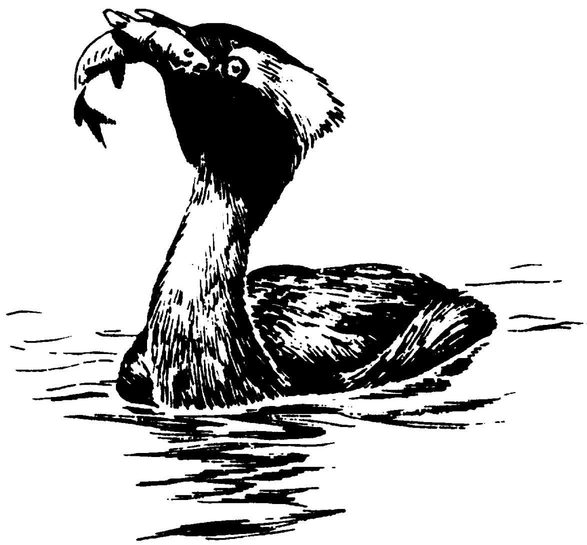
Phase I Watershed Assessment
Final Report and TMDL

Belle Fourche River Watershed
Butte, Lawrence, and Meade Counties, South Dakota



South Dakota Water Resource Assistance Program
Division of Financial and Technical Assistance
South Dakota Department of Environment and Natural Resources
Steven M. Pirner, Secretary

September, 2004

SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM
ASSESSMENT/PLANNING PROJECT FINAL REPORT

Belle Fourche River Watershed
Butte, Lawrence, and Meade Counties, SD

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This project was conducted in cooperation with the State of South Dakota and the United States Environmental Protection Agency, Region 8.

Grant # C9998185-00, C9998185-01, and C6998131-02

Executive Summary

The purpose of this pre-implementation assessment was to 1) assess the current physical, chemical, and biological integrity of the Belle Fourche River and its tributaries, 2) determine the sources of total suspended solids (TSS) in the Belle Fourche River watershed, 3) and define management prescriptions for identified non-point source critical areas in the watershed. This report will result in a TSS Total Maximum Daily Load (TMDL) for two listed waterbodies: the Belle Fourche River and Horse Creek.

The Belle Fourche River is identified in the 1998, 2002 and the 2004 South Dakota 303(d) Waterbody Lists as impaired due to elevated TSS concentrations. The current listing (2004), has been assigned high priority status due to the widespread local support for water quality improvement and the expected development of a TMDL within the next two years. The 2004 listing also includes a fecal coliform bacteria impairment for the Belle Fourche River from the Wyoming border to near Fruitdale, SD. This bacteria listing will be addressed in a future TMDL report.

According to the 2004 South Dakota Integrated Report for Surface Water Quality Assessment (i.e. Integrated Report), the Belle Fourche River from the Wyoming border to Willow Creek failed to support its assigned uses due to high TSS and fecal coliform bacteria. The report states that agricultural activities are deemed a likely source of occasional impairment. The report also explains that a natural source of TSS originates from erosion of extensive exposed shale beds that lie along the river’s course upstream of the city of Belle Fourche.

Horse Creek was listed in the 1998 impaired waterbody list for total dissolved solids (TDS), which was later determined to be a listing error. The Horse Creek listing was corrected in the 2002 report and instead listed for conductivity. The 2004 Integrated Report also reports a conductivity impairment for Horse Creek. During this assessment, approximately 10% of the samples collected from Horse Creek exceeded the water quality standard for TSS. For this reason, a TMDL is needed for Horse Creek for both TSS and conductivity. This report only addresses the TSS impairment for Horse Creek; the conductivity impairment is addressed in a separate document.

Stream entrenchment and bank failure are responsible for approximately 75% of the TSS in the Belle Fourche River system. Stream energy causes natural bank failure, particularly in the eastern portion of the watershed. These areas are dominated by high banks composed of primarily clay soils that, when eroded, supply suspended solids to the channel. Increased quantities of water resulting from irrigation flows also cause the channel to incise, resulting in additional bank failures and resultant suspended solids.

Irrigation and on-farm waste are responsible for approximately 20% of the TSS in the Belle Fourche River system. Much of the irrigation in the watershed is flood-type. This type of irrigation results in sediments being mobilized by three processes: 1) as the tail water/runoff crosses the field, 2) in the channels and laterals, and 3) in the intermittent streams carrying tail water/runoff to the perennial streams within the watershed.

Best management practices (BMPs) are recommended in this report to control the delivery of TSS to the receiving water resources. This can be accomplished by minimizing TSS that is available to the system or by reducing the flow energy to transport TSS. The recommended BMP's will aim to reduce irrigation and on-farm water waste, prevent range erosion, and improve riparian zone condition.

A 55% reduction of TSS concentrations is required to bring the Belle Fourche River into compliance with the water quality standards. A 41% reduction of TSS concentration is required for Horse Creek. For both waterways, the required reduction can be accomplished through riparian rehabilitation and a combination of water efficiency improvement projects within the Belle Fourche Irrigation District system and irrigated acreage.

FUNDING SUMMARY:

PROJECT TITLE: Belle Fourche River Watershed Assessment

PROJECT START DATE: 4/10/01 PROJECT COMPLETION DATE: 12/31/04

FUNDING:

TOTAL EPA GRANT:	$287,742.40
TOTAL EXPENDITURES OF EPA FUNDS:	$246,430.41
TOTAL EXPENDITURES OF NATURAL RESOURCE FEE FUNDS (NRFF):	$75,580.80
TOTAL SECTION 319 MATCH ACCRUED (INCLUDING NRFF):	$155,575.02
BUDGET REVISIONS:	
319 funds added:	$29,500.00
604(b) funds added:	$31,500.00
TOTAL BUDGET:	$438,904.00
TOTAL EXPENDITURES:	$402,005.43

The above budget represents funding sources and expenditures for the Belle Fourche River Watershed Assessment project (grant # C9998185-00, C9998185-01, and C6998131-02). The EPA section 319 grant provided the majority of funding for the project. The Belle Fourche River Watershed Partnership and the South Dakota School of Mines and Technology contributed local match for the project. This grant funded an assessment of four 303(d) listed waters: Belle Fourche River, Horse Creek, Whitewood Creek, and Bear Butte Creek. The original grant agreement was amended to add EPA grant funds (see above budget revisions) for additional sampling expenses, including a more intensive sampling schedule in the Whitewood Creek watershed. This report, however, only addresses the Belle Fourche River and Horse Creek total maximum daily load (TMDL) assessments for the total suspended solids impairment.

Acknowledgements

The cooperation of the following organizations is gratefully appreciated. The assessment of Belle Fourche River and its watershed could not have been completed without their assistance.

Belle Fourche River Watershed Partnership

Belle Fourche Irrigation District

Butte Conservation District

Lawrence Conservation District

Elk Creek Conservation District

South Dakota Department of Game, Fish, and Parks

South Dakota Department of Environment and Natural Resources – Water Resource Assistance Program

South Dakota Department of Environment and Natural Resources – Water Rights

South Dakota School of Mines and Technology

United States Geological Survey

United States Bureau of Reclamation

United States Environmental Protection Agency – Non-Point Source Program

Cities of Sturgis, Belle Fourche, Spearfish, Whitewood, Lead, and Deadwood.

Counties of Lawrence, Meade, and Butte

Natural Resource Conservation Service

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Introduction

Section 303(d)(1) of the Clean Water Act requires that States, Territories, and authorized Tribes submit a list of water bodies to the United States Environmental Protection Agency (USEPA) for which the existing pollution controls are not stringent enough to attain the appropriate water quality standards. For each of these water bodies, a Total Maximum Daily Load (TMDL) must be established for the achievement of the impaired water quality criteria.

A TMDL report identifies the maximum amount of pollutants that a water body can assimilate and still maintain its beneficial uses. By definition, a TMDL is the sum of the individual waste load allocations for point sources of pollution, the load allocations for nonpoint sources of pollution, and a margin of safety to account for uncertainty. The margin of safety can be either included implicitly in the model by making conservative assumptions about the pollutant loads, or explicitly by reserving a fraction of the loading capacity to account for uncertainty.

Under the Clean Water Act, states are required to assign beneficial uses to all streams within the state. The water quality standards are established based on these designated beneficial uses. The beneficial uses of the Belle Fourche River include the following: 1) warm water permanent fish life propagation, 2) immersion recreation, 3) limited contact recreation, 4) fish and wildlife propagation, recreation, and stock watering, and 4) irrigation. The beneficial uses for Horse Creek include the following: 1) warm water semi-permanent fish life propagation, 2) limited contact recreation, 3) fish and wildlife propagation, recreation, and stock watering, and 4) irrigation. To support the warm water permanent and semi-permanent fish life propagation uses, the 30-day average total suspended solids (TSS) concentrations should not exceed 90 mg/L or a daily maximum of 158 mg/L.

The Belle Fourche River is identified in the 1998, 2002 and the 2004 South Dakota 303(d) Waterbody Lists as impaired due to observed concentrations of total suspended solids (TSS) above the state water quality standards. In the 2004 list, the Belle Fourche River is divided into five listing segments or reaches from the Wyoming border to its mouth. Each of these five segments is listed as impaired due to elevated TSS concentrations, so a TMDL must be established for each segment. The 2004 list also includes a fecal coliform bacteria impairment for the Belle Fourche River from the Wyoming border to near Fruitdale, SD. This report will address the TSS listing, while the bacteria listing will be addressed in a future TMDL report.

According to the 2004 South Dakota Integrated Report for Surface Water Quality Assessment (i.e. Integrated Report), the Belle Fourche River from the Wyoming border to Willow Creek failed to support its assigned uses due to high TSS and fecal coliform bacteria. The report states that agricultural activities are deemed a likely source of occasional impairment. The report also explains that a natural source of TSS originates from erosion of extensive exposed shale beds that lie along the river's course upstream of the city of Belle Fourche.

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Scope

The goal of the Belle Fourche River Watershed Assessment Project was to determine and document sources of impairments in the watershed and develop feasible recommendations for restoration. Several objectives were set in the Project Implementation Proposal (PIP) to achieve this goal. The following paragraphs describe these objectives and how they were accomplished.

Objective 1 was to collect discharge measurements and water quality measurements necessary to estimate water quality parameter loadings. Discrete discharge measurements were taken on a regular schedule (monthly) and during storm events. Continuous records of stage were collected with digital recorders, and the corresponding flows were calculated by USGS. Water quality samples were collected from 25 sites within the Belle Fourche River watershed stream network. Please see the Methods section of this report for a detailed description of flow measurements and water quality sampling regimen.

Objective 2 was the characterization of benthic macroinvertebrate communities within the Belle Fourche River watershed. Benthic macroinvertebrate samples were collected during the fall of 2001 and 2002 from 16 sites. A total of 53 samples (including five QA/QC samples) were collected in 2001, and 33 samples (including one QA/QC sample) were collected in 2002. These biological samples were collected to support the physical/chemical results.

Objective 3 was the use of approved quality assurance/quality control procedures to ensure that all samples are accurate and defendable. All QA/QC activities were conducted in accordance with the Nonpoint Source Program Quality Assurance Project Plan. Eleven field blanks and eighteen replicate samples were collected on randomly chosen dates for this assessment.

Objective 4 was to evaluate the agricultural impacts on water quality in the watershed through the use of the Natural Resource Conservation Service (NRCS) River Basin Study. The Belle Fourche River watershed and sub-watersheds were modeled by the NRCS during the River Basin Study, which was conducted concurrently with the 319 assessment. This River Basin Study was completed for the purpose of identifying critical areas of nonpoint source pollution to the surface waters in the watershed. As a product of this study, sources of nutrients and sediments to surface water in the Belle Fourche River watershed and its tributaries were to be identified and recommendations for remediation were to be presented in a final report. This report has not been completed. Watershed management activities are already underway; however, future watershed management activities may utilize this document as a tool to target priority areas.

Objective 5 was to include public participation and involvement in the assessment project. Belle Fourche River Partnership meetings were held on a regular basis (semi-monthly) in addition to several public informational meetings. News releases were also published in local newspapers.

Objective 6 was the development of watershed restoration recommendations. Feasible management practices were compiled into a list of recommendations for the development of an implementation project. Additional recommendations will become available upon the completion of the River Basin Study final report.

Objective 7 was to produce and publish a final project report containing 4 TMDLs, water quality results, and restoration recommendations. Based on the data and information compiled for the project, a description of the physical, chemical, and biological condition of the river and its tributaries was prepared for this report. A description of feasible restoration recommendations for use in planning the watershed nonpoint source implementation project was also included in this report.

The development of TMDLs for four streams (Belle Fourche River, Horse Creek, Whitewood Creek, and Bear Butte Creek) was originally slated for this project. However, not all TMDLs were included in this report. This report includes TMDLs for the TSS impairment of Horse Creek and five 303(d) listed segments of the Belle Fourche River. TMDLs will be completed for the following waterbodies in separate documents: Whitewood Creek (fecal coliform bacteria temperature impairments), Horse Creek (conductivity impairment), and the Belle Fourche River (fecal coliform bacteria impairment). Bear Butte Creek was listed in error for TSS impairment in 2002 and has since been delisted. Consequently, a TMDL is no longer required this stream.

Hypothesis

The hypotheses for this study are the following:

- Average shear stress (Tau, lbs/ft^2)) is greater for Horse Creek (HC4) due to water discharged from the irrigation system. This creek would not experience this flow if the Belle Fourche Irrigation District (BFID) were not irrigating acreage that discharges into Horse Creek and then into the Belle Fourche River.
- Shear stress is greater for the Belle Fourche River at Sturgis (BF7) due to the influence of irrigation than if the system were unaltered (BF7). This difference is more significant during the irrigation season. The resulting forces could be more destructive during the irrigation season due to saturated banks and the absence of riparian vegetation.
- Shear stress is significantly less for the Belle Fourche River at Fruitdale (BF3) due to the removal of flow to fill the Belle Fourche Reservoir.
- There is a relationship between shear stress difference (existing and estimated natural flows) and TSS.

Background

The Belle Fourche River is a natural stream that originates in Wyoming, drains parts of Butte, Lawrence and Meade Counties in South Dakota, and flows to the Cheyenne River in Meade County and ultimately to the Missouri River (Figure 1). The Belle Fourche River watershed is approximately 2,100,000 acres (3,300 sq. miles) in size in South Dakota and approximately 2,400,000 acres (3,700 sq. miles) in Wyoming.

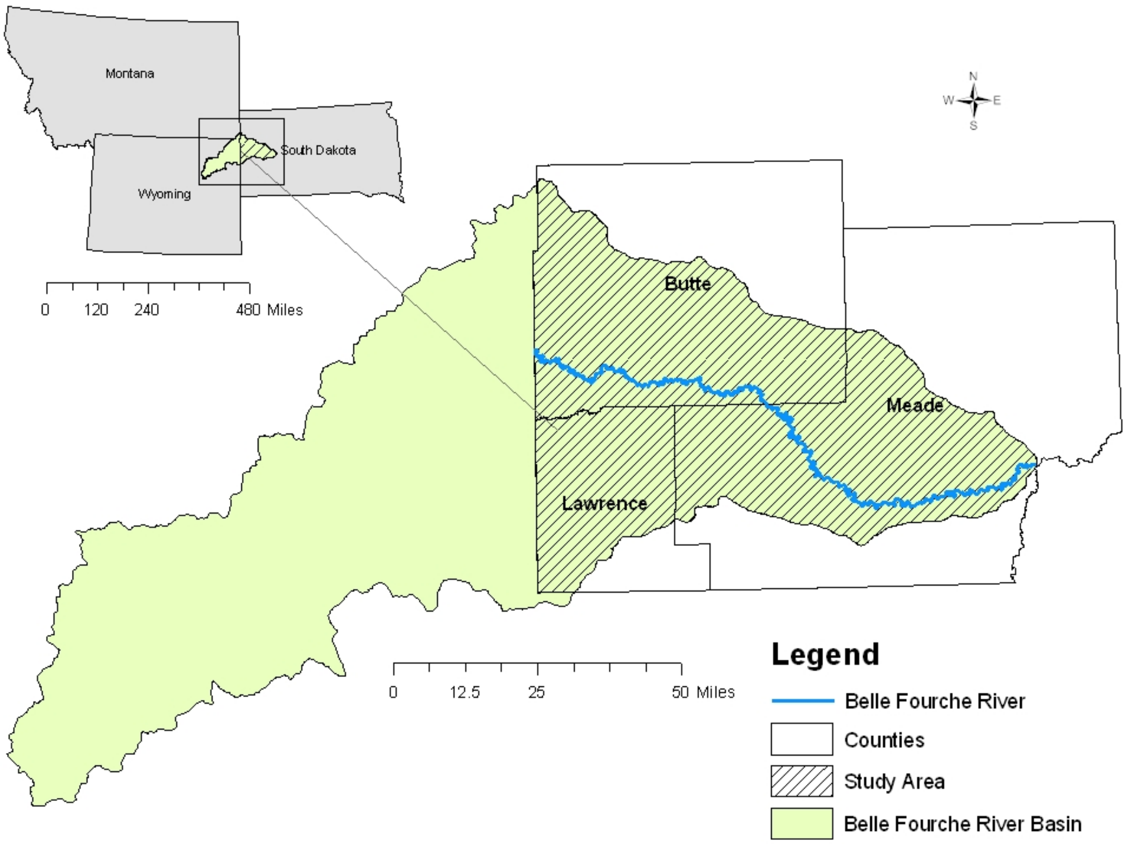


Figure 1. Location of the Belle Fourche River watershed in Butte, Lawrence, and Meade Counties, South Dakota.

Ecoregions

The South Dakota portion of the Belle Fourche watershed, shown in Figure 2, is comprised of seven level IV ecoregions. The ecoregion designations (Bryce 1998) include: Middle Rockies, Black Hills Foothills, Black Hills Plateau, Black Hills Core Highlands, Northwestern Great Plains, River Breaks, Semiarid Pierre Shale Plains, Dense Clay Prairie, and Missouri Plateau.

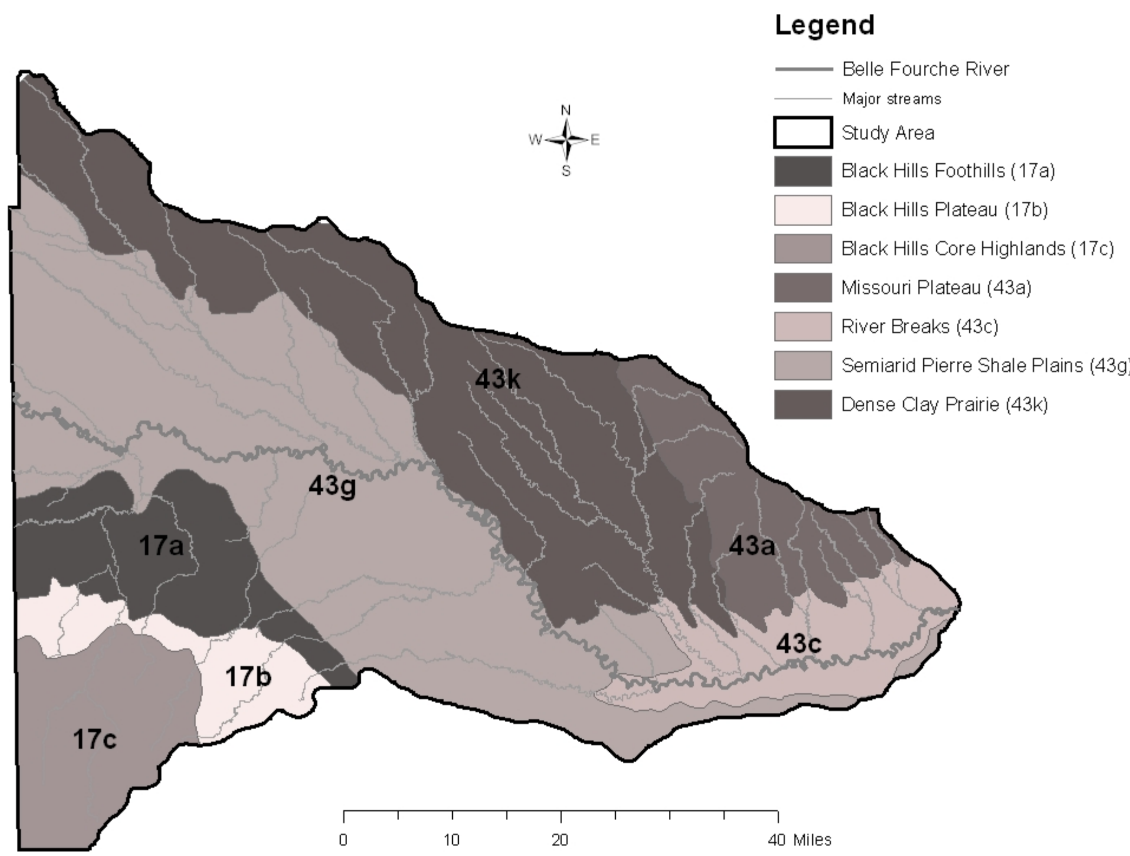


Figure 2. Location of ecoregions within Belle Fourche watershed in Butte, Lawrence, and Meade Counties, South Dakota.

Black Hills Foothills

The Black Hills Foothills are unglaciated, comprising a ring of hills surrounding the Black Hills mountainous core. This ecoregion represents 9% of the watershed. The Dakota Hogback separates the foothills from the plains. The Red Valley is inside the Hogback and encircles the Black Hills Dome. The geology is mesozoic sandstone and shale. The Hogback is composed of

Lakota Sandstone, Fall River Sandstone, Fuson Shale, and Minnewasta Limestone. The Red Valley is composed of the Spearfish Formation, red sandy shale. The soil types are Butche, Canyon, Enning, Nevee, Spearfish, Grummit, Tilford, Vale and Rekop.

The mean annual precipitation in this area is 15-17 inches, supporting a vegetation cover of ponderosa pine woodlands with a grass under story of little bluestem, grama grasses, and leadplant.

Land use includes cattle grazing and ranching with suburban development.

Black Hills Plateau

The Black Hills Plateau is characterized by plateau topography with broad ridges and entrenched canyons. In metamorphic areas, highly dissected tilted rock faces and steep canyon slopes are common. In limestone areas, caves and springs are common, supporting yearly stream flow. This ecoregion represents 5% of the watershed.

The geology is paleozoic limestone from the Englewood Formation of the Devonian Period and the Madison of the Mississippian Period, and sandstone and dolomite shale from the Deadwood, Whitewood and Minnelusa formations. The soils include Citadel, Vanocker, Grizzly, Buska, Pactola, Mocumont and Paunsaugunt.

The mean annual precipitation is 16-18 inches. The dominant natural vegetation is ponderosa pine forest. Aspen, paper birch and spruce are present in drainages and wet meadows. The under story consists of little bluestem, buffalo berry, chokecherry and snowberry.

Land use includes cattle grazing and farming, recreation, hunting and some timber production.

Black Hills Core Highlands

The highlands have mountainous topography with highly eroded outcrops and broad valleys. This ecoregion represents 8% of the watershed. Limestone plateaus are common above 5,500 feet. Granite intrusions form the major peaks, including Terry Peak, within the watershed.

The geology is precambrian igneous and sedimentary rock, and metamorphic schist, slates and quartzite. Higher elevations can be limestone. The soils are Stovho, Trebor, Virkula and Mocumont.

The mean annual precipitation is 19-24 inches, the maximum in the watershed. Vegetation is mostly ponderosa pine with white spruce, paper birch and aspen on northern- facing slopes. Under story vegetation includes sedges, bearded wheat grass, juniper, snowberry, Oregon grape and bearberry.

Land use includes mining in the metamorphic areas, recreation, hunting, timber production and woodland grazing.

River Breaks

The lower portion of the Belle Fourche River is in the River Breaks ecoregion and represents 4% of the watershed. These areas can be characterized as highly dissected hills and uplands bordering major rivers and alluvial plains.

The dominant geology is Cretaceous Pierre Shale. The soils are Sansarc, Opal, Bullock, Cabba, Amor, Flasher, Vebar, Temvik, Mandan, Cherry, Chama, Zahl, Lalie and McKeen.

The mean annual precipitation is 16-18 inches. The vegetation is mostly blue grama, western wheat grass, buffalo grass and some bluestem. Juniper and deciduous trees are present on north-facing slopes. Cottonwood gallery forests exist on the floodplain.

Land use is restricted to mostly cattle grazing in this ecoregion due to the steep slopes.

Semiarid Pierre Shale Plains

The Semiarid Pierre Shale Plains are undulating to rolling plains and is the dominant ecoregion within the watershed, representing 40% of the area. Steep-sided, incised stream channels dominate this ecoregion.

The geology is predominately Cretaceous Pierre Shale. The soils include Pierre, Samsil, Lismas, Satanta and Nunn.

The mean annual precipitation is 14 inches. The vegetation includes short grass prairie grasses such as western wheat grass, green needle grass, blue grama and buffalo grass.

Land use is predominantly cattle grazing, rangeland and dry land farming of winter wheat and alfalfa.

Dense Clay Prairie

The Dense Clay Prairie is characterized as rolling prairie with intermittent streams in rolling valleys, and represents 28% of the watershed.

The geology is similar to the Semiarid Pierre Shale Plains. The soil types are Kyle, Pierre, Winler, Swanboy, Hisle and Lismas.

The mean annual precipitation is 13 inches. The vegetation is primarily western wheat grass with no short grass under story.

Sheep and cattle ranching dominate land use. The grassland cover is fragile and easily disturbed.

Missouri Plateau

The Missouri Plateau is characterized as moderately dissected level to rolling plains with isolated sandstone buttes, and represents 6% of the watershed. The geology is tertiary sandstone, shale and some coal. The soils include Vebar, Chama and Amor.

The mean annual precipitation is 15-17 inches. The vegetation is primarily blue grama, wheat grass, needle grass and a little bluestem.

Land use is dryland farming and cattle grazing. Spring wheat is a predominant crop with native areas consisting of mixed grasses.

Hydrology

Table 1 shows the annual flow from the major sources of inflow and outflows to the Belle Fourche River within the watershed for water year 2001. The table presents the annual mean flow and the flow rate that has been exceeded by a designated percentage (i.e. 10%, 50%, and 90%) of the time (Burr 2001). Spearfish Creek at Spearfish discharges upstream of the Redwater River and contributes approximately half of the Redwater discharge into the Belle Fourche River. On average, over half the flow is taken from the Belle Fourche River just down stream of the town of Belle Fourche to fill the Belle Fourche Reservoir. Whitewood Creek and Horse Creek provide a small amount of water to the system. In general, the majority of water comes into the watershed from the Belle Fourche at the state line and from the Redwater River. Belle Fourche Reservoir inlet takes almost half of this inflow and delivers it to the reservoir. Horse Creek and Whitewater add similar quantities of water.

Table 1. Water Year 2001 major flows to the Belle Fourche River.

	Belle Fourche at State Line	**Spearfish Creek at Spearfish**	**Redwater River above Belle Fourche**	**Belle Fourche Reservoir Inlet**	**Whitewood Creek above Vail**	**Horse Creek above Vail**	**Belle Fourche River at Elms Springs**
Annual Mean Flow (cfs)	165	70.8	165	183	21.3	32.2	230
10 % Exceeds (cfs)	225	84	229	311	46	57	538
50 % Exceeds (cfs)	184	68	184	181	14	11	142
90 % Exceeds (cfs)	64	59	64	26	5.6	2.2	30

The hydrology of the Belle Fourche watershed is significantly altered due to irrigation. The seven major operations that result in this alteration are the following:

- operation of the Belle Fourche reservoir,
- operation of the Keyhole reservoir,
- operation of the Belle Fourche Irrigation District (BFID),
- in- stream removal by the Redwater and Spearfish Irrigation Districts (RWID),
- in-stream removal of irrigation water from the Belle Fourche River,
- operation of the Homestake Power Facility, and
- Homestake's transfer of water from Spearfish Creek to Whitewood Creek.

Belle Fourche Reservoir

The Belle Fourche Reservoir is located in Butte and Meade counties in western South Dakota, about 25 miles east of the Wyoming-South Dakota state line. It is an off-stream storage reservoir supplied by water diverted from the Belle Fourche River. Project construction started in 1905 and the first irrigation water was delivered in 1907. Nearly all the water for the Belle Fourche Reservoir is obtained from the Belle Fourche River. Upstream of the diversion dam, the drainage basin area is about 4,000 square miles. Of this total, about 2,000 square miles are upstream of the Keyhole Dam and Reservoir in Wyoming.

At the diversion dam, about 120,000 ac-ft is diverted annually from the Belle Fourche River through a 6.5-mile inlet canal. A small portion of the inlet canal flow is delivered into the Johnson Lateral prior to reaching the reservoir. The reservoir has an active conservation capacity of 186,000 ac-ft (BOR 1998). The BFID legally is able to divert all of the flow in the Belle Fourche River except 5 cfs until its storage right of 185,000 ac-ft is met.

Water from the reservoir is released into two canals (North Canal and South Canal). These two canals supply water to about 54,500 acres of project lands for irrigation. Figure 3 shows the major laterals and canals. Within the project lands, there are 94 miles of main canals, 450 miles of laterals, 255 miles of open drains and 7 miles of pipe drains (BOR 1998). The irrigation system typically starts operation in May and stops operation in September. The operating agent for the Belle Fourche Reservoir and Irrigation system is the BFID.

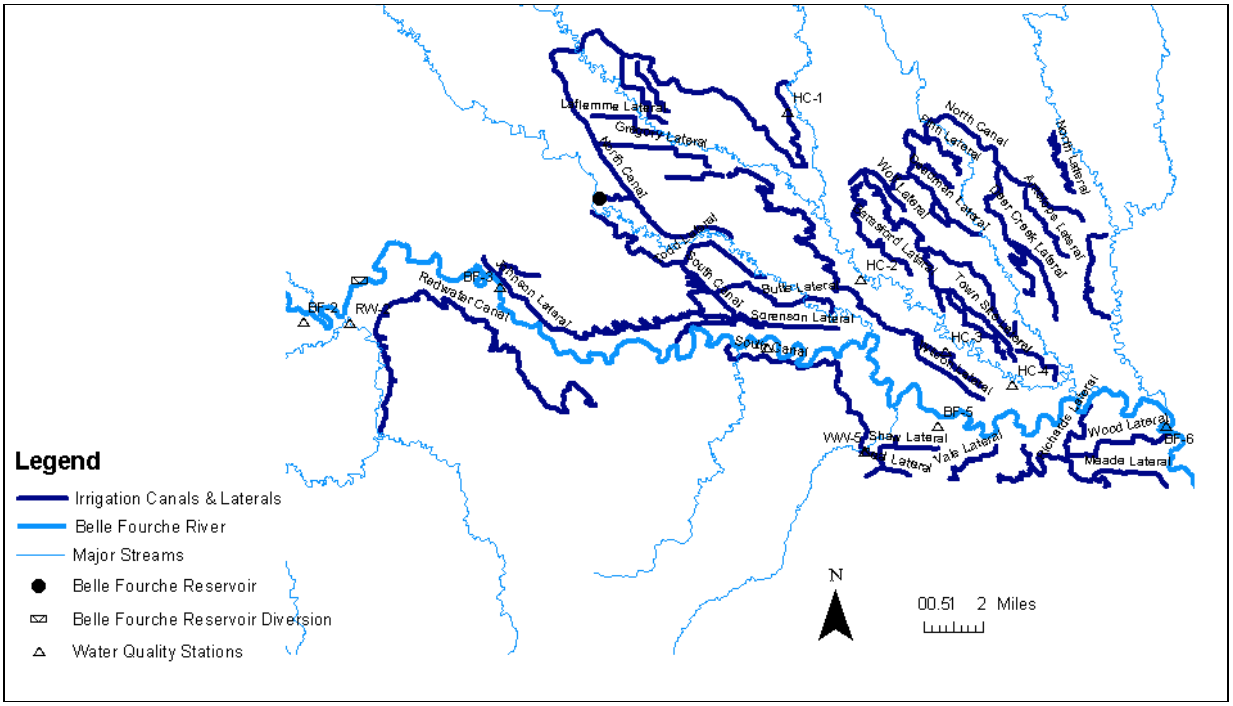


Figure 3. Location of the Belle Fourche Irrigation District (BFID) and the Red Water Irrigation District (RWID) canals and laterals.

The water balance for the BFID is shown in Figure 4 for water year 1995-96. Approximately 36% of the water delivered to both canals is wasted through transportation losses such as canal seepage and operational waste. The system is a gravity delivery system and uses manually operated valves for control. Operational waste is water that discharges primarily from the end of laterals and canals into the natural drainage streams such as Horse Creek, Willow Creek and Nine Mile Creek, ultimately discharging into the Belle Fourche River. This water bypasses croplands and is not used for irrigation.

Approximately 64% of the water delivered to the canal is transported to the farmer. The crops use approximately 32%. The other 32% is wasted and flows to the drainage system and nearby intermittent streams. The primary method of irrigation is flood irrigation delivered by earthen trenches or gated pipe.

In summary, an average of 55,600 ac-ft is delivered to the canals. Approximately 18,000 ac-ft is used by the crops and the other 37,600 ac-ft (68%) is lost or wasted.

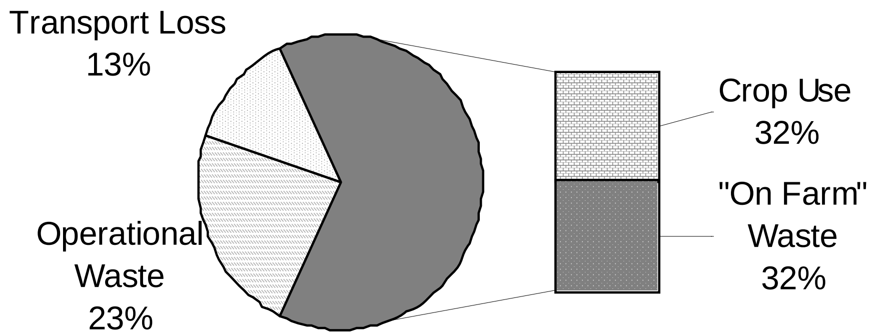


Figure 4. Water balance for Belle Fourche Reservoir outlet flows.

BFID operational information related to reservoir releases during the water quality monitoring period 2001-2002 were as follows:

- 2001
  - Starting May 14, average: 248 cfs
  - June average: 274 cfs
  - July average: 685 cfs
  - August average: 643 cfs
  - September average: 357 cfs
  - South Canal shut-off, 9/22
  - North Canal shut-off, 10/6
- 2002
  - Starting May 6, average: 252 cfs
  - June average: 652 cfs
  - July average: 679 cfs
  - August average: 547 cfs
  - September average: 317 cfs
  - South Canal shut-off , 9/24
  - North Canal shut-off, 10/24

Keyhole Reservoir

Keyhole Reservoir is owned and operated by the Bureau of Reclamation. Keyhole Reservoir is on the Belle Fourche River about 17 miles northeast of Moorcroft, Wyoming. Keyhole was initially built in the 1950s to provide a supplemental water supply to the Belle Fourche Reservoir and for flood control. The reservoir was completed in 1952. It has a conservation capacity of 193,753 ac-ft. The inflows and storage in the reservoir are allocated 10% to Wyoming users and 90% to South Dakota users subject to prior rights.

In 1993 the BFID executed a long-term contract for the use of 7.7% of the active storage space in Keyhole Reservoir. This contract provides BFID 14,307 ac-ft of storage space and an option to purchase additional storage space if available. This water not only supplements the Belle Fourche Reservoir, but also during low flows, is the only source of water for about 2,400 acres of land served by the Inlet Canal and Johnson Lateral. In 1985, the Cook County Irrigation District (CID), located mostly in Wyoming, contracted for 18,080 ac-ft of space in the Keyhole Reservoir. The allocated space is used by each organization to store its pro rata share of inflows to the Keyhole Reservoir. Releases from the reservoir for these storage accounts usually occur between June and September. Peak irrigation demand for both BFID and CID is between 125 and 175 cfs (BOR 1998).

Keyhole Reservoir releases during the water quality monitoring period 2001-2002 were as follows:

- 2001
  - July 9-17, 100 cfs
  - August 10-22, 80 cfs
- 2002
  - Starting June 2, June average: 145 cfs
  - July average: 172 cfs
  - August average 100 cfs
  - Ending September 16

Redwater Irrigation District

The Redwater Irrigation Ditch is the other significant diversion within the watershed. There are approximately 5,300 acres under irrigation from this ditch. The delivery ditch to the Redwater Irrigation Association (RIA) is approximately 23 miles long. High diversion rates are required to deliver water to lands located at the lower end of the ditch. The flume has a capacity of approximately 177 cfs, with a vested water right of 151.7 cfs, and may not exceed 3 ac-ft per irrigated acre per year, and must be used during April 1 – October 31. The Water Management Board recognizes a 50% water loss due to the irrigation method and seepage from the ditch. The Board also requires that water be bypassed for downstream domestic use, livestock water and senior water rights. The end of the canal flows into Maloney Creek, which discharges into the Belle Fourche River approximately 10 miles downstream of the town of Belle Fourche (Ahadi 1992).

Homestake Power Facility

Most of the flow in Spearfish Creek is diverted around the bedrock loss zone of the Madison and Minnelusa formations. A diversion dam is located about 5 miles south of Spearfish. The flow is routed through an aqueduct to a power plant located in Spearfish. Measurements by the USGS in 1995 resulted in an estimated maximum diversion rate of 115 to 135 cfs. Losses within the aqueduct are estimated to average about 2 cfs (Hortness 1998).

Climate

Four meteorological stations were used to represent the watershed. Table 2 presents the annual average climatic parameters for these sites. The Spearfish station is influenced by the Black Hills, resulting in higher precipitation and snow levels. Temperatures are similar at all sites.

Table 2. Annual averages for meteorological data within the Belle Fourche watershed.

Location	Record Period	Air Temp$_{max}$ Avg (^{0}F)	Air Temp$_{min}$ Avg (^{0}F)	Precip Avg (in)	Snow Avg (in)
Spearfish	1/1948-12/2000	59.4	34.9	22.05	69.17
Newell	1/1948-12/2000	58.1	32.2	15.03	30.45
Belle Fourche 22NNW	5/1980-12/2000	58.2	31.6	14.45	20.46
Elms Springs 3 ESE	6/1988-12/2000	60	34.4	16.57	29.58

Threatened and Endangered Species

The whooping crane (*Grus americana*) is the only state and federally listed endangered species documented in the Belle Fourche River watershed. The finescale dace (*Phoxinus neogaeus*) is the only other state listed endangered species documented in the study area.

The bald eagle (*Haliaeetus leucocephalus*) is the only state and federally listed threatened species documented in the Belle Fourche River watershed. Other state listed threatened species documented in the study area are the American dipper (*Cinclus mexicanus*) and longnose sucker (*Catostomus catostomus*).

The activities of the Belle Fourche River watershed assessment did not adversely affect any of the above threatened or endangered species.

Methods

Water Quality Samples

Water samples were collected during two seasons in 2001-02. Samples were collected monthly from 6/13/01 through 10/25/01 and from 3/28/02 through 10/25/02. Figure 5 shows the location of the monitoring sites and Table 3 summarizes the number and type of samples taken at each station along with the site name and USGS reference number. A total of 231 samples were collected, including 12 field blanks and eight duplicates. Field blanks were prepared using de-ionized water and duplicates were taken in the same manner as the stream sample. Forty storm samples were collected during 10 different storms at 23 different sites. Separate monthly samples were not taken at individual sites when storm samples were collected for that month. However, sites where storm samples were not collected were sampled within the monthly time frame. Eight samples were collected at BF1 during two time-frames when water was released from the Keyhole reservoir to supply water to the BFID.

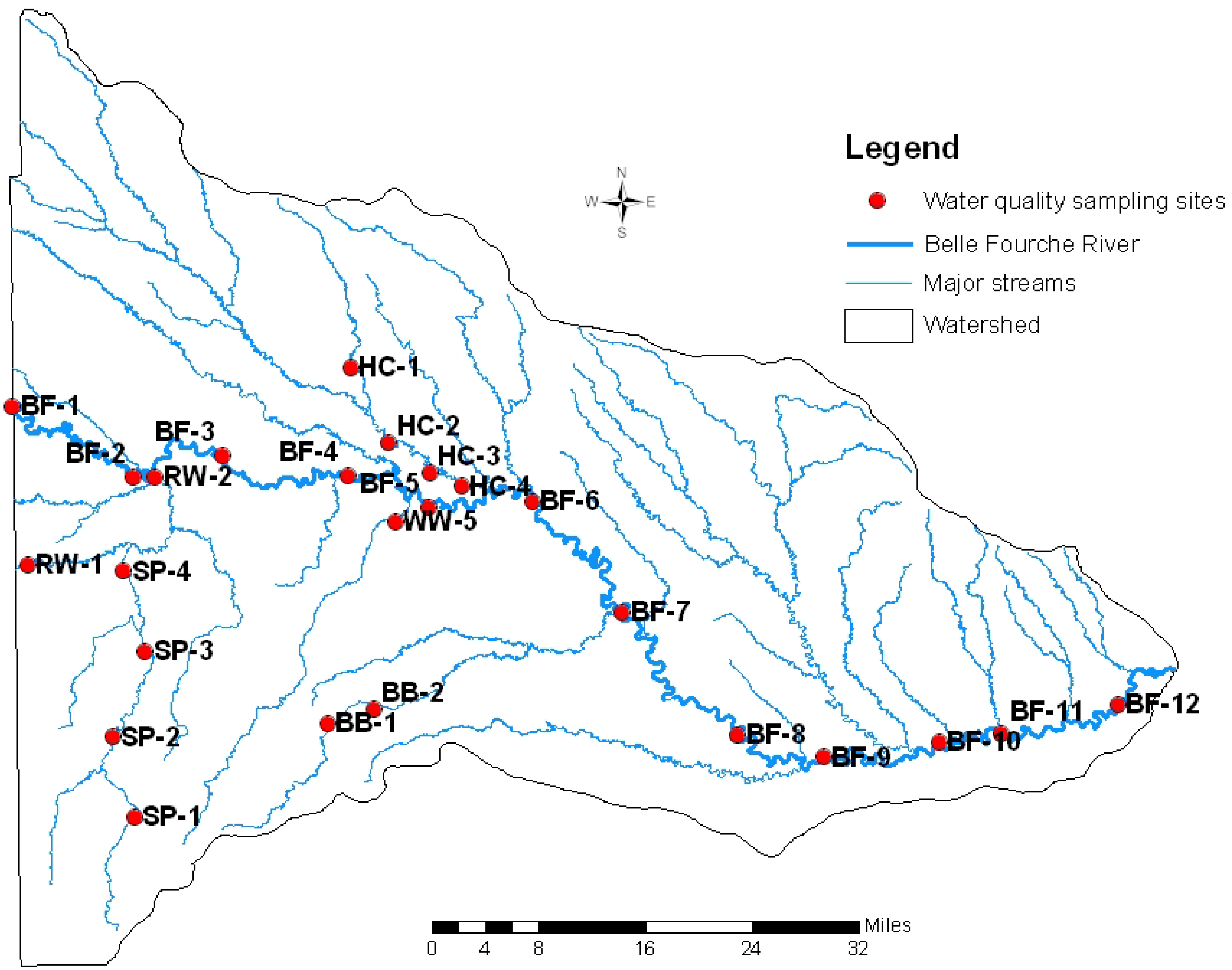


Figure 5. Belle Fourche River Waterhsed showing major streams and location of sampling sites.

Table 3. Sample summary for years 2001-02.

Site ID	USGS Reference Number	Year	Samples	Blanks	Dups	Storm
BB1	Bear Butte Creek near Galena	2001	7			1
BB2	06437400	2001	10		1	3
SP1	06430770	2001	7			2
SP2	Spearfish Creek above Spearfish	2001	7	1		1
SP3	06431500	2001	7		1	2
SP4	Spearfish Creek below Spearfish	2001	9			4
RW1	06430500	2001	7	2		1
RW2	06433000	2001	7			1
HC1	Horse Creek above Indian Creek	2002	8	1		1
HC2	Horse Creek below Indian Creek	2002	9			1
HC3	Horse Creek at HWY 79 bridge	2002	10		1	1
HC4	06436760	2002	12			3
BF1	06428500	2001-02	21	1	2	1
BF2	Belle Fourche River at Belle Fourche	2001	7	1		1
BF3	06436000	2001-02	15		1	1
BF4	Belle Fourche River at Nisland	2001	8	1		1
BF5	Belle Fourche River at Vale	2001-02	13	2		2
BF6	Belle Fourche River near Vale	2001-02	13			2
BF7	06437000	2001-02	12	1		2
BF8	Belle Fourche River above Hereford	2002	10	1	1	2
BF9	Belle Fourche River near Hereford	2002	9		1	3
BF11	06438000	2001-02	13	1		3
BF12	Belle Fourche River near mouth	2002	1			
ELM		2002	1			1
NINE MILE		2002	4			
WILLOW		2002	4			
Total			231	12	8	40

Samples were collected, stored and shipped following the Standard Operating Procedures for Field Samplers (DENR 2003). The samples were then given to Energy Laboratories located in Rapid City, SD for analysis. Chlorophyll-*a* samples were analyzed by DENR at the Floyd L. Matthew Environmental Education and Training Center Laboratory.

Field Measurements

During sample collection, field measurements were also taken. Table 4 lists the parameters measured in the field during sample collection. These measurements were made using the YSI Sonde 6000 series instrument. Stage was recorded using the USGS gauge and corresponding flow calculated by USGS.

Table 4. List of field measurements.

PHYSICAL/FIELD PARAMETERS
Air temperature
Discharge
Dissolved oxygen
Field pH
Specific Conductance
Turbidity
Stage
Visual observations
Water temperature

Flow Measurements

Water level recorders were set up by USGS and ran May - November, 2001 at the following locations:

- BF2 (Belle Fourche River at Belle Fourche),
- BF4 (Belle Fourche River at Nisland),
- BF6 (Belle Fourche River near Vale),
- SP2 (Spearfish Creek above Spearfish),
- SP4 (Spearfish Creek below Spearfish),
- BB1(Bear Butte Creek near Galena), and
- BB2 (Bear Butte Creek at Sturgis).

In addition, the following existing monitoring sites were used:

- BF1 (Belle Fourche River at WY-SD State line),
- BF3 (Belle Fourche River near Fruitdale),
- BF5 (Belle Fourche River at Vale),
- BF7 (Belle Fourche River near Sturgis),
- BF11 (Belle Fourche River near Elm Springs),
- SP1 (Spearfish Creek near Lead),
- SP3 (Spearfish Creek at Spearfish),
- RW1 (Redwater River at WY-SD State line), and
- RW2 (Redwater River above Belle Fourche)
- These sites operated during the entire project during April – November, 2001-02.

Water level recorders were set up by USGS and ran April - November, 2002 at the following locations:

- BF8 (Belle Fourche River above Hereford),
- BF9 (Belle Fourche River near Hereford),
- HC1 (Horse Creek above Indian Creek),
- HC2 (Horse Creek below Indian Creek), and
- HC3 (Horse Creek at HWY 79 bridge near Newell).

Miscellaneous discharge measurements were taken at BF10 (Belle Fourche River below Hereford) and BF12 (Belle Fourche River near mouth) during low flow. In addition, the following existing monitoring sites were being used:

- BF1 (Belle Fourche River at WY-SD State line),
- BF3 (Belle Fourche River near Fruitdale),
- BF5 (Belle Fourche River at Vale),
- BF7 (Belle Fourche River near Sturgis),
- BF11 (Belle Fourche River near Elm Springs), and
- HC4 (Horse Creek above Vale)
- BB2 (Bear Butte Creek at Sturgis) was left operational for April-May 2002 for spring runoff.

One discharge measurement and sample was taken at BF12 (Belle Fourche River near mouth) during low flow. Three additional flow and chemical samples were taken to better characterize the irrigation return flows at Willow Creek and Nine Mile Creek during the summer of 2003.

In addition, two continuous water-quality monitoring stations were installed by USGS at Belle Fourche River near Sturgis (BF7) and Belle Fourche River near Elm Springs (BF11). Continuous water-quality parameters that were measured included water temperature, pH, specific conductance, dissolved oxygen, and turbidity. The water quality data was collected during 2003.

Water quality samples for metals analysis were collected by USGS. Sites selected for trace element sampling in 2001 included BB1, BB2, SP2, SP4, RW1,RW2, BF2, and BF5. Samples were collected in October and November. The following field measurements were also collected: flow, water temperature, air temperature, pH, specific conductance, dissolved oxygen, and barometric pressure.

In 2002, trace element sampling took place at BF3, BF5, HC1, HC2, HC3, HC4, BF6, BF7, Willow Creek, and Nine Mile Creek. Trace element analyses were conducted at the USGS National Water Quality Laboratory in Colorado. Discrete discharge measurements were taken by USGS at each site every 4-6 weeks plus during storm events. Continuous records of stage were obtained with digital recorders. Discharge measurements and stage records were used to generate stage-discharge relationships. These measurements, along with the water quality data, will be published in the USGS South Dakota 2001-02 Annual Water-Data Reports, which should be completed in the spring of 2002 and 2003.

Biological

Anthropogenic impacts on biological integrity of water resources are multifaceted and cumulative. Grab samples, which measure the quality of water at the time of sampling, are not always sufficient indicators of water quality. Biomonitoring allows a better conception of intricate interactions in the complex environment of water bodies. For this reason, biomonitoring was added to the assessment regimen.

Benthic macroinvertebrate samples were collected during the fall of 2001 and 2002 from 16 sites (see Figure 6). The samples were collected following the Standard Operating Procedures for Field Samples (DENR 2003). A total of 53 samples (including five QA/QC samples) were collected in 2001, and 33 samples (including one QA/QC sample) were collected in 2002.

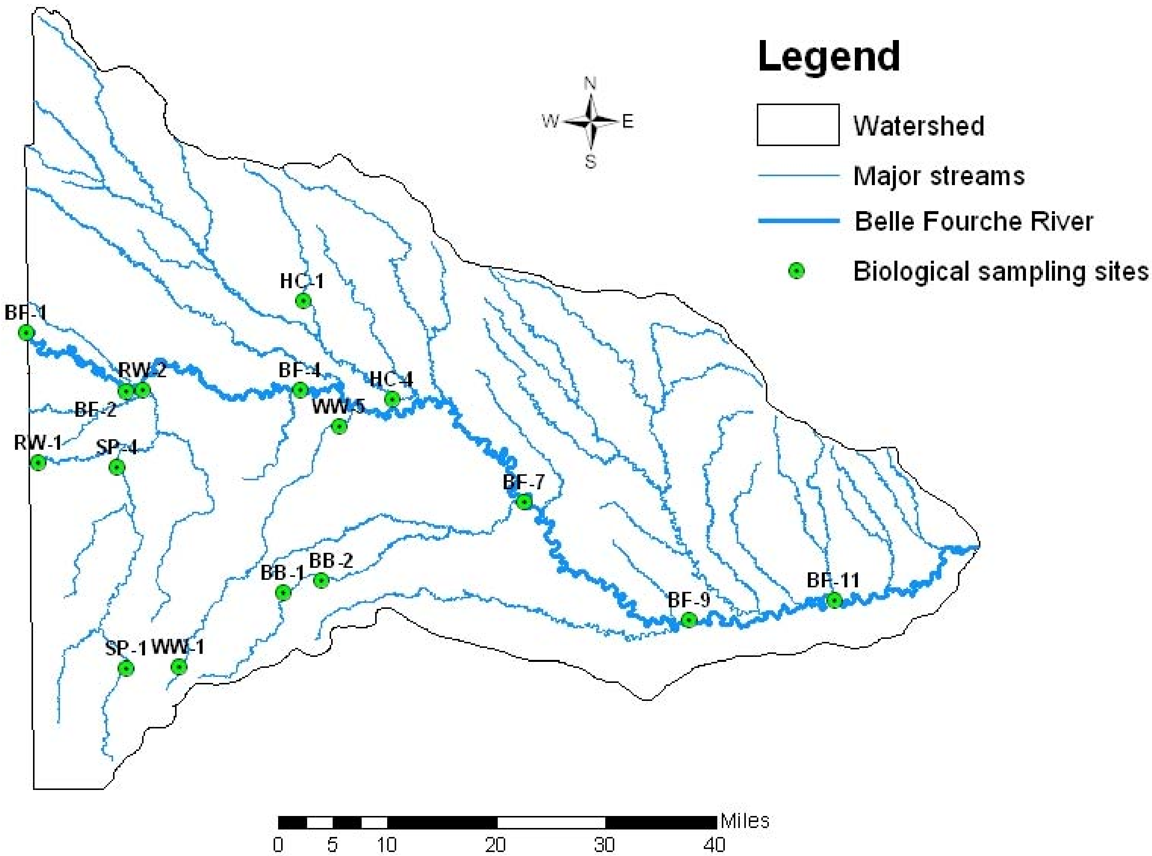


Figure 6. Location of biological sampling sites in the Belle Fourche River watershed.

As part of the biological sampling, habitat condition at each site was assessed to determine the impact of these parameters on the water quality of the stream. Physical parameters included the following:

- available cover,
- pool substrate/embeddedness,
- pool variability,
- sediment deposition,
- channel flow status,

- channel alteration,
- channel sinuosity,
- bank stability,
- bank vegetation, and
- riparian and habitat value.

Each area was rated on a scale of 0 to 20 (0 being poorest). The form used for analysis was the Rapid Habitat Assessment Form for glide/pool streams (EPA 2001a).

Water Quality Parameters

All samples were analyzed by Energy Laboratories in Rapid City. The samples were analyzed for bacterial, inorganic and nutrient components.

Table 5 presents the fifteen constituents measured using EPA's analytical methods and detection levels.

Table 5. List of chemical parameters measured.

CHEMICAL
Alkalinity
Ammonia as N
Ammonia, Un-ionized
Nitrate + Nitrite as N
Nitrogen, Total Kjeldahl (TKN)
Total Dissolved Phosphorus
Total Phosphorus
Total Solids
Total Dissolved Solids
Total Suspended Solids
Total Volatile Suspended Solids
Turbidity
Laboratory pH
Laboratory Specific Conductance
Fecal Coliform Bacteria

DNA "fingerprinting" of E. coli samples were collected at SP4 and BB2 to obtain an indication if the coliform were from humans or animals. The DNA samples were collected using procedures similar to that for coliform samples. The samples were preserved and shipped to Paleoscience, Inc. using preservation techniques provided by Paleoscience.

Results

Quality Assurance/Quality Control (QA/QC)

Quality assurance/quality control (QA/QC) samples were collected throughout the project period to ensure proper laboratory and field sampling methods. Eleven field blanks and eighteen replicate samples were collected on randomly chosen dates for this assessment.
Blank samples were processed, contained, and analyzed using the same methods as routine samples. If proper laboratory analysis and field collection procedures are used, the analysis results for blank samples should be below the detection limits of each parameter. During this assessment, blank sample values above the detection limits were observed for the following parameters: fecal coliform bacteria, alkalinity, total solids, total dissolved solids, total suspended solids, total volatile suspended solids, and total phosphorus. In most cases, these values were only slightly above detection limits. Only one blank sample resulted in a total suspended solids concentration above the detection limit. This blank sample had a suspended solids concentration of 7 mg/L (detection limit = 5 mg/L). These instances of slight contamination were possibly caused by use of different distilled water brands or field contamination during handling.

Replicate sample results were examined using the Industrial Statistic (%I). To calculate the industrial statistic, the following equation was used:

$$\%I = (A-B)/(A+B)*100$$

%I = Industrial Statistic
(A-B) = Absolute difference
(A+B) = Absolute sum

The poorest (i.e. largest) Industrial Statistic was observed for the fecal coliform bacteria parameter (%I = 10.8). This can be explained by the naturally variable concentrations of these organisms in surface water. The average %I for total suspended solids was 8.6%. See Appendix C for all QA/QC data. Although the target number of duplicate and blank samples (10% of the total number of routine samples) was not met, the amount QA/QC data gathered provides adequate evidence of high quality data.

Water Quality Standards Exceedances

Table 6 presents a list of sites where at least one sample exceeded a water quality standard. State water quality standards were exceeded at 20 monitoring sites during this assessment. However, to be included on the 303(d) list or to require a TMDL, the site must have 20 samples for any one parameter; and 10% of those samples must exceed the water quality standard for that parameter. If greater than 25% of samples exceed water quality standards, this threshold was reduced to 10 samples, since impairment is more likely. In addition, the sample threshold has recently been reduced to five samples if 100% of the samples indicated full or nonsupport for that parameter. Sites that met the listing criteria include: BF1 and BF2 for the parameters TSS and fecal coliform bacteria; BF4, BF5, BF7, and BF11 for TSS; and HC4 for TSS and conductivity.

Table 6. Exceedances identified for samples collected 2001-02.

Stream	Stations	Standards Exceeded	Beneficial Uses
Bear Butte Creek	BB2	Fecal Coliform	Limited contact recreation
	BB2	Un-ionized ammonia as N	Coldwater permanent fishery
	BB2	Temperature	Coldwater permanent fishery
Belle Fourche River	BF1,BF2,BF3,BF4,BF5,BF6,BF8	Fecal Coliform	Immersion Recreation
	BF5	pH	Warmwater permanent fishery
	BF3,BF7,BF11	Temperature	Warmwater permanent fishery
	BF1,BF2,BF5,BF11	Total Suspended Solids	Warmwater permanent fishery
Horse Creek	HC1,HC2,HC3,HC4	Conductivity	Irrigation waters
	HC1	Dissolved Oxygen	Warmwater marginal fishery
	HC4	pH	Warmwater semi permanent fishery
	HC1,HC2,HC4	Total Dissolved Solids	Fish and wildlife propagation
	HC4	Total Suspended Solids	Warmwater semi permanent fishery
Redwater	RW1	Temperature	Coldwater permanent fishery
Spearfish Creek	SP3,SP4	Fecal Coliform	Immersion Recreation
	SP1,SP2,SP3,SP4	pH	Coldwater permanent fishery
	SP4	Total Suspended Solids	Coldwater permanent fishery
Willow Creek	Willow	Conductivity	Irrigation waters
	Willow	Total Dissolved Solids	Fish and wildlife propagation

Suspended Solids

The focus of this TMDL report is an assessment of TSS in the Belle Fourche River and Horse Creek. Table 7 presents the descriptive statistics for TSS for the Belle Fourche River and the major tributaries for the sample period (Q1 and Q3 represent the first and third quartile). The mean TSS concentration for sites BF1, BF2 and HC4 are all above the TSS standard of 158 mg/L.

The mean TSS concentration for site BF2 is dominated by two samples. On 6/14/01, a sample was collected as part of storm runoff containing TSS concentrations of over 2,000 mg/L. Another sample, taken at the start of a Keyhole irrigation release, contained concentrations also over 2,000 mg/L. The next highest sample concentration was 20 mg/L. This was a one-season site, and this high concentration may bias the mean at this site. Additional sampling is suggested at site BF2 prior to drawing conclusions about the impairment of this site.

Table 7. Descriptive statistics for TSS analysis, Belle Fourche River and tributaries, 2001-2002.

Station	Number of Samples	Mean (mg/L)	Median (mg/L)	Min (mg/L)	Max (mg/L)	Q1 (mg/L)	Q3 (mg/L)	Standard Deviation (mg/L)
BB2	10	13	1	1	46	1	35	19
BF4	8	25	29	1	43	9	38	16
RW2	7	28	14	5	85	7	59	31
BF9	9	29	32	1	62	11	40	19
BF7	12	29	40	1	58	5	47	21
BF8	10	35	30	1	110	9	52	33
BF6	13	36	38	1	73	19	51	21
BF3	15	39	21	1	130	9	61	38
BF11	13	45	41	1	190	13	59	49
BF5	13	62	43	5	250	18	60	72
SP4	9	68	17	1	280	3	139	104
WW5	7	121	38	1	612	15	85	218
HC4	12	266	100	6	1300	42	183	421
BF1	21	347	240	1	1800	18	325	463
BF2	7	643	24	1	2400	1	2000	1070

Table 8 shows the results from a Kruskal-Wallis Test for one-way design, which tests the equality of medians for the population. It is a generalization of the procedure used by the Mann-Whitney test, offering a nonparametric alternative to the one-way analysis of variance. The Kruskal-Wallis hypotheses are as follows:

H_0: the population medians are all equal.
H_1: the population medians are not equal.

The z-value indicates how the mean rank for a single group differs from the mean rank for all observations. Zero means there is no difference. The H statistic had a p-value of 0.032 adjusted for ties, indicating there is a 97% probability that the null hypothesis can be rejected in favor of the alternative hypothesis of at least one difference among the population (Minitab, 1998). Sites BB2 and BF4 had z-values less than –1, indicating they are the least impaired due to sediment compared to the other sites. Sites BF3, BF7, BF8, BF9, SP4 and RW2 are less impaired, and sites BF2, BF5, BF6, BF11 and WW5 are more impaired. Sites BF1 and HC4 had z-values greater than 2, indicating they are the most impaired compared to the other sites.

Table 8. Kruskal-Wallis test Z-values for TSS concentrations.

Station	Rank	Z
BB2	38.7	-3.04
BF4	64.6	-1.14
RW2	67.3	-0.91
BF7	71.5	-0.89
BF9	71.1	-0.8
SP4	71.6	-0.77
BF3	75.9	-0.64
BF8	76.8	-0.45
BF11	82.3	-0.1
BF6	82.7	-0.07
BF2	82.9	-0.04
WW5	92	0.48
BF5	91.3	0.61
HC4	119.8	2.71
BF1	116.5	3.36

Figure 7 shows the results of the TSS analysis for the Belle Fourche River and its major tributaries that were sampled, including Belle Fourche River, Red Water River, Horse Creek and Whitewood Creek. The line within the box indicates the median, the bottom of the box is the first quartile, and top of the box is the third quartile. The boxes extend to the adjacent value within the upper/lower limits and the asterisks are the outliers (outside the first and third quartile). Sites BF1, BF2, HC4 and WW5 all have higher medians and larger first and third quartiles than the other sites, indicating a higher variance. Sites BF1, HC4 and WW5 all have significant outliers. Site BF2 does not have outliers because there were two samples collected with TSS concentrations above 2,000 mg/L as discussed above.

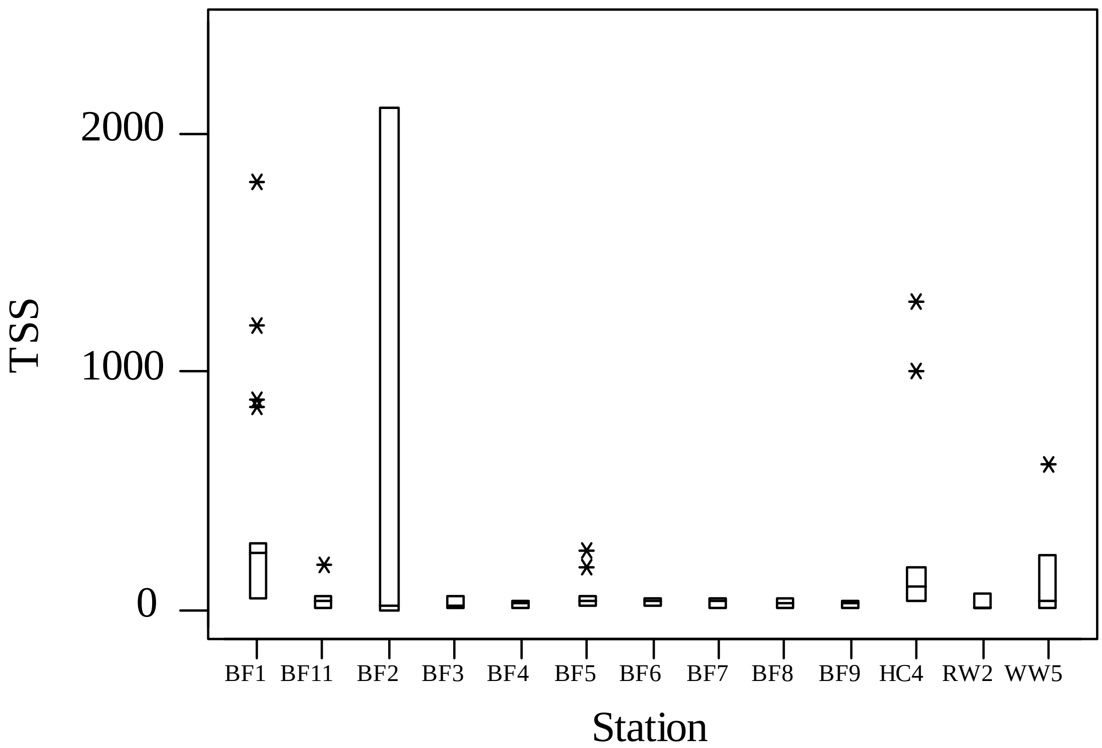


Figure 7. Box plot of TSS concentrations for Belle Fourche River and major tributary sites, 2001-2002.

The correlation between turbidity and total suspended solids was analyzed for the sites located on the Belle Fourche River. Figure 8 shows a high correlation coefficient of $R^2 = 0.98$, indicating a statistically significant relationship between turbidity and total suspended solids. Using this relationship, turbidity can be used as a surrogate to evaluate TSS concentrations in the Belle Fourche River.

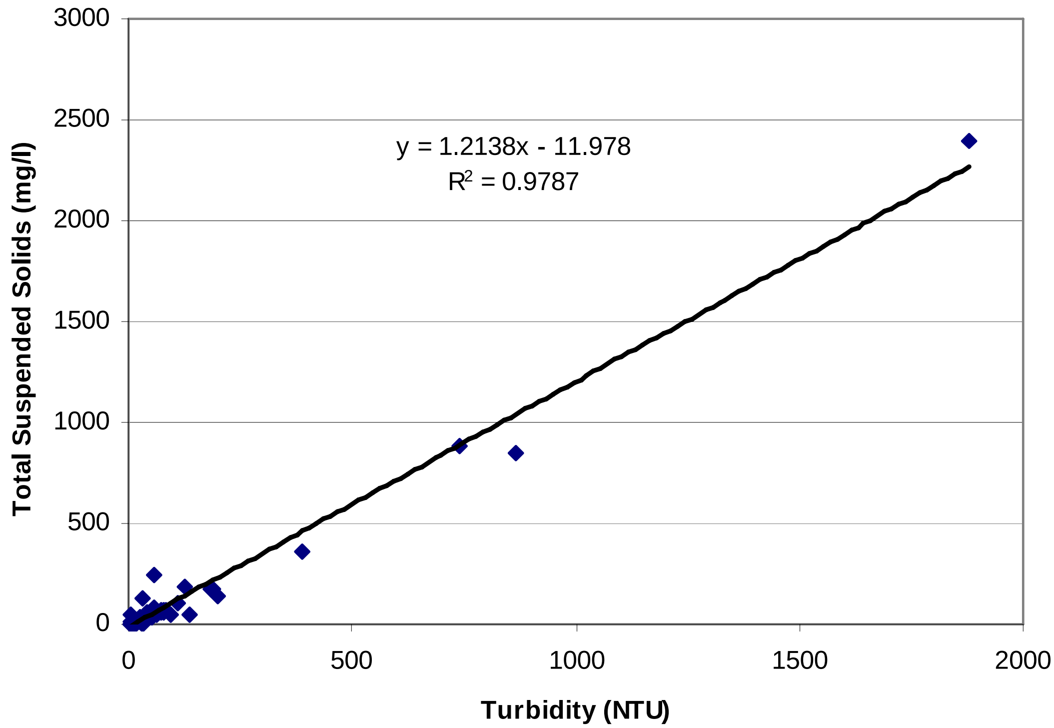


Figure 8. Correlation between turbidity and TSS, Belle Fourche River (2001-2002).

Keyhole Releases and Irrigation Startup

Keyhole releases are required to support the BFID water demand. Keyhole is upstream of site BF1, thus its releases significantly change the measured flow at BF1. In June, 2002, the YSI 6000 series meter was positioned at site BF1 to measure real-time turbidity, temperature, specific conductance and pH. Daily composite flow weighted samples were collected using an ISCO sampler and analyzed for the suite of parameters including TSS. Real-time flow data was available at the USGS stream flow measuring station also located at site BF1.

Figure 9 shows the change in turbidity and specific conductance during the first Keyhole release in 2002. Flow changed from 9 cfs to 74 cfs in 1 hour. It leveled off at about 100 cfs in approximately 5 hours. This significant change in flow resulted in a turbidity increase from 13 NTU to 1300 NTU in less than 3 hours. The change in turbidity represents solids being dislodged from the channel bottom and transported by the increase in shear forces on the wetted perimeter due to the increased flow. (Turbidity measurements greater than 1 standard deviation were removed to reduce the noise in the graph. Debris flowing in the river appeared to affect the ability of the probe to clean itself prior to taking the measurement, resulting in significant decrease or increase in turbidity.) There was no measurable precipitation in the upstream watershed during this time. The table inside Figure 8 summarizes TSS results from the samples collected during the event and analysis.

The slow decrease in specific conductance shown in Figure 9 reflects the dilution of in-place Belle Fourche River water with lower specific conductance water stored in Keyhole. Visually, the stream changed from a clear water flow to a turbid, brown flow, with floating debris such as branches and algae. The debris subsided within 12 hours of the start of the release. The impact of this release could be seen at site BF2. Flow released from Keyhole is diverted from the Belle Fourche River to the Belle Fourche Reservoir at the diversion dam located downstream of site BF2 and upstream of site BF3. Thus, no impact is observed at site BF3 and other downstream sites.

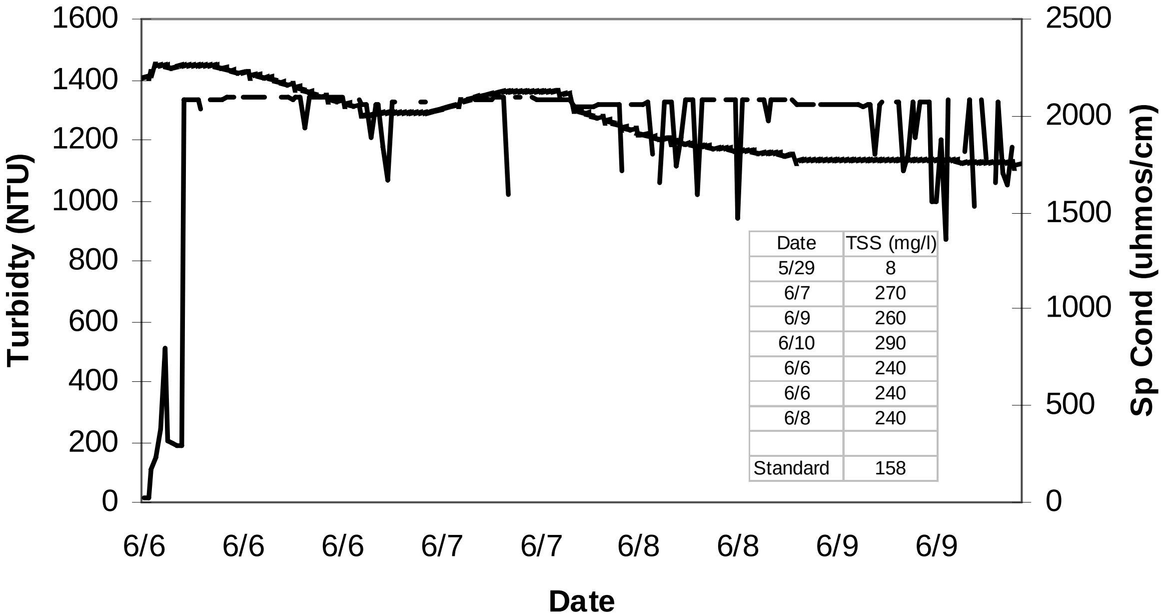


Figure 9. Change in turbidity and specific conductance due to Keyhole Reservoir releases (2002).

Startup of the BFID facilities also causes a significant impact on the downstream portions of the Belle Fourche River. Startup typically includes flushing the main channels and laterals prior to delivering water to local farmers. Dramatic change in flow rates were measured starting at site BF5 and continuing downstream to site BF11. In 2002, BFID started operating on 5/15/02. Consequently, flow at site BF7 increased from 45 cfs to a maximum of 150 cfs. Rate of flow increases were over 50 cfs in 2 hours and happened at least 2 times during the startup period. Turbidity response followed the change in flow similar to the Keyhole release, dominated by re-suspension of solids from the channel bottom.

Prior to flushing, the irrigation channels and laterals are white from the evaporation in the channel from the previous irrigation season and deposition of dissolved solids. The deposited solids are re-dissolved during the flushing actions and result in a significant, but short duration, specific conductance spike at both BF7 and BF11sites, shown in Figure 10. The chemical response is approximately 100 hours after the hydraulic response. This time delay represents the time required for chemical diffusion and transport. Site BF11 is located approximately 60 miles downstream. The flow and specific conductance spikes attenuated, but stayed at significant levels.

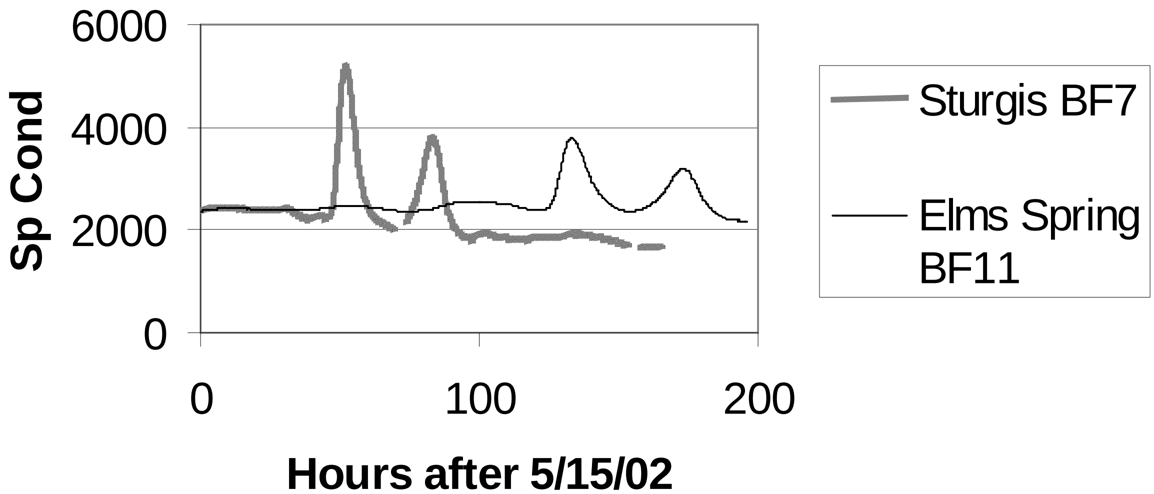


Figure 10. Specific Conductance response to BFID canal/laterals startup.

Biological

Benthic Macroinvertebrates

Benthic macroinvertebrates are excellent indicators of water quality and habitat within stream environments. Some invertebrates spend their entire life in aquatic environments, while the immature stages of other species reside in aquatic habitat before emerging to become terrestrial adults. These animals provide an integrated picture of water quality conditions. In their aquatic stages, they exhibit fairly limited mobility (as compared to fish) and are thus exposed to a variety of water quality conditions.

Invertebrate communities within the Belle Fourche River are quite diverse. A total of 189 different invertebrate taxa were identified in Belle Fourche River samples. Using sample counts, 57 biological metrics (Table 9) were calculated to estimate characteristics of the invertebrate community. Using subsets of candidate metrics, indices of biological integrity (IBI) were developed.

Table 9. List of metric categories, candidate metrics, and response to impairment.

Category	Metric	Response to Impairment
Abundance	Total Abundance	Decrease
	Chironomidae Abundance	Decrease
	EPT Abundance	Decrease
	EPT/Chironomidae Abundance	Decrease
Composition	% Diptera	Increase
	% Gatherers	Increase
	% Sediment Tolerant	Increase
	% Chironomidae	Increase
	% Dominant Taxon	Increase
	% Coleoptera	Decrease
	% Hydropsychidae/Trichoptera	Decrease
	% Hydropsychidae/EPT	Decrease
	% Ephemeroptera	Decrease
	% Plecoptera	Decrease
	% Trichoptera	Decrease
	% EPT	Decrease
	% Odonata	Decrease
	% Gastropods	Increase
	% Non-Insects	Increase
	% Oligochaeta	Increase
	% Tanytarsini	Decrease
Richness	Taxa Richness	Decrease
	Diptera Taxa	Decrease
	Chironomidae Taxa	Decrease
	Coleoptera Taxa	Decrease
	Ephemeroptera Taxa	Decrease
	Plecoptera Taxa	Decrease
	Trichoptera Taxa	Decrease
	EPT Taxa	Decrease
	Shannon-Weiner Index	Decrease
Tolerance	Intolerant Taxa	Decrease
	Biotic Index	Decrease
	% Intolerant	Decrease
	Hilsenhoff Biotic Index	Increase
	% Tolerant Organisms	Increase
Trophic/Habit	% Omnivores+Scavengers	Increase
	Individual Gatherers	Increase
	% Ind. Gatherers+Filterers	Decrease
	% Grazers+Scrapers	Increase
	% Scrapers / (Scrapers+Filterers)	Increase
	Scrapers / Filterers	Increase
	Clinger Taxa	Decrease
	% Clingers	Decrease
	Predator Taxa	Increase
	% Predators	Increase
	% Filterers	Decrease
	% Burrowers	Increase
	% Shredders	Decrease

The use of the multimetric index provides a convenient, yet technically sound method for summarizing complex biological data (Plafkin et al. 1989). Two different multimetric techniques were used to identify biologically impaired sites. The primary difference between the two multimetric methods is that one method uses Spearfish Creek sites as a reference condition for comparison to test sites, while the other uses a statistical approach to compare all sites to each other. The results of both techniques are discussed below.

EPA suggests comparing biological metrics to a reference condition to determine a site's impairment status (Barbour 1999). To facilitate an adequate biological assessment, a reference condition should be defined for comparison. Hughes (1995) defines reference conditions as those approximating presettlement physical, chemical, and biological conditions, or those areas believed to have high ecological integrity. However, due to the difficulty of determining what conditions would be like prior to European settlement, minimal disturbance is often used as a reference condition. No reference sites were selected prior to this biological assessment. After reviewing sample results, taxonomist recommendations and best professional judgment were used to choose Spearfish Creek as a reference stream.

A metric optimization procedure was used to select the best subset of invertebrate metrics and to reduce redundancy in the IBI. The optimization procedure was used to rank candidate metrics. Ten metrics were included in the optimized IBI based on two conditions: 1) high discriminatory power (larges difference in metric values between test sites and reference sites) and 2) low reference site variability. The results of the optimization procedure are shown in Table 10.

Table 10. Optimized metrics for initial index of biotic integrity (IBI).

Top Ten	Metric	Discriminatory Power	Rank	Reference CV	Rank	Sum Rank	Metric Category
1	Total Abundance	1.900	3	0.077	1	4	Abundance
2	Number of Intolerant Taxa	4.359	1	0.121	5	6	Tolerance
3	Biotic Index	2.865	2	0.165	7	9	Tolerance
4	Diptera Taxa	1.349	7	0.228	12	19	Richness
5	Taxa Richness	0.606	16	0.169	8	24	Richness
6	Plecoptera Taxa	1.590	6	0.493	21	27	Richness
7	% Omnivores+Scavengers	0.524	19	0.223	11	30	Trophic/Habit
8	Individual.Gatherers	0.480	21	0.377	18	39	Trophic/Habit
9	Chironomidae Taxa	0.272	24	0.344	15	39	Richness
10	% Sediment Tolerant	0.365	22	0.493	22	44	Composition

These optimized metrics were scored relative to mean reference site values estimated for each metric. Total scores for each metric were summed and divided by the total possible score to reach an overall percent comparability to the reference condition. The maximum possible site score was 60 points (or 100% comparable to the reference condition). Similar to the EPA methodology, this point total was used to assign a condition category for each site (Table 11).

Table 11. IBI Condition categories and criteria.

% of Possible Point Total	Condition Category
>75% (>45 points)	Non-impaired
51-75% (31-45 points)	Slightly Impaired
25-50% (15-30 points)	Moderately Impaired
<25% (<15 points)	Severely Impaired

Grouping the percent comparability scores into quartiles allowed the assignment of a condition category to each site (Table 12). The IBI score for site BF1 was 46.7% and was the only site considered moderately impaired. Most of the sites fell in the slightly impaired category. Only three sites were considered non-impaired (WW1, BB1, RW2). These results correlate well with the suspended solids results reported in a previous section. BF1 and HC4 were found to be most impaired by suspended solids concentrations and ranked 1st and 3rd, respectively, in the extent of biological impairment.

Table 12. IBI Scores, percent comparability, and condition category for each site (in order of increasing impairment).

Site ID	IBI Score	%Comparability	Condition Category
WW1	56.4	94.0%	Non-Impaired
BB1	50.8	84.7%	Non-Impaired
RW2	46.0	76.7%	Non-Impaired
BF9	42.8	71.3%	Slightly Impaired
BF11	41.6	69.3%	Slightly Impaired
BB2	41.2	68.7%	Slightly Impaired
WW5	40.0	66.7%	Slightly Impaired
HC1	39.3	65.6%	Slightly Impaired
RW1	39.2	65.3%	Slightly Impaired
BF4	36.0	60.0%	Slightly Impaired
BF7	35.6	59.3%	Slightly Impaired
HC4	34.8	58.0%	Slightly Impaired
BF2	34.0	56.7%	Slightly Impaired
BF1	28.0	46.7%	Moderately Impaired

Lacking pre-defined biological reference stations, a non-parametric statistical test (Kruskal-Wallis) was also used to group sites into impairment categories. A one-way design Kruskal-Wallis test was performed for all invertebrate data by station. The z-value indicates how the mean rank for a single group differs from the mean rank for all observations. A zero z-value indicates no difference among mean ranks. The H statistic for this test had an average p-value of 0.047 (adjusted for ties), which indicates a 95% probability that the null hypothesis can be rejected in favor of the alternative hypothesis of at least one difference among the population (Minitab 1998). All metrics, excluding % Oligochaeta, had a z-value greater than 2 or less than -2, indicating significant differences among the sites. Thus, nearly all the macroinvertebrate metrics appear to be able to discriminate differences between the sites within the Belle Fourche watershed (Table 13).

Table 13. Descriptive statistics for macroinvertabrate metrics.

Variable	Mean	St. Dev.	Minimum	Maximum	Q1	Q3	Z-value
Taxa Richness	26.94	7.06	14.00	40.00	22.00	32.00	2.73
EPT Taxa	8.40	4.11	2.00	18.00	5.00	11.75	2.19
Ephemeroptera Taxa	3.77	1.97	1.00	8.00	2.00	5.00	-2.36
Trichoptera Taxa	4.15	2.67	0.00	10.00	2.00	6.00	2.77
Plecoptera Taxa	0.48	0.90	0.00	3.00	0.00	1.00	2.73
Coleoptera Taxa	2.27	1.09	0.00	5.00	2.00	3.00	-2.3
Diptera Taxa	11.79	4.06	5.00	22.00	9.00	14.00	2.34
Chironomidae Taxa	9.52	3.23	3.00	17.00	7.00	12.00	-2.49
EPT Abundance	109.70	83.50	3.00	297.00	36.50	150.00	-2.58
Chironomidae Abundance	71.67	50.03	8.00	257.00	37.75	101.00	2.81
EPT/Chironomidae Abundance	2.83	4.11	0.06	19.79	0.49	2.78	2.21
% EPT	35.32	23.17	1.82	87.61	16.03	48.08	2.07
% Ephemeroptera	17.58	14.15	0.91	52.55	6.11	26.81	-2.87
% Plecoptera	0.72	1.63	0.00	7.74	0.00	0.59	2.7
% Trichoptera	17.02	17.82	0.00	63.44	2.72	25.79	2.7
% Coleoptera	15.32	13.51	0.00	49.88	2.60	27.98	-2.32
% Chironomidae	26.85	17.27	2.35	81.33	12.66	35.56	2.62
% Diptera	35.41	19.52	6.14	85.44	19.37	48.06	-2.36
% Hydropsychidae/EPT	32.00	31.23	0.00	97.21	2.03	54.77	-2.49
% Non-Insects	6.11	9.90	0.00	57.63	0.94	6.73	2.49
% Oligochaeta	1.61	3.52	0.00	20.34	0.00	1.56	1.47
No. Intolerant Taxa	30.81	43.81	0.00	165.00	2.25	40.75	-2.04
% Intolerant	73.60	78.40	5.00	335.00	20.00	108.50	2.07
No. Tolerant Individuals	290.80	110.50	38.00	573.00	245.00	339.80	2.79
% Tolerant Organisms	26.85	17.27	2.35	81.33	12.66	35.56	-2.36
%Chironomidae	1.37	3.14	0.00	13.56	0.00	1.26	2.62
%Gastropoda	6.11	9.90	0.00	57.63	0.94	6.73	2.75
%Non-Insects	1.56	2.66	0.00	11.11	0.00	2.04	-2.49
%Odonata	1.61	3.52	0.00	20.34	0.00	1.56	2.7
%Oligochaeta	2.04	2.64	0.00	10.77	0.07	3.12	1.47
%Burrowers	39.52	23.79	4.49	123.19	19.94	54.28	-2.02
% Sediment Tolerant	102.08	61.28	7.00	284.00	61.25	133.75	2.19
No. Dominant Taxon	33.12	11.85	17.16	71.21	23.76	40.18	-2.85
% Dominant Taxon	5.56	1.25	3.54	9.16	4.47	6.12	2.49
Hilsenhoff Biotic Index	9.92	5.82	1.00	22.00	5.25	14.00	-2.87
Biotic Index	290.80	110.50	38.00	573.00	245.00	339.80	-2.11
No. Predator Taxa	86.16	18.56	19.09	127.31	80.46	95.97	2.11
% Omnivores+Scavengers	132.30	88.70	12.00	391.00	55.30	179.30	2.62
Gatherer Abundance	68.80	70.80	1.00	278.00	13.00	93.30	2.87
Filterer Abundance	290.80	110.50	38.00	573.00	245.00	339.80	2.66
% Gatherers+Filterers	44.84	20.05	8.76	84.85	31.12	55.27	-2.36
% Gatherers	22.72	20.36	0.66	81.76	6.09	31.00	-2.66
% Filterers	9.78	12.06	0.00	45.23	1.26	14.65	2.62
% Grazers+Scrapers	1.64	4.12	0.00	26.76	0.05	1.29	2.66
Scrapers / Filterers	32.84	30.22	0.00	96.40	4.95	56.25	-2.32
% Scrapers / (Scrapers+Filterers)	12.85	16.00	0.74	80.91	3.52	14.04	2.66
% Predators	8.83	7.55	0.00	31.43	2.94	15.03	-2.7
% Shredders	24.37	20.42	0.63	76.47	6.35	39.41	2.49
% Clingers	4.19	1.71	1.00	7.00	3.00	5.00	-2.28
Clinger Taxa	45.65	34.16	4.17	100.00	16.67	89.29	2.17
Corrected Abundance	109.70	83.50	3.00	297.00	36.50	150.00	-2.83

For this analysis, only sites BB2, BF1, BF11, BF2, BF4, BF7, BF9, HC1, HC4, RW2, SP4 and WW5 were tested. These sites are located in River Breaks and Semi Arid Pierre Shale ecoregions and are at similar elevations (2,300-3,200ft). In general, elevation appears to have the most significant influence on metric values and is a good method of grouping sites for comparison (Barbour 1999).

The invertebrate metrics were grouped into metric categories proposed by EPA are shown in Table 14. Most metrics in the table decrease with increased impairment. The parameters in italics increase with an increase in impairment (Barbour 1999).

Table 14. Potential metrics proposed by EPA to measure impairment (Barbour 1999).

Richness Measures	**Composition Measures**	**Tolerance Measures**	**Trophic/Habit Measures**
Taxa Richness	% EPT	% Intolerant	Clinger Taxa
EPT Taxa	% Ephemeroptera	*% Tolerant Organisms*	% Filterers
Ephemeroptera Taxa	% Trichoptera	*Hilsenhoff Biotic Index*	% Gatherers
Trichoptera Taxa	% Coleoptera	Biotic Index	
Coleoptera Taxa	*% Diptera*		
Diptera Taxa	*% Chironomidae*		
Chironomidae Taxa			

The resultant z-values serve as indicators of relative impairment compared to all the sites on the Belle Fourche River and its major tributaries. Positive average values indicate less impairment and negative values indicate greater impairment (Barbour 1999). If the parameter is in italics in Table 10, the negative value was added to determine the average z-value for a specific site.

Table 15 presents the results from a Kruskal-Wallis Test for one-way design. The data is sorted by average z-value in ascending order. Sites BF1, BF4, BB2, and HC4 displayed the most biological impairment. Site RW2 stands out alone as the least impaired biologically. Sites BF9, SP4, WW5 appear as a cluster of less impaired, and sites BF11, BF2, BF7 and HC1 are more impaired.

Table 15. Average Z values for the EPA's metric categories in order of descending average Z-values.

Station	Richness Measures	Composition Measures	Tolerance Measures	Tropic/Habit Measures	Average Z Value
RW 2	1.56	0.81	1.25	1.2	1.2
BF 9	0.22	0.55	1.29	1	0.8
WW 5	0.66	0.56	2.04	-0.29	0.7
SP 4	0.85	0.55	1.81	-0.6	0.7
BF 2	0.59	0.22	0.26	0.485	0.4
BF 11	0.08	-0.04	0.41	-0.025	0.1
BF 7	-0.71	0.16	0.06	-0.03	-0.1
HC 1	0.23	-0.12	-1.39	0.485	-0.2
BB 2	-0.5	-0.56	-1.45	0.055	-0.6
HC 4	-1.19	-0.57	-1.52	-0.225	-0.9
BF 1	-1.48	-0.66	-1.09	-0.345	-0.9
BF 4	-0.32	-0.89	-1.66	-1.715	-1.1

Using only the metrics shown in Table 14 did not include an analysis of all the available data. Due to the large number of invertebrate metrics and the lack of a reference condition, z-values were used to determine the relative impairment at each site.

A stepwise regression analysis was performed using all 57 biologic metrics to establish a relationship with TSS and to determine which metrics are best suited for detecting biological impairment due to elevated TSS concentrations. The average of each metric was compared to the average TSS concentration at each site. In the stepwise procedure, if the p-value for any metric is greater than the "alpha to remove", then the variable with the largest p-value is removed from the model, the regression equation is calculated and the next step is initiated. If no variable can be removed, the procedure attempts to add a metric. If the p-value is smaller than the "alpha to remove", the variable with the smallest p value is then added to the model. The regression equation is then calculated and the procedure goes to a new step.

The identified biologic metrics from the stepwise regression are the metrics with the highest correlation to TSS. They can be referred to as "biological response signatures," which are unique community level responses that aid in distinguishing one impairment type over another (Yoder and Rankin 1995). This approach appears to be more direct and reduces the amount of interpretation of the data. The Minitab results are shown in Table 16.

The resulting equation is: TSS = -51.28+ 14.3*% Diptera – 6.4 * Chironomidae Abundance –3.1 * No. Intolerant Taxa + 12.3* % Chironomidae. The signs of each of the metrics indicate the direction of the metric response to increasing perturbation. The signs are similar to the expected response (Barbour 1999).

Table 16. Stepwise regression comparing biologic metrics with TSS.

(All Biologic Parameters, Sites BF1, BF2, BF4, BF7, BF9, BF11, BB2, HC4, SP4 and WW5.)

Alpha-to-Enter: 0.2 Alpha-to-Remove: 0.2
Response is TSS on 56 predictors, with N = 11

Step	1	2	3	4
Constant	-164.45	-78.88	-56.81	-51.28
% Dipter	12.0	17.5	18.5	14.3
T-Value	3.34	6.10	7.31	4.05
P-Value	0.009	0.000	0.000	0.007
Chiro Ab		-4.1	-3.9	-6.4
T-Value		-3.49	-3.80	-3.43
P-Value		0.008	0.007	0.014
Intolera			-2.4	-3.1
T-Value			-1.93	-2.56
P-Value			0.095	0.043
% Chiron				12.3
T-Value				1.56
P-Value				0.170
S	139	92.6	79.9	72.8
R-Sq	55.40	82.33	88.48	91.80
R-Sq(adj)	50.44	77.91	83.54	86.33

A scatter plot of the Kruskal-Wallis one-way design z-values for biological indicators for the EPA metric categories versus total suspended solids for all sites identified above, has a correlation coefficient, $R^2 = 0.09$. Sites BB2 and BF4 are outliers in the graph, indicating the change in metric z-values may not have a high correlation to suspended solids. Site BB2 is located on the edge of the city of Sturgis, SD, and may be heavily influenced by urban runoff. Site BF4 is located adjacent to a sewer lagoon near Nisland, SD. The invertebrate community at site BF4 may be more highly influenced by the lagoon than by sediment impacts. Removing these two sites increases the correlation coefficient to $R^2 = 0.7$. This significant change indicates that sites BB2 and BF4 may have other significant water quality parameters influencing the biologic parameters.

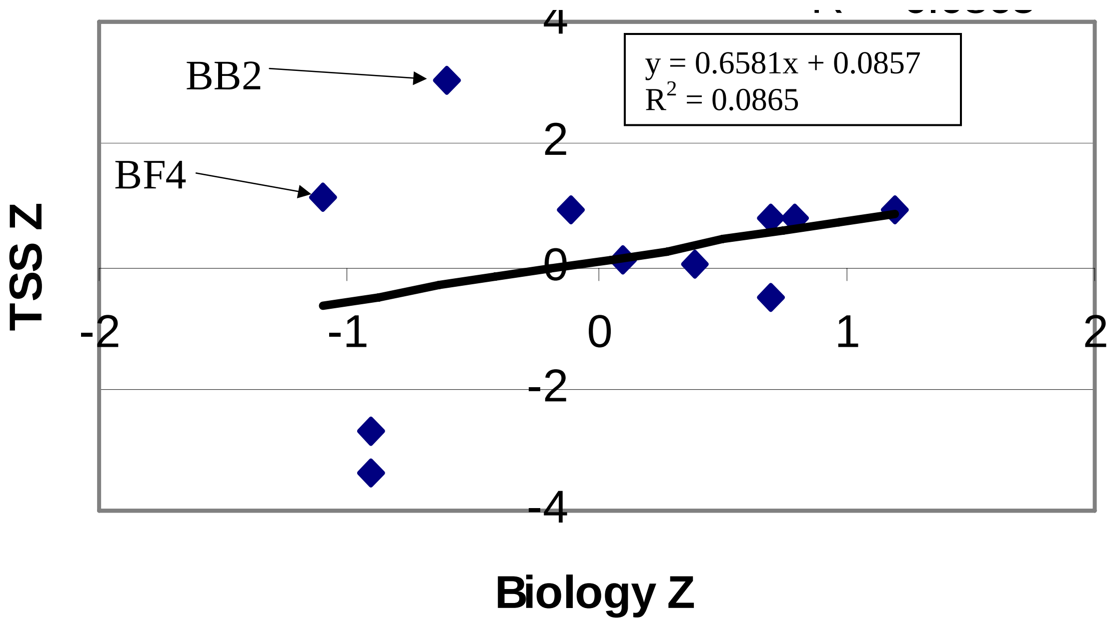


Figure 11. Scatter plot of average Z values for Belle Fourche River sites.

Thus, a second stepwise regression was performed without sites BB2 and BF4, using the 56 biologic metrics and average TSS for each site. The Minitab results are presented in Table 17. The resultant r-value and p-value indicate a more robust regression without sites BB2 and BF4.

The resultant equation is:

TSS = 419.12+ 322.062 * % Odonata – 11.78 * % Intolerant – 4.98 * % Omnivores+Scavengers + 2.5 * % Dominant Taxon + 4.4 * % Non-Insects – 1.53 * Ephemeroptera Taxa + .0795 * % Tolerant Organisms.

The metrics % Tolerant Taxa, % Odonata, % Dominant Taxon, and % Non-Insects should increase with increased impairment (plus sign in equation). On the other hand, Ephemeroptera Taxa and % Intolerant Taxa are expected to decrease with increased impairment (Barbour 1999). The biological parameters presented in this equation represent a good biologic response indicator to use as a measure of response to implemented Best Management Practices (BMPs) to reduce the suspended solids concentration in the Belle Fourche River. Regression assumes that all parameters are independent. The biologic metrics are not independent with each other as well as not being independent with respect to TSS. This lack of independence would slightly reduce the robustness of the regression.

Table 17. Stepwise regression comparing biologic metrics with TSS.

(All Biologic Parameters Sites BF1, BF2, BF7, BF9, BF11, HC4, SP4 and WW5 (without BB2, BF4))

Alpha-to-Enter: 0.2 Alpha-to-Remove: 0.2
Response is TSS on 55 predictors, with N = 9

Step	1	2	3	4	5	6	7
Constant	-14.18	76.23	565.77	501.76	429.73	421.88	419.12
%Odo	280.175	321.988	318.474	324.926	322.730	322.768	322.062
T-Value	4.64	9.53	25.37	95.75	522.04	830.55	15656.06
P-Value	0.002	0.000	0.000	0.000	0.000	0.000	0.000
% Intole		-11.8471	-12.1124	-11.5056	-11.9377	-11.8768	-11.7821
T-Value		-4.29	-11.79	-41.09	-194.14	-255.90	-4448.85
P-Value		0.005	0.000	0.000	0.000	0.000	0.000
% Omnivo			-5.5679	-5.9029	-5.1934	-5.0417	-4.9819
T-Value			-6.21	-24.65	-69.54	-63.49	-1702.95
P-Value			0.002	0.000	0.000	0.000	0.000
% Domina				2.5581	2.5815	2.5376	2.5007
T-Value				8.26	48.11	65.98	1653.82
P-Value				0.001	0.000	0.000	0.000
% Non-In					4.439	4.659	4.400
T-Value					11.42	17.84	423.76
P-Value					0.001	0.003	0.002
Ephemero						-1.087	-1.534
T-Value						-2.37	-84.61
P-Value						0.142	0.008
% Tolera							0.0795
T-Value							43.48
P-Value							0.015
S	111	59.5	22.1	5.81	1.01	0.632	0.0206
R-Sq	75.49	93.97	99.31	99.96	100.00	100.00	100.00
R-Sq(adj)	71.99	91.96	98.89	99.92	100.00	100.00	100.00

Habitat Assessment using the Rapid Bioassessment Protocol (RBP)

Descriptive statistics for each RBP habitat parameter are shown in Table 18. Available cover, pool variability and channel sinuosity displayed the largest standard deviation among the sites. Bank vegetation displayed the smallest standard deviation indicating this rating had the least variability among the sites.

Table 18. Descriptive statistics for RBP habitat parameters.

Variable	Mean	StDev	Min	Max	Q1	Q3
Available Cover	6	4	2	14	3	10
Pool Substrate/Embeddedness	10	3	5	17	7	11
Pool Variability/Velocity--Depth Regime	11	6	3	18	5	16
Sediment Deposition	7	4	3	14	5	11
Channel Flow Status	14	4	7	18	13	17
Channel Alteration	13	3	7	18	11	16
Channel Sinuosity/Frequency of Riffles	7	5	3	16	4	12
Bank Stability	14	4	6	18	11	16
Bank Vegetation	14	2	12	18	12	15
Riparian Habitat	13	4	7	20	10	16
Overall Habitat Value	103	20	73	139	87	118

Sites SP4, RW2 scored best in overall habitat value. Sites BF7, WW5, BF11 and BF1 scored the lowest value (see Table 19).

Table 19. Overall RBP score.

Site	Overall Habitat Value
SP4	139
RW2	122
BF9	115
HC4	113
BF4	103
BB2	91
BF2	91
BF1	88
BF11	87
WW5	85
BF7	73

A regression analysis was performed to determine which RBP habitat parameters resulted in the best response indicators to TSS. Average TSS numbers were compared to all 14 RBP parameters presented in Table14 for each site. Results indicated a weak correlation with a maximum coefficient R^2<0.60 and P Value of <0.3 with bank stability. Thus, RBP does not appear to be a good indicator to measure potential for high TSS within the Belle Fourche River watershed.

Contrast and Comparison of Sediment and Biology

The biological community and TSS level of impairment is compared in Table 20. A scale of least to most was used grouping similar z-values. All sites except BB2 and BF4 are within one level of impairment when comparing biology and TSS. Biological communities at sites BB2 and BF4 appear to be significantly influenced by a water quality parameter other than TSS. These sites have been identified as potentially having different water quality impairments as discussed above.

Table 20. Relative impairment for all sites, TSS and biology.

Level of Impairment	Total Suspended Solids	Biology
Least	BB2, BF4	RW2
Less	BF3, BF7, BF8, BF9, SP4, RW2	BF9, SP4, WW5
More	BF2, BF5, BF6, BF11, WW5	BF2, BF7, BF11, HC1
Most	BF1, HC4	BF1, BF4, BB2, HC4,

Flow Measurements

Tables 21 – 23 present the descriptive statistics of flow for the Belle Fourche sites and major tributaries including Redwater River, Whitewood Creek and Horse Creek during the project period. The tables are separated by all flows, winter flows and non-winter flows. Winter flows are for the months Oct-Feb and non-winter flows are the rest of the months. A Kruskal-Wallis Test for one-way design was performed on the average monthly flows for sites BF7 and BF11 to look for seasonality during 2001-02. Two primary seasons can be detected. The largest z-value was for the months October, November, December, January and February (z greater than -16) and is identified as winter. A second grouping can be seen for the other 7 months and is identified as non-winter. An influence from spring runoff would be expected, but since almost all the flow is diverted into the Belle Fourche Reservoir, that season is masked.

Table 21. Descriptive statistics of all flows.

Site	Flow Record	Mean (cfs)	StDev (cfs)	Min (cfs)	Max (cfs)	Q1 (cfs)	Q3 (cfs)
BF1	4/27/01-11/30/02	57	65	5	574	14	97
BF2	4/27/01-11/15/01	64	90	4	840	16	87
BF3	4/27/01-11/30/02	12	11	2	243	9	13
BF4	4/27/01-11/16/01	27	25	13	357	20	28
BF5	4/27/01-11/20/01	66	39	30	503	46	77
BF6	4/27/01-11/30/02	126	90	28	600	50	204
BF7	4/27/01-11/30/02	246	386	31	3260	70	232
BF8	4/09/02-11/21/02	143	85	38	482	61	212
BF9	4/09/02-11/22/02	141	83	38	494	59	207
BF11	4/27/01-11/30/02	127	100	9	578	46	199
RW2	4/27/01-11/30/02	123	61	6	259	71	166
WW5	4/27/01-11/30/02	17	19	1	102	6	21
HC4	4/27/01-11/30/02	20	20	1	106	3	35

Table 22. Descriptive statistics of winter flows.

Site	Flow Record	Mean (cfs)	StDev (cfs)	Min (cfs)	Max (cfs)	Q1 (cfs)	Q3 (cfs)
BF1	10/30/01-2/28/02,10/1/02-11/30/02	15	4	5	26	12	18
BF2	10/1/01-11/15/01	17	4	10	21	14	21
BF3	10/30/01-2/28/02,10/1/02-11/30/02	11	2	8	22	10	11
BF4	10/1/01-11/16/01	20	3	15	28	17	22
BF5	10/1/01-11/20/01	37	5	30	51	32	41
BF6	10/30/01-2/28/02,10/1/02-11/30/02	52	21	35	171	43	50
BF7	10/30/01-2/28/02,10/1/02-11/30/02	251	499	34	3110	48	171
BF8	10/1/02-11/21/02	56	11	38	89	49	63
BF9	10/1/02-11/22/02	59	13	39	92	48	68
BF11	10/30/01-2/28/02,10/1/02-11/30/02	48	26	10	162	35	54
RW2	10/30/01-2/28/02,10/1/02-11/30/02	160	15	113	226	153	168
WW5	10/30/01-2/28/02,10/1/02-11/30/02	22	23	4	102	9	28
HC4	10/30/01-2/28/02,10/1/02-11/30/02	5	6	2	37	2	5

Table 23. Descriptive statistics for non-winter flows.

Site	Flow Record	Mean (cfs)	StDev (cfs)	Min (cfs)	Max (cfs)	Q1 (cfs)	Q3 (cfs)
BF1	4/27/01-9/30/01,3/1/02-9/30/02	81	71	7	574	28	122
BF2	4/27/01-9/30/01	77	98	4	840	20	104
BF3	4/27/01-9/30/01,3/1/02-9/30/02	12	13	2	243	7	15
BF4	4/27/01-9/30/01	29	28	13	357	20	30
BF5	4/27/01-9/30/01	75	40	41	503	59	81
BF6	4/27/01-9/30/01,3/1/02-9/30/02	168	86	28	600	89	226
BF7	4/27/01-9/30/01,3/1/02-9/30/02	243	303	31	3260	142	245
BF8	4/09/02-9/30/02	169	80	40	482	102	224
BF9	4/09/02-9/30/02	166	79	38	494	95	211
BF11	4/27/01-9/30/01,3/1/02-9/30/02	172	98	9	578	99	227
RW2	4/27/01-9/30/01,3/1/02-9/30/02	102	67	6	259	41	162
WW5	4/27/01-9/30/01,3/1/02-9/30/02	14	15	1	102	4	19
HC4	4/27/01-9/30/01,3/1/02-9/30/02	28	20	1	106	5	41

Table 24 presents the difference in flow measured between stations. A significant decrease in flow occurs between sites BF1 and BF 3. Water is diverted to the Belle Fourche Reservoir between these two sites. Site RW2 also discharges into the Belle Fourche River upstream of the diversion structure to the Belle Fourche Reservoir. There is a slight variation between winter and summer flows.

Between sites BF3 and BF5, there is a significant increase in the all flows. The majority of the increase comes in the non-winter months primarily due to irrigation generated mostly by operational and on-farm waste along with spring runoff. Whitewood flows enter the Belle Fourche River between these two sites also.

Between sites BF5 and BF6, there is an increase in flow, with the majority of the increase occurring during the non-winter months primarily due to irrigation generated mostly by operational and on-farm waste along with spring runoff.

Between sites BF6 and BF7, there is an increase in the flow with the majority occurring during the winter months. The flow is dominated by early spring melts.

Finally, between sites BF7 and BF11 there is a net loss of flow with the majority occurring during the winter months. Bear Butte Creek enters the Belle Fourche River between these two sites. For water years 1954 – 2000, the average flow at site BF7 is 279 and at BF11 is 361 cfs, an increase of 30%. However, during 1991 (a dry year), a reduction of 11% of the annual flow, 17% of winter flow and 9% of non-winter flow was observed. The decrease is assumed to result from irrigation withdrawals, evaporation and recharge of adjacent stream zones.

Table 24. Change in flow between monitoring stations, 2001-02.

Site	% Increase All Flows (cfs)	% Increase Winter Flows (cfs)	% Increase Non-winter Flows (cfs)
BF1-BF3	-1449%	-1552%	-1398%
BF3-BF5	321%	38%	404%
BF5-BF6	61%	28%	86%
BF6-BF7	95%	384%	44%
BF7-BF11	-48%	-81%	-29%

Table 25 presents the hydraulic export coefficient, defined as the change in flow (cfs) divided by the change in drainage area (mi^2). This analysis supports the significant increases from irrigation at the sites described above. The largest increase per square mile is between sites BF6 and BF7 and between sites BF5 and BF6. Irrigation is the prime contributor and is described in the next section.

Table 25. Hydraulic export coefficient between monitoring stations, 2001-02.

Site	Increase All Flows (cfs/mi^2)	Increase Winter Flows (cfs/mi^2)	Increase Non-winter Flows (cfs/mi^2)	Change In Drainage Area (mi^2)
BF1-BF3	-0.043	-0.002	-0.046	1260
BF3-BF5	0.057	0.006	0.055	490
BF5-BF6	0.080	0.025	0.072	640
BF6-BF7	1.480	2.390	1.085	200
BF7-BF11	-0.213	-0.353	-0.153	1340

Irrigation Influence

Statistics were developed for the total sampling time frame, irrigation season and non-irrigation season, and are presented in Table 26. Flow periods influenced by precipitation were removed from the flow data. Looking at the flow periods when precipitation was measured at site HC4 and removing the periods where obvious flow changes resulted from runoff, determined removal of precipitation-influenced flow. The periods removed were the following:

- 7/11-7/28/01 due to two storms of 0.81 inches each within eleven days.
- 7/20-7/29/02 due to one storm of 0.91 inches.

Table 26. Descriptive statistics for irrigation season.

Site	Irrigation Season 5/6-10/24/02 (cfs)	Irrigation Season 6/30-10/6/01 (cfs)
BF3	14	12
WW5	5	7
BF4		25
BF5	61	66
HC4	32	37
BF6	178	209
BF7	183	221

Mean flow for each site was compared to the upstream site to determine the increase in flow and is shown in Table 27. This represents the percent increase in flow relative to the upstream site. The equations used were the following:

- BF3- BF5 = (BF54-BF3-WW5)/BF3
- BF3- BF4 = (BF4-BF3-WW5)/BF3
- BF4- BF5 = (BF5-BF4)/BF4
- BF5- BF6 = (BF6-BF5-HC4)/BF5
- BF6-BF7 = (BF7–BF6)/BF6.

Table 27. Percent increase between stations for irrigation season.

Site	% Increase Irrigation Season 5/6-10/24/02		% Increase Irrigation Season 6/30-10/6/01
		BF3-BF4	45%
BF3-BF5	312%	BF4-BF5	169%
BF5-BF6	139%	BF5-BF6	160%
BF6-BF7	3%	BF6-BF7	6%

Approximately 50% of the increase is between sites BF3 and BF4. The Redwater Irrigation District's canal discharges into Maloney Creek, which in turn empties into the Belle Fourche River between these two sites. In addition, the Johnson Lateral, operated by BFID upstream of the Belle Fourche Reservoir, irrigates these fields.

Just upstream of site BF5, the BFID's south canal crosses the Belle Fourche River. There are irrigated fields on both sides of the river between sites BF4 and BF5, with Owl Creek delivering operational waste and on-farm waste to the Belle Fourche River. Whitewood Creek enters the Belle Fourche River just upstream of site BF5. There was a more significant increase in flow during the dry year, 2002, than during 2001, indicating the large impact of irrigation waste and returns on the system.

Between sites BF5 and BF6, there is a 130-160% increase during the irrigation season. Horse Creek (flow was measured and accounted for), along with unmeasured flows from Cottonwood Creek, Willow Creek and Dry Creek, enter the Belle Fourche River between these two sites. The end of BFID's north canal discharges into Willow Creek.

Between sites BF6 and BF7, there is a minor increase of less than 10%. There is no clear distinction between irrigation and non-irrigation seasons. There is a significant increase between these stations during the winter and spring runoff months. BFID's south canal discharges into Nine Mile Creek which then enters the Belle Fourche River between these two sites. There are no other significant tributaries entering the Belle Fourche River between these two sites.

Conceptual Sediment Budget

Conceptual sediment budgets are important to develop a vision of the relative scales of the sediment processes within a watershed. Any attempt to consider sediment should consider not only changes in sediment load due to land use at the catchments outlet, but also the entire delivery system or conveyance system and to the sinks or stores involved (Walling 1999). This broader perspective will permit improved understanding between land use, erosion, bank failure and channel changes, as well as focusing attention on the fate of the mobilized sediment.

Research assessing the impact of post-colonial agricultural activity on the sediment loads has demonstrated how much of the sediment eroded from the watershed was deposited or stored within the river basin. This material failed to reach the river outlet as TSS, and reflect in part the buffering capacity of the river. Downstream sediment loads did not reflect subsequent reductions in soil erosion or the introduction of soil conservation measures. The reductions in sediment transport were balanced by remobilization of stored sediment. Rivers with high buffering capacity are characterized as having a large sediment storage capacity and the sediment can be remobilized if sediment supplies to the river system declines (Walling 1999). The Belle Fourche River and Horse Creek have similar characteristics.

Analysis of the sediment budget from the Southern Tableland of southeastern Australia indicates that in that landscape, both the total sediment flux and sediment yield of the catchments is dominated by channel erosion. The authors estimated that only about 5% of the sediment reached the channel from sheet and rill erosion. The remainder came from channel incision and bank erosion. Many of the incised channels are developing a new bed form. The new form is wider with sediment accumulation, which helps to protect the channel sides from undercutting. The channel sidewalls are developing lower slope angles and are yielding less sediment. Channel beds are often vegetated with reeds, sedges and grass, especially during long dry periods, encouraging deposition (Wasson 1998). Similar channel changes are evident in the Belle Fourche River, especially in the BF3 area and downstream of sites BF7 through BF11.

Research done on the transport of sediment and attached phosphorus in the Namoi River in New South Wales, Australia, used atmospheric fall-out of radio nuclides as tracers. They concluded that much of the sediment deposited in the lower reaches of the river came from subsoil rather than topsoil. The authors found the dominating process of stream flow and bank erosion due to undercutting, desiccation, block failure and mass wasting of aggregated particles interact to produce in-stream fluxes of suspended sediment. This sediment is transported downstream and redeposit. The sediment load in the stream was limited by in-stream transportation capacity rather than being sediment limited. They also found that livestock consistently affected bank collapse at most sites. The effects of cattle were evident where tracks traversed banks subject to subsurface piping. They found implementing BMPs, such as an off-stream water source, can significantly reduce the rate of bank erosion and associated in-stream concentrations of TSS, total N and P (Green 1999).

Three different discussions were held with NRCS, USGS and SD DENR personnel to develop a conceptual budget using local expertise to support the estimate. Figure 12 presents a graphical representation of the conceptual sediment budget for the Belle Fourche watershed. Approximately 70% of the sediment in the channel is stored in the non-thalweg portion of the stream and is available for transport when the shear stress due to flow is large enough to re-suspend the sediment. Approximately 30% of the sediment stays in suspension and is transported to the Cheyenne River. The amount of sediment transported is limited by the ability of the stream to re-suspend and carry the sediment.

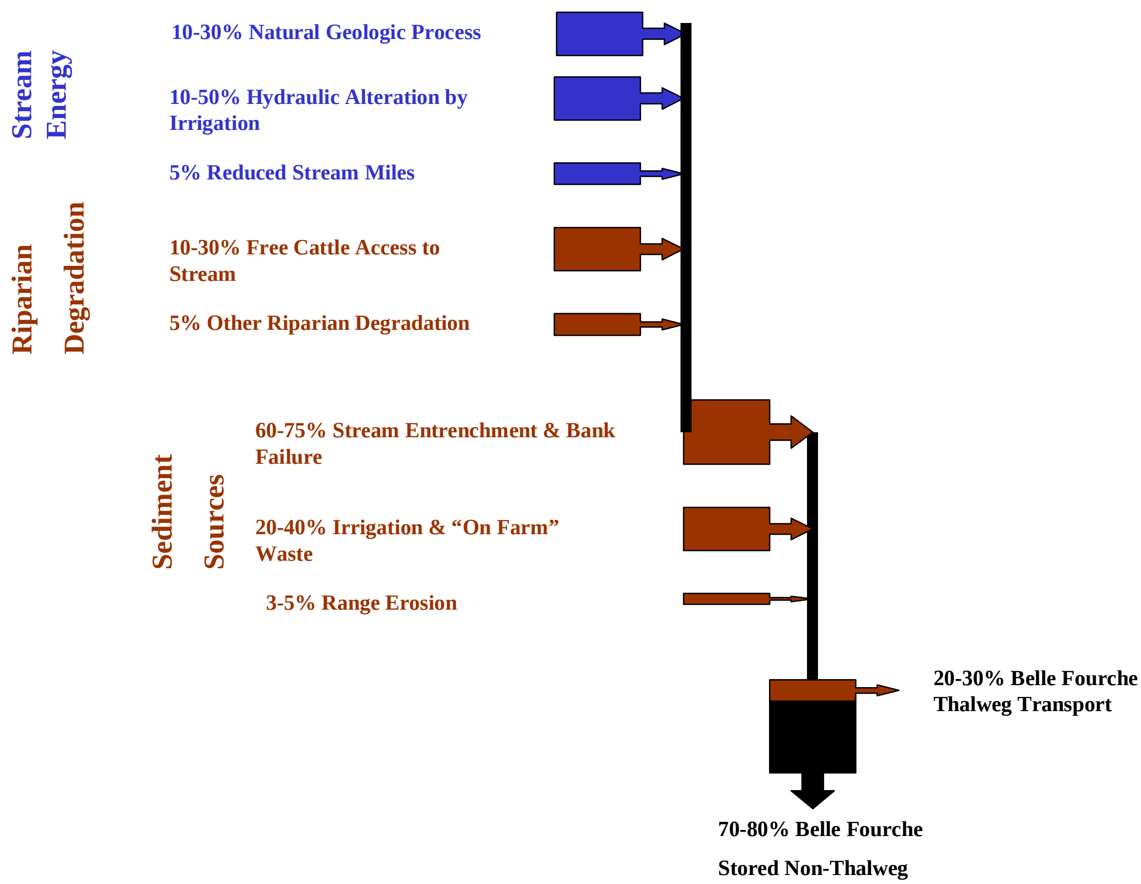


Figure 12. Conceptual sediment budget for the Belle Fourche River watershed.

Approximately 75% of the suspended solids in the system are the result of stream entrenchment and bank failure. Irrigation and on-farm waste are the source of another 20% of the solids. Much of the irrigation in the watershed is flood-type, resulting in sediments being picked up in three areas; as the water crosses the field, in the channels and laterals, and in the intermittent streams carrying the water to the perennial streams within the watershed.

Approximately half of the solids coming from stream entrenchment and bank failure come from a stream energy process, and the other half from riparian degradation. Stream energy causes natural bank failure, particularly in the eastern portion of the watershed, which is dominated by high clay banks adjacent to the flood plain that supply solids to the channel, becoming available for transportation. In addition, increased water resulting from irrigation flows are causing the channel to incise, resulting in additional bank failures and resultant solids. This is particularly evident in Horse Creek and other tributaries within BFID's influence. Much of the riparian area has been disturbed, reducing the number and variety of trees and shrubs in the area. The root structure from the trees and shrubs is not available to add tensile-type strength to the banks, increasing its susceptibility to failure (Simon 2001). In addition, flood irrigation increases seepage and the depositing of leached salts in the soils. These salts weaken the soil structure enhancing bank failure (Burckhard 2003). Depositional-type material can be seen on the side banks where seepage is occurring from irrigated fields. A small amount of additional solids originate from man-induced abandonment of meanders (i.e. stream channel straightening) and result in increased channel bottom slope, which provides additional stream energy.

Riparian degradation occurs primarily from cattle having free access to the streams during the summer months. Cattle often use the river for cooling during hot summer months, damaging the banks and significantly reducing the riparian vegetation (Kauffman 1997). This increases the potential for bank failure and provides a significant source of solids in the channel.

Hydrologic Modeling

Model Selection

Introduction

EPA's Compendium for Watershed Assessment and TMDL Development "summarizes the available models and tools that can be used to support watershed assessment and TMDL development". The document includes a wide range of tools and offers selection criteria to assist the user in choosing the model(s) appropriate for a particular application (USEPA 1997).

Selection Process

The EPA's compendium focuses on approximately 50 different models. They can be divided into 3 different modeling categories: watershed loading, receiving water, and ecological. The compendium lists each of the models, and describes in detail their relative complexity, common applications, capabilities, required input, technical basis, and general facts. It then compares and rates each of the models against all of the other models in its class, using a series of 35 different tables.

After all the models have been described and evaluated, the compendium then proposes a selection process by presenting decision criteria and factors to be considered for the various components included in the three different modeling categories. The objective of this process is to help the user assess the suitability of the models for their specific situation. The selection criteria presented in this process includes hardware availability, availability of trained personnel, long-term commitment to the model, in-house model experience, acceptance and support of the model and commitment to modeling as a tool (USEPA 1997). Other criteria addressed include data requirements, modeling objectives, economic constraints, desired end state, and what level of decisions will be made based on the model results.

Category Selection

The three categories for modeling include watershed loading, receiving water and ecological models. Watershed loading models are used to assess the effects of land uses and practices on pollutant loading in water bodies. A subset of the watershed models is the field scale-loading model. These models typically represent smaller, homogenous areas in more depth.

Receiving water models are used to predict a receiving water body's response to various pollutant-loading scenarios. These models examine the interactions between loading and response. They are most helpful in modeling pollutants that have decay-type relationships or feedback mechanisms, such as oxygen demand, eutrophication, toxic pollutants or mixing zones.

Ecological assessment examines or predicts the status of a habitat, a biological population or a biological community, to provide an interpretation of a water body's ecological health. Ecological assessments can provide additional information and interpretation of watershed and water body conditions.

Watershed Scale Loading Models

There are three levels of watershed loading models; simple, mid-range and detailed. Simple models provide a rapid means of identifying critical areas with minimal effort and data requirements. They can be used to support an assessment of relative significance of different sources and to focus future monitoring efforts.

Mid-range models can evaluate pollution sources and impacts over broad geographic scales and can assist in defining target areas for pollution mitigation programs. The accuracy of the mid-range models are within an order of magnitude, thus restrict their analysis to relative comparisons.

Detailed models best represent the current understanding of watershed processes. They can provide relatively accurate predictions of variable flows and water quality at any point within the watershed.

Most watershed analysis is performed in different phases, starting at screening and ending in implementation monitoring. The TMDL process employs a phased approach. In the early phases, screening tools provide sufficient detail. During the advanced phases of a TMDL study, model selection and configuration need to be defensible, resulting in the need for a detailed model.

Belle Fourche Watershed

Model objectives for the Belle Fourche watershed include:

1. Model the hydraulic processes of the Belle Fourche River.

2. Model TSS within the Belle Fourche Watershed.
3. Identify the potential source of the solids.

Using the decision process described in Chapter 4 of the EPA's Compendium of Tools for Watershed Assessment and TMDL Development, the following decision criteria was applied to this specific project:

Decision Criteria	**Application to this Project**
Hardware availability	PC Workstation
Availability of trained personnel	Limited to guidance from students and professors
Long-term commitment to model	HSPF used on many projects in the past
In-house experience	Includes HSPF, SWMM, QUALIIE, FLUX
Acceptance / Support of model	Will be an important factor in model selection
Commitment to modeling as a tool	Very committed to this process and results

For the Belle Fourche Watershed, sediment does not have a decay component. It is a large-scale watershed, thus the watershed scale-loading model is appropriate.

The Belle Fourche Watershed has the following characteristics:

- Land use
  - Mostly rural, three small urban areas and a few point sources, mostly sewage treatment discharges.
- Time Scale
  - Continuous gauge station data is available for the watershed. Two models have high capabilities; SWRRBWQ/SWAT and HSPF.
- Hydrology
  - Both runoff and base flow are important to the model. Runoff is critical for sediment.
  - Irrigation management.
- Pollution Loading
  - Sediment.
- Pollution Routing
  - Transport for sediment.
  - Best Management Practices (BMP).

Three models have high capabilities for rural land use; ANSWERS, SWRRBWQ/SWAT and HSPF. ANSWERS has no urban component, no base flow component, a limited transportation component, along with limited BMP evaluation and design criteria. These limitations remove ANSWERS from consideration. SWRRBWQ/SWAT has limited urban capabilities, no transformation capabilities and no BMP evaluation capabilities. Thus, HSPF appears to be the model of choice for watershed scale loading and was used for this project.

HSPF Modeling

Model Development

Much of the information needed to develop a model with HSPF is available in the BASINS 3.0 program, including land use, soils, and stream shape files, to name just a few. Table 28 presents the projection and datum for geographic data used in the modeling effort.

Table 28. Geographic Project Datum used for Project.

Coordinate System	UTM Zone 13N
Datum	NAD 1983
Projection	Transverse Mercator
Spheroid	GRS 80
Central Meridian	-105
Reference Latitude	0
Scale Factor	0.9996
False Easting	500000
False Northing	0

Watershed Delineation

The automatic delineation tool in BASINS 3.0 was used to delineate the boundary of the Belle Fourche watershed. The streams from the RF3 stream shape file were burned into the Digital Elevation Model (DEM) to increase the accuracy of the delineation. The DEM included in the BASINS 3.0 dataset has a 300-meter resolution. A 30-meter DEM obtained from the USGS was used instead to increase the accuracy of the delineation.

The watershed contributing to the Belle Fourche River in SD was further divided into twelve sub- watersheds for calibration purposes. Seven of the outlets of these sub-watersheds represented USGS stream gauging stations. Figure 13 shows the delineated watersheds. Sites BF1, RW1, SP4, WW5 and HC4 were used as flow inputs for the model based on USGS records. Sites BF3, BF7 and BF11 were used to calibrate and validate the model.

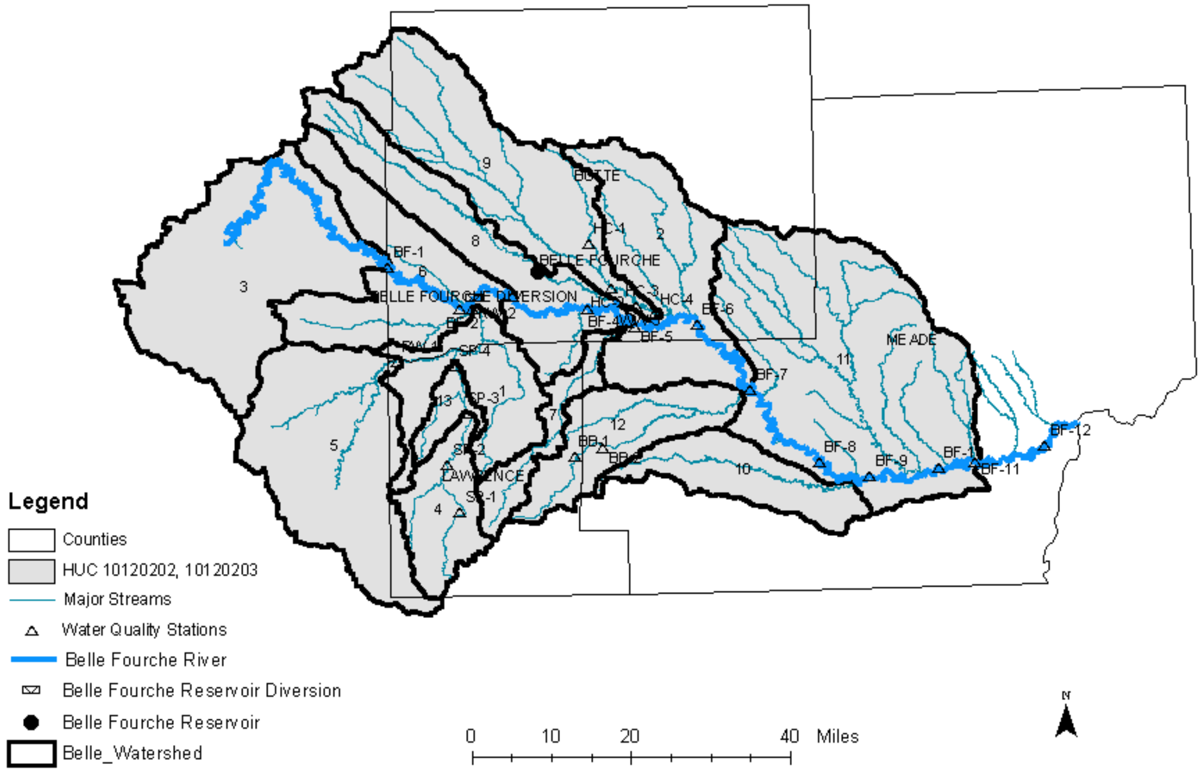


Figure 13. Location of the delineated subwatersheds and gaging sites within the Belle Fourche River watershed.

Land Use and Soils

The land use shape file included in the BASINS 3.0 dataset was used for this project. This shape file is based on the USGS Anderson Level 2 classification system. The following land uses were identified within the study area:

- Commercial Services,
- Cropland and Pasture,
- Evergreen Forest Land,
- Herbaceous Rangeland,
- Industrial,
- Mixed Forest Land,
- Mixed Rangeland,
- Mixed Urban or Built-up Land,
- Other Urban or Built-up Land,
- Residential,
- Strip Mines, Quarries, and Gravel Pits, and
- Transitional Areas.

Table 29 shows the distribution of the land uses for the sub-watersheds. The land use shape file was overlaid onto a digital orthophoto quadrangle (DOQ) of the study area, and it appeared to accurately represent the land uses in the study area. Approximately 84% of the watershed is rangeland and 10% is agricultural.

Table 29. Land use for each sub-watershed used in HSPF (acres).

Sub-basin	1	2	6	8	9	10	11	12	13
Forest	12	0	2	0	0	0	0	12	11
Agricultural	13	41	14	25	20	15	42	33	0
Range Land	108	174	195	178	258	120	527	99	15
Urban-Permeable	2	0	2	0	0	0	0	2	1
Urban-Impermeable	2	0	0	0	0	0	0	2	1
Agricultural Irrigation	8	29	0	10	18	0	0	0	3
Total	145	245	215	213	296	134	569	148	31

BASINS 3.0 further divided the sub-watersheds into land segments based on the land use shape file. For example, all land designated as an evergreen forestland within a sub-watershed was modeled as one land segment in HSPF.

The soils shape file from BASINS 3.0 was used for this project. This shape file is based on the STATSGO classification. Soils for this shape file were grouped into 38 categories based on similar physical and chemical characteristics. A more detailed soils shape file was not available for the study area. Based on this classification system, there are seven different types of soils within the study area. Table 30 lists the soil types represented by each of these map unit codes (MUID).

Table 30. Summary of soil types in the Belle Fourche River's watershed.

MUID	% of Total Acres	Description
SD022	2%	Boneek, Butche, Lakoa, Rock Outcrop, Spanger, Zigwied
SD203	3%	Blackhall, Cabbart, Twilight, Assinniboine, Gerdrum, Eapa, Havre, Pierre, Delridge, Lismas, Grail, Rock Outcrop, Parchin
SD210	3%	Arvarda. Blackpipe, Enning, Glenberg, Hisle, Lohmiller, Manvel, Midway, Savo, Slickspots.
SD010	3%	Absher, Bidman, Haverson, Kyle, Lohmiller, Variant, Redig, Rock Outcrop, Sage, Slickspots, Stetter, Swanboy, Twotop, Wasa
SD029	3%	Lail, Maitland, Marshbrook, Redbird, Rock Outcrop, Stovho, Trebor
SD201	3%	Arvada. Assinniboine, Cabbart, Delridge, Eapa, Glenberg, Havre, Hisle, Kyle, Lohmiller, Pierre, Samsil, Tanna
SD020	4%	Arvada, Broadhurst, Demar, Graner, Grummit, Kyle, Lohmiller Variant, Nunn, Pierre, Rock Outcrop, Sage, Slickspots, Snomo
SD019	5%	Arvada, Baca, Bidman, Enning, Kyle, Manvel, Midway, Minnequa, Razor, Rock Outcrop, Slickspots, Stetter
SD062	6%	Arvada, Bankard, Glenberg, Haverson, Kyle, Lohmiller, Riverwash, Samsil, Satanta
SD040	7%	Hisle, Kyle, Lismas, Nihill, Pierre, Rock Outcrop, Samsil, Slickspots, Stetter, Swanboy
SD028	9%	Citadel, Cordeston, Grizzly, Lakoa, Marshbrook, McCaffery, Paunsaugunt, Pesowyo, Rock Crop, Sawdust, Vanocker
SD024	9%	Arvada, Beckton, Glenberg Variant, Nihill, Nunn, Pierre, Rock Outcrop, Samsil, Satanta, Slickspots, Zigweid
SD009	21%	Hisle, Lismas, Pierre, Rock Outcrop, Sage, Slickspots

Modeling Period

Ideally, a period of at least five consecutive years should be used for calibrating a HSPF model (Fontaine 1995). Within this period, there should be at least one wet year, one dry year, and several storm events (Fontaine 1995). This allows the model to be calibrated to all possible types of hydrologic conditions. Such a period would also meet the critical conditions for this study area. The model should then be validated with a separate series of several years or more after the model has been successfully calibrated (Fontaine 1995).

USGS #06438000, Belle Fourche River near Elms Springs, represents the outlet of the study area. In order to determine the period that would be used for this study, the annual stream flow records for this site were compared to the average annual stream flow for the period of record, 359 cfs. The results of this comparison are shown in Table 31.

Table 31. Comparison of streamflow for model calibration period.

Year	Annual Mean Stream flow (cfs)	Difference from Long-term Mean Stream flow
1991	130	-64%
1992	58	-84%
1993	520	45%
1994	357	-1%
1995	832	132%
1996	1061	195%
1997	911	154%
1998	646	80%

The period from 1992 to 1996 provides for simulation of both low flow and high flow event conditions. Several storm events are also included in this period. For this study, 1991 was used as the start-up period for the model. This year was not considered during calibration. The period from 1992 to 1996 was used for calibration, and the period from 1997 to 1998 was used for validation of the model.

Daily precipitation measurements were available for the entire modeling period for the Newell, Spearfish, Belle Fourche 22 NNW, and Elms Springs 3 ESE National Weather Service stations. However, there were several missing precipitation measurements for these stations. To estimate each missing daily precipitation measurement, the normal-ratio method was used (Gupta 1995). With the normal-ratio method, the missing precipitation measurement is estimated using the following formula:

$$P_x = \frac{N_x}{n} \times \sum_{i=1}^{n} \frac{P_i}{N_i}$$

P_x = missing precipitation value for the station

N_x = average long-term annual precipitation at the station

P_i = precipitation values at the neighboring station for the concurrent period

N_i = average long-term precipitation for the neighboring station

n = number of neighboring stations

Precipitation measurements from at least three neighboring stations are needed for this method. Weather stations adjacent to these stations with precipitation measurements for this period were used. These stations include the following:

- Newell: The three stations used were Belle Fourche, Belle Fourche 22 NNW, and Red Owl.
- Spearfish: The three stations used were Lead, Belle Fourche, and Fort Meade.

- Belle Fourche 22 NNW: The three stations used were Belle Fourche, Newell, and Harding.
- Elm Springs 3 ESE: The three stations used were Philip, Wasta, and Red Owl.

The watershed data management (WDM) files in HSPF hold the various time series used by the program and also hold the output time series. The WDM files provided with BASINS 3.0 included meteorological data from January 1, 1970 through December 31, 1995 for most of the stations. In order to create a model for the desired period, some of the meteorological time series had to be extended. Based on the outlined procedures and the available meteorological data, the following steps were taken to estimate the additional data needed for this period (USESP 2002):

- Dew point temperature: Measured daily dew point temperature was available for the Rapid City WSO station from the “NCDC First Order Summary of the Day” software published by EarthInfo, Inc (EarthInfo 2002). The WDM Utility was used to disaggregate this data into a time series of the hourly dew point temperature required by HSPF.
- Potential evapotranspiration: Daily potential evapotranspiration was calculated using the Hamon Method in the WDM Utility. Required inputs for the method were daily maximum and minimum temperatures. This data was converted into hourly potential evapotranspiration using the disaggregate function in the WDM Utility.
- Solar Radiation: Daily solar radiation was estimated using the computer function in WDM Utility. A data set of daily cloud cover was needed for this computation. The daily cloud cover data set was computed based on the percent sun data from the “NCDC First Order Summary of the Day” for Rapid City WSO station.
- Pan Evaporation: Daily pan evaporation values were computed using the Penman Method in WDM Utility. The maximum and minimum daily temperatures, daily dew point temperatures, and daily wind movement measured at the Rapid City WSO station were obtained from the “NCDC First Order Summary of the Day.” In addition, the calculated daily solar radiation data was used in these calculations. The hourly pan evaporation data set was created using the disaggregate function in WDM Utility.

F-tables

The HSPF model uses F-tables to describe the hydraulic characteristics of a stream reach or completely mixed reservoir. These tables include information about the relationships between stage, surface area, water volume, and discharge of each stream reach or reservoir. The method used in HSPF to simulate hydraulic routing is similar to the kinematic wave method.

The user-controlled input file (UCI) for the HSPF model was created with BASINS 3.0 for WinHSPF, the information for the F-tables was approximated from data included in the RF3 stream shapefile (level 3 streams) in the BASINS 3.0 dataset. In addition to the information provided in the RF3 shapefile, the model uses the slope and hydraulic radius to calculate flow (USEPA 2002).

Hydrologic Calibration

HSPF uses many parameters to represent watershed processes and stream routing. Before the model could be used as a predictive tool, the model was calibrated. The calibration process consisted of changing selected model parameters one by one, within their range of acceptable values, until the model adequately simulated the observed stream flow and water quality.

Measured flow data was available at sites BF3, BF7 and BF11. The locations of these outlets were selected to coincide with the USGS stream gauging stations. Point source flow data was available for sites RW2, WW5, HC4 and the Belle Fourche Diversion to the Belle Fourche Reservoir.

Flow measured from USGS gauge sites were used for the daily flows for each of the point sources. Irrigation within BFID's system was not simulated. A point source was developed at site HC4 to account for the irrigation system flows. Site HC4 flow was increased to account for the flow in the other streams in the area, such as Owl Creek, Cottonwood Creek, Willow Creek and Dry Creek, due to irrigation. Three different analyses were performed to determine how to represent the irrigation flows and the appropriate increase of site HC4 to use in the model. The first analysis performed is shown in Figure 14. The flow at site BF7 minus the contribution of the major tributaries at sites WW5 and BF3 was compared to site HC4. The flow period used was during irrigation discharges from the Belle Fourche Reservoir during the period 1992 through 1996. Periods where major storms affected the flow were taken out. The increase in flow was about 4.5 times the flow at site HC4, resulting in a correlation coefficient R^2 = 0.79 and a P-value <.001 a medium to strong correlation. There are 27 outliers and about 20% of the total error is residual error.

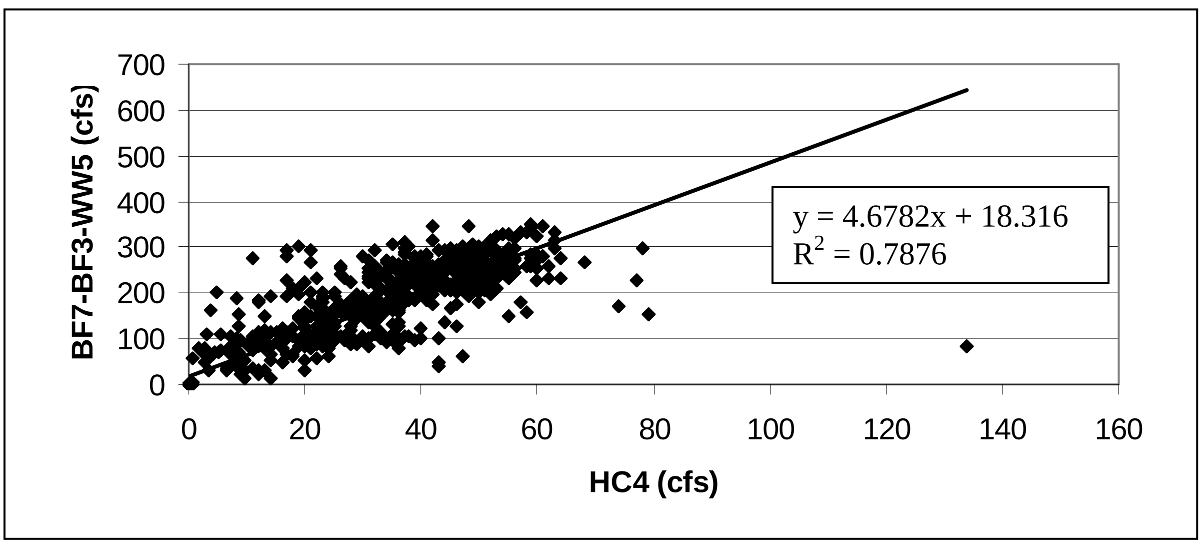


Figure 14. Regression to determine additional flows from BFID as a function HC4 (Irrigation season 1992-1996 without storm flows).

In addition, a regression analysis was performed using daily flows with site BF7 as the response indicator (dependent variable) and sites BF3, WW5 and HC4 as the predictors (independent variables). The resulting equation was: BF7 = 47+0.71*BF3+ 3.4*HC4+2.2*WW5. P-value for this equation was 0.001 with an adjusted correlation coefficient $R^2 = 0.86$ (R^2 adjusted for degrees of freedom). The factor for site WW5 may represent the difference in operation of the north and south canal. Site HC4 receives runoff from fields serviced by the north canal. The south canal services fields downstream of site WW5. The south fields are sandy, resulting in a different response to the fields serviced by the north canal. In addition, the Redwater Irrigation District discharges between sites BF3 and BF7. The other combination that had a high correlation was: BF7-WW5=76.78+0.86*BF3+3.18*HC4. P-value for this equation was 0.001 with an adjusted correlation coefficient $R^2 = 0.82$

There was poor correlation between the flows to the north and south canal at the Belle Fourche Reservoir and downstream gauges. There is extreme variability in the consumptive use versus discharge, and the manual operation of the delivery system causes significant variability in the water that is discharged to the streams. For the HSPF model, the point source flow representing the discharge from the irrigation system was represented by: y = 4.7*HC4 + 18. This equation appears to be a good compromise to represent the irrigation wastes, and results in a model that appears to represent the hydraulic characteristics of the watershed.

It was assumed that approximately 8,000 acres in the watershed were irrigated from the Redwater River and 3,500 acres from Spearfish Creek. The amount taken for irrigation was determined by the equation: irrigation water = RW2-RW1-SP4. The water was allocated to each stream by the percent of acres irrigated within that sub-basin. The amount of water applied to the irrigated acres was 34% of the total withdrawal. SURLI (surface detention inflow) was used and daily time series were created in inches/acre.

During the calibration process an iterative process was used to minimize the differences between the simulated and observed stream flow and water volume at BF3, BF7 and BF11. The calibration measures were as follows:

- Total volume of;
    - Annual runoff
    - Highest 10% flows
    - Lowest 50% flows
    - Storm
    - Seasonal
- Simulated runoff flow
    - Summer
    - Winter
    - Seasonal
    - Storm peaks
    - Daily
- Error in recession rate

The first step in the calibration process was to balance the annual water budget. Snowmelt contributes a significant amount of flow within the Belle Fourche watershed and therefore was included in the calibration. Additional information required for the snow modules included the average elevation, latitude, and fraction of the land surface that is shaded for each of the land segments. The latitude and mean elevation of the sub-watersheds was determined from the DEM. The shaded fraction of the land was estimated based on the land use and the aspect of the land segment.

The snow parameters that appeared to have the most significant impact in the calibration of the snow processes included the factor used to adjust the precipitation data to account for errors in gauge measurements under snow conditions (SNOWCF), the parameter used to represent sublimation from the snow pack (SNOEVP), and the parameter used in the snow condensation/convection equation (CCFACT).

After the snow processes were adequately simulated, the focus of the calibration process shifted to balancing the water budget. The parameters that were most significant in this process were the ground water recession coefficient (AGWRC), the lower soil zone nominal storage (LZSN), and the upper soil zone nominal storage (UZSN).

The next step in the calibration process was to balance the monthly water budget. The soil infiltration capacity (INFILT) values, as well as the monthly values for interception storage (CEPSC) and lower zone evapotranspiration (LZEPT), were the primary parameters used to calibrate the monthly water balance.

After the water budget had been adequately balanced, the focus of the calibration process shifted to trying to simulate the timing and magnitude of peak flow events. The interflow recession parameter (IRC) and the interflow inflow parameter (INTFW) were used to adjust the shapes of the runoff hydrographs for the storm events.

Throughout the calibration process, the parameters were compared to the possible range of values published in "Estimating Hydrology and Hydraulic Parameters for HSPF" (USEPA 2002). This publication provided information for estimating initial values for many of the parameters in the ATEMP, SNOW, PWATER, IWATER, HYDR, and ADCALC modules. After the calibration was completed, none of the parameters were outside the possible ranges of values; however, there were a few which slightly exceeded the typical range of values. None of these exceptions were notable.

The results of the annual and monthly water balances for each of the calibration years at each calibration site are given in Tables 32-34. Daily summer percentage error was calculated at sites BF3, BF7 and BF11 for the months of May to September. Daily runoff percentage error was calculated for the months of February, March and April. The model did not simulate the year 1992 as well as the rest of the years. This was a very dry year. Sites BF3 and BF11 have the largest difference in 1992. Significant irrigation withdrawals directly from the Belle Fourche River would be expected during this dry period; therefore they are not part of the model and would impact the percent error. Overall, the model is good at simulating a five-year period that is representative of the expected conditions within the watershed. The model is capable of representing the summer months with more precision than winter months. The timing and resultant flow and volume during snowmelt is the major source of error during the winter months. The model is more precise during the wet years, 1995 and 1996. The 5 percent error during the dry year of 1992 was the largest, and indicates the model did not simulate the hydraulic process accurately. Significant irrigation withdrawals by farmers along the Belle Fourche River are suspected to be one of the major contributing factors. In 1992 and 2002, both dry years, there is a negative water balance between sites BF7 and BF11. Irrigation withdrawals are suspected to be the major contributor.

Table 32. Comparison of measured and simulated water balance at BF3.

	1992	1993	1994	1995	1996	Average
Annual Water Balance						
Observed Average Flow (cfs)	8	101	92	267	344	162
Simulated Average Flow (cfs)	59	41	72	279	364	163
% Error	-629%	60%	22%	-4%	-6%	0%
Seasonal Water Balance						
Daily Summer % Error	-400%	50%	-9%	0%	0%	-74%
Daily Runoff % Error	-546%	487%	43%	910%	5%	193%

Table 33. Comparison of measured and simulated water balance at BF7.

	1992	1993	1994	1995	1996	Average
Annual Water Balance						
Observed Average Flow (cfs)	66	370	248	559	799	409
Simulated Average Flow (cfs)	195	275	223	592	757	408
% Error	-194%	26%	10%	-6%	5%	0%
Seasonal Water Balance						
Daily Summer % Error	-61%	15%	-11%	-9%	6%	-12%
Daily Runoff % Error	-274%	-38%	33%	76%	18%	-37%

Table 34. Comparison of measured and simulated water balance at BF11.

	1992	1993	1994	1995	1996	Average
Annual Water Balance						
Observed Average Flow (cfs)	58	520	357	832	1066	567
Simulated Average Flow (cfs)	344	486	259	816	923	565
% Error	-489%	7%	27%	2%	13%	0%
Seasonal Water Balance						
Daily Summer % Error	-133%	-9%	4%	3%	-46%	-36%
Daily Runoff % Error	-838%	-46%	53%	54%	22%	-151%

Figures 15-17 show the daily flow comparisons for the calibration period for sites BF3, BF7 and BF11. The precipitation is shown at the top of the graph. As can be seen, the simulated flow has a similar shape as the actual flow. The simulated flow peaks during the spring runoff are slightly delayed and slightly higher than actual flow at all sites.

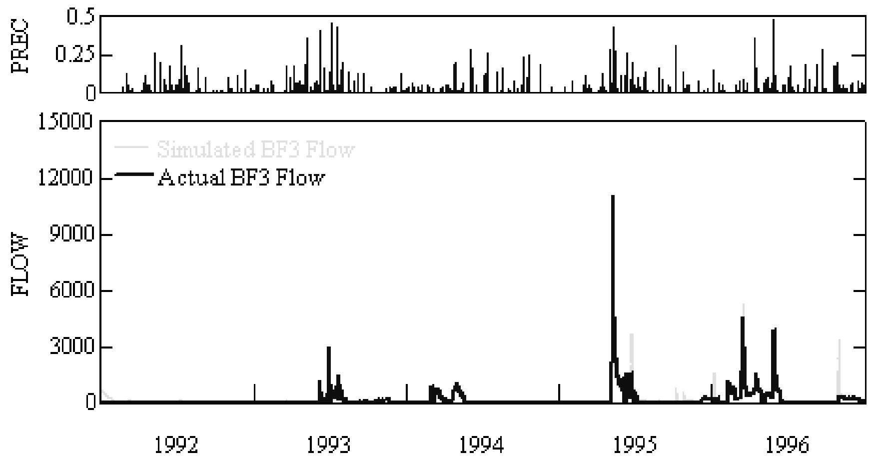


Figure 15. Comparison of simulated and actual flow at BF3.

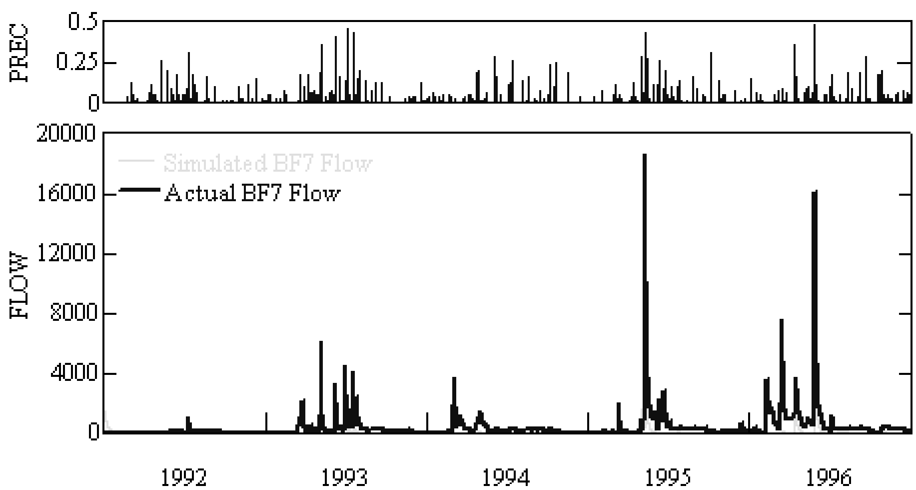


Figure 16. Comparison of simulated and actual flow at BF7.

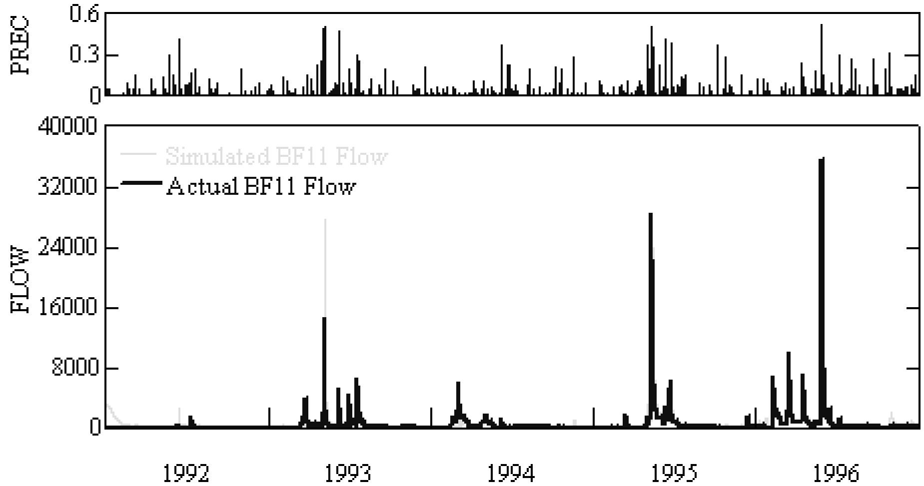


Figure 17. Comparison of simulated and actual flow at BF11.

The residuals, the differences between the observed and simulated flows are shown in Figures 18-20. This indicates that the calibrated model is not biased toward overestimating or underestimating the stream flow.

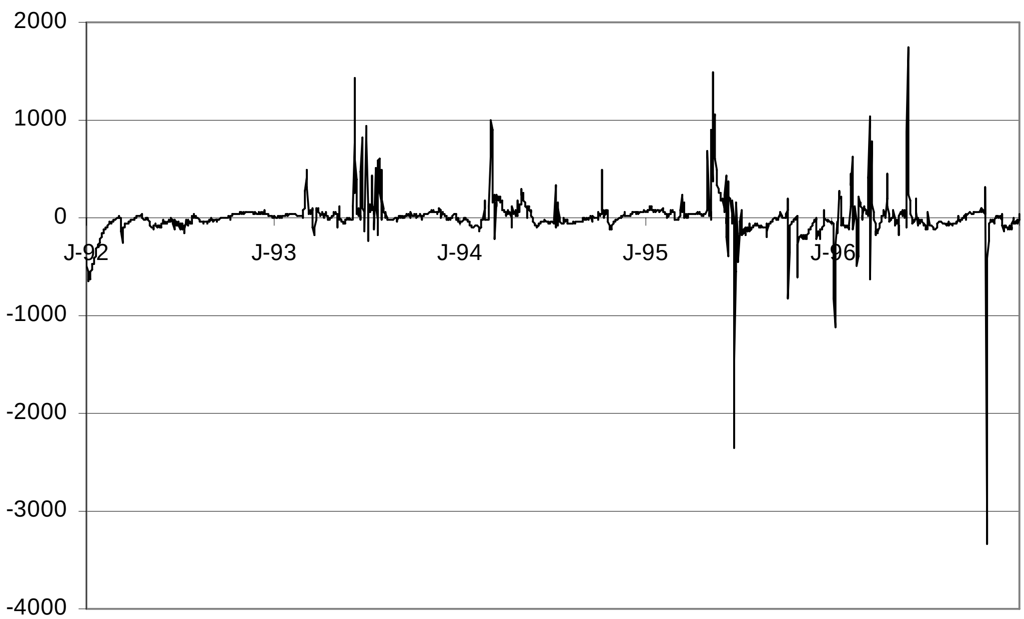


Figure 18. Residual error (i.e. actual minus simulated) of daily average flow at BF3.

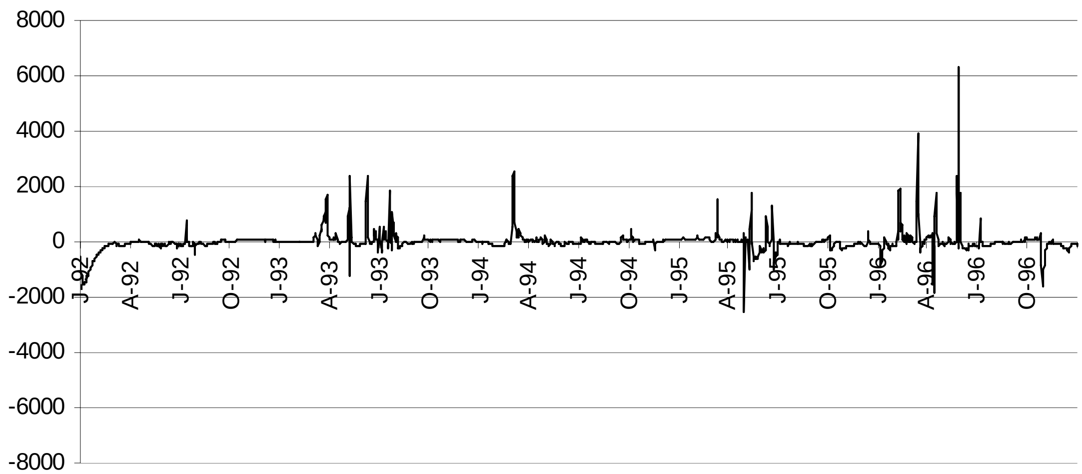


Figure 19. Residual error (i.e. actual minus simulated) of daily average flow at BF7.

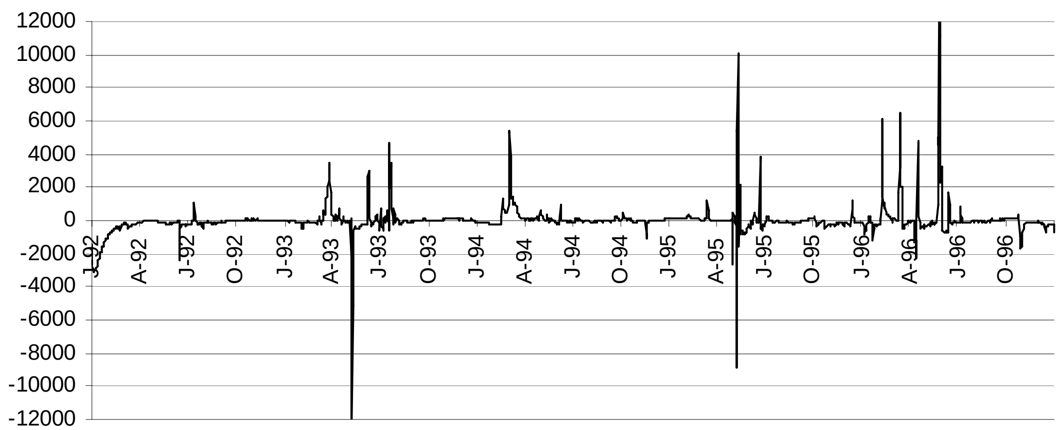


Figure 20. Residual error (i.e. actual minus simulated) of daily average flow at BF11.

Validation

Validation is the process of determining how well the calibrated model describes the observed behavior of the watershed (USEPA 2001a). This requires applying the model using the parameters determined during the model calibration, to a time period outside of that used for calibration. The period from 1997 to 1998 was used for validation of the model. The results of the annual and monthly water balances for each of the validation years are given in Table 35-37. The validation results are also illustrated in Figures 20-22. Annual validation errors less than 10% are considered to be excellent (USEPA 2001a). Annual validation error for site BF7 was less than 10%. Validation error for sites BF3 and BF11 are slightly more than 10%. These low error percentages indicate that the model accurately represents the hydraulic characteristics of the watershed.

Table 35. Comparison of measured-simulated water balance for validation period at BF3.

	1997	1998	Average
Annual Water Balance			
Observed Average Flow (cfs)	278	209	243
Simulated Average Flow (cfs)	219	215	217
% Error	21%	-3%	11%
Seasonal Water Balance			
Daily Summer % Error	18%	9%	13%
Daily Runoff % Error	14%	7%	11%

Table 36. Comparison of measured-simulated water balance for validation period at BF7.

	1997	1998	Average
Annual Water Balance			
Observed Average Flow (cfs)	593	488	540
Simulated Average Flow (cfs)	603	455	529
% Error	-2%	7%	2%
Seasonal Water Balance			
Daily Summer % Error	8%	16%	12%
Daily Runoff % Error	11%	20%	16%

Table 37. Comparison of measured-simulated water balance for validation period at BF11.

	1997	1998	Average
Annual Water Balance			
Observed Average Flow (cfs)		646	778
Simulated Average Flow (cfs)	781	724	752
% Error	14%	-12%	3%
Seasonal Water Balance			
Daily Summer % Error	-46%	20%	-13%
Daily Runoff % Error	46%	-1%	23%

Figure 21-23 show the daily flow comparisons for the validation period for sites BF3, BF7 and BF11. The precipitation is shown at the top of the graph. As can be seen, simulated flow has a similar shape as actual flow. The peaks during the spring runoff are slightly delayed and slightly lower than actual at all sites.

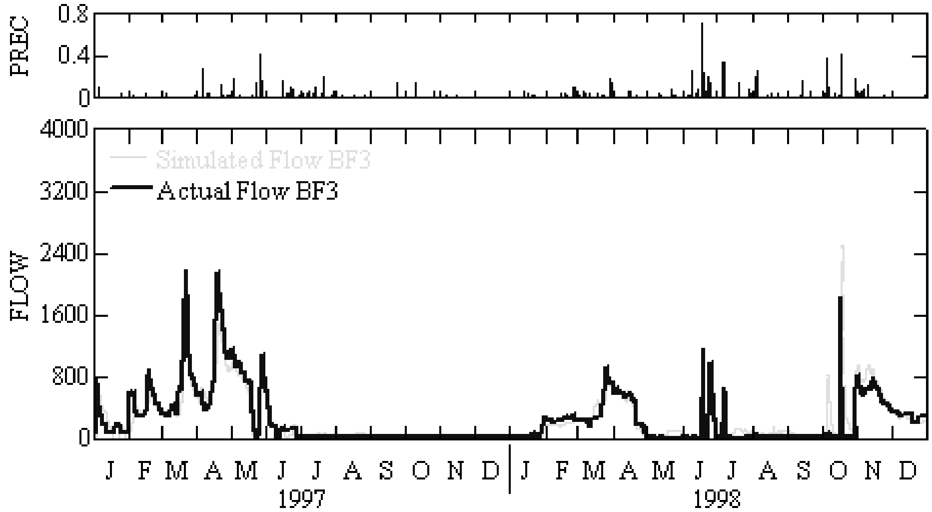


Figure 21. Comparison of simulated and actual flow during validation period at BF3.

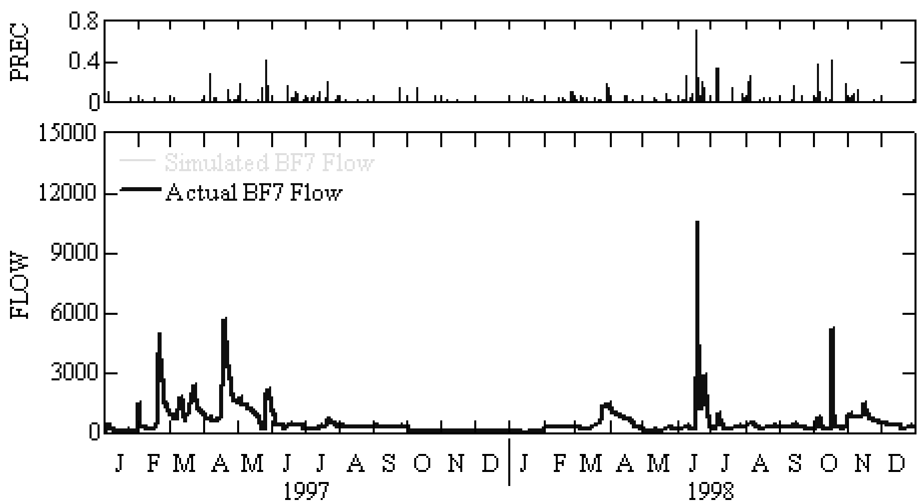


Figure 22. Comparison of simulated and actual flow during validation period at BF7.

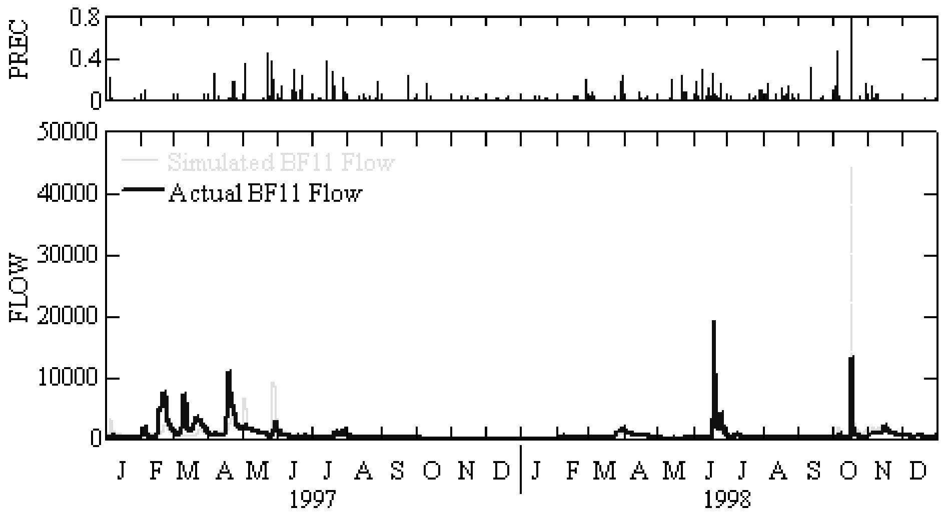


Figure 23. Comparison of simulated and actual flow during validation period at BF11.

Sediment Load Analysis

FLUX is a program developed by the US Army Corps of Engineers. It is an interactive program designed for use in estimating the loadings of water quality parameters, such as TSS, at a sampling station over a given period (Walker 1999). These estimates can be used in formulating stream loading over annual or seasonal averaging periods. Data requirements include sample concentrations, corresponding flow measurements, and complete flow records for the period of interest.

Using six calculation techniques, FLUX evaluates the flow/concentration relationship developed from the sample record, and maps this relationship onto the entire flow record to calculate total mass discharge and associated error statistics. An option to stratify the data into groups based on flow, date and/or seasons is included. Uncertainty is characterized by error variances of the loading estimate (Walker 1999).

FLUX was used to analyze the suspended solids loading at sites BF2, BF4, BF5, BF7, BF11, and HC4 for the 303(d) listing period, October 1, 1998 to September 30, 2003. The method resulting in the lowest coefficient of variability (CV) value was used to calculate the load. Method 2 was used to calculate loadings at sites BF2, BF7, and BF11 (Table 38). Method 2 bases the loading estimate on flow-weighted average concentration, times the mean flow, over the averaging period. This amounts to the “ratio estimate” according to the classical sampling theory. This method performs best when flow and concentration are unrelated or weakly related. Method 2 requires one parameter estimate for each stratum. This is perhaps the most robust and widely applicable method, especially when applied to stratified data sets. Method 3 was used for sites BF4 and BF5. This method adjusts the Method 2 estimate by a factor that is designed to correct for potential bias in situations where concentration varies with flow (Walker, 1999).

Table 38. Results of FLUX analysis for Belle Fourche River and Horse Creek. TSS loads for the Belle Fourche River sites are based on data collected from 1998-2003. Horse Creek (HC4) loads are based on data collected during March-October 2002, because sample data was not available for the entire 303(d) listing period.

Station	Method	CV	TSS Load (tons/yr)
BF-2	Method 2, Q WTD	0.383	81,958
BF-4	Method 3, IJC	0.448	6,112
BF-5	Method 3, IJC	0.238	18,004
BF-7	Method 2, Q WTD	0.511	235,047
BF-11	Method 2, Q WTD	0.706	527,109
HC-4	Method 1, AV LOAD	0.431	4,959

Table 38 presents the results of the FLUX analysis. Uncertainty in the loading estimate is reflected by CV. The equation for CV equals standard error of the mean loading divided by the mean loading. The CV reflects sampling error in the flow-weighted mean concentration. CV values should range between 0.1 and 0.2. If higher CVs are found, the user should consider refining and extending the stream monitoring program to obtain better data sets for load estimating (Walker 1999). All CV values were greater than 0.2. This suggests that additional monitoring is required for a more accurate estimation of loads. This source of error was accounted for in the TMDL margin of safety.

Remediation Alternatives

Management practices can control the delivery of nonpoint source pollutants to the receiving water resources by minimizing pollutants available (source reduction), retarding the transport and/or delivery of pollutants, or intercepting the pollutant before or after it is delivered to the water resource through chemical or biological transformation. The following two sections discuss recommended management practices for both irrigation waters and riparian zones. Detailed descriptions of specific practices can be found in Appendix D.

Management Measures for Irrigation Waters

Management practices can be designed to reduce soil detachment from bank failure, control amounts of water transported, (such as waste irrigation water), and to intercept the sediment through filters and riparian habitat. The goal of these management measures is to reduce the movement of pollutants from land into surface waters caused by the practice of irrigation. This can be accomplished through consideration of the following aspects of an irrigation system, in order of potential impact on sediment reduction:

- irrigation scheduling,
- efficient application of irrigation water,
- efficient transport of irrigation water, and
- use of runoff or tail water.

Management Measures for Riparian Zones

A lack of livestock grazing management affects all four components of the water riparian system: banks and shores, water column, channel morphology, and riparian vegetation.

Stream bank stability is directly related to the species composition of the riparian vegetation and the distribution and density of these species. The BMPs are presented in order of potential impact on reducing the sediment in the Belle Fourche River System.

Riparian Area Improvements

Properly functioning riparian areas can significantly reduce nonpoint source pollution by intercepting surface runoff, by settling, filtering and storing sediment and associated pollutants, and by stabilizing banks. Proposed BMPs include use exclusion and stream bank protection.

Grazing Management

The grazing management measures were selected based on an evaluation of the available information that documents the beneficial effects of improved grazing management. Specifically, the information indicates that riparian habitat conditions are improved with proper livestock management. The BMPs that can be applied successfully for grazing include the following:

- Grazing management practices including use exclusion and planned grazing systems
- Alternative water supply
- Land and stream bank stabilization

Reductions due to BMP Implementation

Installation of structures for water control throughout BFID’s delivery system in conjunction with runoff water or tail water control could almost eliminate operational waste discharging at the ends of these systems. Lining the canals and drains would significantly reduce transportation losses. Full implementation of these BMPs could potentially increase efficiency from 60% to over 90%.

The Angostura Unit, an irrigation system located in the southern Black Hills near Hot Springs, SD, has a delivery efficiency of 80% (BOR 1998). The Belle Fourche system has a delivery efficiency of about 60% (BOR 1998). Since Belle Fourche has a much more expansive delivery system, it was assumed 70% delivery efficiency is a realistic improvement. Upgrading the system to an efficiency of 70% would save approximately 5,500 ac-ft/year of water (based on

55,600 ac-ft/year diverted into the BFID's system). For the potential TSS load reduction estimates, it was assumed that the water savings was not discharged to the system.

Implementation of irrigation water scheduling, efficiency improvements in irrigation water application, and use of tail water or runoff water, can significantly improve on-farm efficiencies. Measured improvements from scheduling, sprinkler application and use of tail water or runoff can be greater than 85% (Dressing 2002).

The Angostura Unit has an on-farm efficiency of 70% (BOR 1998). The Belle Fourche system has an on-farm efficiency of about 50% (BOR 1998). Upgrading the system to an efficiency expected at the Angostura Unit would save approximately 7,000 ac-ft of water (based on 35,000 ac-ft delivered to the farmers). This represents a reduction in discharges from about 11,000 ac-ft to about 5,600 ac-ft, and has the added benefit of conserving water for other beneficial uses. For the potential TSS load reduction estimates, it was assumed that the water savings was not discharged to the system. These waters would either be stored in the Belle Fourche Reservoir, Keyhole Reservoir, or maintained in the Belle Fourche River and diverted to the reservoir.

The resultant reduction of flow, as a result of both delivery improvement efficiency and improvement in on-farm efficiency, represents about a 25% combined efficiency improvement.

Riparian area rehabilitation and management systems have resulted in a reduction of over 70% of TSS concentrations (Dressing 2000). Similar reductions have been found for total nitrogen and total phosphorus concentrations. For this study, a 70% reduction of TSS is assumed for the portion resulting from free cattle access to streams and other types of riparian degradation. An estimate of TSS was performed assuming 100% participation by the local ranchers, but the TSS concentrations did not drop below the standard. Thus, riparian BMPs need to be coupled with water savings BMPs.

To calculate the flow, expected delivery improvements and on-farm use efficiency flow changes were extrapolated to a daily flow and distributed uniformly throughout the irrigation season. FLUX was run using the new daily flows, and the resultant load of TSS was estimated. Then, the percent reduction of load was calculated. The percent reduction in the sediment budget from hydraulic alteration by irrigation were correlated with the percent reduction calculated using FLUX. For Horse Creek, Table 35 the percent reduction of hydraulic alteration by irrigation correlated to 37% reduction.

The percent reduction for hydraulic alteration was then extrapolated using the water savings/load reduction ratio to determine the additional water savings to meet the TSS standard of 158 mg/L. This extrapolated water savings number was then reapplied to the daily flows during the irrigation season. FLUX was rerun using the new daily flows and resultant load of TSS was estimated. This resulted in a new load reduction, usually slightly greater than the reduction required. The ratio of water efficiency/load reduction was then used to determine the water savings required. This water savings was then allocated between transportation and application efficiency improvements.

For the estimated reduction of irrigation and on-farm waste, it was assumed that the percentage reduction in solids was equal to the hydraulic alteration by irrigation. For Horse Creek, the hydraulic reduction was 31% resulting in a TSS reduction of 37%. A similar process was used for the Belle Fourche River.

Horse Creek TSS Reduction

Table 39 presents the expected TSS concentration using similar water efficiency numbers as the Angostura Unit. A TSS concentration reduction from 266 mg/L to 207 mg/L, or a 22% reduction, is estimated. The assumed water efficiency improvements would result in the following:

- Water application efficiency from 50% to above 70%.
- Water transportation efficiency from 60% to above 70%.

Reducing the flow in this system would reduce the potential for erosion and sediment transfer. The resultant concentration at site HC4, 207 mg/L, is still above the standard of 158 mg/L.

Table 39. TSS reduction using BMPs similar to Angostura Unit at HC4.

Sediment Source HC 4	Sediment Budget Contribution		Reduction		Predicted Contribution
	TSS (%)	TSS (mg/L)	TSS (%)	TSS (mg/L)	TSS (mg/L)
Total Sediment Source	**100%**	**266**	**22%**	**59**	**207**
Irrigation and on-farm waste	20%	53	37%	20	34
Range Erosion	3%	8	0%	0	8
Total Stream Entrenchment & Bank Failure	**77%**	**205**	**19%**	**39**	**166**
Total Riparian Degradation	**25%**	**67**	**0%**	**0**	**67**
Free Cattle Access to Stream	20%	53	0%	0	53
Other Riparian Degradation	5%	13	0%	0	13
Total Stream Energy	**52%**	**138**	**28%**	**39**	**99**
Natural Geologic Process	10%	27	0%	0	27
Hydraulic alteration by irrigation	40%	106	37%	39	67
Reduced Stream Miles	2%	5	0%	0	5

Using an iterative approach, percent reduction for irrigation and on-farm waste and hydraulic alteration by irrigation would have to approach 65 % to bring the TSS concentration at site HC4 to below the TSS standard. Table 40 presents the expected TSS concentration using water efficiency BMPs needed to meet the TSS standard. A TSS concentration reduction from 266 mg/L to 158 mg/L, or a 41% reduction, is estimated. This translates into a water savings of approximately 20,000 ac-ft. The improvements would include the following:

- Water application efficiency from 50% to above 80%.
- Water transportation efficiency from 60% to above 75%.

Table 40. TSS reduction at HC4 using water efficiency BMPs only.

Sediment Source HC 4	Sediment Budget Contribution		Reduction		Predicted Contribution
	TSS (%)	TSS (mg/L)	TSS (%)	TSS (mg/L)	TSS (mg/L)
Total Sediment Source	**100%**	**266**	**41%**	**108**	**158**
Irrigation and on-farm waste	20%	53	68%	36	17
Range Erosion	3%	8	0%	0	8
Total Stream Entrenchment & Bank Failure	**77%**	**205**	**35%**	**72**	**133**
Total Riparian Degradation	**25%**	**67**	**0%**	**0**	**67**
Free Cattle Access to Stream	20%	53	0%	0	53
Other Riparian Degradation	5%	13	0%	0	13
Total Stream Energy	**52%**	**138**	**52%**	**72**	**66**
Natural Geologic Process	10%	27	0%	0	27
Hydraulic alteration by irrigation	40%	106	68%	72	34
Reduced Stream Miles	2%	5	0%	0	5

Table 41 presents the expected reduction at site HC4 when only BMPs for riparian degradation are implemented. Even if 100% of the riparian areas are rehabilitated, the predicted concentration is 200 mg/L which is above the TSS standard of 158 mg/L.

Table 41. TSS reduction at HC4 using riparian BMPs only.

Sediment Source HC 4	Sediment Budget Contribution		Reduction		Predicted Contribution
	TSS (%)	TSS (mg/L)	TSS (%)	TSS (mg/L)	TSS (mg/L)
Total Sediment Source	**100%**	**266**	**25%**	**67**	**200**
Irrigation and on-farm waste	20%	53	0%	0	53
Range Erosion	3%	8	0%	0	8
Total Stream Entrenchment & Bank Failure	**77%**	**205**	**32%**	**67**	**138**
Total Riparian Degradation	**25%**	**67**	**100%**	**67**	**0**
Free Cattle Access to Stream	20%	53	100%	53	0
Other Riparian Degradation	5%	13	100%	13	0
Total Stream Energy	**52%**	**138**	**0%**	**0**	**138**
Natural Geologic Process	10%	27	0%	0	27
Hydraulic alteration by irrigation	40%	106	0%	0	106
Reduced Stream Miles	2%	5	0%	0	5

A combination of irrigation efficiency improvements and riparian rehabilitation appears to be the most practical for site HC4. Table 42 presents the results of an interactive calculation, set the TSS to 158 mg/L, and changing the percentage irrigation efficiency columns, and the irrigation and on-farm waste and hydraulic alteration by irrigation line items. The percent reduction for free cattle access to streams was assumed a constant of 70%. Using an iterative approach, percent reduction for irrigation and on-farm waste, and hydraulic alteration by irrigation, would have to approach 40 % to bring the TSS concentration at site HC4 to below the TSS standard. This translates into a water savings of approximately 12,000 ac-ft within the BFID. The improvements would include the following:

- Water application efficiency from 50% to above 70%.
- Water transportation efficiency from 60% to above 70%.

Table 42. TSS reduction at HC4 using riparian and water efficiency BMPs.

Sediment Source HC 4	Sediment Budget Contribution		Reduction		Predicted Contribution
	TSS (%)	TSS (mg/L)	TSS (%)	TSS (mg/L)	TSS (mg/L)
Total Sediment Source	**100%**	**266**	**41%**	**108**	**158**
Irrigation and on-farm waste	20%	53	39%	20	33
Range Erosion	3%	8	0%	0	8
Total Stream Entrenchment & Bank Failure	**77%**	**205**	**43%**	**88**	**117**
Total Riparian Degradation	**25%**	**67**	**70%**	**47**	**20**
Free Cattle Access to Stream	20%	53	70%	37	16
Other Riparian Degradation	5%	13	70%	9	4
Total Stream Energy	**52%**	**138**	**30%**	**41**	**97**
Natural Geologic Process	10%	27	0%	0	27
Hydraulic alteration by irrigation	40%	106	39%	41	65
Reduced Stream Miles	2%	5	0%	0	5

An efficiency improvement similar to the Angostura Unit along with the riparian improvement should bring the mean TSS concentration below the standard of 158 mg/L. This analysis was performed on yearly data, predicting changes to mean loads. Daily fluctuations may result in concentrations that are greater in the summer months or less in the winter months. However, the suggested BMPs and predicted changes in concentrations should bring site HC4 into compliance for TSS. The TSS load reduction predicted from the improved irrigation efficiency is consider to be more accurate, because in this case, TSS is transportation limited not supply limited. TSS reductions due riparian improvements are less accurate, because this affects the supply side of the equation. Riparian improvements may take 6-10 years to realize TSS reductions (Kauffman 1997). Monitoring is suggested during implementation to confirm the expected reductions.

The participation level for the riparian BMPs is assumed to be 30-50% of the stream bank impacted by cattle. Additional participation could reduce TSS concentration further. The 70% TSS reduction number reported in literature is the overall TSS concentration reduction expected. It is not clear as to which BMPs were implemented to reach these reductions. Thus, assuming the 70% reduction applies to only the load attributed to riparian degradation results in a conservative estimate. This conservative approach provides the factor of safety required in the TMDL calculations.

Site BF1 Reduction

Table 43 presents the expected TSS concentration at BF1 using similar water efficiency numbers as the Angostura Unit. A TSS concentration reduction from 347 mg/L to 272 mg/L, or a 22% reduction, is estimated. The assumed water efficiency improvements would include the following:

- Water application efficiency from 50% to above 70%.
- Water transportation efficiency from 60% to above 70%.

Reducing the flow in this system would reduce the potential for erosion and sediment transfer. For the estimated reduction of irrigation and on-farm waste, it was assumed that the percentage reduction in solids was equal to the hydraulic alteration by irrigation, 31% for site BF1. The resultant concentration at site BF1, 272 mg/L, is still above the standard of 158 mg/L.

Table 43. TSS reduction at BF1 using BMPs similar to Angostura Unit.

Sediment Source BF 1	Sediment Budget Contribution		Reduction		Predicted Contribution
	TSS (%)	TSS (mg/L)	TSS (%)	TSS (mg/L)	TSS (mg/L)
Total Sediment Source	**100%**	**347**	**22%**	**75**	**272**
Irrigation and on-farm waste	20%	69	31%	22	48
Range Erosion	3%	10	0%	0	10
Total Stream Entrenchment & Bank Failure	**77%**	**267**	**20%**	**54**	**213**
Total Riparian Degradation	**15%**	**52**	**0%**	**0**	**52**
Free Cattle Access to Stream	10%	35	0%	0	35
Other Riparian Degradation	5%	17	0%	0	17
Total Stream Energy	**62%**	**215**	**25%**	**54**	**161**
Natural Geologic Process	10%	35	0%	0	35
Hydraulic alteration by irrigation	50%	174	31%	54	120
Reduced Stream Miles	2%	7	0%	0	7

Using an iterative approach, percent reduction for irrigation and on-farm waste and hydraulic alteration by irrigation would have to approach 80% to bring the TSS concentration at site BF1 to below the TSS standard. Table 44 presents the expected TSS concentration estimates. A TSS concentration reduction from 347 mg/L to 158 mg/L, or a 54% reduction, is estimated. This translates into a water savings of approximately 4,500 ac-ft (assuming yearly flow of 14,307 ac-ft from Keyhole Reservoir). The improvements would include the following:

- Water application efficiency from 50% to above 75%.
- Water transportation efficiency from 60% to above 75%.

Table 44. TSS reduction at BF1 using water efficiency BMPs only.

Sediment Source BF 1	Sediment Budget Contribution		Reduction		Predicted Contribution
	TSS (%)	TSS (mg/L)	TSS (%)	TSS (mg/L)	TSS (mg/L)
Total Sediment Source	**100%**	**347**	**54%**	**189**	**158**
Irrigation and on-farm waste	20%	69	78%	54	15
Range Erosion	3%	10	0%	0	10
Total Stream Entrenchment & Bank Failure	**77%**	**267**	**51%**	**135**	**132**
Total Riparian Degradation	**15%**	**52**	**0%**	**0**	**52**
Free Cattle Access to Stream	10%	35	0%	0	35
Other Riparian Degradation	5%	17	0%	0	17
Total Stream Energy	**62%**	**215**	**63%**	**135**	**80**
Natural Geologic Process	10%	35	0%	0	35
Hydraulic alteration by irrigation	50%	174	78%	135	39
Reduced Stream Miles	2%	7	0%	0	7

Table 45 presents the expected reduction at site BF1 when BMPs for riparian degradation are implemented only. Even if 100% of the riparian areas are rehabilitated, the predicted concentration, 295 mg/L, is above the TSS standard of 158 mg/L.

Table 45. TSS reduction at BF1 using riparian BMPs only.

Sediment Source BF 1	Sediment Budget Contribution		Reduction		Predicted Contribution
	TSS (%)	TSS (mg/L)	TSS (%)	TSS (mg/L)	TSS (mg/L)
Total Sediment Source	**100%**	**347**	**15%**	**52**	**295**
Irrigation and on-farm waste	20%	69	0%	0	69
Range Erosion	3%	10	0%	0	10
Total Stream Entrenchment & Bank Failure	**77%**	**267**	**19%**	**52**	**215**
Total Riparian Degradation	**15%**	**52**	**100%**	**52**	**0**
Free Cattle Access to Stream	10%	35	100%	35	0
Other Riparian Degradation	5%	17	100%	17	0
Total Stream Energy	**62%**	**215**	**0%**	**0**	**215**
Natural Geologic Process	10%	35	0%	0	35
Hydraulic alteration by irrigation	50%	174	0%	0	174
Reduced Stream Miles	2%	7	0%	0	7

A combination of irrigation efficiency improvements and riparian rehabilitation appears to be the most practical for site BF1. Table 46 presents the results of an interactive calculation, setting the TSS to 158 mg/L and changing the percentage irrigation efficiency columns, and irrigation and on-farm waste and hydraulic alteration by irrigation line items. Using an iterative approach, percent reduction for irrigation and on-farm waste and hydraulic alteration by irrigation would have to approach 63 % to bring the TSS concentration at site BF1 to below the TSS standard. The percent reduction for free cattle access to streams was assumed a constant of 70%. This translates into a water savings of approximately 3,700 ac-ft within the BFID (supplied by summer releases from Keyhole). The savings will result in less demand for the water stored in Keyhole Reservoir. The improvements would include the following:

- Water application efficiency from 50% to above 70%.
- Water transportation efficiency from 60% to above 75%.

Table 46. TSS reduction at BF1 using riparian and water efficiency BMPs.

Sediment Source BF 1	Sediment Budget Contribution		Reduction		Predicted Contribution
	TSS (%)	TSS (mg/L)	TSS (%)	TSS (mg/L)	TSS (mg/L)
Total Sediment Source	**100%**	**347**	**54%**	**189**	**158**
Irrigation and on-farm waste	20%	69	63%	44	26
Range Erosion	3%	10	0%	0	10
Total Stream Entrenchment & Bank Failure	**77%**	**267**	**54%**	**145**	**122**
Total Riparian Degradation	**15%**	**52**	**70%**	**36**	**16**
Free Cattle Access to Stream	10%	35	70%	24	10
Other Riparian Degradation	5%	17	70%	12	5
Total Stream Energy	**62%**	**215**	**51%**	**109**	**106**
Natural Geologic Process	10%	35	0%	0	35
Hydraulic alteration by irrigation	50%	174	63%	109	65
Reduced Stream Miles	2%	7	0%	0	7

An efficiency improvement similar to the Angostura Unit along with the riparian improvement should bring the mean TSS concentration below the standard of 158 mg/L. This analysis was performed on yearly data predicting changes to mean loads. Daily fluctuations may result in concentrations that are greater in the summer months or less in the winter months. However, the suggested BMPs and predicted changes in concentrations should bring site BF1 into compliance for TSS. Monitoring is suggested during implementation to confirm the expected reductions. Similar to the assumption for site HC4, the participation level for the riparian BMPs for site BF1 reductions is assumed to be 30-50% of the stream bank. Additional participation could reduce the concentration further. The 70% reduction number reported in literature is the overall TSS concentration reduction expected. Thus, assuming the 70% reduction in only the load attributed to riparian degradation, results in a conservative estimate. This conservative approach provides the factor of safety required in the TMDL calculations.

Stream Bottom Shear Stress as an Indicator of Channel Incision

An incised channel exists within its geomorphology because the eroding forces exerted by concentrated flowing water exceed the resistance of the earth materials comprising the channel. The development of an incised channel may depend upon controls acting at the site, or upstream/downstream changes that may affect the site. External changes may include flow, land-use, channel modifications, change of base level, and climatic changes. Internal changes, such as deposition and subsequent slope changes, cause a channel to incise in order to maintain its slope. Irrespective of the cause, the presence of incision indicates that a threshold of stability has been exceeded (Harvey 1986).

Stream flow quantity and timing are critical components of water supply, water quality and the ecological integrity of river systems. Stream flow is strongly correlated with many critical physicochemical characteristics of rivers such as water temperature, channel geomorphology, and habitat diversity and regulates the ecological integrity of the flowing water system. Human modification of natural hydrologic processes disrupts the natural equilibrium of the movement of water as well as the dynamic equilibrium of water and of sediment movement. This disruption alters both gross and fine-scale geomorphic features (Poff 1997).

Channel widening by bank collapse is a common process in incised river channels, similar to what is experienced in the Belle Fourche watershed (Simion and Rinaldi 2000). An important feature of bank stability in deeply incised channels is the significance of negative pore water pressure (matric suction) above the water table in maintaining sufficient soil strength to withstand destabilizing forces (Simion 2001). Apparent cohesion incorporates both electro–chemical bonding within the soil matrix and cohesion due to surface tension at the air-water interface of the unsaturated soil. As the soil dries, the negative pore water pressure increases, resulting in increased cohesive forces. Thus, soils are less stable when saturated.

Using HSPF software, changes in flow due to human activity can be modeled. In addition, HSPF can simulate suspended solids transport. Using the channel bottom shear stress, the program models deposition or re-suspension of solids resulting from the flow. The program tracks the mass balance of solids in the channel bed and allows scour and re-suspension of solids until the mass available is gone.

The general correlation between flow and river incision has been published (Poff 1998, Kondolf 1995). However, the ability to predict the potential for a river to incise due to human alteration of the natural flow regime is an area of knowledge that has not been published. A relationship of the change in channel bottom shear stress to the potential for a river to incise would be useful. The change in channel bottom shear stress could be modeled based on proposed future developments and the potential for the water body incising evaluated using this approach.

Sediment transport in stream is a function of the boundary shear stress between water and the channel bottom. Sediment is transported when the critical shear stress is greater than the attractive forces of the sediment on the channel bottom. Shear stress is a function of density, hydraulic radius and slope. Critical shear force is dependent on the material deposited on the channel bottom (Bricknell 2000). The hypothesis is that modeling change in shear stress between exiting and the natural condition can help evaluate the potential for a stream to incise.

Proposal

The flow in the Belle Fourche River is significantly influenced by irrigation activities. The river is entrenching in areas, particularly near the USGS gaging station on the Belle Fourche River at Sturgis (BF7). It is less entrenched near the USGS gaging station on the Belle Fourche River at Fruitdale (BF3). This site is just downstream of where water is taken to fill the Belle Fourche Reservoir. In addition, at least one of the tributaries of the Belle Fourche River, Horse Creek, is entrenched and will be evaluated at the USGS gauge, Horse Creek above Vale (HC4).

One cause of entrenchment in the Belle Fourche River may be a result of increased flows of low magnitude, but long duration, due to irrigation. The more "natural flow regime" that originally controlled the geomorphology of the river was of short duration, but higher peak flows, due to spring runoff and intense thunderstorm activity. The irrigation-related flow regime might also cause more entrenchment at lower flows due to increased saturation of the banks, caused by irrigation of the surrounding fields.

Objectives and Hypotheses

The hypotheses are the following:

- Shear stress (lbs/ft^2) is greater than if the system was unaltered for Horse Creek due to water discharged from the irrigation system. This creek would not experience this flow if the BFID were not irrigating acreage that discharges into Horse Creek and then into the Belle Fourche River.
- Shear stress is greater for the Belle Fourche River at Sturgis (site BF7) due to the influence of irrigation than if the system was unaltered. This difference is more significant during the irrigation season. The resulting forces may be more destructive during the irrigation season due to saturated banks and the absence of riparian vegetation.
- Shear stress is significantly less for the Belle Fourche River at Fruitdale (Site BF3) due to the removal of flow to fill the Belle Fourche Reservoir.
- There is a relationship between the magnitude of delta shear stress (existing flow minus unaltered flows) and TSS.

Approach

HSPF was used to calculate two daily time series for shear stress (lbs/ft^2) and flow (cfs) using the calibrated model for 1992-1996. The first set was for the existing system. The second set excluded the flows from the existing irrigation system. The flows that were altered to develop the data without existing irrigation included the elimination of the following:

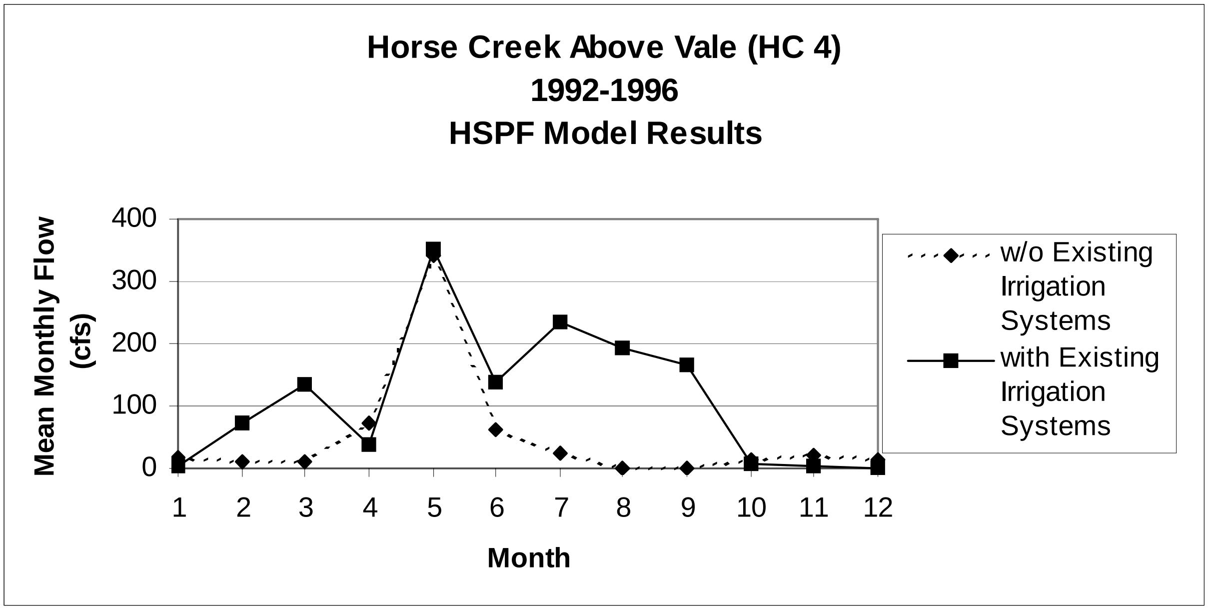
- Keyhole Reservoir release for irrigation: The flows into the Keyhole Reservoir (Belle Fourche River at Moorcroft) were added to the flows at site BF1 to simulate the flows without Keyhole Reservoir releases.
- Flows to the inlet of the Belle Fourche Reservoir upstream of site BF3 (point source from the Belle Fourche River was turned off).
- Flows from Horse Creek due to irrigation above site HC4: Site HC4 point source was replaced with flows estimated by the model due to natural precipitation.

Results

The change in shear stress and flow for the daily time series for 1992 -1996 were calculated (with existing irrigation – without existing irrigation). Table 47 presents the 5-year monthly descriptive statistics for shear stress and flow with and without irrigation for site HC4. Figure 24 plots the monthly values for flow and shear stress. A comparison of mean flows during the non-irrigation months (October -May) should be similar. As can be seen in Figure 24, there is a divergence in flow in the February and March months. As discussed in earlier sections of this report, the early flow/snow melt in February and March is not modeled by HSPF very well. However, it accurately represents the flows in April and May during the spring runoff period. During the June through September time frame, the flow at site HC4 is dominated by irrigation runoff.

Table 47. Descriptive statistics monthly shear stress, flow with/without existing irrigation at HC4.

Month	Shear stress w/existing irrigation (lbs/ft^2)		Shear stress w/o existing irrigation (lbs/ft^2)		Flow w/existing irrigation (cfs)		Flow w/o existing irrigation (cfs)	
	Mean	**StD**	**Mean**	**StD**	**Mean**	**StD**	**Mean**	**StD**
1	0.001	0.001	0.005	0.008	2	3	16	27
2	0.011	0.027	0.003	0.005	73	217	11	15
3	0.025	0.030	0.004	0.006	133	264	12	19
4	0.010	0.016	0.011	0.027	37	67	74	286
5	0.042	0.060	0.031	0.056	351	852	341	1155
6	0.035	0.021	0.011	0.024	139	134	61	177
7	0.051	0.023	0.006	0.015	235	272	24	75
8	0.052	0.011	0.000	0.001	192	62	0	2
9	0.042	0.025	0.000	0.000	166	108	0	1
10	0.003	0.005	0.004	0.010	8	18	13	34
11	0.001	0.001	0.006	0.011	3	3	22	47
12	0.000	0.000	0.004	0.008	2	2	14	25
Average	0.023		0.007		112		49	
June-August Average	0.046		0.006		188		28	



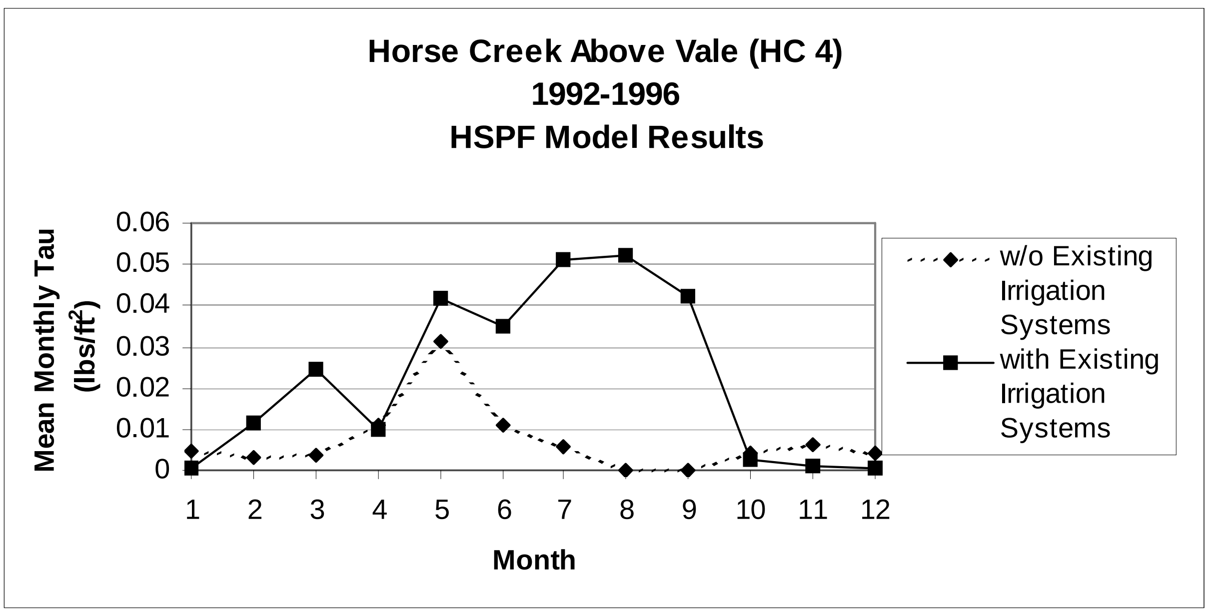


Figure 24. Monthly flow and shear stress, HC4, with and without existing irrigation.

Table 48 presents the changes in shear stress and flow for the irrigation seasons and for all months. The table also presents the average TSS concentration for the two time periods. This was estimated by developing a daily flow time series for 1992 -1996 using actual flow rates for the three months of irrigation. Monthly averages were calculated for the 5 years. Over all, there is a yearly average of 63 cfs difference between the two flow regimes and a difference in shear stress of 0.016 lbs/ft^2 (flow/shear stress with existing irrigation minus flow/shear stress without existing irrigation). There is a significant difference in flow of about 160 cfs during irrigation periods and a difference in shear stress of 0.040 lbs/ft^2. Delta flow and shear stress are about 2.5 times greater for the irrigation months than for all months. The proposed hypothesis that shear stress should be significantly greater at HC4 and is a significant contributor to the observed incising process is supported by these results.

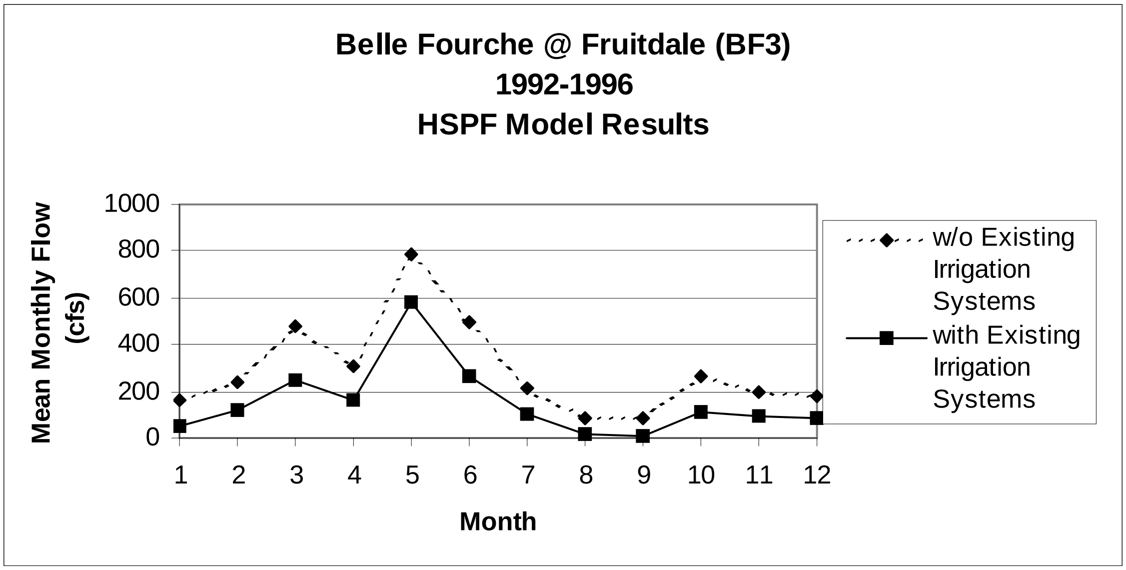
Table 48. TSS concentration and change in shear stress, flow at HC4, BF3, BF7.

Site	All Months			Irrigation Months (June-August)		
	Delta shear stress (lbs/ft^2)	Delta Flow (cfs)	Mean Concentration (mg/L)	Delta shear stress (lbs/ft^2)	Delta Flow (cfs)	Mean Concentration (mg/L)
HC4	-0.016	63	295	0.040	160	423
BF3	-0.056	-139	40	-.047	-136	42
BF7	-0.003	-62	42	0.003	40	52

BF3 is the first site downstream of the diversion to the Belle Fourche Reservoir. Thus, the flows with existing irrigation at this site will always be below the flows without irrigation. Table 49 presents the 5-year monthly descriptive statistics for shear stress and flow with and without irrigation for site BF3. Figure 25 plots the monthly values for flow and shear stress. The most significant flow difference is during the high flow periods March - June. The flows with irrigation are –139 cfs less than without irrigation due to the diversion to the Belle Fourche Reservoir and there is little difference between the averages for irrigation months and all months. Change in shear stress is –0.055 lbs/ft^2. This change represents a depositional-type environment due to reduction of flow. The proposed hypothesis that shear stress should be significantly less at BF3 and is a significant contributor to the observed depositional process is supported by these results.

Table 49. Descriptive statistics monthly shear stress, flow with/without existing irrigation at BF3.

Month	Shear stress w/existing irrigation (lbs/ft^2)		Shear stress w/o existing irrigation (lbs/ft^2)		Flow w/existing irrigation (cfs)		Flow w/o existing irrigation (cfs)	
	Mean	StD	Mean	StD	Mean	StD	Mean	StD
1	0.019	0.043	0.077	0.041	51	184	163	190
2	0.032	0.064	0.090	0.052	117	274	236	284
3	0.060	0.110	0.135	0.100	248	684	479	770
4	0.046	0.072	0.114	0.045	164	292	310	259
5	0.108	0.154	0.164	0.149	577	1422	789	1450
6	0.066	0.096	0.126	0.095	264	558	497	604
7	0.049	0.045	0.091	0.043	101	137	214	171
8	0.012	0.015	0.050	0.032	18	25	82	68
9	0.003	0.007	0.057	0.030	4	10	89	48
10	0.033	0.069	0.094	0.068	112	393	266	420
11	0.045	0.049	0.091	0.035	90	110	196	124
12	0.041	0.052	0.089	0.031	87	119	181	104
Average	0.043		0.098		153		292	
June-August Average	0.042		0.089		128		264	



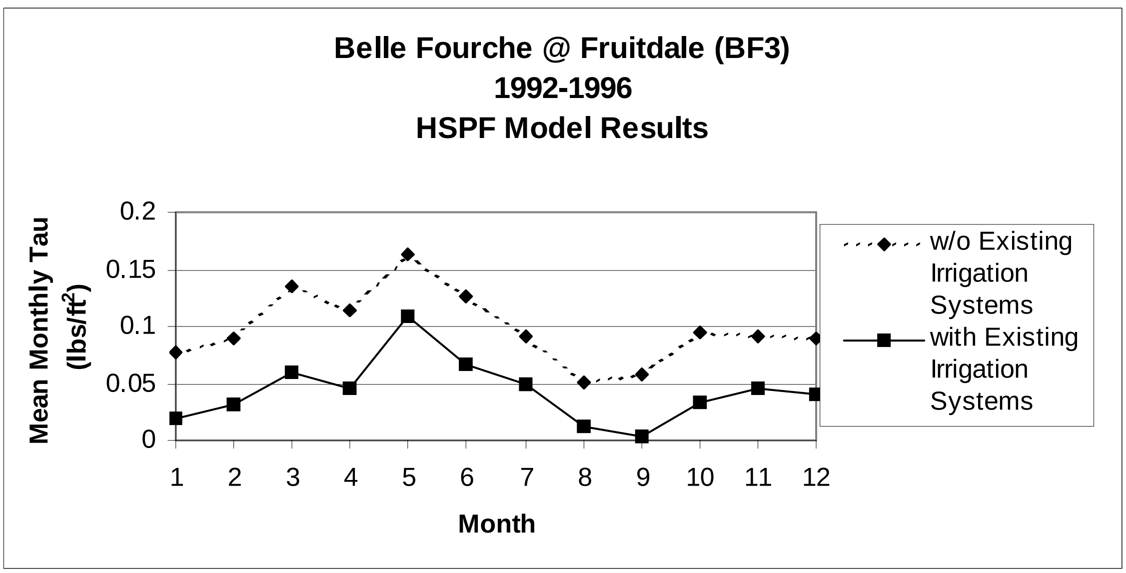
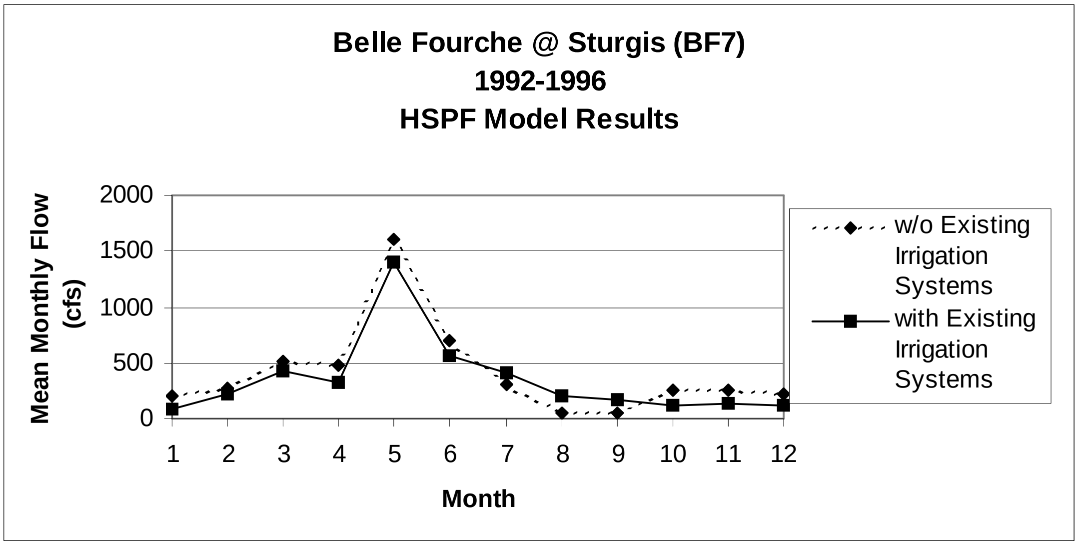


Figure 25. Monthly flow and shear stress, BF3, with and without existing irrigation.

BF7 is the site downstream of both the diversion to the Belle Fourche Reservoir and BFID's system. Table 50 presents the 5-year monthly descriptive statistics for shear stress and flow with and without irrigation for site BF7. Figure 26 plots the monthly values for flow and shear stress. The flows with irrigation are less in all months (-62 cfs) than without irrigation. This is expected due to evaporation losses and crop consumption. However, in the irrigation months, the flow with irrigation is more (40 cfs) than without irrigation. This is also expected due to irrigation. Change in shear stress is -0.003 lbs/ft^2 for all months, indicating a slight depositional type environment, and 0.003 lbs/ft^2 for irrigation months, indicating a slight incising- type environment. Site BF7 is slightly incising, indicating that delta shear stress may be more significant during the summer months.

Table 50. Descriptive statistics monthly shear stress, flow with/without existing irrigation at BF7.

Month	Shear stress w/existing irrigation (lbs/ft^2)		Shear stress w/o existing irrigation (lbs/ft^2)		Flow w/existing irrigation (cfs)		Flow w/o existing irrigation (cfs)	
	Mean	**StD**	**Mean**	**StD**	**Mean**	**StD**	**Mean**	**StD**
1	0.005	0.009	0.011	0.012	84	166	200	207
2	0.012	0.024	0.015	0.017	222	460	270	296
3	0.020	0.028	0.026	0.026	425	783	521	730
4	0.016	0.026	0.024	0.026	319	553	483	733
5	0.041	0.054	0.049	0.055	1395	2987	1602	3456
6	0.029	0.031	0.035	0.034	565	697	708	787
7	0.021	0.021	0.017	0.019	408	515	300	358
8	0.012	0.006	0.003	0.005	207	100	50	83
9	0.010	0.006	0.002	0.003	170	112	44	49
10	0.006	0.015	0.014	0.018	116	284	252	365
11	0.008	0.010	0.015	0.012	141	186	262	222
12	0.007	0.008	0.012	0.009	119	147	220	154
Average	0.016		0.019		347		409	
June-August Average	0.021		0.018		393		353	



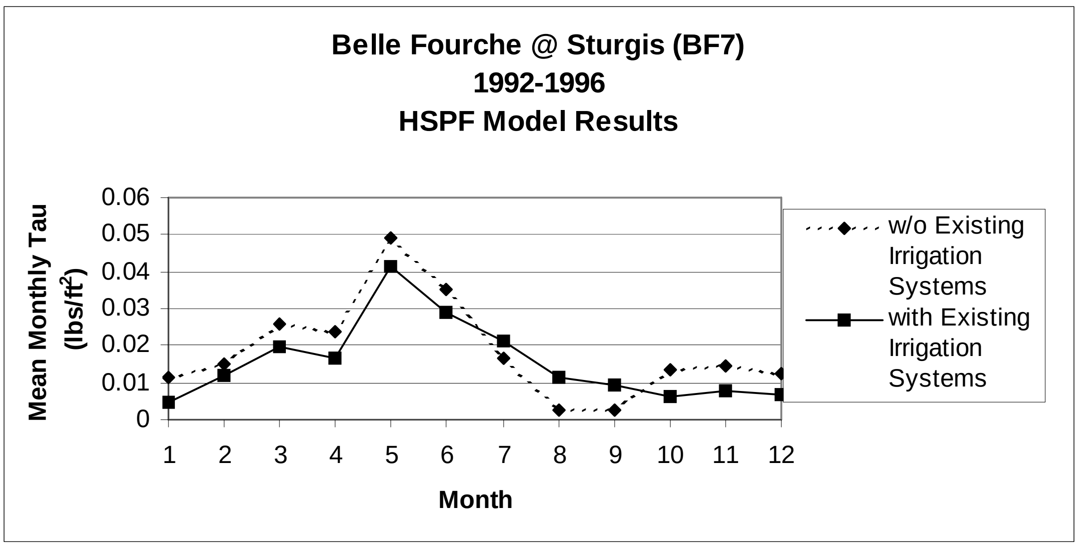


Figure 26. Monthly flow and shear stress, BF7, with and without existing irrigation.

The shear stress and flow data from sites HC4, BF1 and BF7 were compared to TSS data. The daily TSS concentration for 1992 -1996 was estimated using actual flow rates for the three sites, and the flow concentration relationship developed with FLUX to calculate a new daily TSS concentration. Monthly averages were calculated. Table 51 presents the results of this analysis using the correlation coefficient (R^2adj) for comparison. The most robust regression was achieved using the 5-year monthly average without the months of April and May (10 data points). Both shear stress and flow had strong correlations with concentrations for sites HC4 and BF7. The months of April and May appeared to be outliers, and removing them improved the R^2adj from 0.62 to 0.79 for site HC4, and from 0.59 to 0.70 for site BF7 with respect to shear stress. These months represent different sediment loading characteristics than are found during the summer irrigation months. Loading in April and May maybe dominated by spring runoff carrying a significant load, and not from channel bottom shear stress re-suspending the solids.

These months are important because the sediment storage is recharged, providing additional solids to re-suspend and become transported downstream. Load is a function of flow and concentration and thus the R-values reported are not as robust because the variables are related, not independent.

Table 51. Regression analysis of shear stress/flow versus extrapolated concentration/load.

Analysis Time Frame (1992-1996)	Response Variable	HC4 R^2adj		BF3 R^2adj		BF7 R^2adj	
		Delta shear stress	**Delta Flow**	**Delta shear stress**	**Delta Flow**	**Delta shear stress**	**Delta Flow**
Yearly (5 years)	Load	0.42	0.34	0	0.46	0	0
	Concentration	0.48	0.79	0.39	0.26	0.25	0.46
Monthly (12- month average for 5 years)	Load	0	0	0	0.49	0	0
	Concentration	0.62	0.47	0	0.37	0.59	0.46
Monthly (12 –month average for 5 years without April-May)	Load	0.24	0.43	0.26	0.74	0	0
	Concentration	0.79	0.76	0	0.25	0.70	0.65

For the regression using the 5-year average for all months except April and May, the equation and p-values are presented in Table 52. The equation for BF7 suggests that a flow of 1700 cfs would be needed to increase the TSS to 158 mg/L. This equation does not work because the TSS ranges were narrow, minimum of 1 mg/L and max of 58 mg/L. This does not provide a large enough variance to support an equation.

Flow is a slightly better indicator than shear stress at HC4. There does not appear to be a strong relationship between shear stress and flow or TSS at site BF3. Like BF7 there was not a large range of concentration values, in addition there was not a large range of flow values. The equations should be different at each site, indicating that the relationship is site dependent.

Table 52. Proposed equations of TSS concentration and shear/flow at HC4.

Equation	R^2 adj	P Value
HC4 Concentration (mg/L) = 184 + 5665*Delta shear stress (lbs/ft^2)	0.79	0.001
HC4 Concentration (mg/L) = 177 + 1.38*Delta Flow (cfs)	0.76	0.001
BF7 Concentration (mg/L) = 45 + 1238*Delta shear stress (lbs/ft^2)	0.70	0.002
BF7 Concentration (mg/L) = 45 + 0.064*Delta Flow (cfs)	0.65	0.003
BF3 Concentration (mg/L) = 39.6 - 3.9*Delta shear stress (lbs/ft^2)	0.00	0.965
BF3 Concentration (mg/L) = 39.6 + 0.026*Delta Flow (cfs)	0.25	0.082

Application

The equation for site HC4 concentration was applied to determine change in flows required to meet the TSS criteria of 158 mg/L. A reduction of 13.9 cfs or approximately 10,000 ac-ft/year is required. This is similar to the savings determined using a combination of water efficiency improvements and riparian habitat rehabilitation discussed in the remediation alternatives section of this report.

However, water efficiency improvement changes required to meet the TSS standard without riparian improvements were estimated to be –20,000 ac-ft. The apparent differences in water savings required to meet the standard is thought to be due to the fact that the shear stress and flow relationships assume all of the TSS is coming from re-suspension of solids in the channel. During the irrigation months, a significant amount of TSS is suspected to come from on-farm wastewater. The allocation of solids in the sediment budget may be low for TSS for the categories of hydraulic alteration by irrigation, and irrigation and on-farm waste, resulting in an increased water savings to meet the TSS standard. The budget also includes the sources of solids that are stored within the channel and are available for transport. Thus, the flow and shear stress-generated water savings of approximately 10,000 ac-ft, compared with the water efficiency and riparian improvements water savings of approximately 12,000 ac-ft, appear to support each other and represent a good improvement target for the BFID.

Proposed Actions

Water Efficiency Improvements

A combination of irrigation scheduling, efficiency improvements in both the transport and application of irrigation water, and use of runoff and tail water, is proposed to reduce the amount of water entering the streams from both the Keyhole and the Belle Fourche Reservoirs. Bringing the BFID's system and the farmer's systems up to a similar standard as the Angostura Unit is recommended. An overall water savings of approximately 4,500 ac-ft of Keyhole Reservoir releases and approximately 12,000 ac-ft of the Belle Fourche Reservoir releases would be achieved.

Riparian Rehabilitation

In addition to the water efficiency improvements, it is recommended that riparian areas adjacent to the Belle Fourche River be rehabilitated. A combination of erosion and sediment control, riparian re-vegetation and grazing management should be implemented to reestablish the riparian areas along the water body. Passive-type measures are suggested rather than in-stream structures. Significant changes in water quality from this effort may take 6-10 years to occur after implementation of the measures.

Monitoring

Monitoring will be necessary to determine that the proposed actions have been completed and to determine the impact on the water quality of the Belle Fourche watershed. Specifically, the monitoring should include the following:

- Yearly summaries of implementation status of the proposed actions.
- Measurements of daily flow; monthly turbidity, specific conductance, temperature, and pH; and yearly full chemical analysis for:
  - USGS sites
    - BF1 (USGS 06430500)
    - Inlet Canal (USGS 06434505)
    - BF3 (USGS 06436000)
    - BF7 (USGS 0647000)
    - BF11 (USGS 06438000)
    - HC4 (USGS 06436760)
    - WW5 (USGS 06436198)
    - RW1 (USGS 06430500)
    - SP3 (USGS 06431500)
    - BFID's system
  - Daily flows at all discharge points including fields, streams and drains during irrigation.
  - Monthly turbidity, specific conductance, temperature, and pH measurements at all discharge stream and drain discharge locations.
  - Full chemical analysis once per year.
  - Yearly water mass balance report.
- After the BFID measurement system is implemented, a one -year study of flows in minor streams within the BFID, such as Owl, Willow and Nine Mile.

Sources of Uncertainty

When evaluating the use of a model as a predictive tool, it is important to consider the sources of uncertainty associated with developing the model. In creating and calibrating the model, the modeler must make several decisions about how the study area would be best represented. The modeler is responsible for estimating initial conditions for the model. In this research, a start-up period of one year was used to try to limit the error resulting from inaccurate initial conditions. During the calibration process, the modeler must determine when the best fit between the simulated and observed data has been reached. It is possible that similar results could have been achieved from an entirely different set of parameters.

Meteorological data, such as dew point temperature, wind speed, solar radiation, potential evapotranspiration, cloud cover, and evaporation were not available for the study area; therefore, data from the Rapid City WSO was used with this model. However, the ecology, topography, and climate of the study area are different from those at the Rapid City WSO, so this could be a source of error in the model. Additionally, the daily observed meteorological data had to be converted to hourly measurements. For the precipitation data, this meant that the timing and intensity of the rainfall had to be estimated.

The flow estimates representing the small tributaries receiving the irrigation wastes was estimated using the HC4 site. There are significant differences in flow, soil conditions and method of application between the fields serviced by the north canal, south canal and the

Redwater Irrigation Association. A better water balance within the irrigation system could significantly reduce the uncertainty and greatly improve the accuracy of the model.

Both the flow rate and quality of discharge from the BFID irrigated farms are significant. These measurements represent a significant uncertainty in the analysis. Daily flow out of the Belle Fourche Reservoir is measured. There is not another flow measurement system in the BFID system. The impact of the BFID system on the Belle Fourche River and tributaries is significant from both hydraulic and chemical perspectives.

The FLUX model develops a concentration-flow relationship. This model was used to determine the load reduction under different flow regimes. A basic assumption was that the concentration-flow relationship remains. Under significantly different flow regimes, such as reducing the flow by 30%, a different flow regime would result. Consequently, sediment amount and type transported may also change. Thus, a new concentration-flow relationship may develop.

Additional Recommendations for Research

The conceptual sediment budget was a useful tool to support the evaluation of TSS within the watershed. The budget accuracy could be strengthened to help focus the TSS reduction effort. Determining the age and or source of the solids within the channel system would be extremely useful. Interpreting historical photos from fieldwork to document the channel evolution, along with using naturally occurring chemical half-lives to determine the age of the solids, would add significant understanding to the sediment budget.

Future monitoring is planned during the post-implementation phase of this project. Details of the monitoring can be found in the TMDL summary (see Appendix D) in the section titled, "Follow-up Monitoring." Ambient monitoring will also continue on the five WQM sites sampled by SD DENR Surface Water Quality Program. Greater understanding of the impacts of the irrigation system should result from additional monitoring, so management recommendations made in this report may be revised in the future.

Summary and Conclusions

The following summarize the points of the study:

- The hydrology of the Belle Fourche River is significantly altered due to irrigation. Major irrigation structures influencing the hydrology include the Belle Fourche Reservoir, Keyhole Reservoir and the canals and laterals operated by the BFID.
- More than 230 water quality samples were collected during two seasons in 2001and 2002, along with daily flow measurements, to characterize the water quality within the watershed. Eight standards were exceeded at 20 water quality-monitoring sites. Mean TSS concentrations exceeded the standard of 158 mg/L at sites BF1, BF2 and HC4. There is a robust regression equation relating TSS and turbidity for the water quality stations on the Belle Fourche River.

- Benthic macroinvertebrate samples were collected at 16 sites to support the water quality analysis. Significant impairment was evident at sites BF1 and HC4. A robust regression equation was developed relating TSS and seven biologic indicators. Sites BF4 and BB2 appear to be impaired by something other than TSS.
- Release of water from Keyhole Reservoir for irrigation purposes, as well as startup of the BFID facilities, have significant impacts on TSS and specific conductance.
- Significant flow increases were observed between sites BF3, BF5 and BF6 during the irrigation seasons due to irrigation return flows.
- The most significant source of sediment is expected from stream entrenchment and bank failure.
- The FLUX model was used to estimate the source of loadings based on a relationship between flow and TSS concentration. The results indicate the most significant loading occurs at sites BF1, HC4, BF7 and BF11. Loading at sites BF1 and HC4 come from high concentration, low flow sources, where-as sites BF7 and BF11 are low concentration, high flow sources.
- The HSPF model was used to determine the changes in flow and resultant channel bottom shear stress between the existing system dominated by irrigation influences and a more natural system without irrigation. The model was calibrated for the period between 1992 -1996 and validated between the years 1997 and 1998.
- Remediation alternatives were identified for sites BF1 and HC4 to reduce the TSS concentrations by 55% and 41 % respectively. Management measures for irrigation waters along with riparian rehabilitation are recommended to meet this reduction. Water efficiency improvement would bring the BFID's system, along with the farmer's systems, up to the standards met by the Angostura Unit irrigation project.
- There is an increase in channel bottom shear stress (Tau) with and without the existing irrigation system at those sites where channel incision is evident. There is a decrease in shear stress at those sites where channel deposition is evident.
- There is a correlation between changes in flow and resultant shear stress, and TSS concentration at sites BF7 and HC4. The changes were estimated using model results from HSPF for existing conditions with irrigation and flows that would occur if irrigation did not exist (representing more natural flow regimes for the major streams in the area).

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Appendix A

Water Quality Sample Results

Sample Data

SITE ID	DATE & TIME	METHOD	EVENT	FECAL COL (CFU/100 ml)	ALKA (mg/L)	TOT SOL (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (% of TSS)	AMM (mg/L)	TKN (mg/L)	NIT (mg/L)	TDP (mg/L)	TOT P (mg/L)
BB1	6/13/2001 17:43	GRAB	ROUTINE	72	248	990	910	11	99	ND	0.6	1.02	0.02	0.04
BB1	7/27/2001 00:35	GRAB	RAIN EVENT	40	264	980	870	5	99	ND	ND	0.94	ND	0.04
BB1	8/30/2001 06:45	GRAB	ROUTINE	10	248	1000	880	ND	ND	ND	ND	0.83	0.03	0.03
BB1	10/9/2001 13:46	GRAB	STORM EVENT	66	220	930	820	ND	ND	ND	ND	1.21	0.02	0.04
BB1	9/27/2001 16:00	GRAB	ROUTINE	2	212	1000	910	ND	ND	ND	ND	0.73	0.01	0.03
BB1	4/4/2002 08:18	GRAB	ICE COVER	ND	248	1200	990	ND	ND	ND	0.6	1.5	0.02	0.05
BB1	4/23/2002 16:05	GRAB	ROUTINE	ND	ND	990	900	ND	ND	ND	ND	0.9	ND	0.01
BB2	6/13/2001 07:30	GRAB	ROUTINE	610	214	770	680	5	99	ND	0.6	2.26	ND	0.03
BB2	7/27/2001 01:00	GRAB	RAIN EVENT	6500	212	720	680	ND	ND	ND	0.6	1.67	0.01	0.04
BB2	8/30/2001 08:00	GRAB	ROUTINE	110	270	990	900	ND	ND	ND	ND	2.2	0.03	0.04
BB2	10/9/2001 13:01	GRAB	STORM EVENT	TNTC	334	360	290	32	49	0.2	1.2	1.33	0.03	0.13
BB2	9/27/2001 15:36	GRAB	ROUTINE	70	240	910	750	ND	ND	ND	ND	2.25	0.02	0.04
BB2	3/28/2002 13:25	GRAB	ROUTINE	20	248	970	920	ND	ND	ND	ND	3.2	0.01	0.02
BB2	3/28/2002 13:25	GRAB	ROUTINE	13	246	950	890	ND	ND	ND	ND	3.3	ND	0.01
BB2	4/23/2002 16:25	GRAB	ROUTINE	ND	210	1000	870	ND	ND	ND	ND	2.7	ND	ND
BB2	5/11/2002 14:19	GRAB	STORM EVENT	2200	92	330	230	46	78	0.1	0.5	0.72	0.05	0.13
BB2	8/21/2002 00:00	AUTO	STORM EVENT	140	258	1100	960	45	40	ND	0.9	2.6	0.03	0.06
BF1	6/14/2001 15:13	EWI	ROUTINE	2200	102	1900	950	880	13	ND	1.2	0.16	0.04	0.64
BF1	6/14/2001 15:27	EWI	ROUTINE	1600	106	1900	940	850	12	ND	1.8	0.15	0.03	0.61
BF1	7/13/2001 12:00	AUTO	IRRIGATION	TNTC	118	3000	1600	1200	14	ND	3.9	0.05	1.77	1.77
BF1	7/24/2001 14:00	AUTO	RAIN EVENT	TNTC	134	2800	1100	1800	12	ND	3.6	ND	0.02	1.18
BF1	8/28/2001 06:30	GRAB	ROUTINE	230	168	1400	1200	28	65	ND	0.6	ND	ND	0.06
BF1	10/25/2001 13:15	GRAB	ROUTINE	40	138	2000	1700	ND	ND	ND	ND	ND	ND	ND
BF1	9/27/2001 11:25	GRAB	ROUTINE	30	144	2100	1900	ND	ND	ND	ND	ND	ND	ND
BF1	3/28/2002 11:42	GRAB	ICE COVER	27	156	1500	1300	58	21	ND	0.5	0.1	ND	0.09
BF1	4/23/2002 12:50	GRAB	ROUTINE	12	176	1400	1200	5	99	ND	ND	ND	ND	0.03
BF1	5/29/2002 11:04	GRAB	ROUTINE	260	134	1900	1600	8	28	ND	ND	ND	ND	0.01
BF1	6/7/2002 00:00	AUTO	KEYHOLE	1900	108	2100	1700	270	18	ND	1.3	ND	0.1	0.35
BF1	6/9/2002 00:00	AUTO	KEYHOLE	710	176	1700	1300	260	17	ND	1.3	ND	0.1	0.32
BF1	6/10/2002 00:00	AUTO	KEYHOLE	300	186	1600	1200	290		ND	1.3	ND	0.1	0.32
BF1	6/6/2002 14:30	GRAB	KEYHOLE	4300	124	2200	1800	240	12	ND	1	ND	0.08	0.28
BF1	6/6/2002 00:00	AUTO	KEYHOLE	3200	132	2200	1800	240	18	ND	1.2	ND	0.09	0.3
BF1	6/8/2002 00:00	AUTO	KEYHOLE	810	132	2000	1600	240	21	ND	1	ND	0.08	0.29
BF1	6/8/2002 00:00	AUTO	KEYHOLE	860	130	2000	1700	230	24	ND	1	ND	0.08	0.28

SITE ID	DATE & TIME	METHOD	EVENT	FECAL COL (CFU/100 ml)	ALKA (mg/L)	TOT SOL (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (% of TSS)	AMM (mg/L)	TKN (mg/L)	NIT (mg/L)	TDP (mg/L)	TOT P (mg/L)
BF1	7/30/2002 13:10	GRAB	ROUTINE	600	200	1500	1100	360	16	ND	1.2	ND	ND	0.24
BF1	8/27/2002 06:28	GRAB	ROUTINE	100	194	1300	1100	180	15	ND	1.75	ND	0.02	0.26
BF1	9/13/2002 07:25	GRAB	ROUTINE	260	238	1400	1100	140	16	ND	0.9	ND	0.01	0.18
BF1	10/23/2002 08:30	GRAB	ROUTINE	14	156	1800	1600	ND	ND	ND	0.6	ND	0.03	ND
BF11	6/14/2001 07:47	GRAB	ROUTINE	210	138	1700	1400	29	41	ND	0.6	0.19	ND	0.06
BF11	7/26/2001 10:15	GRAB	RAIN EVENT	140	122	1600	1300	190	15	ND	1.2	0.08	0.01	0.27
BF11	8/29/2001 13:32	GRAB	ROUTINE	50	128	1500	1300	54	33	ND	0.6	ND	ND	0.07
BF11	10/25/2001 07:50	GRAB	ROUTINE	17	156	1900	1800	12	99	ND	0.6	0.68	ND	0.02
BF11	9/14/2001 14:30	GRAB	STORM EVENT	36	126	1500	1200	42	38	ND	0.6	0.18	ND	0.06
BF11	3/28/2002 06:57	GRAB	ICE COVER	5	208	2100	1800	ND	ND	ND	0.6	2.2	ND	ND
BF11	4/23/2002 06:55	GRAB	ROUTINE	8	146	1900	1600	25	44	ND	0.6	0.61	ND	0.03
BF11	5/20/2002 10:00	GRAB	ROUTINE	20	160	2400	3000	14	53	ND	0.8	ND	0.01	0.02
BF11	6/27/2002 06:45	GRAB	ROUTINE	300	132	1600	1400	63	33	ND	0.9	0.14	ND	0.08
BF11	7/30/2002 07:00	GRAB	ROUTINE	100	104	1500	1300	67	30	ND	1	ND	ND	0.07
BF11	8/26/2002 07:30	GRAB	ROUTINE	80	128	1600	1600	48	31	ND	0.9	0.17	ND	0.07
BF11	10/1/2002 09:10	GRAB	STORM EVENT	20	134	1600	1500	41	29	ND	0.7	0.29	0.05	0.05
BF11	10/25/2002 06:45	GRAB	ROUTINE	40	154	1900	1800	ND	ND	ND	0.7	0.59	0.02	0.06
BF12	10/11/2002 10:05	GRAB	ROUTINE	6	146	2000	1700	20	100	ND	2.2	0.3	0.1	0.14
BF2	6/14/2001 16:32	GRAB	ROUTINE	1500	70	3400	760	2400	12	ND	2.7	0.23	0.02	1.56
BF2	7/24/2001 15:00	GRAB	RAIN EVENT	TNTC	66	3100	740	2000	10	ND	3.3	0.22	0.03	1.27
BF2	8/28/2001 08:15	GRAB	ROUTINE	66	168	1400	1200	24	50	ND	0.6	ND	ND	0.06
BF2	10/25/2001 12:00	GRAB	ROUTINE	23	148	2100	1800	ND	ND	ND	ND	ND	ND	ND
BF2	9/27/2001 09:45	GRAB	ROUTINE	250	140	2200	1800	ND	ND	ND	ND	ND	ND	0.02
BF2	4/4/2002 11:10	GRAB	ROUTINE	ND	156	1400	1200	70	68	ND	ND	0.1	0.01	0.11
BF2	4/23/2002 12:10	GRAB	ROUTINE	10	ND	1300	1200	5	99	ND	ND	ND	ND	0.02
BF3	6/14/2001 13:14	GRAB	ROUTINE	140	178	1200	1000	21	48	ND	ND	0.1	0.02	0.06
BF3	6/14/2001 16:55	GRAB												
BF3	7/24/2001 08:41	GRAB	RAIN EVENT	1400	210	1500	1300	26	43	ND	0.6	ND	0.03	0.08
BF3	8/29/2001 06:30	GRAB	ROUTINE	18	230	1600	1300	38	40	ND	0.9	ND	ND	0.12
BF3	10/25/2001 11:30	GRAB	ROUTINE	13	242	1400	1300	ND	ND	ND	ND	0.19	ND	0.02
BF3	9/27/2001 09:20	GRAB	ROUTINE	110	228	1600	1300	17	59	ND	0.6	0.14	0.04	0.04
BF3	3/28/2002 10:35	GRAB	ICE COVER	2	258	1600	1500	9	83	ND	ND	0.59	ND	0.02
BF3	4/23/2002 11:30	GRAB	ROUTINE	2	224	1500	1200	52	27	0.1	0.6	0.12	ND	0.09
BF3	5/29/2002 08:00	GRAB	ROUTINE	300	244	1800	1700	90	44	ND	0.9	ND	ND	0.06
BF3	5/29/2002 08:00	GRAB	ROUTINE	320	238	1800	1700	21	28	ND	0.8	ND	0.01	0.05
BF3	6/27/2002 11:55	GRAB	ROUTINE	250	246	1800	1600	130	28	ND	1	0.19	ND	0.1
BF3	7/30/2002 12:25	GRAB	ROUTINE	ND	238	1700	1400	85	32	ND	1.1	0.36	ND	0.08

SITE ID	DATE & TIME	METHOD	EVENT	FECAL COL (CFU/100 ml)	ALKA (mg/L)	TOT SOL (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (% of TSS)	AMM (mg/L)	TKN (mg/L)	NIT (mg/L)	TDP (mg/L)	TOT P (mg/L)
BF3	8/27/2002 10:07	GRAB	ROUTINE	30	234	1600	1400	61	30	ND	0.9	0.1	0.04	0.11
BF3	9/13/2002 08:15	GRAB	ROUTINE	220	242	1500	1300	21	57	ND	0.6	0.09	ND	0.07
BF3	10/23/2002 09:15	GRAB	ROUTINE	8	234	1400	1300	5	100	ND	ND	0.18	0.04	0.06
BF4	6/14/2001 11:49	EWI	ROUTINE	1100	170	1200	1100	38	26	ND	0.6	ND	ND	0.08
BF4	7/24/2001 09:20	GRAB	RAIN EVENT	3700	194	1600	1400	35	63	ND	0.6	0.42	ND	0.11
BF4	7/24/2001 09:20	GRAB	RAIN EVENT	5600	182	1600	1400	36	41	ND	0.9	0.44	ND	0.1
BF4	8/29/2001 07:00	GRAB	ROUTINE	200	214	1700	1500	43	40	ND	0.9	0.15	0.02	0.1
BF4	10/25/2001 10:45	GRAB	ROUTINE	18	244	1600	1400	ND	ND	ND	0.6	0.14	ND	0.03
BF4	9/27/2001 08:45	EWI	ROUTINE	140	192	1500	1400	19	53	ND	0.6	0.12	ND	0.05
BF4	4/4/2002 11:40	GRAB	ICE COVER	ND	204	1700	1500	5	ND	ND	0.9	0.26	0.02	0.03
BF4	4/23/2002 10:55	GRAB	ROUTINE	26	240	2000	1700	23	43	0.1	0.6	0.11	ND	0.08
BF5	6/14/2001 11:18	GRAB	ROUTINE	260	172	1400	1100	57	16	ND	0.9	0.93	ND	0.11
BF5	7/24/2001 09:45	GRAB	RAIN EVENT	20000	142	1400	1100	180	17	ND	1.2	1.19	ND	0.33
BF5	8/29/2001 10:35	GRAB	ROUTINE	150	186	1600	1400	45	33	ND	0.9	0.26	ND	0.11
BF5	10/25/2001 09:50	GRAB	ROUTINE	37	226	1600	1300	5	99	ND	0.6	1.12	0.01	0.01
BF5	9/27/2001 07:54	GRAB	ROUTINE	220	194	1600	1400	17	39	ND	0.6	0.45	0.02	0.05
BF5	3/28/2002 09:35	GRAB	ICE COVER	60	208	1500	1300	250	26	ND	0.5	1.4	ND	0.06
BF5	4/23/2002 08:55	GRAB	ROUTINE	130	184	1500	1300	39	33	ND	0.6	0.73	0.02	0.09
BF5	5/11/2002 17:20	GRAB	STORM EVENT	1000	164	1500	1200	62	52	ND	0.6	0.57	0.02	0.08
BF5	6/27/2002 09:30	GRAB	ROUTINE	36	108	1600	1400	57	33	ND	1	0.16	ND	0.11
BF5	7/30/2002 10:45	GRAB	ROUTINE	200	180	1600	1400	43	30	ND	0.9	0.13	ND	0.1
BF5	8/26/2002 10:05	GRAB	ROUTINE	230	182	1600	1400	30	38	ND	0.8	0.46	ND	0.08
BF5	9/13/2002 10:10	GRAB	ROUTINE	350	200	1600	1400	19	57	ND	0.6	0.28	0.02	0.06
BF5	10/25/2002 10:45	GRAB	ROUTINE	55	226	1600	1500	5	100	ND	0.6	1.5	0.04	0.05
BF6	6/14/2001 10:37	GRAB	ROUTINE	170	164	1500	1300	56	25	ND	0.9	0.93	ND	0.12
BF6	7/24/2001 10:15	GRAB	RAIN EVENT	580	152	1400	1200	52	27	ND	0.9	0.81	ND	0.14
BF6	8/29/2001 11:15	GRAB	ROUTINE	<9	154	1500	1300	30	43	ND	0.9	0.4	ND	0.08
BF6	10/25/2001 09:30	GRAB	ROUTINE	13	222	1900	1600	7	99	ND	0.6	1.18	ND	0.1
BF6	9/27/2001 06:40	GRAB	ROUTINE	45	152	1600	1300	31	35	ND	0.6	0.49	0.01	0.07
BF6	3/28/2002 09:07	GRAB	ICE COVER	12	224	2100	1900	ND	ND	ND	0.5	2.8	ND	0.01
BF6	4/23/2002 08:30	GRAB	ROUTINE	84	188	1900	1600	43	26	ND	0.9	1	0.01	0.08
BF6	5/11/2002 17:45	GRAB	STORM EVENT	280	168	1900	1500	38	68	ND	1	0.31	0.01	0.08
BF6	6/27/2002 09:15	GRAB	ROUTINE	170	166	1600	1300	73	29	ND	0.8	0.36	0.02	0.14
BF6	7/30/2002 11:00	GRAB	ROUTINE	80	146	1500	1300	49	35	ND	0.9	0.32	0.01	0.12
BF6	8/26/2002 09:45	GRAB	ROUTINE	110	160	1600	1400	35	38	ND	0.9	0.46	ND	0.07
BF6	9/13/2002 10:30	GRAB	ROUTINE	150	160	1500	1400	47	34	ND	0.8	0.41	0.01	0.09
BF6	10/25/2002 08:00	GRAB	ROUTINE	50	234	2000	1800	6	100	ND	0.6	1.2	0.04	0.05

SITE ID	DATE & TIME	METHOD	EVENT	FECAL COL (CFU/100 ml)	ALKA (mg/L)	TOT SOL (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (% of TSS)	AMM (mg/L)	TKN (mg/L)	NIT (mg/L)	TDP (mg/L)	TOT P (mg/L)
BF7	6/14/2001 08:50	GRAB	ROUTINE	96	156	1500	1300	43	23	ND	0.6	0.6	ND	0.09
BF7	7/26/2001 12:15	GRAB	ROUTINE	130	154	1400	1300	58	26	ND	0.9	0.96	0.03	0.1
BF7	8/29/2001 12:30	GRAB	ROUTINE	36	154	1500	1300	38	37	ND	0.9	0.24	0.01	0.09
BF7	10/25/2001 08:50	GRAB	ROUTINE	5	204	1900	1700	ND	ND	ND	0.6	0.97	ND	ND
BF7	9/14/2001 13:20	GRAB	STORM EVENT	100	152	1400	1200	17	65	ND	0.6	0.39	ND	0.05
BF7	4/23/2002 07:55	GRAB	ROUTINE	42	164	1700	1500	5	99	ND	0.6	0.84	ND	0.03
BF7	5/11/2002 18:46	GRAB	STORM EVENT	20	148	2100	1600	6	99	ND	0.7	0.68	ND	0.03
BF7	6/27/2002 08:40	GRAB	ROUTINE	170	146	1500	1300	47	36	ND	0.9	0.23	0.01	0.08
BF7	7/30/2002 07:50	GRAB	ROUTINE	ND	130	1500	1400	47	42	ND	0.9	0.06	ND	0.06
BF7	8/26/2002 09:05	GRAB	ROUTINE	10	164	1600	1400	47	38	ND	0.8	0.38	ND	0.07
BF7	9/13/2002 11:15	GRAB	ROUTINE	500	156	1600	1300	42	38	ND	0.9	0.31	ND	0.08
BF7	10/25/2002 09:16	GRAB	ROUTINE	20	210	2000	1800	ND	ND	ND	0.6	1	0.03	0.1
BF8	3/28/2002 08:12	GRAB	ICE COVER	2	236	2200	1900	ND	ND	ND	0.6	2.5	ND	0.01
BF8	4/23/2002 05:42	GRAB	ROUTINE	>=400	156	1800	1500	10	99	ND	0.6	0.73	ND	0.03
BF8	4/23/2002 05:42	GRAB	ROUTINE	>=400	154	1800	1600	11	55	ND	0.6	0.74	ND	0.02
BF8	5/11/2002 19:32	GRAB	STORM EVENT	2600	140	2100	1700	110	32	ND	0.9	0.93	ND	0.14
BF8	6/27/2002 08:10	GRAB	ROUTINE	130	150	1600	1400	63	32	ND	0.7	0.2	ND	0.09
BF8	7/30/2002 06:20	GRAB	ROUTINE	ND	114	1500	1300	36	47	ND	0.8	ND	ND	0.05
BF8	8/26/2002 08:30	GRAB	ROUTINE	10	152	1700	1400	48	33	ND	0.8	0.31	0.03	0.06
BF8	8/26/2002 08:30	GRAB	ROUTINE	10	150	1600	1400	44	34	ND	0.8	0.32	ND	0.06
BF8	10/1/2002 08:25	GRAB	STORM EVENT	30	152	1700	1500	24	50	ND	0.7	0.5	0.17	0.65
BF8	10/25/2002 07:45	GRAB	ROUTINE	90	184	2000	1700	7	100	ND	0.6	0.83	0.02	0.08
BF9	3/28/2002 07:41	GRAB	ICE COVER	5	224	2200	1900	ND	ND	ND	0.5	2.6	ND	ND
BF9	4/23/2002 06:15	GRAB	ROUTINE	46	152	1800	1600	13	62	ND	ND	0.69	ND	0.01
BF9	5/11/2002 20:28	GRAB	STORM EVENT	36	140	2100	1700	28	93	ND	0.7	0.64	ND	0.05
BF9	6/27/2002 07:30	GRAB	ROUTINE	100	136	1600	1400	62	29	ND	1.1	0.28	ND	0.07
BF9	7/30/2002 05:40	GRAB	ROUTINE	ND	114	1500	1400	37	43	ND	1.3	ND	ND	0.05
BF9	8/26/2002 08:15	GRAB	ROUTINE	50	138	1700	1400	43	41	ND	0.8	0.24	ND	0.05
BF9	10/1/2002 08:00	GRAB	STORM EVENT	120	144	1600	1400	32	41	ND	0.8	0.41	0.04	0.05
BF9	10/1/2002 08:00	GRAB	STORM EVENT	60	146	1600	1500	32	47	ND	0.5	0.41	0.04	0.04
BF9	10/25/2002 07:15	GRAB	ROUTINE	50	170	2000	1800	9	100	ND	0.6	0.67	0.02	0.05
ELM	5/11/2002 00:00	GRAB	STORM EVENT	82	194	5000	4400	32	81	0.3	ND	ND	0.01	0.05
HC1	4/23/2002 10:20	GRAB	ROUTINE	6	308	5000	4400	23	43	ND	0.6	ND	ND	0.03
HC1	5/11/2002 16:40	GRAB	STORM EVENT	91	292	5100	4300	40	70	ND	0.9	ND	ND	0.05
HC1	5/20/2002 13:40	GRAB	ROUTINE	600	332	5800	5000	32	56	ND	0.9	ND	ND	0.08
HC1	6/27/2002 11:10	GRAB	ROUTINE	340	178	1800	1600	ND	ND	ND	ND	0.05	0.03	0.05
HC1	7/30/2002 08:47	GRAB	ROUTINE	100	166	1700	1500	ND	ND	ND	0.6	ND	ND	0.02

SITE ID	DATE & TIME	METHOD	EVENT	FECAL COL (CFU/100 ml)	ALKA (mg/L)	TOT SOL (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (% of TSS)	AMM (mg/L)	TKN (mg/L)	NIT (mg/L)	TDP (mg/L)	TOT P (mg/L)
HC1	8/26/2002 10:55	GRAB	ROUTINE	230	356	4200	3800	ND	ND	ND	0.6	ND	ND	0.03
HC1	9/13/2002 08:50	GRAB	ROUTINE	150	296	3200	2800	ND	ND	ND	ND	ND	0.03	0.06
HC1	10/23/2002 09:40	GRAB	ROUTINE	ND	414	4700	4300	5	100	ND	0.6	ND	0.03	0.04
HC2	4/4/2002 12:05	GRAB	ICE COVER	ND	278	3400	3100	11	60	0.5	2.4	0.94	0.06	0.14
HC2	4/23/2002 09:55	GRAB	ROUTINE	2	242	3800	3200	39	31	ND	0.9	ND	0.01	0.08
HC2	5/11/2002 16:09	GRAB	STORM EVENT	130	304	4600	3900	66	42	ND	0.9	ND	0.01	0.09
HC2	5/20/2002 13:20	GRAB	ROUTINE	60	310	5500	4900	52	40	ND	ND	ND	ND	0.07
HC2	6/27/2002 10:45	GRAB	ROUTINE	190	190	1900	1600	73	23	ND	1	ND	0.01	0.04
HC2	7/30/2002 09:10	GRAB	ROUTINE	100	162	1600	1400	48	33	ND	1	ND	ND	0.1
HC2	8/26/2002 11:10	GRAB	ROUTINE	210	158	1800	1600	42	33	ND	0.9	ND	0.02	0.09
HC2	9/13/2002 09:10	GRAB	ROUTINE	230	160	1600	1400	42	24	ND	0.8	ND	0.01	0.11
HC2	10/23/2002 10:00	GRAB	ROUTINE	10	ND	4100	3700	17	76	ND	0.7	0.05	0.02	0.05
HC3	4/4/2002 12:20	GRAB	ICE COVER	ND	258	3200	2900	16	99	0.4	2.1	0.63	0.05	0.13
HC3	4/23/2002 09:10	GRAB	ROUTINE	ND	260	4100	3400	84	18	ND	1.2	ND	0.01	0.13
HC3	5/11/2002 15:46	GRAB	STORM EVENT	100	286	4400	3700	80	40	ND	0.9	ND	0.01	0.11
HC3	5/20/2002 12:55	GRAB	ROUTINE	ND	288	5100	4300	72	34	ND	1.2	ND	ND	0.08
HC3	6/27/2002 10:15	GRAB	ROUTINE	210	180	1700	1500	74	31	ND	0.07	ND	0.02	0.15
HC3	7/30/2002 09:10	GRAB	ROUTINE	100	166	1600	1500	77	19	ND	0.8	ND	ND	0.13
HC3	7/30/2002 09:10	GRAB	ROUTINE	100	166	1700	1400	76	17	ND	0.8	ND	ND	0.12
HC3	8/26/2002 11:25	GRAB	ROUTINE	210	170	1800	1600	41	36	ND	0.9	ND	0.03	0.09
HC3	9/13/2002 09:25	GRAB	ROUTINE	190	158	1600	1500	44	18	ND	0.8	ND	0.02	0.1
HC3	10/23/2002 10:25	GRAB	ROUTINE	ND	304	3900	3400	7	100	ND	0.6	0.05	0.04	0.04
HC4	3/28/2002 09:53	GRAB	ICE COVER	5	380	4700	4100	7	58	ND	0.6	0.67	ND	0.03
HC4	4/23/2002 09:30	GRAB	ROUTINE	ND	272	4100	3600	26	42	ND	1.2	0.35	ND	0.07
HC4	5/11/2002 00:00	AUTO	STORM EVENT	9400	286	4700	4100	90	52	ND	1.5	0.5	0.03	0.17
HC4	5/11/2002 00:00	GRAB	STORM EVENT	2600	288	3700	4000	100	26	ND	1.8	0.47	0.02	0.2
HC4	5/20/2002 12:20	GRAB	ROUTINE	150	302	5200	4400	160	14	ND	1.3	0.18	0.05	0.25
HC4	5/24/2002 10:00	AUTO	IRRIGATION	>=2000	294	5400	1100	100	45	0.1	1.7	ND	0.07	0.19
HC4	6/2/2002 19:49	AUTO	STORM EVENT	1600	182	2100	1800	120	20	ND	1.3	ND	0.08	0.19
HC4	6/27/2002 09:55	GRAB	ROUTINE	340	210	2900	1400	1300	3	ND	0.8	0.12	0.01	0.24
HC4	7/30/2002 10:05	GRAB	ROUTINE	200	170	2700	1400	1000	13	ND	1.1	0.26	0.02	0.19
HC4	8/26/2002 11:45	GRAB	ROUTINE	500	168	2000	1600	190	15	ND	1	0.24	0.01	0.14
HC4	9/13/2002 09:55	GRAB	ROUTINE	150	154	1700	1400	96	13	ND	1.1	0.12	0.01	0.32
HC4	10/25/2002 10:15	GRAB	ROUTINE	ND	326	3900	3400	6	100	ND	0.9	0.92	ND	0.08
NM	7/30/2002 11:15	GRAB	ROUTINE	500	120	1300	1100	130	18	ND	0.8	ND	ND	0.19
NM	9/13/2002 10:45	GRAB	ROUTINE	670	134	1300	1100	90	17	ND	0.7	ND	ND	0.13
NM	8/26/2002 09:25	GRAB	ROUTINE	580	150	1400	1200	24	46	ND	0.8	0.06	ND	0.06

SITE ID	DATE & TIME	METHOD	EVENT	FECAL COL (CFU/100 ml)	ALKA (mg/L)	TOT SOL (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (% of TSS)	AMM (mg/L)	TKN (mg/L)	NIT (mg/L)	TDP (mg/L)	TOT P (mg/L)
NM	10/25/2002 10:06	GRAB	ROUTINE	450	230	1700	1600	ND	ND	ND	0.5	0.19	0.03	0.05
RW1	6/13/2001 14:56	EWI	ROUTINE	8	178	1100	1000	5	99	ND	ND	0.35	ND	0.05
RW1	7/26/2001 22:56	GRAB	RAIN EVENT	470	168	1200	1100	29	52	ND	0.6	0.25	ND	0.04
RW1	8/28/2001 11:00	EWI	ROUTINE	92	178	1200	1100	ND	ND	ND	ND	0.29	ND	0.04
RW1	10/25/2001 14:15	EWI	ROUTINE	30	188	1300	1200	ND	ND	ND	ND	0.48	ND	0.12
RW1	9/27/2001 12:20	EWI	ROUTINE	48	172	1300	1200	ND	ND	ND	ND	0.4	0.02	0.03
RW1	3/28/2002 12:30	GRAB	ROUTINE	3	186	1300	1200	15	69	ND	ND	0.37	ND	0.02
RW1	4/23/2002 13:45	GRAB	ROUTINE	>=400	160	1300	1200	9	67	ND	ND	0.26	ND	ND
RW2	6/13/2001 16:09	EWI	ROUTINE	100	192	916	807	59	95	ND	0.6	0.27	0.03	0.09
RW2	7/26/2001 23:30	GRAB	RAIN EVENT	>/= 800	182	960	780	85	4	ND	0.6	0.14	ND	0.13
RW2	8/28/2001 09:45	GRAB	ROUTINE	110	184	910	790	8	99	ND	ND	0.09	0.04	0.04
RW2	10/25/2001 11:45	GRAB	ROUTINE	7	208	870	700	5	99	ND	ND	0.26	0.02	0.04
RW2	9/27/2001 00:00	GRAB	ROUTINE	50	190	950	830	7	99	ND	ND	0.14	0.02	0.07
RW2	3/28/2002 11:10	GRAB	ROUTINE	2	198	900	820	18	45	ND	ND	0.21	0.01	0.04
RW2	4/23/2002 11:50	GRAB	ROUTINE	12	178	850	740	14	64	ND	ND	0.07	ND	0.04
SP1	6/13/2001 09:40	EWI	ROUTINE	3	238	270	240	ND	ND	ND	ND	0.14	0.02	0.02
SP1	7/26/2001 20:34	GRAB	RAIN EVENT	52	240	230	220	ND	ND	ND	ND	0.1	0.01	0.03
SP1	8/28/2001 14:30	GRAB	ROUTINE	2	242	260	220	ND	ND	ND	ND	0.12	ND	0.02
SP1	10/9/2001 14:44	GRAB	STORM EVENT	20	246	260	210	ND	ND	ND	ND	0.17	0.02	0.04
SP1	9/27/2001 16:45	GRAB	ROUTINE	3	246	270	200	ND	ND	ND	ND	0.13	0.03	0.03
SP1	4/4/2002 09:05	GRAB	ROUTINE	ND	246	260	240	ND	ND	ND	ND	0.18	0.03	0.03
SP1	4/23/2002 15:40	GRAB	ROUTINE	ND	224	240	200	ND	ND	ND	ND	0.14	ND	0.01
SP2	6/13/2001 11:18	GRAB	ROUTINE	4	240	260	240	ND	ND	ND	ND	0.13	0.04	0.07
SP2	7/26/2001 21:05	GRAB	RAIN EVENT	88	226	230	210	ND	ND	ND	ND	0.08	0.02	0.02
SP2	8/28/2001 14:00	GRAB	ROUTINE	<2	226	230	210	ND	ND	ND	ND	0.1	ND	0.03
SP2	10/9/2001 15:30	GRAB	STORM EVENT	42	234	250	210	ND	ND	ND	ND	0.16	0.03	0.05
SP2	9/27/2001 17:09	GRAB	ROUTINE	2	240	270	200	ND	ND	ND	ND	0.1	0.03	0.03
SP2	4/4/2002 09:35	GRAB	ROUTINE	ND	236	250	220	ND	ND	ND	ND	0.12	0.02	0.03
SP2	4/23/2002 15:15	GRAB	ROUTINE	ND	214	230	190	ND	ND	ND	ND	0.06	ND	0.03
SP3	6/13/2001 12:35	GRAB	ROUTINE	10	234	260	240	ND	ND	ND	ND	0.14	0.03	0.06
SP3	7/26/2001 21:30	GRAB	RAIN EVENT	460	224	220	200	ND	ND	ND	ND	0.06	0.02	0.03
SP3	8/28/2001 13:20	GRAB	ROUTINE	5	232	250	210	ND	ND	ND	ND	0.09	ND	0.1
SP3	10/9/2001 15:59	GRAB	STORM EVENT	42	228	250	210	5	99	ND	ND	0.14	0.03	0.03
SP3	9/27/2001 17:32	GRAB	ROUTINE	15	236	270	200	ND	ND	ND	ND	0.09	0.03	0.03
SP3	4/4/2002 10:00	GRAB	ROUTINE	ND	250	240	220	ND	ND	ND	ND	0.09	0.01	0.03
SP3	4/23/2002 14:50	GRAB	ROUTINE	ND	224	230	200	ND	ND	ND	ND	0.1	ND	0.02
SP4	6/13/2001 13:28	GRAB	ROUTINE	23	222	370	340	9	89	ND	ND	0.2	0.02	0.04

SITE ID	DATE & TIME	METHOD	EVENT	FECAL COL (CFU/100 ml)	ALKA (mg/L)	TOT SOL (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (% of TSS)	AMM (mg/L)	TKN (mg/L)	NIT (mg/L)	TDP (mg/L)	TOT P (mg/L)
SP4	7/23/2001 10:00	AUTO	RAIN EVENT	800	218	690	390	280	13	ND	0.9	0.34	0.17	0.17
SP4	7/26/2001 22:03	GRAB	RAIN EVENT	>/= 3300	160	530	290	210	14	ND	1.5	0.3	ND	0.32
SP4	8/28/2001 12:30	GRAB	ROUTINE	32	254	450	400	ND	ND	0.2	ND	0.34	ND	ND
SP4	10/9/2001 16:32	GRAB	STORM EVENT	TNTC	212	390	330	17	41	ND	0.6	0.4	0.02	0.06
SP4	9/27/2001 13:45	GRAB	ROUTINE	18	236	450	370	ND	ND	ND	ND	0.29	0.03	0.03
SP4	4/4/2002 10:30	GRAB	ROUTINE	ND	224	370	320	19	63	ND	ND	0.17	0.01	0.04
SP4	4/23/2002 14:20	GRAB	ROUTINE	32	204	810	290	5	99	ND	ND	0.08	ND	0.02
SP4	7/21/2002 10:00	AUTO	STORM EVENT	4000	248	610	460	68	38	ND	ND	0.52	ND	0.06
WL	7/30/2002 10:25	GRAB	ROUTINE	560	144	1700	1500	65	25	ND	1.2	1.2	0.05	0.16
WL	8/26/2002 12:00	GRAB	ROUTINE	650	142	1600	1400	60	20	ND	1.1	1.3	0.09	0.19
WL	9/13/2002 09:45	GRAB	ROUTNE	370	136	1700	1400	150	11	ND	1.3	1.6	0.05	0.23
WL	10/23/2002 10:45	GRAB	ROUTINE	ND	290	7100	6000	6	100	ND	0.7	22	0.03	0.06

Appendix B

Field Measurements

SITE ID	DATE & TIME	FLOW	TEMP	TURBIDITY	PH	SPECIFIC COND	DO	DO	PRESSURE
		(cfs)	(Celsius)	(NTU)	(su)	(uS/cm)	(mg/L)	(% saturation)	(mm Hg)
BB1	6/13/2001 17:43	4.67	17.3	1.3	8.02	1154	6.66	69.3	663.1
BB1	7/27/2001 00:35	5.82	15.89	1	7.88	1230	7.51	76.1	663.4
BB1	8/30/2001 06:45	3.682	10.81	4.1	7.89	1271	10.18	90.6	662.5
BB1	10/9/2001 13:46	6.33	8.37	6.3	8.25	597	11.9	98.5	656.1
BB1	9/27/2001 16:00	4.887	16.54	6	8.08	1124	10.23	105.3	664.4
BB1	4/4/2002 08:18	0.15	0.19	m	7.93	1452	13.4	92.6	667
BB1	4/23/2002 16:05	8.654	13.22	7.1	8.26	1138	11.83	112.9	655.3
BB2	6/13/2001 07:30	5.159	12.65	7.3	7.59	1001	8.14	76.8	664
BB2	7/27/2001 01:00	2.92	17.03	21	7.53	970	6.82	67.3	673.4
BB2	8/30/2001 08:00	3.16	13.91	5.2	7.87	1278	9.29	90.9	672.5
BB2	10/9/2001 13:01	16.77	10.51	77.1	8.59	365	8.98	80.5	667.8
BB2	9/27/2001 15:36	2.92	18.74	12	8.09	1106	9.74	105	675.1
BB2	3/28/2002 13:25	m	8.6	1.6	8.15	1283	11.95	102.7	665.1
BB2	3/28/2002 13:25	m	8.6	1.6	8.15	1283	11.95	102.7	665.1
BB2	4/23/2002 16:25	2.473	15	6.1	8.06	1232	10.86	107.9	666.1
BB2	5/11/2002 14:19	11.49	7.79	79.5	7.79	699	10.54	88	674.7
BB2	8/21/2002 00:00	m	m	m	m	m	m	m	m
BF1	6/14/2001 15:13	164.5	16.17	742	7.78	1505	8.15	82.2	672.9
BF1	6/14/2001 15:27	161.8	16.18	868	7.79	1511	8.11	82.9	670.9
BF1	7/13/2001 12:00	139	m	m	m	m	m	m	m
BF1	7/24/2001 14:00	67	m	m	m	m	m	m	m
BF1	8/28/2001 06:30	31	20.41	24.4	8.14	1794	7.71	86.7	677.9
BF1	10/25/2001 13:15	17	3.58	12.8	8.4	1426	12.78	97.1	682.2
BF1	9/27/2001 11:25	9.6	15.68	7.3	8.1	2057	9.79	99.3	680.4
BF1	3/28/2002 11:42	197.7	0.14	66.5	8.23	1731	12.31	85	678.2
BF1	4/23/2002 12:50	41.2	14.7	7.5	8.34	1593	10.26	100	673.3
BF1	5/29/2002 11:04	19	21.23	m	8.21	2244	9.8	111.2	681.6
BF1	6/7/2002 00:00	217	m	m	m	m	m	m	m
BF1	6/9/2002 00:00	201	m	m	m	m	m	m	m
BF1	6/10/2002 00:00	212	m	m	m	m	m	m	m
BF1	6/6/2002 14:30	99	m	m	m	m	m	m	m
BF1	6/6/2002 00:00	88	m	m	m	m	m	m	m
BF1	6/8/2002 00:00	106	m	m	m	m	m	m	m
BF1	6/8/2002 00:00	106	m	m	m	m	m	m	m
BF1	7/30/2002 13:10	212	25.02	388.6	8.48	1721	7.29	88.9	680.5
BF1	8/27/2002 06:28	234	19.53	191	8.32	1748	8.75	96.8	682.1
BF1	9/13/2002 07:25	364	16.89	197	8.32	1866	8.7	90.2	677.6
BF1	10/23/2002 08:30	18	0.1	4.1	8.28	2335	14.01	96.8	685.4
BF11	6/14/2001 07:47	177	19.02	24.5	7.79	2220	7.74	84.7	694.6
BF11	7/26/2001 10:15	526	22.63	126	8.3	1837	8.7	86.9	688.6
BF11	8/29/2001 13:32	264	22.94	43	8.3	1848	9.23	108	700.7
BF11	10/25/2001 07:50	258	1.58	11.4	8.31	1319	13.58	97.7	705.3

SITE ID	DATE & TIME	FLOW	TEMP	TURBIDITY	PH	SPECIFIC COND	DO	DO	PRESSURE
		(cfs)	(Celsius)	(NTU)	(su)	(uS/cm)	(mg/L)	(% saturation)	(mm Hg)
BF11	9/14/2001 14:30	54	14.96	38	8.4	1712	9.44	94.1	704.3
BF11	3/28/2002 06:57	25.8	0.07	5.7	7.94	2430	12.92	90	695.6
BF11	4/23/2002 06:55	47.5	10.12	32.4	8.3	2187	7.62	68.9	694.3
BF11	5/20/2002 10:00	103.3	11.51	26.8	8.28	3127	10.2	95.2	708.9
BF11	6/27/2002 06:45	191.7	23.7	71.7	7.84	1827	6.33	75.2	702.4
BF11	7/30/2002 07:00	234	23.72	72.4	8.29	1818	6.78	80.6	701.6
BF11	8/26/2002 07:30	246	20.47	5.1	7.56	2067	8.07	90.3	703.3
BF11	10/1/2002 09:10	96.6	13.42	50	8.2	2075	9.88	95.4	705.4
BF11	10/25/2002 06:45	54.2	2.14	5.5	8.69	2478	13.73	100	m
BF12	10/11/2002 10:05	62.2	11.4	m	7.77	2256	9.27	85.8	m
BF2	6/14/2001 16:32	274	15.93	1878	7.65	1196	8.2	84.7	670.1
BF2	7/24/2001 15:00	138	m	m	m	m	m	m	m
BF2	8/28/2001 08:15	31	20.48	29.4	8.32	1773	7.77	87	680.3
BF2	10/25/2001 12:00	19	3.58	4.8	8.28	2064	12.54	94.9	685.1
BF2	9/27/2001 09:45	11	14.31	8	8	2039	9.67	95.3	683
BF2	4/4/2002 11:10	145	2.17	82.8	8.1	1665	13.31	97.4	689.1
BF2	4/23/2002 12:10	145	13.99	10.5	8.29	1580	10.09	98.4	675.6
BF3	6/14/2001 13:14	14.2	16.6	26.7	8.17	1538	7.69	93.1	676.7
BF3	6/14/2001 16:55	14.2	m	32.6	m	m	m	m	m
BF3	7/24/2001 08:41	30	22.33	22.3	7.91	1735	6.96	80.4	684.3
BF3	8/29/2001 06:30	11	19.38	36	7.77	1845	7.27	81.1	679.5
BF3	10/25/2001 11:30	13	4.11	5.6	8.16	1115	12.69	96.5	686.9
BF3	9/27/2001 09:20	12	14.57	28.6	7.8	1538	8.94	88.3	683.5
BF3	3/28/2002 10:35	6.2	3.31	7.3	m	1684	12.32	93.1	676
BF3	4/23/2002 11:30	4.1	13.99	60.9	7.96	1634	9.96	97.1	677
BF3	5/29/2002 08:00	106	19.02	m	7.62	2177	6.16	67.1	682.3
BF3	5/29/2002 08:00	106	19.02	m	7.62	2177	6.16	67.1	682.3
BF3	6/27/2002 11:55	12.6	26.84	29.4	7.81	1730	8.55	107.5	684.4
BF3	7/30/2002 12:25	234	26.08	59.9	8.18	2009	9.07	112.6	684.7
BF3	8/27/2002 10:07	234	19.99	39.6	7.94	2011	8.92	98.6	688.3
BF3	9/13/2002 08:15	364	17.09	28.8	7.89	1925	8.01	82.3	681.7
BF3	10/23/2002 09:15	57	2.13	8.3	7.96	1862	13.62	99.6	687.9
BF4	6/14/2001 11:49	43	18.03	39.6	8.04	1569	8.23	88	680.1
BF4	7/24/2001 09:20	41	23.62	26.8	7.84	1777	6.69	79.2	684.3
BF4	7/24/2001 09:20	41	23.62	26.8	7.84	1777	6.69	79.2	684.3
BF4	8/29/2001 07:00	32	20.3	37.4	7.85	1944	5.96	66.3	682.2
BF4	10/25/2001 10:45	21	3.58	8.3	8.2	1216	98.7	12.95	692.3
BF4	9/27/2001 08:45	24	15.26	28.2	7.83	1554	8.62	86.5	688
BF4	4/4/2002 11:40	14	4.03	7	8.05	1756	13.59	105.3	689.8
BF4	4/23/2002 10:55	13.85	11.28	31.2	8.07	1880	10.19	93.6	682.4
BF5	6/14/2001 11:18	27.98	16.77	55.5	8.03	1686	8.53	88.3	681.7
BF5	7/24/2001 09:45	27.95	22.45	183	7.9	1503	6.87	79.3	686.8
BF5	8/29/2001 10:35	75	20.59	46	8.08	1890	8.76	98	686.3
BF5	10/25/2001 09:50	38	2.95	12.1	8.17	1203	12.74	95.2	691

SITE ID	DATE & TIME	FLOW	TEMP	TURBIDITY	PH	SPECIFIC COND	DO	DO	PRESSURE
		(cfs)	(Celsius)	(NTU)	(su)	(uS/cm)	(mg/L)	(% saturation)	(mm Hg)
BF5	9/27/2001 07:54	48	13.91	24.9	7.81	1592	8.95	87.2	687.8
BF5	3/28/2002 09:35	25	0.45	59.3	8.18	m	12.59	87.7	681
BF5	4/23/2002 08:55	28.2	8.47	54	8.18	1770	7.95	68.3	679.5
BF5	5/11/2002 17:20	49.9	10.05	57.2	9.2	2718	10.61	98.1	690
BF5	6/27/2002 09:30	54.2	23.61	67.6	7.83	1810	6.94	82.4	689
BF5	7/30/2002 10:45	16	24.08	55.5	8.35	1937	9.99	119.4	689.8
BF5	8/26/2002 10:05	74.4	19.92	46	8	2040	9.42	104	689.5
BF5	9/13/2002 10:10	66	17.75	32.8	8.03	2039	8.74	92.4	686.4
BF5	10/25/2002 10:45	38	2.65	10.3	8.3	2204	13.43	99.6	m
BF6	6/14/2001 10:37	179	17.66	52.9	8.07	1822	8.48	89.9	683.5
BF6	7/24/2001 10:15	404	23.3	48.1	8.1	1642	7.48	87.7	688.9
BF6	8/29/2001 11:15	247	20.42	51.1	8.2	1831	9.65	108.1	688.5
BF6	10/25/2001 09:30	46	2.64	10.1	8.17	1347	12.61	93.9	693.8
BF6	9/27/2001 06:40	159	14.97	37.7	7.74	1580	8.28	82.6	689.8
BF6	3/28/2002 09:07	35	0.13	3.9	8.09	2291	12.42	85.9	683.9
BF6	4/23/2002 08:30	40.5	9.31	45	8.19	2158	7.8	68.7	682.6
BF6	5/11/2002 17:45	44.8	11.51	36.7	8.28	3425	11.9	110.8	692
BF6	6/27/2002 09:15	157	23.35	81.2	7.95	1798	6.79	80.1	690.9
BF6	7/30/2002 11:00	195	23.77	138	8.4	1804	9.43	112.1	692.9
BF6	8/26/2002 09:45	218	19.37	45	8.08	2013	9.11	99.2	691.6
BF6	9/13/2002 10:30	222	17.39	59.1	8.16	1981	8.01	84.2	688.6
BF6	10/25/2002 08:00	46	m	m	m	m	m	m	m
BF7	6/14/2001 08:50	189.3	17.17	39.4	8.14	1863	8.49	90.6	685.8
BF7	7/26/2001 12:15	407	23.36	81	8.08	1631	7.93	89.3	694.1
BF7	8/29/2001 12:30	284	21.8	31	8.35	1799	9.88	113.2	696.5
BF7	10/25/2001 08:50	235	1.05	8.7	8.12	1301	14.17	100.6	698.8
BF7	9/14/2001 13:20	45	14.54	15.3	8.38	1759	9.83	97.2	696.2
BF7	4/23/2002 07:55	52.2	9.99	11.2	8.3	1967	7.97	71	685.4
BF7	5/11/2002 18:46	48.1	10.36	9.8	8.34	3479	11.01	99.5	690
BF7	6/27/2002 08:40	183.2	23.06	46.8	7.98	1770	7.09	83.1	693.5
BF7	7/30/2002 07:50	223	22.27	52.6	8.29	1825	7.42	85.8	693.6
BF7	8/26/2002 09:05	222	19.41	47.8	8.09	2061	9.06	99.1	694.1
BF7	9/13/2002 11:15	314	17.98	92.2	8.23	1982	8.67	92.1	691.4
BF7	10/25/2002 09:16	55.1	0.88	16	8.32	2552	14.05	99.4	m
BF8	3/28/2002 08:12	62	0.07	4.4	8.1	2523	12.96	90.1	688.7
BF8	4/23/2002 05:42	62	10.25	18.4	8.39	2026	7.53	67.9	687.9
BF8	4/23/2002 05:42	62	10.25	18.4	8.39	2026	7.53	67.9	687.9
BF8	5/11/2002 19:32	61	10.61	109.1	8.28	3655	10.8	94.7	698.3
BF8	6/27/2002 08:10	180	23.69	65.6	7.96	1794	6.82	81	696.8
BF8	7/30/2002 06:20	209	23.52	41.8	8.2	1804	6.51	77	696.2
BF8	8/26/2002 08:30	220	19.81	40.7	8.01	2069	8.73	96.5	697.9
BF8	8/26/2002 08:30	220	19.81	40.7	8.01	2069	8.73	96.5	697.9
BF8	10/1/2002 08:25	89	13.17	24.2	8.11	2191	9.44	90.4	699.6
BF8	10/25/2002 07:45	63	1.24	8.8	8.29	2536	14.05	100	m

SITE ID	DATE & TIME	FLOW	TEMP	TURBIDITY	PH	SPECIFIC COND	DO	DO	PRESSURE
		(cfs)	(Celsius)	(NTU)	(su)	(uS/cm)	(mg/L)	(% saturation)	(mm Hg)
BF9	3/28/2002 07:41	62	0.1	3.7	8.11	2484	12.71	88	691.3
BF9	4/23/2002 06:15	51	9.75	15.8	8.31	2113	7.82	69.4	690.3
BF9	5/11/2002 20:28	55	10.84	25.6	8.31	3780	10.28	94.1	700.8
BF9	6/27/2002 07:30	192	23.83	61.4	7.94	1826	6.72	80	698.9
BF9	7/30/2002 05:40	208	23.84	44.1	8.26	1830	6.53	77.8	698.2
BF9	8/26/2002 08:15	208	19.95	42	7.95	2074	8.45	93.4	699.7
BF9	10/1/2002 08:00	92	13.69	39.3	8.11	2127	9.36	90.7	701.5
BF9	10/1/2002 08:00	92	13.69	39.3	8.11	2127	9.36	90.7	701.5
BF9	10/25/2002 07:15	68	m	m	m	m	m	m	m
ELM	5/11/2002 00:00	m	10.27	25.6	8.09	8428	10.29	94.2	699
HC1	4/23/2002 10:20	0.48	10.38	17.5	8.33	4894	12.97	118	689.5
HC1	5/11/2002 16:40	0.54	10.04	27.9	8.18	8448	9.92	90.7	680.8
HC1	5/20/2002 13:40	0.35	13.32	42.3	8.33	6619	11.11	108.9	688
HC1	6/27/2002 11:10	1.47	22.09	4.2	7.63	1930	9.1	104.9	685.9
HC1	7/30/2002 08:47	1.08	20.46	3	7.81	2081	2.85	32.2	686.2
HC1	8/26/2002 10:55	0.28	18.93	9.3	7.79	4816	8.5	93	686.7
HC1	9/13/2002 08:50	m	16.04	4.8	7.67	3836	4.28	43.9	683.8
HC1	10/23/2002 09:40	m	1.27	7	7.73	5395	14.37	104	689.7
HC2	4/4/2002 12:05	2.63	1.04	17.9	7.89	3740	12.47	88.3	691.2
HC2	4/23/2002 09:55	1.11	9.7	50.8	8.24	3948	10.14	90.4	680.6
HC2	5/11/2002 16:09	2.41	11.13	67.7	8.18	7724	10.27	96	688.9
HC2	5/20/2002 13:20	< 1	15.1	52.4	8.35	6428	10.53	107	691.5
HC2	6/27/2002 10:45	13.2	24.4	89.3	7.77	2124	5.91	71.2	687.3
HC2	7/30/2002 09:10	19	22.05	63	8.12	1945	6.38	73.4	688.5
HC2	8/26/2002 11:10	19	19.43	54.1	8.06	2201	9.18	100.5	688.6
HC2	9/13/2002 09:10	m	17.27	57.8	7.99	2104	7.75	81.4	685.5
HC2	10/23/2002 10:00	m	2.34	35.2	7.95	4803	13.08	97.1	680
HC3	4/4/2002 12:20	2.27	1.54	17.6	8.06	3620	13.95	100	694.8
HC3	4/23/2002 09:10	6.25	9.87	92.7	8.24	4086	9.22	82.6	679.9
HC3	5/11/2002 15:46	1.8	10.75	72.4	8.2	7302	10.46	96.8	689.5
HC3	5/20/2002 12:55	< 1	16.25	56.4	8.38	5910	10.97	114.2	691.8
HC3	6/27/2002 10:15	27.73	23.28	79	7.93	1957	7.32	86.2	687.6
HC3	7/30/2002 09:10	22.9	22.46	81	8.25	1936	6.99	81.1	688.9
HC3	7/30/2002 09:10	22.9	22.46	81	8.25	1936	6.99	81.1	688.9
HC3	8/26/2002 11:25	22.4	20.3	55.3	8.15	2218	9.34	104.1	689.2
HC3	9/13/2002 09:25	m	17.16	62.4	8.04	2086	8.02	83.8	686.1
HC3	10/23/2002 10:25	m	1.46	11.3	8.05	4572	13.29	95.7	691.2
HC4	3/28/2002 09:53	1	0.25	9.3	9.03	4933	13.07	91.7	681.5
HC4	4/23/2002 09:30	2.4	9.42	33.2	8.22	3037	8.54	75.4	680.5
HC4	5/11/2002 00:00	1.99	10.69	82.4	8.12	7572	8.12	50.1	690.2
HC4	5/11/2002 00:00	1.99	m	82.4	m	m	m	m	m
HC4	5/20/2002 12:20	6.6	13.5	34.1	8.39	6061	10.26	97.2	697.7
HC4	5/24/2002 10:00	15.4	8.02	130.9	8.1	2160	10.2	87	690.6
HC4	6/2/2002 19:49	42.67	17.81	93.9	8.18	2231	7.36	78.1	687.7

SITE ID	DATE & TIME	FLOW	TEMP	TURBIDITY	PH	SPECIFIC COND	DO	DO	PRESSURE
		(cfs)	(Celsius)	(NTU)	(su)	(uS/cm)	(mg/L)	(% saturation)	(mm Hg)
HC4	6/27/2002 09:55	26.08	23.45	74.3	8	1974	7.06	83.5	689.5
HC4	7/30/2002 10:05	36	22.53	76.5	8.3	1934	7.78	90.5	693.6
HC4	8/26/2002 11:45	32	20.87	57.4	8.18	2272	9.52	107.2	690.8
HC4	9/13/2002 09:55	50	17.44	94	8.08	2089	8.49	89.3	687.7
HC4	10/25/2002 10:15	3.21	1.96	173.4	8.02	4535	14.15	100	m
NINE MILE	7/30/2002 11:15	40.3	23.21	133	8.23	1512	7.35	86.4	691.4
NINE MILE	9/13/2002 10:45	28.2	18.59	77	8.13	1664	7.64	82.2	687.9
NINE MILE	8/26/2002 09:25	9.12	18.33	28.2	7.9	1823	8.9	95.1	690.6
NINE MILE	10/25/2002 10:06	0.9	2.18	94.5	8.16	2252	12.93	94.7	m
RW1	6/13/2001 14:56	61.3	17.08	17.6	8.18	1329	8.28	86.2	663.1
RW1	7/26/2001 22:56	34	18.81	20.6	7.84	1417	7.25	78.1	672.1
RW1	8/28/2001 11:00	31	16.29	12.5	7.96	1438	9.58	90.6	669.9
RW1	10/25/2001 14:15	38	6.69	9.1	8.46	1684	11.45	94.1	674.6
RW1	9/27/2001 12:20	25	13.7	7.5	8.07	1290	10.65	103.2	675.6
RW1	3/28/2002 12:30	40.9	8.02	13.5	8.17	1518	10.97	93.1	664.2
RW1	4/23/2002 13:45	37.5	13.62	10.6	8.28	1455	10.92	105.5	667.2
RW2	6/13/2001 16:09	124.3	19.1	34.4	8.26	1082	6.51	70.6	673.2
RW2	7/26/2001 23:30	117	19.88	43	8.1	1091	7.47	83.5	681.2
RW2	8/28/2001 09:45	79	18.35	15.9	8.06	1126	8.52	91.3	679.7
RW2	10/25/2001 11:45	173	4.82	5.6	8.42	722	13.63	106.8	684.8
RW2	9/27/2001 00:00	134	13.39	12.6	8.18	942	10.14	97.2	682.6
RW2	3/28/2002 11:10	173.3	6.05	13.1	8.37	1120	12.34	99	673.2
RW2	4/23/2002 11:50	170.2	10.88	12.1	8.46	1057	12.26	111.1	677.1
SP1	6/13/2001 09:40	34.9	8.12	0.7	8.38	433	10.2	85	618.3
SP1	7/26/2001 20:34	46	10.82	8.2	7.96	418	9.13	86.4	627
SP1	8/28/2001 14:30	7.6	11.09	4.2	8.38	439	9.68	88.5	627.2
SP1	10/9/2001 14:44	36	6.34	8.6	8.53	304	11.7	95.5	639.8
SP1	9/27/2001 16:45	31	9.52	7	8.33	333	9.73	85.4	628.8
SP1	4/4/2002 09:05	m	1.65	2.7	8.42	430	12.4	88.9	626.3
SP1	4/23/2002 15:40	m	7.99	5.7	8.65	429	10.15	85.8	618.6
SP2	6/13/2001 11:18	72	9.7	1.3	8.51	419	9.71	85.6	640.2
SP2	7/26/2001 21:05	75	16.9	4.6	8.28	1	8.24	85.7	645.1
SP2	8/28/2001 14:00	67	12.77	3	8.51	426	9	91.6	645.7
SP2	10/9/2001 15:30	74	7.01	14.4	8.62	302	11.65	96.2	639.6
SP2	9/27/2001 17:09	57	10.76	7.3	8.54	333	9.75	88	647.7
SP2	4/4/2002 09:35	57.5	1.3	1.9	8.43	447	13.39	97	648.4
SP2	4/23/2002 15:15	64.5	9.04	7	8.75	412	10.36	89.8	639.1
SP3	6/13/2001 12:35	74.9	10.41	2.7	8.3	413	9.18	82	657.2
SP3	7/26/2001 21:30	85	13.17	3.7	8.4	402	9.39	91.1	663.5
SP3	8/28/2001 13:20	70	11.25	4.1	8.3	435	10.27	94.9	663.8
SP3	10/9/2001 15:59	78	7.32	8.2	8.64	303	12.4	100	641.8
SP3	9/27/2001 17:32	56	10.77	9.7	8.58	330	10.07	91	665.5
SP3	4/4/2002 10:00	50.7	1.51	1.6	8.49	441	13.95	99.7	667.6
SP3	4/23/2002 14:50	70.9	6.56	7.2	8.7	419	11.85	97.7	658.1

SITE ID	DATE & TIME	FLOW	TEMP	TURBIDITY	PH	SPECIFIC COND	DO	DO	PRESSURE
		(cfs)	(Celsius)	(NTU)	(su)	(uS/cm)	(mg/L)	(% saturation)	(mm Hg)
SP4	6/13/2001 13:28	73	15.15	2.6	8.44	551	8.65	85.5	666.7
SP4	7/23/2001 10:00	64	m	m	m	m	m	m	m
SP4	7/26/2001 22:03	76	15.69	185	7.82	493	7.82	79.7	m
SP4	8/28/2001 12:30	50	14.92	4.7	8.24	662	9.9	98.2	674
SP4	10/9/2001 16:32	85	8.86	23.3	8.44	430	11.62	99.6	666.8
SP4	9/27/2001 13:45	55	13.82	9	8.36	551	11.09	107.4	676.6
SP4	4/4/2002 10:30	m	3.08	10	8.34	576	13.27	99.8	681.4
SP4	4/23/2002 14:20	m	12.6	8.8	8.62	526	11	103.6	669.4
SP4	7/21/2002 10:00	m	m	m	m	m	m	m	m
WILLOW	7/30/2002 10:25	62.6	21.7	66.6	8.37	1853	8.67	99.2	690.5
WILLOW	8/26/2002 12:00	47.4	20.07	61.2	8.19	2003	10.1	111.8	690.9
WILLOW	9/13/2002 09:45	42.5	17.12	134.3	8.12	2044	8.65	90.3	687.3
WILLOW	10/23/2002 10:45	0.27	0.86	4.1	8.19	7903	14.77	106	693.1

Appendix C

Quality Assurance / Quality Control (QA/QC) Data

QA/QC: Replicate samples

SITE ID	DATE & TIME	QA/QC	FECAL COL	ALKA	TOT SOL	TDS	TSS	TVSS	AMM	TKN	NIT	TDP	TOT P
		BLK/REP	(CFU/100 ml)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(% of TSS)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
BF1	6/14/2001 15:13	REPLICATE	2200	102	1900	950	880	13	ND	1.2	0.16	0.04	0.64
BF1	6/14/2001 15:27	REPLICATE	1600	106	1900	940	850	12	ND	1.8	0.15	0.03	0.61
Industrial Statistic= (Abs(A-B)/(A+B)))			**15.8%**	**1.9%**	**0.0%**	**0.5%**	**1.7%**	**4.0%**	**0.0%**	**20.0%**	**3.2%**	**14.3%**	**2.4%**
BB2	3/28/2002 13:25	REPLICATE	20	248	970	920	ND	ND	ND	ND	3.2	0.01	0.02
BB2	3/28/2002 13:25	REPLICATE	13	246	950	890	ND	ND	ND	ND	3.3	ND	0.01
Industrial Statistic= (Abs(A-B)/(A+B)))			**21.2%**	**0.4%**	**1.0%**	**1.7%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**1.5%**	**0.0%**	**33.3%**
BF8	4/23/2002 05:42	REPLICATE	>=400	156	1800	1500	10	99	ND	0.6	0.73	ND	0.03
BF8	4/23/2002 05:42	REPLICATE	>=400	154	1800	1600	11	55	ND	0.6	0.74	ND	0.02
Industrial Statistic= (Abs(A-B)/(A+B)))			**0.0%**	**0.6%**	**0.0%**	**3.2%**	**4.8%**	**28.6%**	**0.0%**	**0.0%**	**0.7%**	**0.0%**	**20.0%**
BF3	5/29/2002 08:00	REPLICATE	300	244	1800	1700	90	44	ND	0.9	ND	ND	0.06
BF3	5/29/2002 08:00	REPLICATE	320	238	1800	1700	21	28	ND	0.8	ND	0.01	0.05
Industrial Statistic= (Abs(A-B)/(A+B)))			**3.2%**	**1.2%**	**0.0%**	**0.0%**	**62.2%**	**22.2%**	**0.0%**	**5.9%**	**0.0%**	**0.0%**	**9.1%**
BF1	6/8/2002 00:00	REPLICATE	810	132	2000	1600	240	21	ND	1	ND	0.08	0.29
BF1	6/8/2002 00:00	REPLICATE	860	130	2000	1700	230	24	ND	1	ND	0.08	0.28
Industrial Statistic= (Abs(A-B)/(A+B)))			**3.0%**	**0.8%**	**0.0%**	**3.0%**	**2.1%**	**6.7%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**1.8%**
BF4	7/24/2001 09:20	REPLICATE	3700	194	1600	1400	35	63	ND	0.6	0.42	ND	0.11
BF4	7/24/2001 09:20	REPLICATE	5600	182	1600	1400	36	41	ND	0.9	0.44	ND	0.1
Industrial Statistic= (Abs(A-B)/(A+B)))			**20.4%**	**3.2%**	**0.0%**	**0.0%**	**1.4%**	**21.2%**	**0.0%**	**20.0%**	**2.3%**	**0.0%**	**4.8%**
HC3	7/30/2002 09:10	REPLICATE	100	166	1600	1500	77	19	ND	0.8	ND	ND	0.13
HC3	7/30/2002 09:10	REPLICATE	100	166	1700	1400	76	17	ND	0.8	ND	ND	0.12
Industrial Statistic= (Abs(A-B)/(A+B)))			**0.0%**	**0.0%**	**3.0%**	**3.4%**	**0.7%**	**5.6%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**4.0%**
BF8	8/26/2002 08:30	REPLICATE	10	152	1700	1400	48	33	ND	0.8	0.31	0.03	0.06
BF8	8/26/2002 08:30	REPLICATE	10	150	1600	1400	44	34	ND	0.8	0.32	ND	0.06
Industrial Statistic= (Abs(A-B)/(A+B)))			**0.0%**	**0.7%**	**3.0%**	**0.0%**	**4.3%**	**1.5%**	**0.0%**	**0.0%**	**1.6%**	**0.0%**	**0.0%**
BF9	10/1/2002 08:00	REPLICATE	120	144	1600	1400	32	41	ND	0.8	0.41	0.04	0.05
BF9	10/1/2002 08:00	REPLICATE	60	146	1600	1500	32	47	ND	0.5	0.41	0.04	0.04
Industrial Statistic= (Abs(A-B)/(A+B)))			**33.3%**	**0.7%**	**0.0%**	**3.4%**	**0.0%**	**6.8%**	**0.0%**	**23.1%**	**0.0%**	**0.0%**	**11.1%**
Average Industrial Statistic			**10.8%**	**1.1%**	**0.8%**	**1.7%**	**8.6%**	**10.7%**	**0.0%**	**7.7%**	**1.0%**	**1.6%**	**9.6%**

QA/QC: Blank Samples

SITE ID	DATE & TIME	QA/QC BLK/DUP	FECAL COL (CFU/100 ml)	ALKA (mg/L)	TOT SOL (mg/L)	TDS (mg/L)	TSS (mg/L)	TVSS (mg/L)	AMM (mg/L)	TKN (mg/L)	NIT (mg/L)	TDP (mg/L)	TOT P (mg/L)
RW1	6/13/2001 14:56	FIELD BLANK	<2	2	<5	<5	<5	<5	<0.1	<0.05	<0.5	<0.01	<0.01
BF2	8/28/2001 08:15	FIELD BLANK	7	2	<5	<5	<5	<5	<0.1	<0.05	<0.5	<0.01	<0.01
RW1	9/27/2001 12:20	FIELD BLANK	<2	2	46	<5	<5	<5	<0.1	<0.05	<0.5	<0.01	<0.01
BF5	10/25/2001 09:50	FIELD BLANK	<2	2	<5	<5	<5	<5	<0.1	<0.05	<0.5	<0.01	<0.01
SP2	4/4/2002 09:35	FIELD BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
BF7	4/23/2002 07:55	FIELD BLANK	ND	8	ND	ND	ND	ND	ND	ND	ND	ND	0.01
BF1	5/29/2002 11:04	FIELD BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF5	6/27/2002 09:30	FIELD BLANK	ND	46	ND	22	ND	ND	ND	ND	ND	ND	ND
HC1	7/30/2002 08:47	FIELD BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF8	8/26/2002 08:30	FIELD BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF11	10/1/2002 09:10	FIELD BLANK	ND	ND	ND	ND	7	7	ND	ND	ND	ND	ND

(yellow) = values above detection limit

Appendix D

Potential Remediation Alternatives

Management Measures for Irrigation Waters

Management practice systems can be designed to reduce soil detachment from bank failure, control amounts of water transported, (such as waste irrigation water), and to intercept the sediment through filters and riparian habitat. The goal of these management measures is to reduce the movement of pollutants from land into surface waters caused by the practice of irrigation. This can be accomplished through consideration of the following aspects of an irrigation system:

- irrigation scheduling,
- efficient application of irrigation water,
- efficient transport of irrigation water, and
- use of runoff or tail water.

In the following paragraphs, BMPs are presented for each of the areas of concern in order of potential impact on reducing the sediment in the Belle Fourche River System. The practices set forth have been found by the EPA to be representative of the types of practices that can be applied successfully to achieve the management measures (Dressing 2002). These BMPs are presented with the NRCS code number (Dressing 2002).

Irrigation Scheduling

Irrigation scheduling is a key element in irrigation water management. Scheduling should be based on knowing the daily water use of the crop, the water-holding capacity of the soil, the lower limit of soil moisture for each crop and soil, and measuring the amount of water applied to the field. A practice that may be used to accomplish proper scheduling is the following:

- Irrigation Water Management (449): Determining and controlling the rate, amount, and timing of irrigation water in a planned and efficient manner. Tools to assist include:
    - Water Measuring Device: An irrigation water meter, flume, weir or other water-measuring device installed in a pipeline or ditch.
    - Soil and Crop Water Use Data: From soils information, the available water holding capacity of the soil can be determined along with the amount of water that the plant can extract from the soil before additional irrigation is needed. Methods to measure or estimate the soil moisture should be employed, especially for high-value crops or where the water holding capacity of the soil is low.

Efficient Irrigation Water Application

Irrigation water should be applied in a manner that ensures efficient use and distribution, minimizes runoff or deep percolation, and minimizes soil erosion. The method employed will vary with type of crop, topography and soil. There are four basic methods of applying irrigation water: surface (flood), sprinkler, trickle, and subsurface. The primary method within the Belle Fourche River watershed is surface irrigation. The most common method of application is a level furrow with either an earth or a pipe delivery system to the furrows (Quinn 2002). Irrigation can contribute to erosion if water application rates are excessive. Practices that may be used to increase application efficiency include the following:

- Irrigation System, Sprinkler (442): A planned irrigation system in which necessary facilities are installed to efficiently apply water by means of perforated pipes or nozzles operated under pressure.
- Irrigation System, Surface and Subsurface (443): A planned irrigation system in which all necessary water control structures have been installed for efficient distribution of irrigation water by surface means, such as furrows, borders, contour levees, contour ditches, or by subsurface means.
- Irrigation Field Ditch (388): A permanent irrigation ditch constructed to convey water from the source of supply to a field or fields in a farm distribution system.

Efficient Irrigation Water Transport

Irrigation water transportation systems that move water from the source of supply to the irrigation system should be designed and managed in a manner that minimizes evaporation, seepage, and flow-through losses from canals and ditches. Delivery and timing need to be flexible enough to meet varying plant water needs throughout the growing season. A water quality concern is the potential for erosion within the canals and at their turnouts. Practices to increase water transportation efficiency include the following:

- Structure for Water Control (587): A structure in an irrigation, drainage, or other water management system that conveys water, controls the direction or rate of flow, or maintains a desired water surface elevation.
- Irrigation Water Conveyance Pipeline (430), Ditch and Canal Lining (428): A fixed lining of impervious material installed in an existing or newly constructed irrigation field, ditch or irrigation canal or lateral.

Use of Runoff Water or Tail water

The use of runoff water to provide additional irrigation, or to reduce the amount of water diverted, increases the efficiency of use of irrigation water. For surface irrigation systems that require runoff or tail water as part of the design and operation (such as the existing BFID and farmer systems), a tail water management practice is needed. Better control strategies with the BFID canals and laterals along with more efficient water applications would reduce the need for tail water systems, but would not eliminate the need. The NRCS practice to reduce runoff water or tail water is defined as the following:

- Irrigation System, Tail Water Recovery (447): A facility to collect, store, and transport irrigation tail water for reuse in the farm irrigation distribution system.

Riparian Zone Rehabilitation

A lack of livestock grazing management affects all four components of the water riparian system: banks and shores, water column, channel morphology, and riparian vegetation. The potential effects of improper grazing management or improper use of grazing lands directly related to sediment include: 1) shore and banks, 2) shear or sloughing of stream bank soils by hoof or head action, 3) water, ice and wind erosion of exposed stream bank and channel soils because of loss of vegetation cover (Dressing 2002).

Elimination or loss of stream bank vegetation.

- Water Column
    - Pollutants, such as sediment, in return water from grazing lands.
    - Changes in stream morphology, such as increases in stream width and decreases in stream depth, including reduction of stream shore water depth.
    - Changes in timing and magnitude of stream flow events from changes in watershed vegetative cover.
- Channel Morphology
    - Changes in channel morphology.
    - Altered sediment transport processes.
- Changes in Riparian Vegetation
    - Changes in plant species composition.
    - Reduction of floodplain and stream bank vegetation.
    - Decrease in plant vigor.
    - Changes in timing and amount of organic energy leaving the riparian zone.
    - Elimination of riparian plant communities.

Improperly managed livestock grazing can significantly contribute to stream bank erosion and riparian habitat degradation. In a study of 60 streams in the Intermountain West, it was found that grazed stream habitats were substantially degraded with poor riparian conditions (Roberson and Minshal 1995). Problems associated with improper grazing management included reduced riparian cover, exposed stream banks, high sediment levels, elevated water temperatures, higher nutrient levels, and a shifting to more stress-tolerant invertebrates (Dressing 2002). When animals repeatedly graze directly on erodible stream banks, bank structure may be weakened causing the soil to move directly into the stream. Improper grazing management can contribute to the removal of most vegetative cover, soil compaction, exposure of the soil, degradation of the soil structure, and loss of soil infiltration capacity. Due to steep slopes, highly erodible soils and storm and irrigation events, the sediment delivery ratio from rangeland can be very high.

Riparian areas constitute important sources of livestock grazing. One acre of riparian meadow has the potential grazing capacity equal to 10 to 15 acres of surrounding forest rangeland. In the Pacific Northwest, riparian meadows often cover only 1-2% of the summer rangeland, but can provide about 20% of the summer forage (Dressing 2002).

Stream bank stability is directly related to the species composition of the riparian vegetation and the distribution and density of these species. The BMPs are presented in order of potential impact on reducing the sediment in the Belle Fourche River System.

Healthy Riparian Areas

Properly functioning riparian areas can significantly reduce nonpoint source pollution by intercepting surface runoff, by settling, filtering and storing sediment and associated pollutants, and by stabilizing banks. The proposed BMPs are the following:

Use Exclusion (472): Excluding animals, people, or vehicles from an area, primarily by means of fencing.

Stream Bank and Shoreline Protection (580): Using vegetation or structures to stabilize and protect banks of streams, lakes, estuaries, or excavated channels, against scour and erosion.

Grazing Management

The grazing management measures were selected based on an evaluation of the available information that documents the beneficial effects of improved grazing management. Specifically, the information indicates that riparian habitat conditions are improved with proper livestock management.

The amount of time livestock spend drinking and loafing in the riparian zone was dramatically reduced through the provision of supplemental water and fencing. Developing off-stream watering sources without building fences has also been found to reduce the amount of time that cattle spend in streams (Ritter and Shirmohammadi 2001). Researchers have found that the amount of time cattle spend in streams could be reduced by 81-90% with this practice (Ritter and Shirmohammadi 2001). However, livestock may still spend time in streams for other reasons such as grazing riparian vegetation and escaping from hot temperatures. Nutrient and sediment delivery is reduced through the proper use of vegetation, stream bank protection, planned grazing systems, and livestock management (Dressing 2002).

Both pasture and rangeland areas should provide livestock watering, supplemental minerals, and shade that are located away from the stream banks and riparian zones. Managing livestock grazing can accomplish this by providing facilities for water, minerals and shade, as needed. The BMPs that can be applied successfully for grazing include the following:

- Grazing management practices
    - Use Exclusion (472): Excluding animals, people, or vehicles from an area, to protect, maintain, or improve the quantity and quality of the plant, animal, soil, air, water and aesthetic resources and human health and safety. Studies indicate that exclusion from 6-10 years is needed to naturally recreate a riparian area. After this time, the riparian area production decreases (Dressing 2002). Passive rehabilitation systems appear to be most successful and recommended as the first step of rehabilitation. After the 6-10 year period, success should be assessed and measures that are more active implemented if required.
    - Grazing Management Plan: A strategy or systems designed to manage the timing, intensity, frequency and duration of grazing to protect and/or enhance environmental values, while maintaining or increasing the economic viability of the grazing operation.
- Alternative Water Supply Practices
    - Off- stream Water Supply: Pipeline (516), Pond (378), Trough or Tank (514), Well (642) or Spring Development (574).
    - Riparian Grazing Practices.
    - Fence (382): A constructed barrier to livestock, wildlife or people.
    - Stream Crossing (interim): A stabilized area to provide controlled access across streams for livestock and machinery.
- Land and Stream Bank Stabilization Practices
    - Channel Vegetation (322): Establishing and maintaining adequate plants on channel banks, spoil, and associated areas. Critical Area Planting (342), Riparian Forest Buffer/Herbaceous Cover (391A/390): Establish an area of trees, shrubs, grasses, or forbs adjacent to and up gradient from water bodies.
    - Stream Channel Stabilization (584): Using vegetation and structures to stabilize and prevent scouring and erosion of stream channels, Stream bank and Shoreline Protection (580).

Appendix E

Belle Fourche River

Total Suspended Solids

Total Maximum Daily Load (TMDL) Summary

TOTAL MAXIMUM DAILY LOAD EVALUATION

of

Total Suspended Solids

for

5 Listed Segments of the Belle Fourche River

(From the Wyoming Border to the Confluence with the Cheyenne River)

(HUC 10120202 and 10120203)

Butte, Lawrence, and Meade Counties, South Dakota

South Dakota Department of Environment and Natural Resources

5/9/2006

Belle Fourche River Total Maximum Daily Load

Waterbody Type:	River
303(d) Listing Parameter:	Total suspended solids (TSS)
Designated Uses:	• Warmwater permanent fish propagation • Immersion recreation • Limited contact recreation • Fish and wildlife propagation, recreation, and stock watering • Irrigation
Size of Waterbody:	204 stream miles (in South Dakota)
Size of Watershed:	2,103,040 acres (in South Dakota)
Water Quality Standards:	Narrative and Numeric
Indicators:	TSS concentrations
Analytical Approach:	Models including BASINS 3.0, HSPF and FLUX
Location:	HUC Code: 10120202 and 10120203
Goal:	Reduction of TSS load
Target:	Mean TSS concentration ≤ 158 mg/L

Objective

The intent of this summary is to clearly identify the components of the TMDL submittal, to support adequate public participation, and facilitate the US Environmental Protection Agency (EPA) review and approval. This TMDL was developed in accordance with Section 303(d) of the federal Clean Water Act and guidance developed by EPA.

Introduction

The Belle Fourche River is a natural stream that drains portions of Butte, Lawrence and Meade Counties in South Dakota (Figure 1). The Belle Fourche River watershed is approximately 2,100,000 acres (3,300 miles^2) in South Dakota and approximately 2,400,000 acres (3,700 miles^2) in Wyoming. Land use in the watershed includes cattle grazing, farming, mining, timber production, hunting and other recreation. Approximately 84% of the watershed is rangeland and 10% is agricultural.

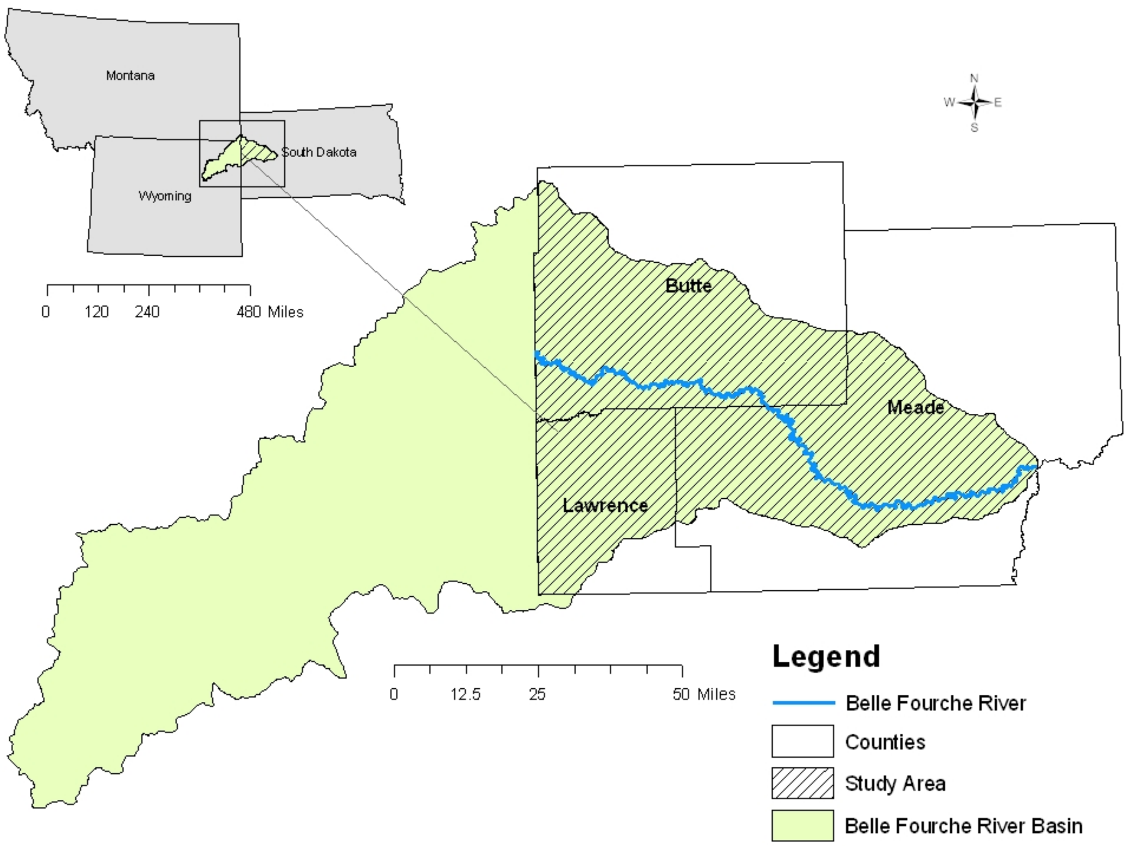


Figure 1. Location of the Belle Fourche River watershed in Butte, Lawrence, and Meade Counties, South Dakota.

Problem Identification

The Belle Fourche River carries an excessive sediment load that degrades the water quality of the river. Approximately 527,109 tons of TSS is delivered from the Belle Fourche River watershed to the Cheyenne River each year, as measured by TSS load at site BF11. TSS load at site BF12 was not calculated, because only one sample was collected at this location (Figure 2). TSS sample concentrations from all sites ranged from less than detection to 11,000 mg/L (mean = 208 mg/L).

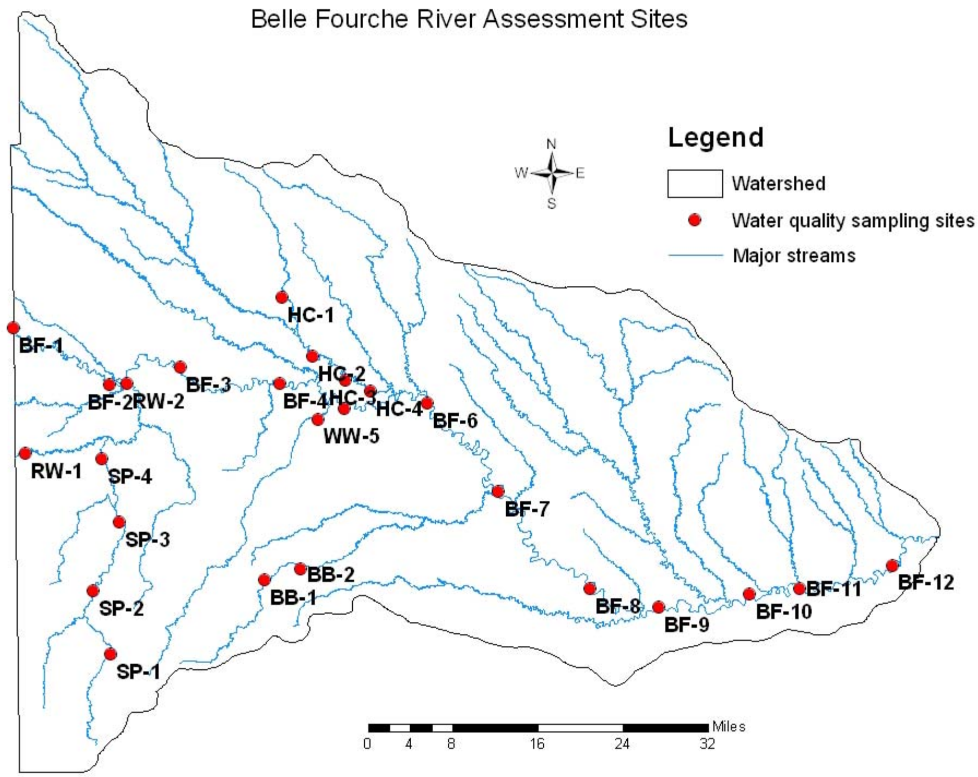


Figure 2. Delineation of the Belle Fourche River watershed in Lawrence, Meade, and Butte Counties, South Dakota and location of sampling sites.

The Belle Fourche River is identified in the 1998, 2002 and the 2004 South Dakota 303(d) Waterbody Lists as impaired due to elevated TSS concentrations. The current listing (2004), has been assigned high priority status due to the widespread local support for water quality improvement and the expected development of a TMDL within the next two years. The 2004 listing also includes a fecal coliform bacteria impairment for the Belle Fourche River from the Wyoming border to near Fruitdale, SD. This bacteria listing will be addressed in a future TMDL report.

According to the 2004 South Dakota Integrated Report for Surface Water Quality Assessment (i.e. Integrated Report), the Belle Fourche River from the Wyoming border to Willow Creek failed to support its assigned uses due to high TSS and fecal coliform bacteria. The report states that agricultural activities are deemed a likely source of occasional impairment. The report also explains that a natural source of TSS originates from erosion of extensive exposed shale beds that lie along the river's course upstream of the city of Belle Fourche. This watershed assessment has identified hydrologic alteration, irrigation practices, and riparian degradation as sources of increased TSS concentrations.

The 2004 Integrated Report divides the river into five segments (R8, R9, R10, R11, and R12) based on the location of SD DENR Surface Water Quality Program's ambient water quality monitoring (WQM) sites (Figure 3). SD DENR collects data from the WQM sites on a quarterly basis, except for site WQM 76 (Belle Fourche River northwest of Elm Springs), which is visited monthly. Data collected by SD DENR from these five stations, in addition to the data collected at these sites during the watershed assessment, will be used to calculate a TMDL for each of the

five listed segments of the Belle Fourche River. Table 1 lists the five segments, their location, map ID (Figure 3), listing basis, cause (i.e. parameter of concern), and priority status.

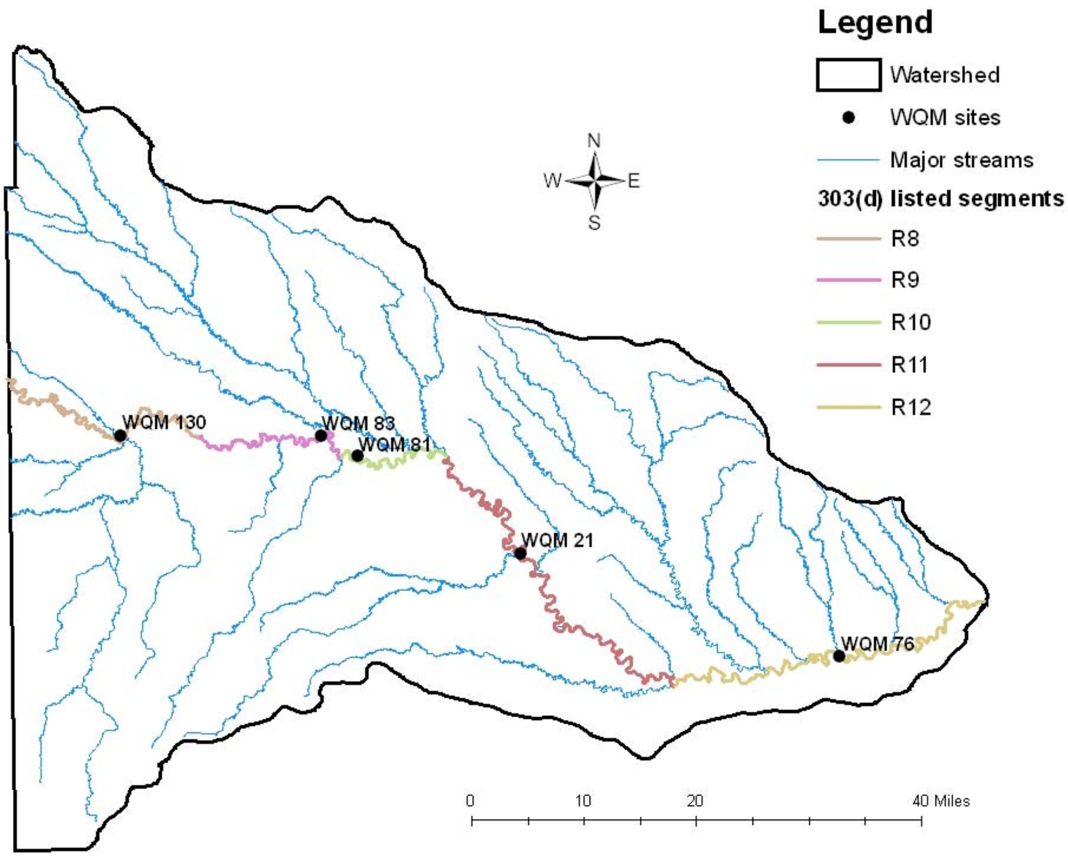


Figure 3. 303(d) listed segments of the Belle Fourche River (from SD DENR 2004 Integrated Report for Surface Water Quality Assessment) and location of water quality monitoring stations (WQM sites) established by the SD DENR Surface Water Quality Program.

Table 1. Excerpt from the 2004 303(d) list (i.e. Impaired Waterbody List) showing waterbody name, location, map ID (see Figure 3), listing basis, cause of listing (parameters of concern), and priority status. The following segments of the Belle Fourche River have been assigned high priority status due to the widespread local support for water quality improvement and the expected development of a TMDL within the next two years.

Waterbody Name	Location	Map ID	Basis	Cause	Priority
Belle Fourche River	WY border to near Fruitdale	R8	DENR WQM 130	Fecal Coliform TSS	1
Belle Fourche River	Near Fruitdale, SD to Whitewood Creek	R9	DENR WQM 83	TSS	1
Belle Fourche River	Whitewood Creek to Willow Creek	R10	DENR WQM 81	TSS	1
Belle Fourche River	Willow Creek to Alkali Creek	R11	DENR WQM 21	TSS	1
Belle Fourche	Alkali Creek to	R12	DENR	TSS	1

River	mouth		WQM 76		

Source: 2004 South Dakota Integrated Report for Surface Water Quality Assessment

Description of Applicable Water Quality Standards & Numeric Water Quality Targets

The Belle Fourche River has been assigned beneficial uses by the state of South Dakota Surface Water Quality Standards regulations. Along with these assigned uses are narrative and numeric criteria that define the desired water quality of the river. These criteria must be maintained for the river to satisfy its assigned beneficial uses, which are listed below:

- Warmwater permanent fish propagation
- Immersion recreation
- Limited contact recreation
- Fish and wildlife propagation, recreation, and stock watering
- Irrigation

Individual parameters, including TSS concentrations, determine the support of beneficial uses and compliance with standards. In the case where there is more than one applicable criterion for a water quality constituent, the most stringent of these criteria is used. For warm water permanent fish life propagation waters, 30-day average total suspended solids (TSS) should not exceed 90 mg/L or a daily maximum of 158 mg/L. As a result of watershed erosion and stream channel entrenchment, TSS concentrations in the Belle Fourche River have been found to exceed the daily maximum TSS standard.

Pollutant Assessment

Point Sources

Several municipalities are located within the Belle Fourche River watershed including Belle Fourche, Central City, Deadwood, Fruitdale, Lead, Newell, Nisland, Spearfish, Sturgis, Vale, and Whitewood. The following municipalities within the Belle Fourche River watershed have point-source discharge permits for wastewater treatment effluent: Lead/Deadwood Sanitary District (Lead, Deadwood, and Central City), Nisland, Newell, Spearfish, and Whitewood. All other municipalities have non-discharge wastewater treatment facilities. Additional point sources of TSS occur in watershed and were included in the TMDL calculation below.

Nonpoint Sources

The impacts of irrigation on the TSS load in the Belle Fourche River were observed during this study. The TSS water quality standard (158 mg/L) was exceeded at sites BF1, BF2, BF4, BF5, BF7, and BF11 during non-winter months. All exceedences occurred during spring and summer months (March-July). During the irrigation season (June-September), the average TSS concentration for sites BF-1 and BF-11 is over 2.5 times the 12-month average. For the same sites, over 95% of the load occurs during months of irrigation. As much as 50% of the TSS load in the Belle Fourche River is attributed to hydraulic alteration from irrigation activities.

Improper grazing management can contribute to the removal of most vegetative cover, soil compaction, exposure of the soil, degradation of the soil structure, and loss of soil infiltration capacity. In the Belle Fourche River watershed, higher rates of sediment delivery from rangeland can be attributed to steep slopes, highly erodible soils, and storm events. While not as extreme as the observed irrigation impacts, improperly managed livestock grazing has also contributed to increased TSS concentrations. According to the conceptual sediment budget, approximately 15-35% of the TSS load in the Belle Fourche River is attributed to riparian degradation, and approximately 3-5% of the sediment source is attributed to range erosion. Figure 12 on page 45 of the final assessment report illustrates this conceptual sediment budget.

Linkage Analysis

Water samples were collected monthly for this assessment project during two sampling periods in 2001-2002: from June 2001 through October 2001 and from March 2002 through October 2002. Samples collected at each site were taken according to South Dakota's EPA approved Standard Operating Procedures for Field Samplers. Water samples were sent to Energy Laboratories in Rapid City, SD for analysis. Quality Assurance/Quality Control samples were collected according to South Dakota's EPA approved Nonpoint Source Quality Assurance/ Quality Control Plan. Details concerning water sampling techniques, analysis, and quality control are addressed in the methods section of the assessment final report (page 13).

Water samples collected during this two-year assessment at the five WQM sites (Figure 3), in addition to samples collected by SD DENR Surface Water Quality Program, will be used in TMDL calculations for the five listed segments of the Belle Fourche River. These sites will continue to be sampled by SD DENR, so the success of watershed remediation activities in achieving the TMDL can be assessed at these stations over time.

Hydrologic Simulation Program-Fortran (HSPF) was used to simulate the hydraulic processes of the Belle Fourche River, estimate TSS loads within the watershed, and identify the potential source(s) of TSS. See the HSPF modeling section of the final report (page 49) for a complete summary of the results.

TMDL and Allocations

Total Maximum Daily Load (TMDL)

TMDLs were calculated for each of the five listed segments of the Belle Fourche River. FLUX, a program developed by the US Army Corps of Engineers, was used to estimate the current TSS load at the five WQM sites. To determine the TMDL for each listed segment, sample concentrations exceeding the daily maximum TSS standard were replaced with the standard value (158 mg/L) and the model was executed again. See page 64 of the final assessment report for details concerning the FLUX analysis.

The water quality target of each TMDL is to meet the TSS water quality standard. The percent reduction from the current TSS load to the TMDL for each segment is considered a secondary goal/target to achieve the desired TSS load.

A goal of 55% reduction of mean TSS concentration was set for the entire Belle Fourche River (See page 66 of final report for discussion of TSS concentration reductions from the installation of BMPs). This goal will meet or exceed the required reductions for each listed segment of the Belle Fourche River (Table 2).

Table 2. Percent reduction of mean TSS concentrations required to meet the TSS water quality standard (158 mg/L).

Listed Segment	Percent Reduction of Mean TSS Concentration
Segment 8	341 mg/L → 158 mg/L = 53% reduction
Segment 9	114 mg/L → 158 mg/L = 0% reduction
Segment 10	104 mg/L → 158 mg/L = 0% reduction
Segment 11	329 mg/L → 158 mg/L = 52% reduction
Segment 12	306 mg/L → 158 mg/L = 48% reduction

To calculate a TMDL for each segment, the FLUX model was first executed with the actual sample concentrations from water years 1998-2003. Then, the sample concentrations that exceeded the water quality standard were replaced with the standard value (158 mg/L) and the model was executed again. The TMDLs presented in Table 3 show results of the FLUX model that was run with replacement values.

Table 3. Total Maximum Daily Load (TMDL) for each Belle Fourche River segment (tons/year).

Segment 8

Load Allocation (LA)	9,271.3
Waste Load Allocation (WLA)	
GF&P McNenny Fish Hatchery	28.8
City of Spearfish	20.5
LAC Minerals	6.8
Wharf Resources	65.0
Margin of Safety (MOS)	
Explicit (10% of TMDL)	1,043.6
Total Maximum Daily Load (TMDL)	**10,436**

Segment 9

Load Allocation (LA)	1,795.1
Waste Load Allocation (WLA)	
Town of Nisland	0.1
Margin of Safety (MOS)	
Explicit (10% of TMDL)	199.5
Total Maximum Daily Load (TMDL)	**1,995**

Segment 10

Load Allocation (LA)	6,244.1
Waste Load Allocation (WLA)	
Lead-Deadwood Sanitary District	63.8
City of Whitewood	7.3
Town of Newell	1.4
Golden Reward	33.9
Homestake Mining Company	37.3
Margin of Safety (MOS)	
Explicit (10% of TMDL)	709.8
Total Maximum Daily Load (TMDL)	**7,098**

Segment 11

Load Allocation (LA)	23,217.9
Waste Load Allocation (WLA)	0.0
Margin of Safety (MOS)	
Explicit (10% of TMDL)	2,579.8
Total Maximum Daily Load (TMDL)	**25,798**

Segment 12

Load Allocation (LA)	37,585.8
Waste Load Allocation (WLA)	0.0
Margin of Safety (MOS)	
Explicit (10% of TMDL)	4,176.2
Total Maximum Daily Load (TMDL)	**41,762**

*** WLA was calculated using system design flow rates and effluent limit concentrations for each permitted facility.**

Wasteload Allocations (WLAs)

The wasteload allocation (WLA) portion of the TMDL identifies the portion of the loading capacity allocated to existing and future point sources. There are several point sources of TSS in Belle Fourche River watershed.

Based on permit limits and system design flow rates, point source discharge facilities in the Belle Fourche River watershed can discharge approximately 265 tons/year of TSS. However, the calculated actual TSS load from these facilities is considerably less at approximately 38.6 tons/year. Individual point source estimates for the WLA were calculated using system design flow rates and effluent limit concentrations for each permitted facility.

Load Allocations (LAs)

The load allocation (LA) portion of the TMDL identifies the portion of the loading capacity allocated to existing and future non-point sources. Natural background sources are included in the non-point source load allocation to represent the portion of the loading capacity attributed to natural geologic processes.

The required reductions of TSS concentrations may be achieved through the implementation of BMPs including irrigation scheduling, efficient irrigation application and transport, reuse of runoff/tail-water, riparian zone rehabilitation, and grazing management. An irrigation efficiency improvement coupled with the riparian condition improvement should bring the mean TSS concentrations at each segment below the standard of 158 mg/L. This analysis was performed on yearly data predicting changes to mean loads. Daily fluctuations may result in concentrations that are greater in the summer months or less in the winter months. Still, the suggested BMPs and resulting reduction in TSS concentrations should bring the Belle Fourche River into compliance for TSS concentrations.

Most of the recomended BMP's will directly affect TSS load *below* site BF-1. However, the water savings generated by irrigation improvements will indirectly affect the load at BF-1 by decreasing the water demand of the irrigation districts, thereby decreasing the water delivery at BF-1.

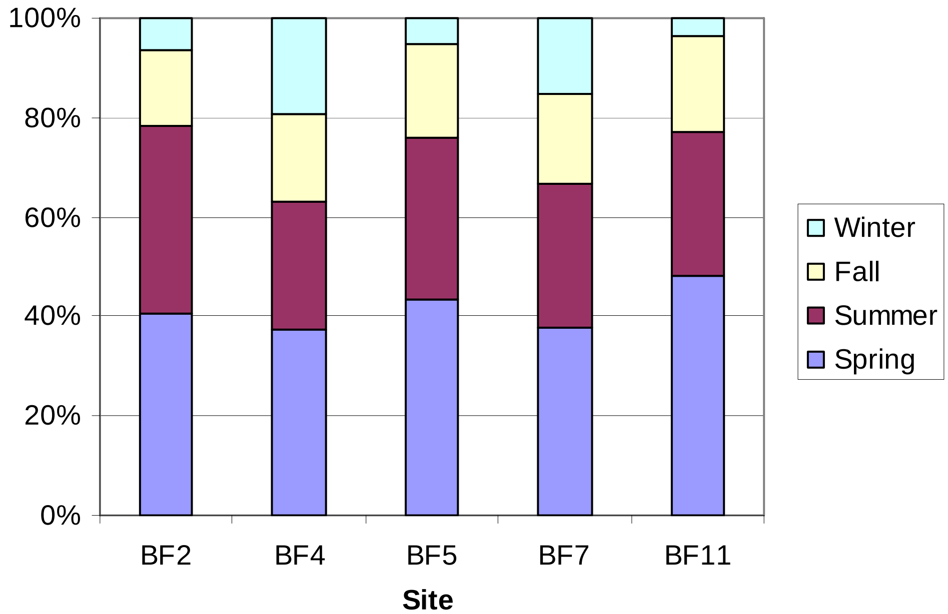
Seasonal Variation

Different seasons of the year can yield differences in water quality due to changes in precipitation and landuse practices. The monthly hydrologic contributions from each segment for the 1998-2003 listing period were calculated by the FLUX program in kg/year. These monthly loads were grouped together by season as follows:

Winter – December, January, February
Spring – March, April, May
Summer – June, July, August
Fall – September, October, November

A majority of the annual TSS load occurs during the spring and summer months. Approximately 40% of the load occurs during the spring for most sites. Nearly half of the annual load at BF11 occurs during the spring months (Figure 4). The variation in monthly loads is attributed to seasonal variation in hydrologic contributions.

Figure 4. Percent of annual load from each season by site (October 1, 1998- September 30, 2003).



Seasonal variation in flow was also observed in the HSPF model output. Overall, the model is good at simulating a five-year period that is representative of the expected conditions within the watershed. However, the model was able to represent the summer months with more precision than winter months. Snowmelt is the major source of error during the winter months. The model was also more precise for years with higher precipitation.

Margin of Safety

Substantial uncertainty is often inherent in estimating TSS loads from nonpoint sources. To account for uncertainty in the TMDL calculations, a portion of the available TSS loading capacity was not allocated. Ten-percent of the TMDL was reserved as the margin of safety, a required component of the TMDL.

An implicit margin of safety can also be justified, as conservative estimations were used in predicting the achievable TSS reductions from the implementation of BMPs. The participation level for the implementation of riparian BMPs is assumed to be 30-50% of the stream bank; however additional participation could reduce TSS concentrations even further.

Critical Conditions

Critical conditions associated with flow, TSS loading, and other water quality factors seem to be driven by irrigation practices in the watershed. The impairments to the Belle Fourche River are most severe during the irrigation season (June-September).

Some modeling error can also be attributed to irrigation practices. A 5 percent error during the dry year of 1992 was the largest, and indicates the model did not simulate the hydraulic process accurately. Significant irrigation withdrawals by farmers along the Belle Fourche River are suspected to be one of the major contributing factors. In 1992 and 2002, both dry years, there is a negative water balance between sites BF7 and BF11.

Follow-up Monitoring

Monitoring will be necessary to determine whether or not the proposed implementation actions have had an impact on water quality in the Belle Fourche watershed. Once the implementation project is completed, post-implementation monitoring will be necessary to assure that the TMDL has been reached. At a minimum, quarterly monitoring will continue for the followng SD DENR ambient monitoring sites:

- WQM 130 (BF2)
- WQM 83 (BF4)
- WQM 81 (BF5)
- WQM 21 (BF7)
- WQM 76 (BF11)

Monitoring and evaluation efforts will be targeted toward the effectiveness of implemented BMP's. Sample sites will be based on BMP site selection and parameters will be based on a product specific basis. Specifically, the monitoring should include measurements of daily flow and monthly turbidity, specific conductance, temperature, and pH. Water quality samples should be collected at least once per year. This monitoring is suggested for all discharge points in the BFID system during the irrigation season, in addition to the following USGS sites:

- BF1 (USGS 06430500)
- Inlet Canal (USGS 06434505)
- BF3 (USGS 06436000)
- BF7 (USGS 0647000)
- BF11 (USGS 06438000)
- HC4 (USGS 06436760)
- WW5 (USGS 06436198)
- RW1 (USGS 06430500)
- SP3 (USGS 06431500)

Public Participation

Efforts were taken to gain public education, review, and comment during development of the TMDL including local newspaper articles, general public meetings, Technical Group meetings, and Belle Fourche River Watershed Partnership meetings. The general public meetings provided an opportunity to present assessment results and to receive input from the stakeholders. The comments/findings from these public meetings have been taken into consideration in development of the Belle Fourche River TMDL.

Implementation Plan

The Belle Fourche River Watershed Partnership was awarded a 319 implementation grant to support a one-year project. The goals of this project segment are to begin initial implementation of BMPs in the watershed to reduce TSS, develop a 10-year watershed strategic implementation plan to guide the long-term process to reduce TSS in a cost effective manner, and conduct public education and outreach to stakeholders within the Belle Fourche watershed to codevelop the 10-year strategic implementation plan.

Appendix F

Horse Creek

Total Suspended Solids

Total Maximum Daily Load (TMDL) Summary

TOTAL MAXIMUM DAILY LOAD EVALUATION

of

Total Suspended Solids

for

Horse Creek

Butte County, South Dakota

South Dakota Department of
Environment and Natural Resources

5/9/2006

Horse Creek Total Maximum Daily Load

Waterbody Type:	Stream
303(d) Listing Parameter:	Total suspended solids (TSS)
Designated Uses:	• Warmwater semipermanent fish propagation • Limited-contact recreation • Fish and wildlife propagation, recreation, and stock watering • Irrigation
Size of Waterbody:	50 stream miles
Size of Watershed:	296,319 acres
Water Quality Standards:	Narrative and Numeric
Indicators:	TSS concentrations
Analytical Approach:	Models including BASINS 3.0, HSPF and FLUX
Location:	Butte County, South Dakota
Goal:	Reduction of TSS load
Target:	Mean TSS concentration ≤ 158 mg/L

Objective

The intent of this summary is to clearly identify the components of the TMDL submittal, to support adequate public participation, and facilitate the US Environmental Protection Agency (EPA) review and approval. This TMDL was developed in accordance with Section 303(d) of the federal Clean Water Act and guidance developed by EPA.

Introduction

Horse Creek was listed in the 1998 impaired waterbody list due to elevated total dissolved solids (TDS) concentrations. SD DENR later determined this to be a listing error. The Horse Creek listing was corrected in the 2002 report and instead listed for conductivity. Horse Creek is currently listed for conductivity impairment in the 2004 Integrated Report. During this assessment, approximately 10% of the samples collected from Horse Creek also exceeded the water quality standard for TSS. For this reason, a TMDL is needed for Horse Creek for both TSS and conductivity.

An assessment of the Horse Creek sub-watershed was included within the larger Belle Fourche River watershed assessment, which was conducted in 2001-2002. Since the Belle Fourche River watershed assessment final report addresses only TSS, this TMDL summary will also only address the TSS portion of the TMDL. A conductivity TMDL for Horse Creek will follow in a separate document.

The Horse Creek watershed drains approximately 296,300 acres (463 $miles^2$) in Butte County, South Dakota (Figure 1). Land use in the watershed includes agriculture, forest, and rangelands. In the study reach, agriculture is the major land use. Irrigated alfalfa and hay account for nearly half of the project area.

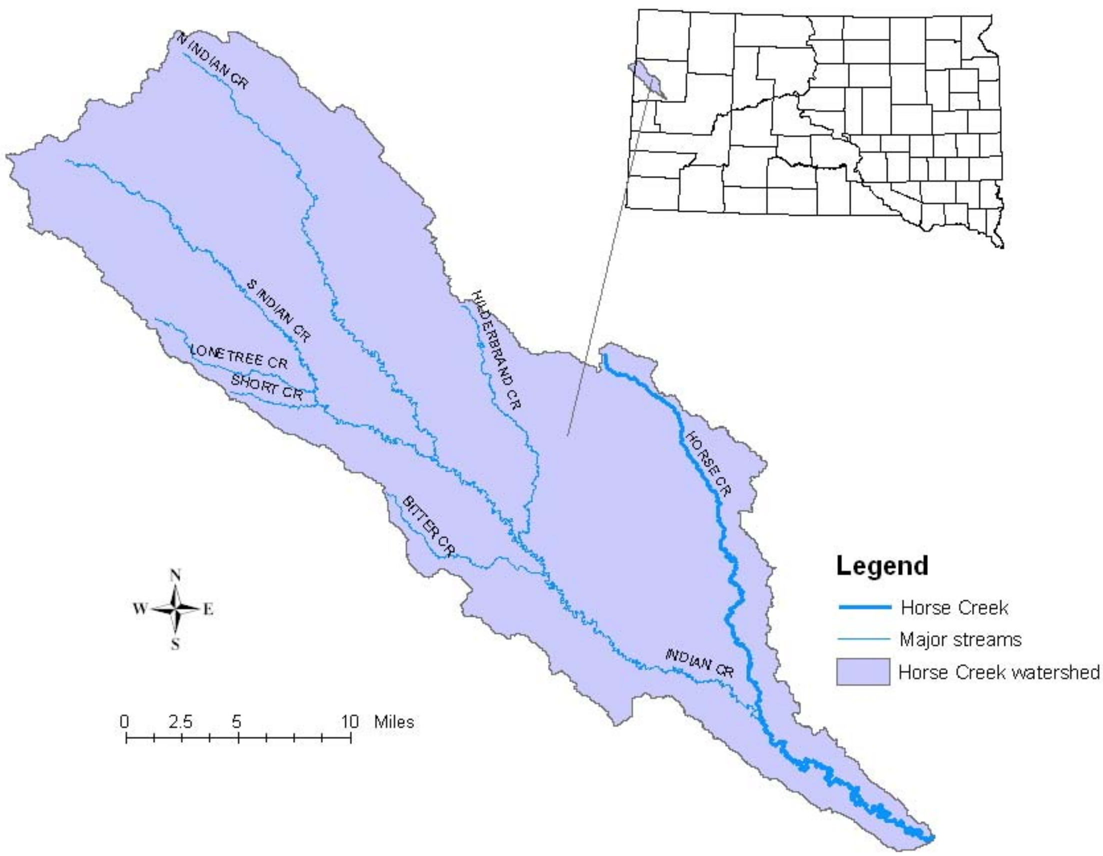


Figure 1. Location of the Horse Creek watershed in Butte County, South Dakota.

Problem Identification

Horse Creek, a tributary of the Belle Fourche River, carries an excessive sediment load that degrades its water quality. For comparison, the total suspended solids (TSS) load in the Belle Fourche River watershed was approximately 527,109 tons/year (as measured by site BF11 over the period 1998-2003). An estimated, 4,959 tons was contributed by the Horse Creek watershed in 2002.

According to the 2002 South Dakota Report to Congress (The 305(b) Water Quality Assessment), Horse Creek failed to support its assigned uses due to high conductivity. In the report, irrigation return flows are deemed a likely source of conductivity impairment. The report also predicts that TSS may be frequently excessive in Horse Creek, according to limited historical data. This watershed assessment has identified hydrologic alteration, irrigation practices, and riparian degradation as sources of increased TSS concentrations.

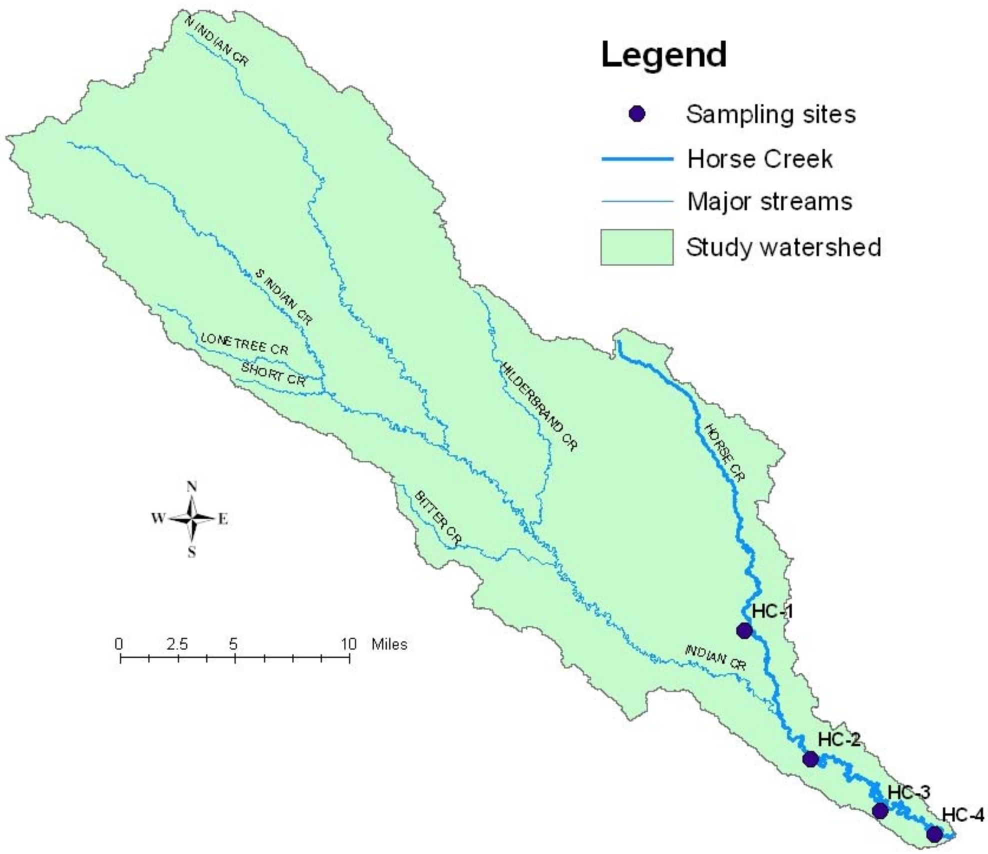


Figure 2. Delineation of the Horse Creek watershed in Butte County, South Dakota and location of sampling sites.

Description of Applicable Water Quality Standards & Numeric Water Quality Targets

Horse Creek has been assigned beneficial uses by the state of South Dakota Surface Water Quality Standards regulations. Along with these assigned uses are narrative and numeric criteria that define the desired water quality of the river. These criteria must be maintained for the river to satisfy its assigned beneficial uses, which are listed below:

1) Warmwater semipermanent fish propagation
2) Limited-contact recreation
3) Fish and wildlife propagation, recreation, and stock watering
4) Irrigation

Individual parameters, including TSS concentrations, determine the support of beneficial uses and compliance with standards. In the case where there is more than one applicable criterion for a water quality constituent, the most stringent of these criteria is used. For warm water semipermanent fish life propagation waters, 30-day average total suspended solids (TSS) should not exceed 90 mg/L or a daily maximum of 158 mg/L. As a result of watershed erosion and stream channel entrenchment, TSS concentrations in Horse Creek have been found to exceed the water quality standard.

Pollutant Assessment

Point Sources

There are no point source pollutants of concern in this watershed.

Nonpoint Sources

The impacts of irrigation on the TSS load in Horse Creek were observed during this study. The TSS water quality standard (≤ 158 mg/L) was often exceeded at site HC4. During irrigation months (June-September), the TSS concentration average at site HC4 is 1.75 times the 12-month average for the same time frame. Irrigation and on-farm waste account for 20% of the TSS load, and hydraulic alteration from irrigation practices account for 40% of the TSS load.

Improper grazing management can contribute to the removal of most vegetative cover, soil compaction, exposure of the soil, degradation of the soil structure, and loss of soil infiltration capacity. In the Belle Fourche River watershed, higher rates of sediment delivery from rangeland can be attributed to steep slopes, highly erodible soils, and storm events. While not as extreme as the observed irrigation impacts, improperly managed livestock grazing has also contributed to increased TSS concentrations. Approximately 25% of the TSS load is attributed to riparian degradation, and approximately 3% of the load is attributed to range erosion.

Natural geologic processes and reduced stream miles (i.e. channel alteration) account for the remaining 12% of the TSS load in the Belle Fourche River. Table 46 on page 74 of the final assessment report summarizes this sediment budget.

Linkage Analysis

Water samples were collected monthly from March 2002 through October 2002. Samples collected at each site were taken according to South Dakota's EPA approved Standard Operating Procedures for Field Samplers. Water samples were sent to Energy Laboratories in Rapid City, SD for analysis. Quality Assurance/Quality Control samples were collected according to South Dakota's EPA approved Nonpoint Source Quality Assurance/ Quality Control Plan. Details concerning water sampling techniques, analysis, and quality control are addressed in the assessment final report (page 13).

Hydrologic Simulation Program-Fortran (HSPF) was used to simulate the hydraulic processes of Horse Creek, estimate TSS loads within the watershed, and identify the potential source(s) of TSS. See the HSPF modeling section of the final report (page 49) for a complete summary of the results.

FLUX, a program developed by the US Army Corps of Engineers, was also used to estimate TSS loadings. On average, Horse Creek contributes approximately 4,959 tons of TSS to the Belle Fourche River per year. See page 64 of the final assessment report for details concerning the FLUX analysis.

TMDL and Allocations

FLUX, a program developed by the US Army Corps of Engineers, was used to estimate the current TSS load at the five WQM sites. To determine the TMDL for each listed segment, sample concentrations exceeding the daily maximum TSS standard were replaced with the standard value (158 mg/L) and the model was executed again. See page 64 of the final assessment report for details concerning the FLUX analysis.

The water quality target of each TMDL is to meet the TSS water quality standard. The percent reduction from the current TSS load to the TMDL for each segment is considered a secondary goal/target to achieve the desired TSS load.

The mean TSS concentration for site HC4 was 266 mg/L. A goal of 41% reduction of mean TSS concentration was set for the entire Horse Creek watershed (See page 66 of final report for discussion of TSS concentration reductions from the installation of BMPs).

To calculate a TMDL for Horse Creek, the FLUX model was first executed with the actual sample concentrations and daily flow data from 2002. Then, the sample concentrations that exceeded the water quality standard were replaced with the standard value (158 mg/L) and the model was executed again. The TMDL presented in Table 1 show results of the FLUX model that was run with replacement values.

Table 1. Total Maximum Daily Load for Horse Creek (tons/year).

Total Maximum Daily Load	
Load Allocation (LA)	1,681.2
Waste Load Allocation (WLA)	0.0
Margin of Safety (MOS)	186.8
Total Maximum Daily Load (TMDL)	**1,868**

Wasteload Allocations (WLAs)

The wasteload allocation (WLA) portion of the TMDL identifies the portion of the loading capacity allocated to existing and future point sources. There are no point sources of TSS in the Horse Creek watershed, so the recommended WLA component of this TMDL is considered a zero value. The TMDL is considered wholly included within the load allocation and natural background components (see below).

Load Allocations (LAs)

The load allocation (LA) portion of the TMDL identifies the portion of the loading capacity allocated to existing and future non-point sources. Natural background sources are included in the non-point source load allocation to represent the portion of the loading capacity attributed to natural geologic processes.

A 41% reduction of TSS load to Horse Creek may be achieved through the implementation of BMPs including irrigation scheduling, efficient irrigation application and transport, reuse of runoff/tail-water, riparian zone rehabilitation, and grazing management. An irrigation efficiency improvement coupled with the riparian condition improvement should bring the mean TSS concentration below the standard of 158 mg/L.

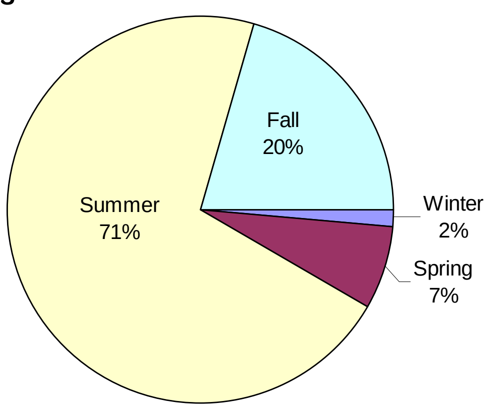
Seasonal Variation

Different seasons of the year can yield differences in water quality due to changes in precipitation and landuse practices. The monthly hydrologic contributions from each segment for the 1998-2003 listing period were calculated by the FLUX program in kg/year. These monthly loads were grouped together by season as follows:

Winter – December, January, February
Spring – March, April, May
Summer – June, July, August
Fall – September, October, November

A majority of the annual TSS load in Horse Creek occurs during the irrigation season (June-September). Approximately 70% of the load occurs during the summer, and 20% of the annual load occurs during the fall months (Figure 3).

Figure 3. Percent of annual load from each season by site (2002).



Margin of Safety

Substantial uncertainty is often inherent in estimating TSS loads from nonpoint sources. To account for uncertainty in the TMDL calculations, a portion of the available TSS loading capacity was not allocated. Ten-percent of the TMDL was reserved as the margin of safety, a required component of the TMDL.

The margin of safety can also be considered implicit, because conservative estimations were used in predicting the achievable TSS reductions from the implementation of BMPs. The participation level for the implementation of riparian BMPs is assumed to be 30-50% of the stream bank. Additional participation could reduce TSS concentrations even further. The 70% reduction percentage reported in literature is the overall TSS concentration reduction expected. Thus, assuming the 70% reduction in only the load attributed to riparian degradation, results in a conservative estimate. This conservative approach provides a margin of safety required in the TMDL calculation.

Critical Conditions

Critical conditions associated with flow, TSS loading, and other water quality factors seem to be driven by irrigation practices in the watershed. The impairments to Horse Creek are most severe during the irrigation season.

Follow-Up Monitoring

Monitoring will be necessary to determine whether or not the proposed implementation actions have had an impact on water quality in Horse Creek. Once the implementation project is completed, post-implementation monitoring will be necessary to assure that the TMDL has been reached and improvement to the beneficial uses occurs.

Monitoring and evaluation efforts will be targeted toward the effectiveness of implemented BMP's. Sample sites will be based on BMP site selection and parameters will be based on a product specific basis. Specifically, the monitoring should include measurements of daily flow and monthly turbidity, specific conductance, temperature, and pH at site HC4 (USGS 06436760). The efficiency of irrigation delivery and application is a major contributing source of TSS. Thus, monitoring and the development of a detailed mass balance of flow and TSS are recommended within the BFID system and irrigated acreage. Monitoring of the discharge points in the BFID system and irrigated acreage (during irrigation) including fields, streams, and drains is recommended during the upcoming irrigation season. Subsequent monitoring of critical areas is recommended after BMPs have been implemented to measure changes.

Water quality samples should be collected once per year and a full water quality analysis and water mass balance report should be submitted to the SD Department of Environment and Natural Resources.

Public Participation

Efforts were taken to gain public education, review, and comment during development of the TMDL including local newspaper articles, general public meetings, Technical Group meetings, and Belle Fourche River Watershed Partnership meetings. The general public meetings provided an opportunity to present assessment results and to receive input from the stakeholders. The comments/findings from these public meetings have been taken into consideration in development of the Horse Creek TMDL for TSS.

Implementation Plan

SD DENR is working with the Belle Fourche River Watershed Partnership to initiate an implementation project beginning in 2004. It is expected that the local sponsor will request implementation project assistance during the spring 2004 EPA Section 319 funding round.