Recommendations for Water Quality Standards Revisions

Reclassification of Beneficial Uses for Beaver Creek, Fall River County

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South Dakota Department of Environment and Natural Resources

Protecting South Dakota's Tomorrow ... Today

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Executive Summary

During a Total Maximum Daily Load (TMDL) assessment project for Beaver Creek conducted during September 2003 through September 2005, the 2004 Integrated Report for Surface Water Quality Assessment (SD DENR, 2004) was published. In this publication, Beaver Creek (from Wyoming border to mouth) was listed as an impaired water body due to high values of water temperature, conductivity, total dissolved solids (TDS), and total suspended solids (TSS). In the most recent Integrated Report for Surface Water Quality Assessment (SD DENR, 2008), the water temperature and TSS impairments of Beaver Creek are no longer listed because data from the TMDL assessment was inadvertently excluded from the analysis.

Reclassifying Beaver Creek's fishery beneficial use designation from a coldwater marginal fishery to a warmwater semipermanent fishery is recommended. Based on continuous temperature data collected during the TMDL assessment, reclassifying Beaver Creek to warmwater semipermanent fishlife propagation use would designate an aquatic life use more appropriately aligned with the naturally occurring physical conditions and limitations present in this watershed.

The warmwater semipermanent temperature criterion is not currently fully attained in Beaver Creek, mostly due to the influence of natural conditions (air temperature). DENR anticipates the temperature criterion can be met following designation of an appropriate aquatic life use and improvements outlined in the TMDL assessment. The warmwater semipermanent fish life propagation use also carries the same TSS criteria (158 mg/L daily maximum and 90 mg/L 30-day average limits) as the coldwater marginal fish life propagation use. Thus, Beaver Creek will likely continue to exceed the TSS criteria during high stream flow conditions, even with the proposed beneficial use reclassification. It is anticipated that site-specific TSS criteria are warranted for this stream, however further analysis is required to confirm this.

A fishery beneficial use reclassification is supported by a low-flow frequency analysis of Beaver Creek that shows frequent return periods of very low/no-flow conditions, as well as warm water temperatures observed during the TMDL assessment that do not support a coldwater aquatic life use. In addition, local contacts and landowners assert that no trout exist in Beaver Creek (Putnam, pers comm. 2008). According to South Dakota Department of Game, Fish and Parks stocking records, fish have never been stocked in Beaver Creek (SD GFP, unpublished data). Fish surveys were conducted at two sites on Beaver Creek by SD GFP on April 16, 2008, and no coldwater fish species were found during these surveys. While warmwater species of fish may survive in pools remaining during periods of no stream flow, it is very unlikely that coldwater fish could survive the no-flow, naturally occurring warm-water conditions present in Beaver Creek.

Beaver Creek is currently assigned the limited contact recreation use, but not the immersion recreation use. The stream does not appear to be used or suitable for immersion recreation. While the stream is relatively accessible, it appears unsuitable for

immersion recreation due to channel morphology and sustained periods of low water depth. Maintaining Beaver Creek's current recreational use classification is recommended.

Watershed and Monitoring Site Information

Beaver Creek drains the southeastern portion of Weston County in Wyoming before entering Custer County in South Dakota and discharging to the Cheyenne River south of Burdock in Fall River County. Beaver Creek drains approximately 1670 square miles (1,069,000 acres); 71% of the watershed is in Wyoming and 29% is in South Dakota.

Beaver Creek is a plains stream that flows into South Dakota from Wyoming. The stream was classified as a Rosgen Type G with a well-entrenched channel (entrenchment ratios <1.4), low width to depth ratios and a moderate slope. The riparian corridor of Beaver Creek in South Dakota is populated with trees along the first 10-15% of the stream length. Grasses and sedges grow to the stream edge along the entire reach.

Two sites on Beaver Creek were monitored during the TMDL assessment project. Site BC-1 was located approximately 2 miles upstream of the confluence with the Cheyenne River, where Argentine Road bridges Beaver Creek west of Burdock in Fall River County. During the TMDL study, stream flow data and water-quality samples were collected from this site. SD DENR continues to monitor water quality at this site on a monthly basis (SD DENR site #WQM 128). Site BC-3, located at the border of Wyoming and South Dakota, was added to the TMDL study in April 2005. This site was used only for collection of temperature and flow data. Figure 1 shows the Beaver Creek watershed in Wyoming and South Dakota and the locations of the two Beaver Creek sampling sites.

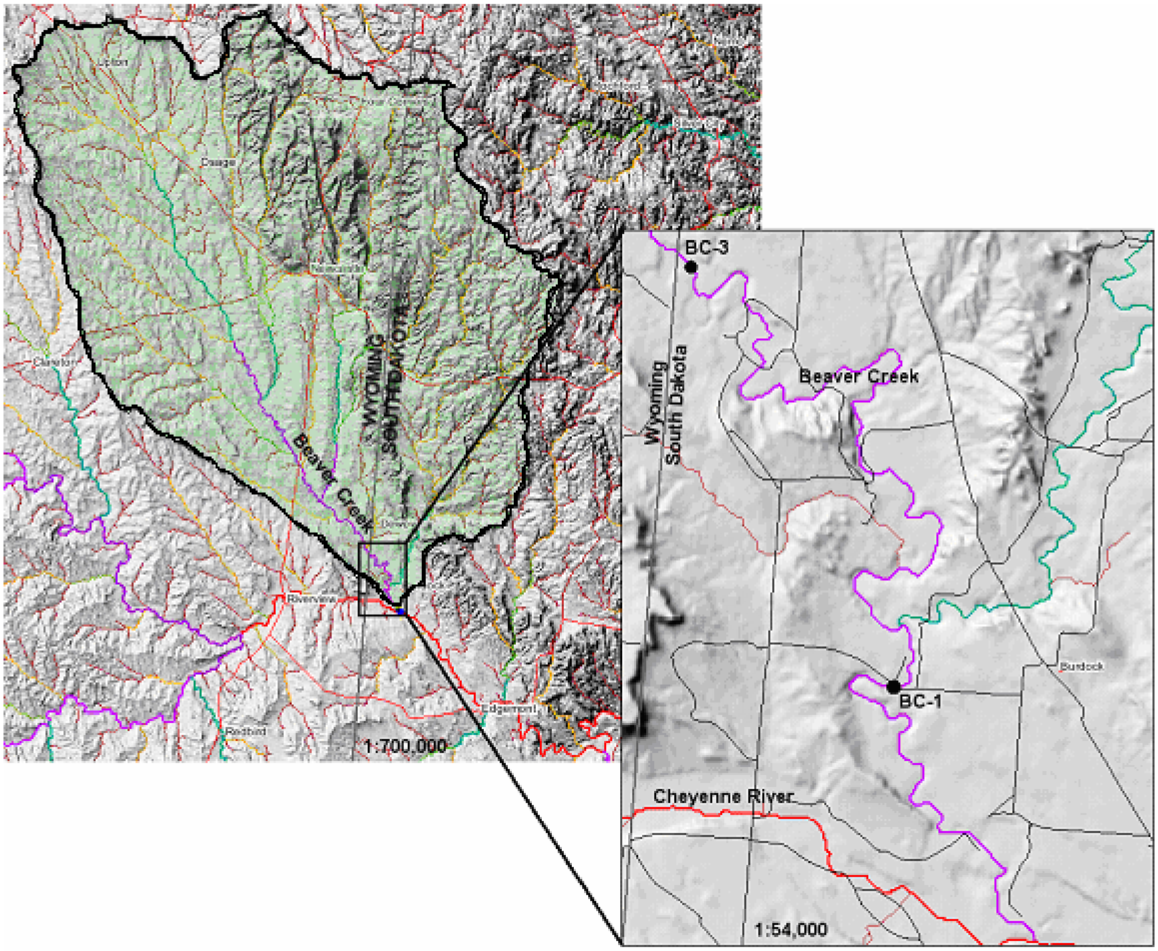

Figure 1. Beaver Creek watershed and sampling sites.

Beneficial Uses and Water Quality Criteria

Chapter 74:51:03 of the Administrative Rules of South Dakota (ARSD) assigns the following beneficial uses to Beaver Creek:

- Coldwater marginal fish life propagation
- Limited contact recreation
- Fish and wildlife propagation, recreation and stock watering
- Irrigation

Water quality criteria to protect these beneficial uses are contained in ARSD 74:51:01, and some of the water quality criteria are not being met. The 2004 Integrated Report for Surface Water Quality Assessment (SD DENR, 2004) lists Beaver Creek (from Wyoming border to mouth) as an impaired water body due to high values of water temperature, conductivity, total dissolved solids (TDS), and total suspended solids (TSS). In the most recent Integrated Report for Surface Water Quality Assessment (SD DENR, 2008), the water temperature and TSS impairments of Beaver Creek are no longer listed because data from the TMDL assessment was inadvertently excluded from the analysis. According to the 2008 South Dakota Integrated Report for Surface Water Quality Assessment, Beaver Creek is impaired due to fecal coliform bacteria, conductivity, TDS, TSS, and salinity (i.e. sodium adsorption ratio) (SD DENR, 2008).

Presently, Beaver Creek is designated with the beneficial use of coldwater marginal fish life propagation (ARSD §74:51:03:08). Coldwater marginal fish life propagation is defined as "a beneficial use assigned to waters which support aquatic life and are suitable for stocked catchable-size coldwater fish during portions of the year, but due to critical natural conditions including low flows, siltation, or warm temperatures, are not suitable for a permanent coldwater fish population. Warmwater fish may also be present." (SD DENR, 1999).

DENR finds the current coldwater aquatic life use classification to be inappropriate for the natural conditions observed in this watershed. Based on measures of stream temperature and physical habitat, verbal communications with state fishery managers and local landowners, as well as direct assessments of the fishery, Beaver Creek should be reclassified to a warmwater semipermanent fish life propagation water. Warmwater semipermanent fish life propagation is defined as "a beneficial use assigned to lakes and streams which support aquatic life and are suitable for the propagation or maintenance, or both, of warmwater fish but which suffer occasional fish kills because of critical natural conditions." Beaver Creek provides aquatic life habitat more appropriately classified as warmwater semipermanent.

Wyoming classifies Beaver Creek as a "2AB-ww" stream (WY DEQ, 2001). This classification is based on the assumption that warm-water fish species dominate the fish assemblage and carries a water temperature criterion of 86°F.

Assessment Results

STREAM FLOW ANALYSIS

Figure 2 depicts flow duration curves for Beaver Creek at two sites. The upper line represents average daily flow data for the period 1944-1997 at USGS site 06394000, Beaver Creek near Newcastle, WY. This site is located approximately 7 miles upstream of the Wyoming-South Dakota border. The lower line in the graph represents average daily flow data collected during this study at BC-1, from September 2003 to August 2005. Although the two gaging sites are at different locations, they are close enough in proximity to allow for flow comparison. This graph shows that flows during the study period were less than average and implies that drought conditions were being experienced in the watershed at the time of the TMDL study. The stream was flowing at site BC-1 for about 84% of the study period; the remainder of the period the stream was dry. Upstream, USGS site 06394000 flows about 97% of the time based on 53 years of daily average discharge data from 1944-1997. During the study period, water depth at site BC-1 ranged from approximately 0 – 0.5 m (median = 0.2 m).

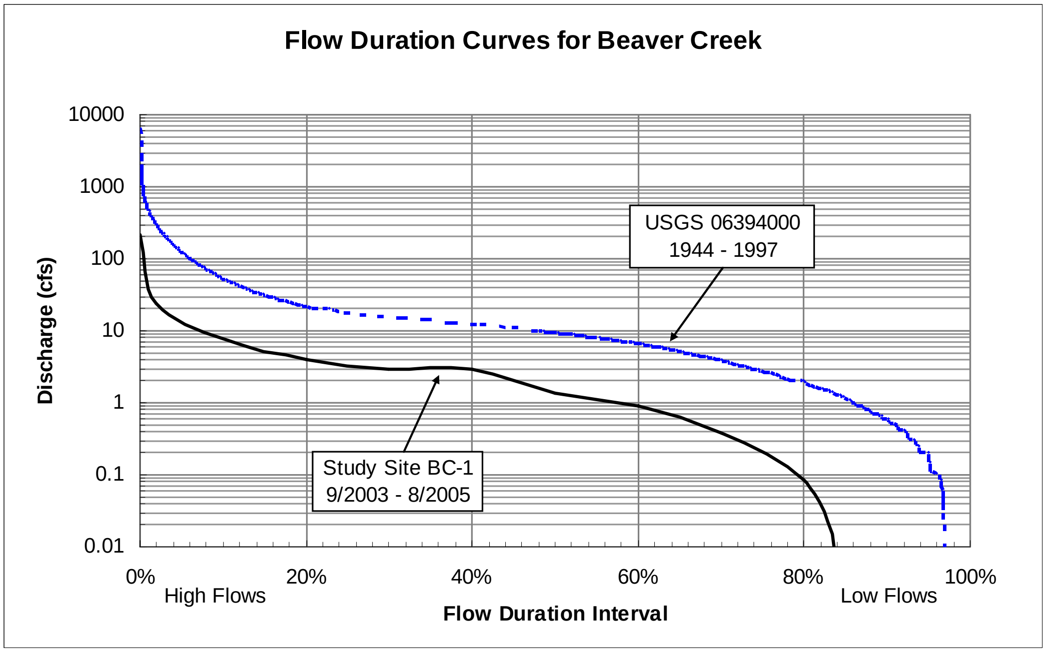

Figure 2. Flow-duration curves for two sites on Beaver Creek.

Low stream flows can upset the ecological balance of a stream and its riparian corridor. For this reason a low-flow frequency analysis was made on Beaver Creek. Daily average stream flow records from United States Geological Survey (USGS) data at USGS stream flow gaging site 06394000 (Beaver Creek near Newcastle, Wyoming[1]) were used. Complete stream flow records exist from 1945 to 1997.

[1] USGS stream flow gaging site 06394000 is located approximately 7 miles upstream of SD-WY border site (BC-3). No streams flow into Beaver Creek between these two sites.

DFLOW 3, a low flow frequency-analysis software developed by the Great Lakes Environmental Center for the United States Environmental Protection Agency, was used to compute the "xQy" stream flow, where "x" is the number of consecutive days of low-flow ("Q") expected to return every "y" years. The results indicate that the return frequency of extended low-flow periods is high. No-flow conditions for periods of 7 to 14 days are expected to occur an average of at least once every 3 years, and no-flow conditions for periods of 21 to 28 days are expected to occur an average of at least once every 4 years (

Table 1).

Table 1. Low-flow frequency analysis of Beaver Creek at USGS gaging site 06394000.

Days of consecutive low-flow (x)	Return Period, Years (y)	Flow, cfs (Q)
7	2	0.06
7	3	0
14	2	0.14
14	3	0
21	2	0.36
21	3	0.01
21	4	0
28	2	0.45
28	3	0.01
28	4	0

Water Quality Sampling Results

Descriptive statistics for samples collected at BC-1 are shown in Table 2. These data include monthly samples collected during the TMDL study and quarterly samples collected by SD DENR from 1999-2003. Discharge data for samples collected by SD DENR were not available, and thus were estimated using regression analysis between discharge data collected at Beaver Creek during the TMDL study and historical data collected by USGS at Cheyenne River at Edgemont (CR-2; USGS site 06395000).

Table 2. Descriptive statistics for samples and field measurements at Beaver Creek site BC-1, showing number of samples (n), sample mean, median, standard deviation, and minimum and maximum values.

Beaver Creek (BC-1)	n	Mean	Median	Standard Deviation	Min	Max
Discharge (cfs)	47	24.2	9.05	56.9	0.003	346
Temp (ºF)	48	53.1	53.9	16.5	31.7	83.3
Spec Cond (µS/cm)	45	4334	4300	1645	1170	7448
pH	44	8.00	8.07	0.265	7.35	8.51
D.O. (mg/L)	47	10.6	10.5	2.23	4.80	15.0
Turb (NTU)	26	125	7.50	316	1.20	1259
NO_2 + NO_3 (mg/L)	47	0.234	0.050	0.352	0.00	1.96
NH_3 Diss (mg/L)	47	0.033	0.020	0.037	0.00	0.130
TKN (mg/L)	47	1.05	0.700	2.01	0.000	13.6
P Diss (mg/L)	27	0.018	0.005	0.027	0.005	0.140
P Total (mg/L)	47	0.183	0.060	0.365	0.005	2.22
SO_4 (mg/L)	32	1773	1639	661	497	2896
Cl (mg/L)	32	599	604	302	81.3	1330
Ca (mg/L)	47	365	393	124	93.0	550
Mg (mg/L)	47	120	116	52.0	24.0	220
Na (mg/L)	32	625	507	353	196	1600
K (mg/L)	27	6.81	6.30	2.76	3.20	12.6
Hardness as $CaCO_3$ (mg/l)	45	1398	1467	502	367	2200
TDS (mg/L)	47	3448	3262	1359	823	6225
Alk as $CaCO_3$ (mg/L)	46	144	148	51.6	2.50	238
TOC (mg/L)	26	7.73	5.70	9.55	1.15	49.9
TSS (mg/L)	47	325	30.0	1341	5.62	9074
TVS (mg/L)	27	43.0	9.10	102	1.00	488
TS (mg/L)	45	3972	3684	1718	830	10630
SAR	27	6.25	5.71	2.50	2.30	11.6
Fecal (colonies/100mL)	32	1251	36.0	4152	2.00	21000

FISH SURVEY RESULTS

The South Dakota Department of Game, Fish and Parks (SD GFP) conducted fish community surveys on April 16, 2008 at two sites on Beaver Creek. Site BVC01 is co-located at the TMDL study site BC-1 (Latitude 43°26’57”, Longitude 104°00’57”), and Site BVC04 is located at the USGS gage near Newcastle, WY (Latitude 43°32'07", Longitude 104°07'02"). Fish were collected from a 100-meter stream reach and measured for length and weight.

At site BVC01, four fish species were collected: fathead minnow, plains killifish, green sunfish, and long-nosed dace. The fathead minnow (Pimephales promelas) was the most abundant species (Table 3), and fathead minnow size classes were fairly evenly distributed (Figure 3). This species composition shows a clear dominance of warmwater fishes inhabiting the site. Due to the proximity of this site to the confluence with the Cheyenne River, some fish recruitment from the Cheyenne River is expected to occur.

Table 3. Total number, size range and total weight of fish species collected by SD GFP from site BVC01 on April 16, 2008.

Fish Species	Common Name	Total Number	Size Range (mm)	Total Weight (grams)
Pimephales promelas	Fathead Minnow	64	29-68	81
Fundulus zebrinus	Plains Killifish	2	41-48	8
Lepomis cyanellus	Green Sunfish	1	120	25
Rhinichthys cataractae	Long-nosed Dace	1	48	<1

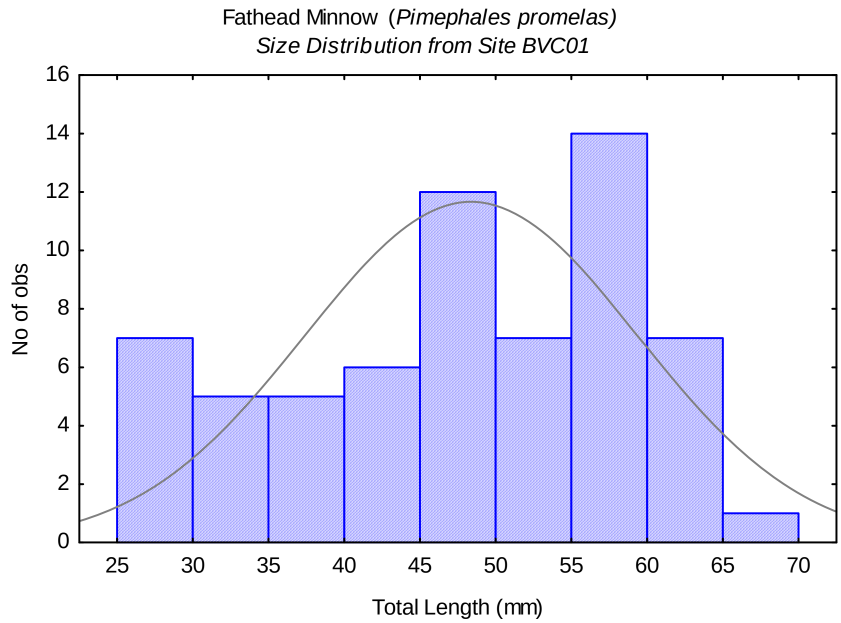

Figure 3. Frequency histogram of fathead minnow (*Pimephales promelas*) size classes observed at site BVC01.

At site BVC04, five fish species were also observed: fathead minnow, plains killifish, green sunfish, common carp, and channel catfish. Again, the species composition and numbers demonstrate a clear dominant presence of warmwater species inhabiting the site. Like at site BVC01, the fathead minnow (*Pimephales promelas*) was the most abundant species (Table 4), and fathead minnow size classes were normally distributed (Figure 4). Plains killifish observed at both sites were low in abundance and relatively small in size ranging from about 4-6 cm (adults are about 15 cm in length). No coldwater species were found at either location.

Table 4. Total number, size range and total weight of fish species collected by SD GFP from site BVC04 on April 16, 2008.

Fish Species	Common Name	Total Number	Size Range (mm)	Total Weight (grams)
Pimephales promelas	Fathead Minnow	84	21-66	92
Fundulus zebrinus	Plains Killifish	10	42-66	14
Lepomis cyanellus	Green Sunfish	4	49-112	30
Cyprinus carpio	Common Carp	3	53-111	28
Ictalurus punctatus	Channel Catfish	1	215	72

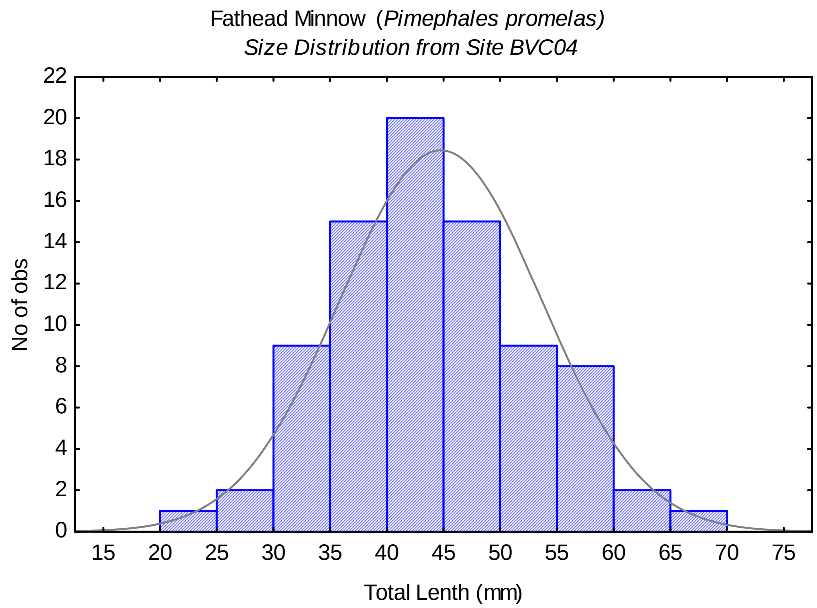

Figure 4. Frequency histogram of fathead minnow (*Pimephales promelas*) size classes observed at site BVC04.

STREAM TEMPERATURE MONITORING RESULTS

Quarterly stream temperatures recorded at BC-1 by SD DENR from April of 1999 to August of 2003 (n=19) indicate that during this period Beaver Creek exceeded its temperature criterion of 75°F at least three times: July 12, 2000 (78.98°F), July 12, 2001 (80.78°F), and July 15, 2003 (79.34°F). There were no summer samples during 2002. Incidentally, these three days also had the highest field measurements of air temperature recorded during this time period. This suggests that high in-stream water temperatures are strongly influenced by naturally occurring high air temperatures. Monthly temperature data collected during 2004 for the TMDL study shows one exceedance on July 13 (77.3°F). These records of exceeding the temperature criterion prompted the SD DENR to more closely examine the water temperature impairment of Beaver Creek.

In the spring of 2005, a second monitoring site was established on Beaver Creek and temperature and stage data were collected from April through August (see Figure 1 for site locations). Site BC-3 (upstream) was located on the South Dakota-Wyoming border, in the extreme southwest corner of Custer County. Site BC-1 (downstream), already an established monitoring site, was located where Argentine Road bridges Beaver Creek west of Burdock in Fall River County. Onset HOBO Water Temp Pro monitors were used to collect temperature data and OTT Thalimedes shaft encoder monitors were used to collect stage data at each site. Stage data collected at BC-3 and BC-1 were converted to discharge data using the regression analysis procedure outlined by Gupta (1989). Temperature and discharge data were then used to model stream temperature for the portion of Beaver Creek in South Dakota.

Stream temperature was recorded every 15 minutes from 4/7/05 to 8/30/05. Maximum daily temperature was determined by isolating the maximum temperature from each day's recordings. Temperature data collected at BC-3 and BC-1 are shown in Figure 5 and Figure 6. The graphs present percent exceedance of a given temperature for all temperature data collected during the summer as well as percent exceedance for the isolated daily maximums.

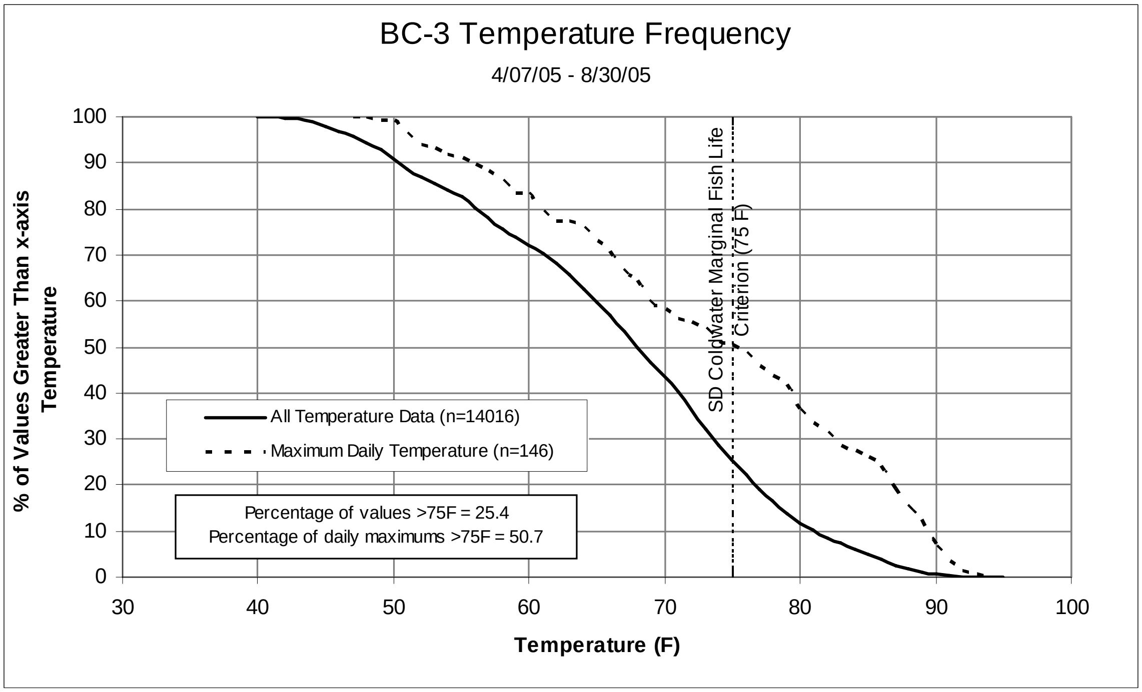

Figure 5. Temperature frequency plot, showing the percent of temperature measurements at site BC-3 (upstream) that exceeded the temperature criterion.

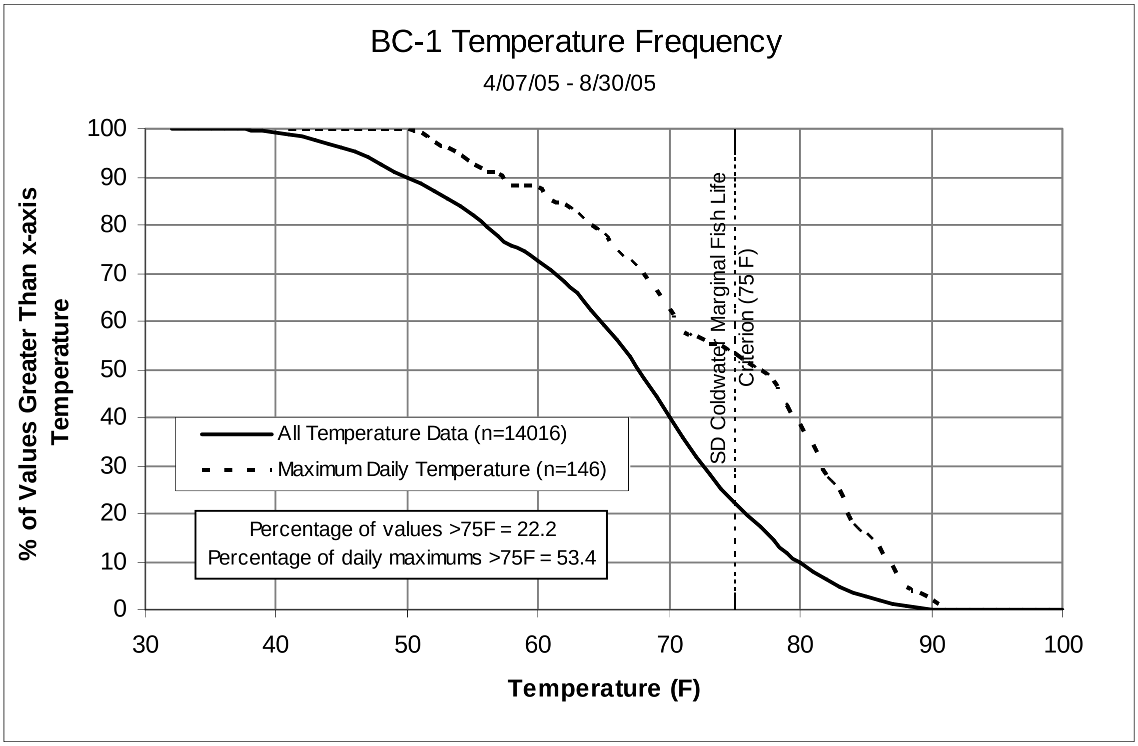

Figure 6. Temperature frequency plot, showing the percent of temperature measurements at site BC-1 (downstream) that exceeded the temperature criterion.

Beaver Creek exceeded the South Dakota criterion for temperature 25.4% of the time at BC-3 (upstream site), and 22.2% of the time at BC-1 (downstream site). (For comparison, values recorded at BC-3 exceeded Wyoming's less stringent criterion of 86°F 1.9% of the time). Maximum daily temperature exceeded State criterion 50.7% of the time at BC-3 and 53.4% of the time at BC-1. This shows that fewer continuous values, but more daily maximums, exceeded the standard at BC-1 than at BC-3. Further, a summation of continuous and daily maximum temperature values for equal time periods (4/7/05 to 8/30/05) shows that temperatures at BC-1 were 1.2% lower than at BC-3, while daily maximum temperatures were 0.4% greater. This analysis suggests that stream temperatures are not increasing as Beaver Creek flows downstream from the Wyoming-South Dakota border to its confluence with the Cheyenne River.

STREAM TEMPERATURE MODELING RESULTS

Beaver Creek temperature was modeled using Stream Segment Temperature Model (SSTEMP), Version 2.0.8. SSTEMP was developed by the United States Geological Survey and is a scaled down version of their Stream Network Temperature Model (SNTEMP). It is designed to model stream segments over a 24-hr period and assumes all input data are 24-hr mean values. This model is especially useful for performing sensitivity and uncertainty analysis (Bartholow, 2002).

SSTEMP estimates stream temperature by calculating heat fluxes within a given homogeneous section of stream. The model predicts daily mean and maximum temperatures of the water leaving the stream segment. Model input defines the stream in terms of location, geometry, steam discharge, meteorology, and shading characteristics.

The modeled stream segment begins at the Wyoming-South Dakota border (BC-3) and extends through private land approximately 12.9 miles to BC-1. The elevation change through this reach is 48 feet.

Discussion of Modeling Input Parameters

Segment Inflow:	Stream inflow is based on monitoring data obtained from an OTT Thalimedes stage recorder at BC-3. The Thalimedes was calibrated using a staff gage, and stage was recorded at 15-minute intervals. Discharge was measured using a Marsh-McBirney flow meter according to the procedures outlined in Standard Operating Procedures for Field Samplers, Volume 1 (SD DENR, 2003a). During low flows, discharge was measured using a 3” Parshall flume. A discharge rating curve was developed to convert stage values to discharge values. Discharge values input to SSTEMP are daily means.
Inflow Temperature:	Inflow temperatures were obtained from an Onset Hobo Water Temp Pro temperature monitor, which was installed at BC-3 during the spring of 2005. The instrument was set to record temperature values every 15 minutes. Mean daily temperatures were obtained by averaging all temperature data from each respective 24-hour period.
Segment Outflow:	Segment outflow was obtained similarly to segment inflow (see “Segment Inflow” above).
Outflow Temperature:	Outflow temperature data were obtained from an Onset Hobo Water Temp Pro temperature monitor located at BC-1.
Accretion Temperature:	Accretion temperature was based on temperature readings taken from an artesian well located near the Pass Creek bridge on Dewey Road near Burdock, South Dakota. This data is considered representative due to its proximity to the monitoring sites. A YSI sonde was used to collect this data.
Latitude:	Latitude for each site was obtained from USGS topographic maps and checked with a Garmin Etrex GPS unit.
Segment Length:	Segment length was determined by measuring the stream-length distance between BC-3 and BC-1 on a USGS topographic map.
Elevations:	Elevations for each site were obtained from USGS topographic maps of the area and checked with a Garmin Etrex GPS unit.

Width "A & B" terms:	These terms were calculated by plotting the natural log of the stream width vs. natural log of discharge values obtained from discharge measurements made at BC-1 and BC-3. A line was fitted to the plot. The "B" term was the slope of that line and the "A" term the untransformed Y-intercept. These functions are used to characterize the top width and estimate average stream depth of the stream segment.
Manning's n:	Manning's "n" of 0.032 was used. The stream has a muddy bottom and few weeds.
Time of Year:	Two days were used to calibrate and model with SSTEMP: June 28 and July 30, 2005. Stream temperatures collected during this period were not influenced by precipitation and were some of the warmest stream temperatures collected during 2005.
Air Temperature:	Air temperature data for Edgemont, SD were obtained from National Climatic Data Center (NCDC) and distributed by Southern Regional Climate Center (SRCC, 2006). Data are monthly average temperatures for the period 1971-2000. Edgemont is located approximately 14.3 miles southeast of BC-1 and 18.2 miles southeast of BC-3.
Relative Humidity:	Relative humidity data for Oral, SD were obtained from an auto-sampler and distributed by South Dakota State University (SDSU) at http://climate.sdstate.edu/w_info/monthlyreports/monthlyreportsnewfr.htm. Because of high daily fluctuations in relative humidity and the uncertainty of this parameter, relative humidity was used as a calibration parameter.
Wind Speed:	Wind speed was estimated from field observations at each site. Because of the uncertainty associated with the parameter, it was one of the parameters adjusted to calibrate the model.
Ground Temperature:	Ground temperature was based on temperature of artesian well water flowing near the Pass Creek bridge on Dewey Road near Burdock, South Dakota. A sonde was used to measure this parameter.
Possible Sun %:	Possible sun was estimated from field observations. Because of the difficulty in accurately estimating sun, it was used as a calibration parameter.
Dust Coefficient:	A dust coefficient for summer between 3 and 10 is recommended by the USGS for use in SSTEMP modeling. As this location is relatively dry and windy, dust coefficient was assumed to be 6.
Ground Reflectivity:	Based on values developed by the Tennessee Valley Authority a value of 20 was assumed. Meadows and fields are estimated to have a value of 14. Vegetation (early summer) is estimated to have a value of 19 whereas vegetation (late summer) is estimated

to have a value of 29. Flat ground, grass covered, is estimated to have a value ranging from 15 to 33.

Solar Radiation: SSTEMP gives the user the option of either entering a dust coefficient and a ground reflectivity (with which it calculates solar radiation), or, the user can directly enter a solar radiation value. Pyrometer measurements of solar radiation were not obtained during this study. Because of this, dust coefficient and ground reflectivity values were entered, and the program calculated solar radiation.

Percent Shade: The program provides the user with the option of entering a percent shade value or entering values for azimuth, topographical altitude, vegetation height, crown width, vegetation offset, and vegetation density. It then calculates percent shade based on these values. These shading values were entered based on field measurements, and SSTEMP computed percent shade.

Shading Parameters: Shading parameters were chosen to best reflect the average condition of the riparian corridor along the entire modeled stream reach. Estimates of vegetation characteristics were adjusted among the two calibration runs according to time of year.

Segment Azimuth: Segment azimuth was obtained by drawing a straight line from the beginning to end of the reach on a 7½ minute USGS topographical map and using a protractor to measure the angle of the line.

Topographical Altitude: Topographical altitude was estimated from visual observation and field measurements taken during the course of the study at sites BC-1 and BC-3.

Vegetation Height: Vegetation height was estimated from field measurements taken during the study at two sites and estimates from walking the stream bank at several reaches. The upstream 10%-15% of the modeled reach is lined with trees having average height of 20', while downstream, grasses of height 1-3' are the predominant shading vegetation. Values for the July 30 model are slightly greater than June 28 values to take into account summer vegetation growth.

Vegetation Crown: A vegetation crown of 3-4 feet was assumed. This value represents the entire modeled reach combining upstream trees and downstream grasses. Values for the July 30 model are slightly greater than June 28 values to take into account summer vegetation growth.

Vegetation Offset: Grasses along the entire reach grow to the edge of the water, while upstream, shading trees are an estimated average distance of 5-10 feet from the stream's edge. A value of one inch was assumed.

Vegetation Density: Vegetation density is the density quantity (how much area is taken by shade vegetation) multiplied by the density quality (how much light gets filtered out by those that are there). The grasses along the entire reach do not intercept much sunlight, and thus have low density quality (20%-30%). Grasses are, however, very abundant, and therefore the density quantity is high (80%-90%). The trees in the riparian zone are low in quantity (25%-35%) but have relatively high density quality (70%-80%). Overall density is the average of these based on grasses found along 90% of the reach and trees along 10% of the reach. Values for the July 30 model are slightly greater than June 28 values to take into account summer vegetation growth.

Model Calibration

Values obtained for the parameters listed above were entered into the SSTEMP program and an initial run was made for each time of year. The model predicts the mean and maximum temperatures of the stream water flowing out of the reach. The theoretical foundation for the model is strongest for mean temperature, while maximum temperature predicted by SSTEMP is largely an estimate (Bartholow, 2002) and therefore was not modeled in this analysis. The model output mean daily temperatures were compared to measured values. Input data for the base cases are shown in Table 5.

Table 5. SSTEMP input data with calibration values for Beaver Creek.

	Segment Inflow (cfs)	Mean Inflow Temp (ºF)	Segment Outflow (cfs)	Accretion Temp (ºF)	Latitude (deg)	Segment Length (mi)	Upstream Elev. (ft)
6/28/2005	2.98	74.25	5.38	55.22	43.475	12.9	3598
7/30/2005	1.13	78.02	1.35	55.22	43.475	12.9	3598
	Dnstream Elev. (ft)	Width "A" Term (s/ft^2)	Width "B" Term	Manning's n	Air Temp (ºF)	Max Air Temp	Relative Humidity %
6/28/2005	3550	16.849	0.157	0.032	74	N/A	55 (45)*
7/30/2005	3550	15.696	0.157	0.032	79	N/A	52 (45)*
	Wind Speed (mph)	Ground Temp (ºF)	Thermal grad. (j/m^2/s/C)	Possible Sun %	Dust coef.	Ground Reflectivity %	Solar Radiation (L/day)
6/28/2005	2 (5)*	55.22	1.65	90 (75)*	6	20	N/A
7/30/2005	2 (4)*	55.22	1.65	90 (82)*	6	20	N/A
	Percent	Segment Azimuth (deg)	Altitude West (deg)	Veg Ht West (ft)	Veg Crown West (ft)	Veg Offset West (ft)	Veg Density West %
6/28/2005	N/A	-29.745	25	4	3	1	16
7/30/2005	N/A	-29.745	25	5	4	1	26
	Altitude East (deg)	Veg Ht East (ft)	Veg Crown East (ft)	Veg Offset East (ft)	Veg Density East %	**Predicted Outflow Temp (ºF)**	**Measured Outflow Temp (ºF)**
6/28/2005	20	4	3	1	16%	80.1 (74.2*)	74.17
7/30/2005	20	5	4	1	26%	82.0 (78.0*)	77.98

* calibrated value

For the 06-28-2005 model run, the base case predicted a mean temperature of 80.08 ºF. This compares with an actual mean temperature of 74.17 ºF. The model was calibrated by adjusting relative humidity from 55% to 45%, possible sun from 90% to 75%, and wind speed from 2 to 5 mph. The calibrated model predicted a mean daily stream temperature of 74.21 ºF.

For the 07-30-2005 model run, the base case predicted a mean temperature of 81.97 ºF. Actual mean stream temperature was measured to be 77.98 ºF. The model was calibrated by adjusting relative humidity from 52% to 45%, wind speed from 2 to 4 mph, and possible sun from 90% to 82%. The calibrated model predicts a mean daily stream temperature of 77.98 ºF.

Sensitivity Analysis

Both time periods modeled were subjected to a sensitivity analysis to determine which parameters had the greatest effect on temperatures in Beaver Creek. The SSTEMP sensitivity-analysis routine subsequently increases and decreases each input parameter by 10% and estimates the change in downstream temperature. Each parameter is then rated to determine its relative impact to in-stream temperature. Table 6 lists the results of the sensitivity analysis. The three major factors affecting stream temperature are air temperature, relative humidity, and percent possible sun. Although the relative humidity and % possible sun do have a marginal effect on the modeling outcome, their effect is much less significant on stream temperature than ambient air temperature. None of these three naturally occurring climatic factors (air temperature, % sun, or humidity) can be controlled in the watershed.

Table 6. SSTEMP sensitivity analysis for Beaver Creek model.

		6/28/2005			7/30/2005	
Variable	**Decreased**	**Increased**	**Relative Sensitivity**	**Decreased**	**Increased**	**Relative Sensitivity**
Segment Inflow (cfs)	-0.15	0.15	1	-0.1	0.1	1
Inflow Temperature (°F)	-0.02	0.02	0	-0.02	0.02	0
Segment Outflow (cfs)	0.23	-0.24	2	0.1	-0.1	1
Accretion Temp. (°F)	-0.33	0.33	2	-0.04	0.04	0
Width's A Term (s/ft²)	-0.13	0.16	1	-0.09	0.12	1
B Term where W = A*Q**B	-0.03	0.03	0	0	0	0
Manning's n	0	0	0	0	0	0
Air Temperature (°F)	-4.46	4.27	**30**	-5.07	4.88	**30**
Relative Humidity (%)	-0.8	0.82	**6**	-0.89	0.92	**5**
Wind Speed (mph)	0.4	-0.42	3	0.36	-0.38	2
Ground Temperature (°F)	-0.26	0.26	2	-0.27	0.27	2
Thermal gradient (j/m²/s/C)	0.09	-0.09	1	0.11	-0.11	1
Possible Sun (%)	-0.61	0.63	**4**	-0.56	0.58	**3**
Dust Coefficient	0.05	-0.05	0	0.05	-0.05	0
Ground Reflectivity (%)	-0.03	0.03	0	-0.03	0.03	0
Segment Azimuth (degrees)	-0.07	0.06	0	-0.07	0.06	0
West Side:						
Topographic Altitude (degrees)	0.12	-0.1	1	0.13	-0.11	1
Vegetation Height (ft)	0.01	-0.01	0	0.04	-0.04	0
Vegetation Crown (ft)	0.01	-0.01	0	0.02	-0.02	0
Vegetation Offset (ft)	-0.01	0.01	0	-0.01	0.01	0
Vegetation Density (%)	0.02	-0.02	0	0.05	-0.05	0
East Side:						
Topographic Altitude (degrees)	0.08	-0.07	1	0.06	-0.06	0
Vegetation Height (ft)	0.01	-0.01	0	0.03	-0.03	0
Vegetation Crown (ft)	0.01	-0.01	0	0.01	-0.01	0
Vegetation Offset (ft)	0	0	0	-0.01	0.01	0
Vegetation Density (%)	0.01	-0.01	0	0.03	-0.03	0

Determination of Controlling Parameters

Several scenarios were modeled to provide a more in-depth sensitivity analysis of physical parameters that have the most control over stream temperatures, and to evaluate effects of possible mitigation practices. Sections below describe modeling attempts to determine which parameters had the most control of stream temperatures, including vegetation shading, air temperature, stream discharge, and inflow temperature.

Evaluation of Riparian Vegetation Effects on Stream Temperature

Physical parameters that could be modified along the riparian corridor to decrease temperatures in Beaver Creek are limited to changes in the vegetation condition. Although sensitivity-analysis results indicated that vegetation was not a primary factor affecting in-stream temperature, sensitivity analysis as computed by SSTEMP is limited to a 10% change in any parameter. In order to model the planting of trees along the corridor and increasing vegetation shading by more than a 10% change, the calibrated SSTEMP models were run with larger changes in the vegetation shading parameters to determine the effects of increased shading on water temperature.

The values used to model vegetation shading are a combination of measured and observed values that represent the spatially varying condition of the riparian zone in this stream reach. For example, the base case value for vegetation height for the June 28 model (4 feet) is derived from a combination of 85%-90% downstream condition where grasses range from 1-3 feet in height and 10%-15% upstream condition where trees range from 10-30 feet in height. Values used to model increases in shading were also a combination of values representing the entire stream section. For example, vegetation height of 10 feet might represent trees with average height of 10 feet along the entire reach, or trees of average height 17 feet along 50% of the reach and grasses of average height 3 feet along the other 50% of the reach.

Both days were modeled to estimate in-stream temperature decreases due to increased vegetation. Values for current vegetation height, crown and density were based on a visual survey of the stream reach. Values for the increased vegetation height and density scenarios were arbitrarily selected. Values for increased vegetation crown were selected based on what a typical tree’s crown might be given the tree’s height. Figure 7 and Figure 8 show SSTEMP model output of estimated stream temperatures due to increasing vegetation along Beaver Creek.

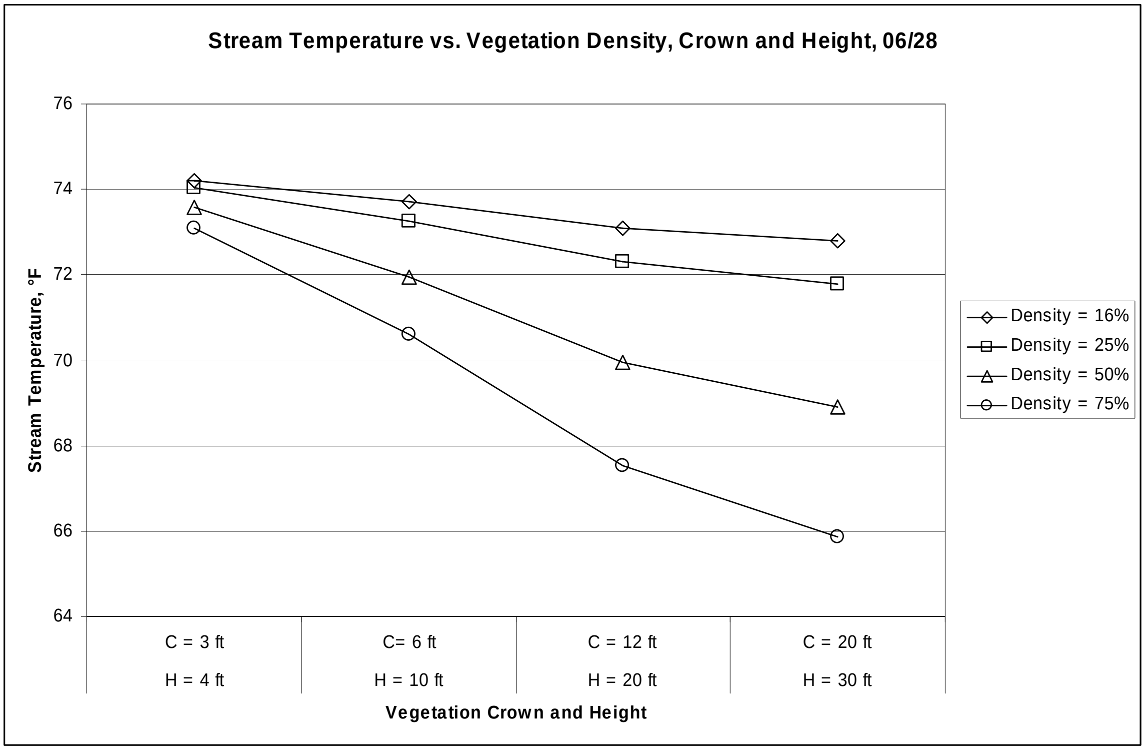

Figure 7. Modeling results showing the effect of increased vegetation crown (C), height (H) and density on stream temperature for the 6/28/05 model run

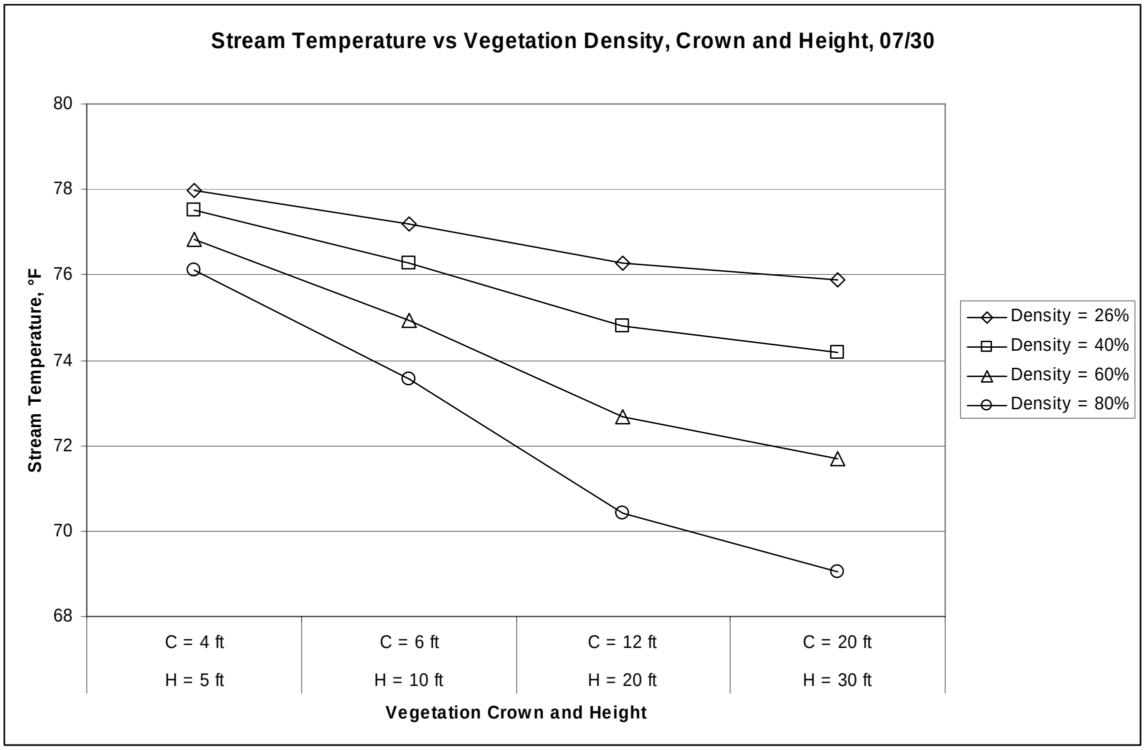

Figure 8. Modeling results showing the effect of increased vegetation crown (C), height (H) and density on the stream temperature for the 7/30/05 model run.

The model indicates that both vegetation density and height would have to be increased for any substantial decrease to occur in stream outflow temperatures. The effects of change in stream shading are summarized in Table 7.

Table 7. Beaver Creek percentage decrease in temperature due to increased vegetation shading (from the 07/30 model).

		Percentage decrease in temperature for 07/30 model			
Height (ft)	Crown (ft)	Density = 26%	Density = 40%	Density = 60%	Density = 80%
H = 5 ft	C = 4 ft	Base case	0.6	1.5	2.4
H = 10 ft	C = 6 ft	1.0	2.2	3.9	5.7
H = 20 ft	C = 12 ft	2.2	4.1	6.8	9.7
H = 30 ft	C = 20 ft	2.7	4.9	8.1	11.5

The model indicates that stream temperatures could potentially be reduced by increasing vegetation shading. The maximum modeled temperature reduction was 11.5%, which would require vegetation height of 30 feet, crown of 20 feet, and density of 80%.

Because the temperature of Beaver Creek as it flows across the Wyoming-South Dakota border complies with Wyoming water-quality standards, it is anticipated that no mitigation measures to reduce stream temperature would be implemented upstream from the border. Therefore, any increase in vegetation density or height on the South Dakota side would affect stream temperature only in the lower region of the watershed.

Evaluation of Stream flow Effects on Stream Temperature

Keeping all other parameters equal, stream flow was adjusted in the 07/30 model to determine impacts to temperature at different flows. Values used to simulate increased stream flow were arbitrarily selected, and outflow values were made equal to inflow values. The base case is also included for comparison purposes. Table 8 shows model results.

Table 8. Beaver Creek modeling results showing the effect of increased flow on stream temperature for the 7/30/05 model run.

Inflow, cfs	Outflow, cfs	Stream Temperature, °F	Temperature Change
1.13	1.35	77.98	(base case)
2	2	78.21	+ 0.29%
4	4	78.30	+ 0.41%
6	6	78.35	+ 0.47%
10	10	78.40	+ 0.54%
20	20	78.44	+ 0.59%
50	50	78.39	+ 0.53%

The model indicates that adjusting stream flow, if possible, would not decrease downstream temperatures of Beaver Creek. On the contrary, model results show small increases in stream temperature (less than 1%) when discharge is increased.

Evaluation of Air Temperature Effects on Stream Temperature

An evaluation of air temperature effects at different stream flows was undertaken using the 07/30 model. Air temperature changes were modeled at the base-case stream flow of 1.13 cfs, and at increased stream flows of 6 cfs and 10 cfs. Table 9 shows modeling results of increased flows at different air temperatures. Results are also displayed graphically in Figure 9.

Table 9. Beaver Creek stream temperature at increased flows and different air temperatures.

Discharge, cfs	Air Temperature, °F	Stream Temperature, °F	Temperature Change
1.13	85	81.81	+ 4.91%
1.13	80	78.61	+ 0.81%
1.13	75	75.48	- 3.21%
1.13	70	72.43	- 7.12%
1.13	65	69.44	- 10.95%
1.13	60	66.50	- 14.72%
1.13	55	63.61	- 18.43%
1.13	50	60.76	- 22.08%
6	85	82.18	+ 5.39%
6	80	78.98	+ 1.28%
6	75	75.86	- 2.72%
6	70	72.81	- 6.63%
6	65	69.83	- 10.45%
6	60	66.91	- 14.20%
6	55	64.05	- 17.86%
6	50	61.24	- 21.47%
10	85	82.19	+ 5.40%
10	80	79.02	+ 1.33%
10	75	75.96	- 2.59%
10	70	72.99	- 6.40%
10	65	70.11	- 10.09%
10	60	67.32	- 13.67%
10	55	64.61	- 17.15%
10	50	61.97	- 20.53%

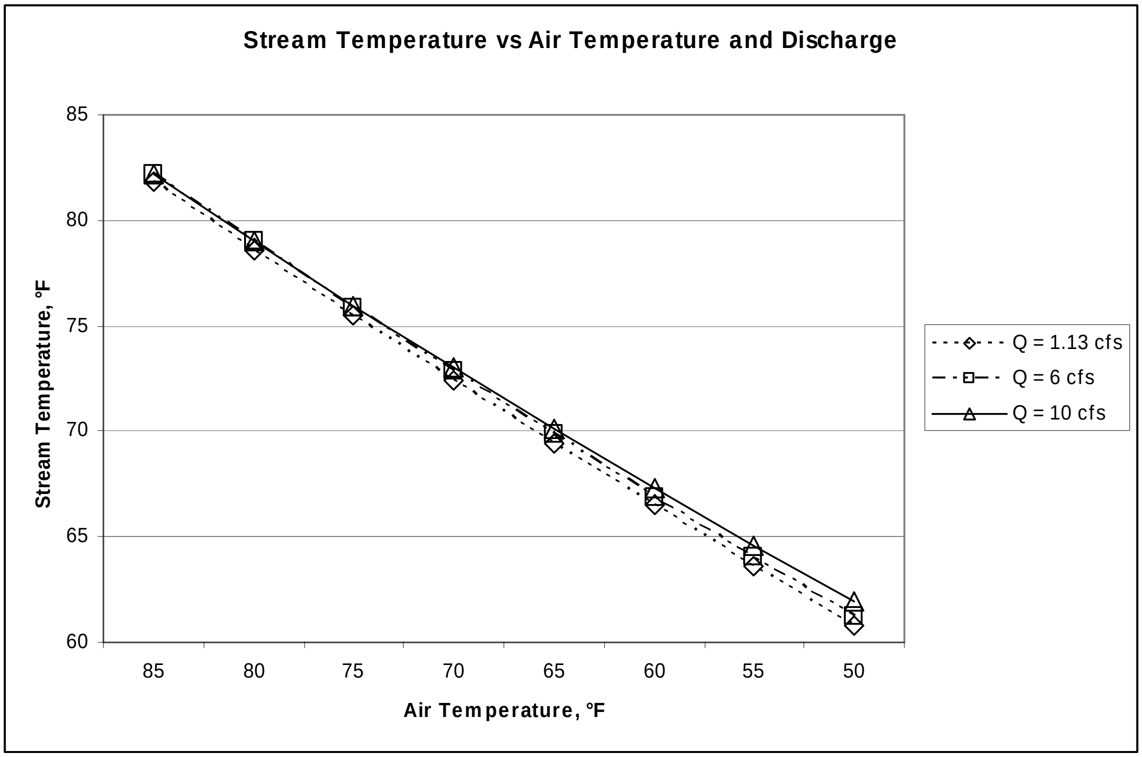

Figure 9. Air temperature and flow versus stream temperature.

Results indicate that air temperature drives stream temperature. Increasing stream discharge makes little difference. In fact, increases in discharge slightly increased modeled stream temperatures, but the effect of air temperature on stream temperature greatly overwhelm any increase in discharge.

Evaluation of Reduced Inflow Temperatures and Increased Discharge on Stream Temperature

Effects of coupling reduced inflow temperatures and increased discharge on stream temperatures was modeled using the 07/30 case. Table 10 shows results of this model. Figure 10 shows these results graphically.

Table 10. Beaver Creek stream temperature at reduced inflow temperature and increased discharge.

Inflow, cfs	Outflow, cfs	Inflow Temperature, °F	Stream Temperature, °F	Temperature change
1.13	1.35	78.02	77.98	(base case)
		75	77.97	-0.01%
		70	77.95	-0.04%
		65	77.94	-0.05%
		60	77.92	-0.08%
6	6	78.02	78.35	0.47%
		75	78.34	0.46%
		70	78.33	0.45%
		65	78.32	0.44%
		60	78.30	0.41%
10	10	78.02	78.40	0.54%
		75	78.35	0.47%
		70	78.25	0.35%
		65	78.14	0.21%
		60	78.02	0.05%

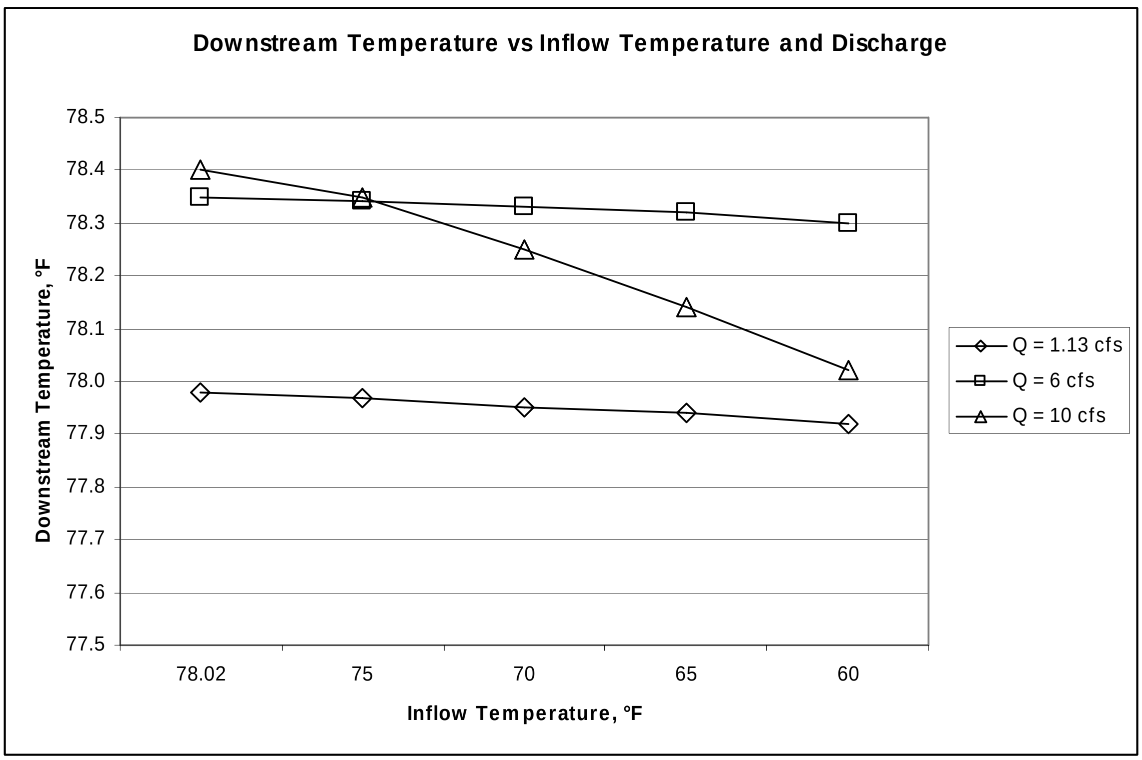

Figure 10. Stream Temperature at Reduced Inflow Temperatures and Increased Discharge

Modeling efforts show less than one percent change in outflow temperatures by decreasing inflow temperatures (note the scale of the Y-axis in this figure). Decreasing inflow temperatures at the base-case stream flow of 1.13 cfs and increased stream flow to 6 cfs result in almost no change in estimated downstream temperatures. In the case of 10 cfs stream flow, the reduction of inflow temperatures shows slight effects on downstream temperature; however, the change is almost negligible.

STREAM TEMPERATURE MODELING CONCLUSIONS

To determine which factors were controlling stream temperature in Beaver Creek, several scenarios were modeled, including increased vegetation height, crown and density, increased discharge, reduced inflow temperature, reduced air temperature, and combinations of these factors. Modeling results indicated that air temperature was the primary factor controlling stream temperature in Beaver Creek, while small reductions in stream temperature were predicted when increases in vegetative shading was modeled. Reducing air temperatures in the model significantly reduced stream temperatures at both high and low flows, while increasing discharge and reducing inflow temperature had little effect. Air temperature and inflow temperature cannot, of course, be controlled, and it is highly unlikely that discharge can be increased.

Observation of the Beaver Creek riparian corridor shows few agricultural impacts to riparian vegetation. A stream walk of several miles along several accessible segments of the creek was conducted on October 13, 2005. During this walk, only two livestock crossings were observed and good vegetation growth was present along all observed reaches. Much of the riparian corridor was fenced off above the stream embankment. Furthermore, the steepness and height of embankments along much of the stream would make livestock access difficult. Therefore, it is assumed that high Beaver Creek temperatures are not due to poor livestock management practices, and that current livestock management practices in the Beaver Creek watershed in South Dakota are not resulting in increased temperatures in Beaver Creek. Livestock-management BMPs, such as fencing the riparian corridor and reducing the number of livestock stream crossings, are not likely to significantly reduce temperatures of Beaver Creek.

The original base case was modeled with an overall vegetation height of 5 feet and a crown of 4 feet, with density of 26%[2]. This is believed to accurately reflect vegetation conditions at Beaver Creek at the time period modeled. Large increases in overall vegetation shading resulted in minimal reductions of temperature. The model shows that it is possible to achieve an in-stream temperature reduction of 2.4% to 2.7% by increasing vegetation density to 80%, or increasing vegetation height to 30 feet and crown to 20 feet, or some combination of an increase of vegetation height, crown, and density by planting trees in the riparian corridor along Beaver Creek. The maximum temperature reduction modeled was 11.5%, which incorporated an overall vegetation height of 30 feet, a crown of 20 feet, and a density of 80%.

[2] Only the model results of the July model case are discussed here. The results of the June model case are similar.

As stated previously, SSTEMP calculates shading factors as overall vegetation conditions for the entire segment modeled. The values input for vegetation height and crown are a combination of all vegetation that contributes to shading the stream, from grasses, sedges, and emergent aquatic macrophytes to trees. Vegetation density is likewise a combination of all vegetation along the stream that contributes to shading, and is estimated by multiplying the overall vegetation density (which can be thought of as how many plants are along the corridor) by the density of each individual plant (which can be thought of as how much light is filtered by each plant). For instance, trees along 50% of the corridor, each blocking 80% of the sunlight that would otherwise fall on the stream water, would give a vegetation density of 40% (0.50 * 0.80). Although SSTEMP model output for 80% vegetation density with height of 30 feet and crown of 20 feet predicts a decrease of stream temperatures of 11.5%, this abundance of vegetation is not likely to occur in the watershed, even with coordinated effort of plantings of trees. This temperature reduction would require trees along the entire stream that blocked 80% of the light, or trees along 80% of the stream that blocked 100% of the light, or some combination of trees and aquatic macrophytes that achieve the same net shading.

If one assumes that increases in vegetation height to 30 feet and vegetation density to 40% are reasonable, then a reduction in stream temperature of 5% is possible. Based on this assumption, the effect of 5% temperature reduction on compliance with the coldwater marginal fish life propagation criterion was analyzed. This was done by simply reducing the measured stream temperatures by 5% and graphing the results, shown in Figure 11. A 5% reduction of all measured stream temperature values would still result in 12% of the measurements exceeding the current temperature criterion. The temperature criterion for the beneficial-use of warmwater permanent fish life propagation (80°F) would be exceeded 3.5% of the time, while the warmwater semipermanent fish life propagation criterion (90°F) would not be exceeded.

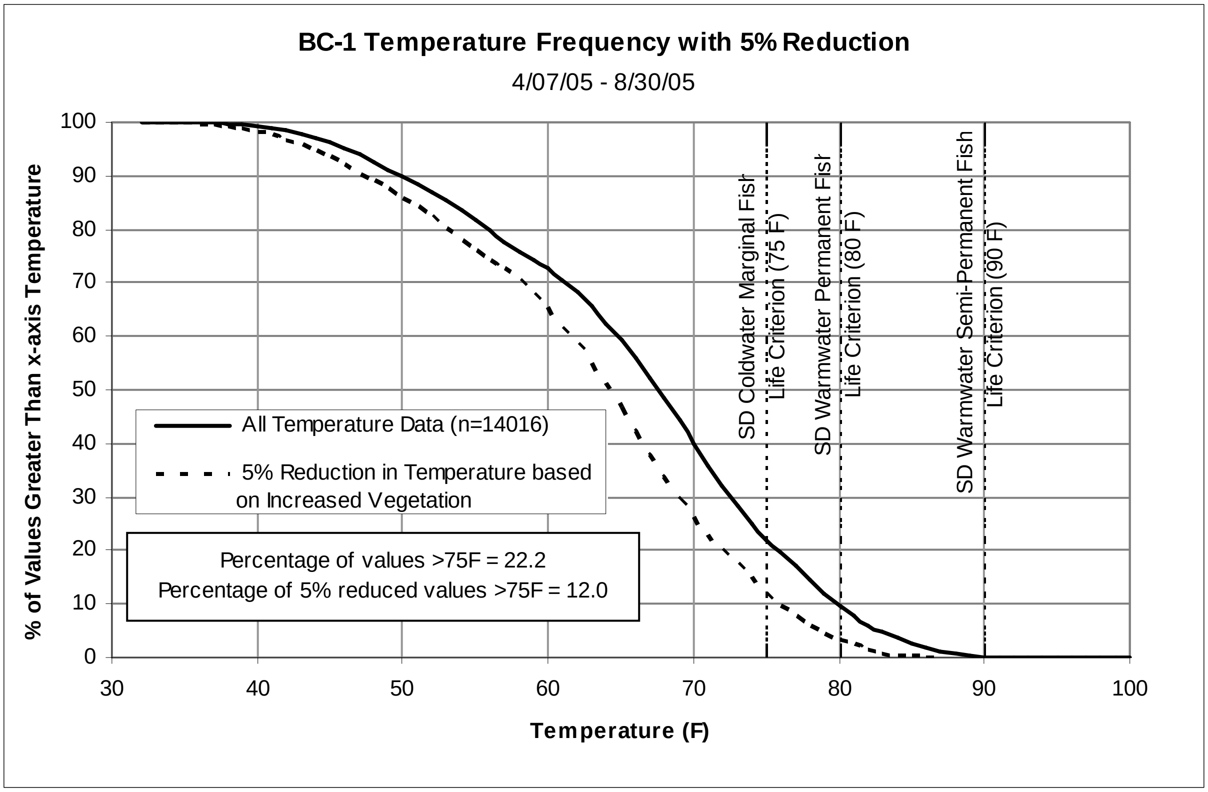

Figure 11. Temperature frequency plot showing the percentage of temperature measurements (solid line) that exceeded criterion. Dotted line shows 5% reduction in temperatures.

It is also important to note that increases of vegetation along the Beaver Creek corridor would only reduce temperatures after the water had time to cool. Any reduction in temperatures would only be realized downstream. Increased vegetation shading would not affect stream temperatures at the BC-3 site, as water flowing in from Wyoming already exceeds State regulatory standards.

Summary and Recommendations

The majority of Beaver Creek's stream miles and watershed lies in Wyoming. The Wyoming water-quality temperature criterion for Beaver Creek is 86°F, while the current daily maximum criterion in South Dakota is 75°F. The naturally warm water and recurring no/low-flow conditions present in Beaver Creek are more appropriately classified as a warmwater semipermanent aquatic life use.

A change in South Dakota beneficial use classification of Beaver Creek from cold-water marginal fish-life propagation to warmwater semipermanent fish-life propagation would increase the daily maximum temperature criterion from 75°F to 90°F. Continuous data collected during this study at BC-3 would exceed this standard 0.67% of the time, a reduction of 24.8%, and data collected at BC-1 would exceed this standard 0.17% of the time, a reduction of 22.0%. If the stream temperatures were reduced by increased riparian vegetation shading to the maximum practical extent, resulting in a predicted 5% reduction of water temperatures, the stream would not exceed the current daily maximum criteria for warmwater semipermanent fisheries.

Local contacts and landowners assert that no trout exist in Beaver Creek (Putnam, pers comm. 2008). Beaver Creek has never been stocked by the South Dakota Department of Game, Fish and Parks (SD GFP, unpublished data). Fish surveys were conducted at two sites on Beaver Creek by SD GFP on April 16, 2008, and no coldwater fish species were found during these surveys, while warmwater species appear to be thriving.

Beneficial use reclassification to warmwater semipermanent fish-life propagation is supported by low-flow frequency analysis of Beaver Creek, showing frequent return periods of very low/no-flow conditions and warmwater temperatures observed during the TMDL assessment. While warmwater species of fish may survive in pools remaining during periods of no stream flow, it is very unlikely that coldwater fish could survive the no-flow, warm-water conditions present in frequently by Beaver Creek.

Beaver Creek is currently assigned the limited contact recreation use, but not the immersion recreation use. The stream does not appear to be used or suitable for immersion recreation. While the stream is relatively accessible by the public on state lands such as School and Public Lands and public “walk-in” hunting areas, U.S. Bureau of Land Management grazing lands, and at road crossings; the stream appears unsuitable for immersion recreation due to channel morphology and sustained periods of low water depth. The stream channel is incising, and the entrenched channel precludes access to the stream in many areas. The stream was flowing at site BC-1 for about 84% of the study period, and the remainder of the period the stream was dry. During the study period, water depth at site BC-1 ranged from approximately 0 – 0.5 m (median = 0.2 m). For these reasons, maintaining Beaver Creek’s current recreational use classification is recommended.

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