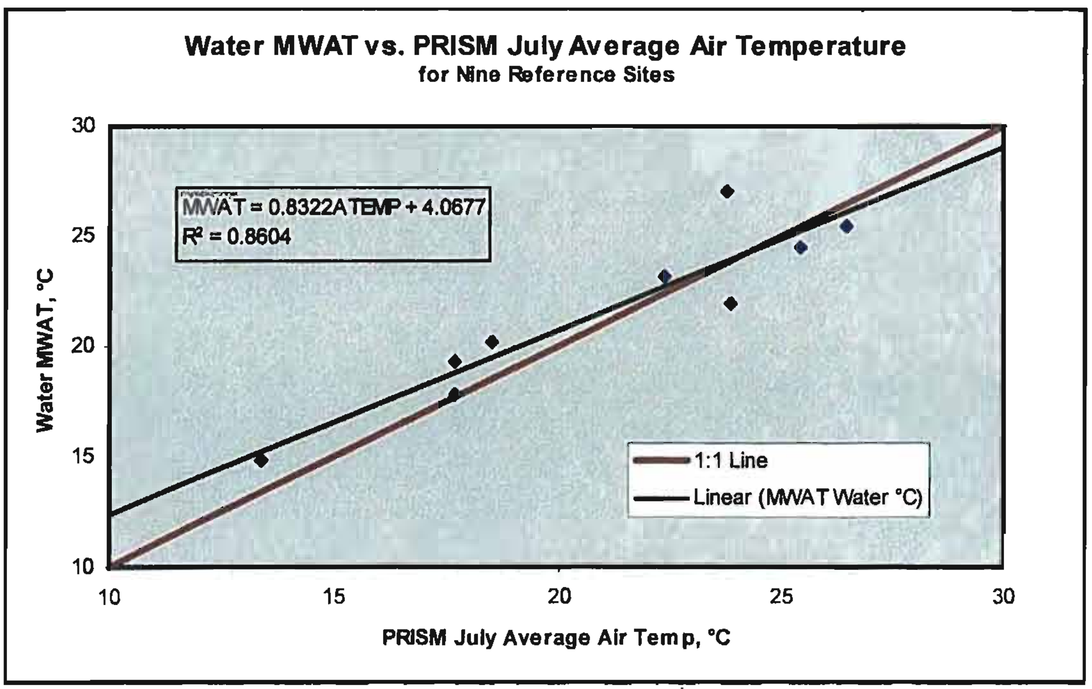
The Dry Cimarron River @ Jesus Mesa site had an air – water difference slightly greater than 4°C, and the air temperature was lower than the water temperature. Although the water temperature exhibited diel variation, the difference between the daily maximum and minimum was less than expected, indicating 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 25th 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 25th percentile does not appear to be useful in estimating the naturally attainable water temperature unless there is specific local information to suggest otherwise.

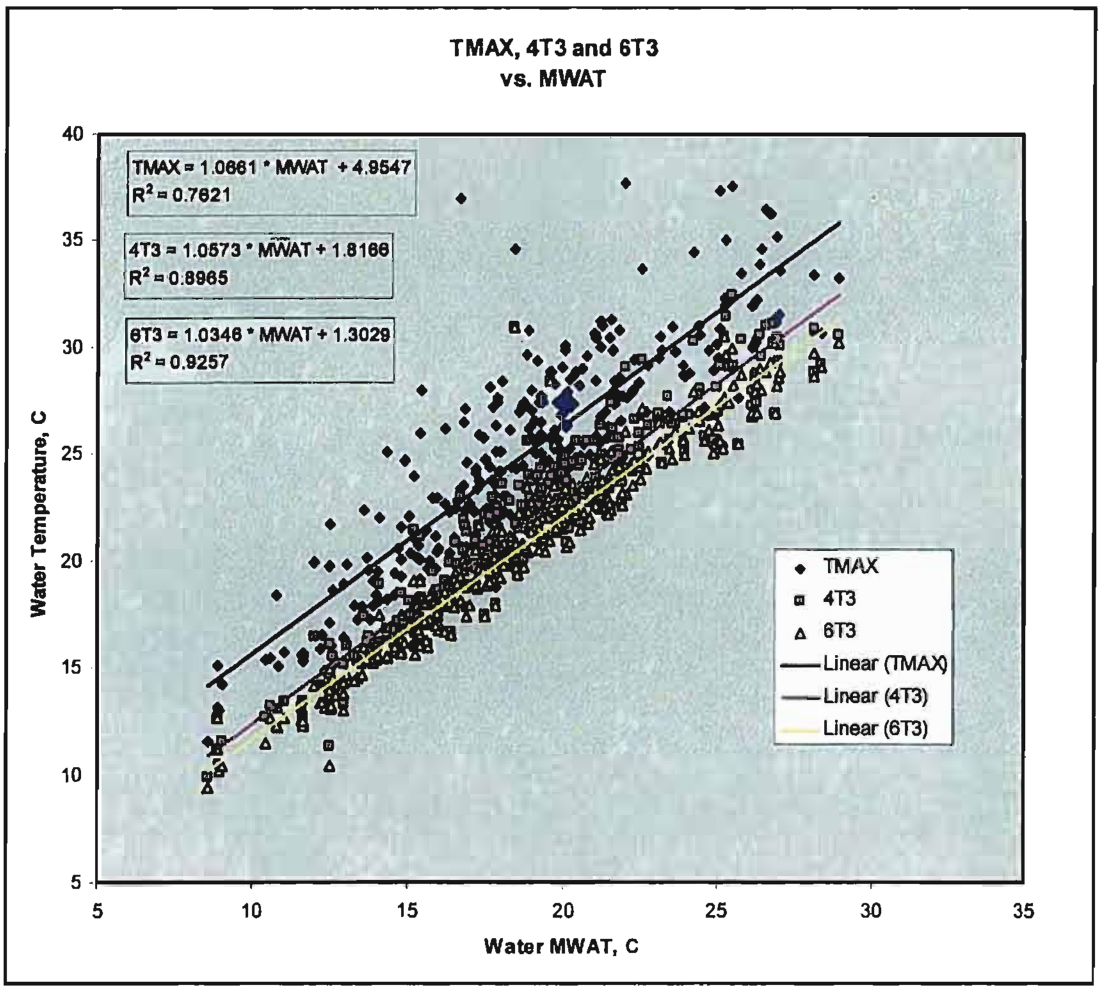
Relationship of MWAT and Air Temperature to NM Criteria

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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