WATER QUALITY, STREAM HABITAT AND MACROINVERTEBRATES OF SAGE CREEK, BADLANDS NATIONAL PARK

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ABSTRACT

The Badlands of the Dakotas are rugged landscapes with unique biota, habitats and water quality characteristics. Sage Creek is a Badlands stream, flowing through Badlands National Park and into the Cheyenne River. The objectives of our study were to characterize water quality, stream habitat and aquatic macroinvertebrate communities of Sage Creek. Three reaches, 40x channel width, were sampled using Environmental Monitoring and Assessment (EMAP) protocols alongside other streams and rivers of the National Park Service (NPS) Northern Great Plains Network (NGPN) during the summers of 2004 and 2005. Sage Creek flows displayed intermittency during our project period (0.000 – 0.015 cms). Conductance (636 – 5158 uS/cm), dissolved oxygen (0.6 – 13.2 mg/L), total suspended solids (5 – 1067 mg/L), total phosphorus (0.05 – 18.8 mg/L) and fecal coliform bacteria (<5 – 8900 /100ml) all displayed alarming ranges and extremes. Stream banks were notably incised and with low vegetative cover, while channel bottoms were covered by fine silt and clay. Median total invertebrate abundance (250/smpl) and generic richness (7.5/smpl) from Sage Creek were over 50% lower compared to other network streams. Communities were dominated by Chironomidae, and no Plecoptera or Trichoptera were collected. Parasite and scraper feeding guilds and the glider habit guild were not collected. The three dominant genera (metric) comprised 98% of total abundance from Sage Creek but only 71% from other network streams, while Hilsenhoff HBI values were similar. Results of this assessment correspond with the harsh environmental setting and suggest different management goals may be necessary for Badlands streams.

Keywords

Badlands National Park, water quality, macroinvertebrates

INTRODUCTION

Prairie streams are some of the most variable aquatic systems in North America and pose daunting challenges to natural resource managers (Dodds et al. 2004). Large land areas within the northern plains are drained by intermittent channels (Dodds et al. 2004, Fritz and Dodds 2004). Stream flow within these watersheds may be interrupted by months or even years of dry conditions. However, significant snowmelt runoff or rainfall events are likely to generate flooding of these dry stream beds. Water chemistries are equally variable (Matthews 1988), and many of the organisms inhabiting these systems display adaptations which allow them to thrive under these harsh conditions (Williams 1996).

The United States national park system comprises 390 parks, national monuments and historic sites. These areas total 84 million acres and host approximately 300 million visitors each year. The Northern Great Plains Network comprises 13 national parks, national monuments and historic sites in Nebraska, North Dakota, South Dakota and Wyoming. Natural resources of these areas draw many visitors and serve as the focus for management efforts by the National Park Service (NPS).

The NPS initiated its Inventory and Monitoring (I&M) Program to (1) inventory natural resources within park boundaries and (2) initiate the collection of data to monitor change in park conditions (National Park Service 2008). Monitoring efforts designed as part of this program focus on "vital signs", measurable signals that indicate changes that may impair the long-term health of natural resources or ecosystems (Oakley et al. 2003). Vital signs are indicators. They tend to be both sensitive to a broad array of environmental changes and integrative of ecological structure and function across levels of biological organization.

Regulatory water quality monitoring is an added concern of park staff. Streams and rivers flowing through park lands may be influenced by park management. These water resources support beneficial uses within and downstream of park management areas. Similarly, management upstream of a park may impair beneficial uses within park boundaries. Thus, water quality monitoring is deemed necessary to verify support of assigned beneficial uses.

Effective monitoring poses several challenges for the NPS. Many parks lack baseline data against which changes in water quality might be measured. For example, aquatic macroinvertebrate community structure has been identified as one potential vital sign for monitoring NPS aquatic resources (National Park Service 2006). However, many parks lack macroinvertebrate inventory information and existing monitoring data (Rust and Troelstrup 2006, Troelstrup and Rust 2006). In addition, streams of some parks drain unusual landscapes or local features which impart extreme natural conditions. These extreme environments may not comply with established regulatory standards and yet may support their beneficial uses. The objectives of this project were to collect baseline water quality, habitat and macroinvertebrate data from NPS streams in support of future monitoring. This paper summarizes baseline I&M Program data collected from Sage Creek, a stream of the extreme environment within Badlands National Park and draws comparisons between Sage Creek and other similarly sized park streams within the Northern Glaciated Plains Network.

STUDY AREA

Badlands National Park is the largest of 13 NPS units within the Northern Glaciated Plains Network (Figure 1). This park is located within the White River Badlands ecoregion of western South Dakota (Bryce et al. 1998). The landscape is unglaciated and displays significant topographic relief as a result of surface erosion. Mean annual precipitation is approximately 406 mm and temperatures range from -18C during winter months to near 38C during the summer. Potential natural vegetation is dominated by sagebrush, western wheatgrass, grama grass and buffalograss. Many of the streams draining this landscape display ephemeral or intermittent flow and run turbid as a result of surface erosion of clay and siltstone.

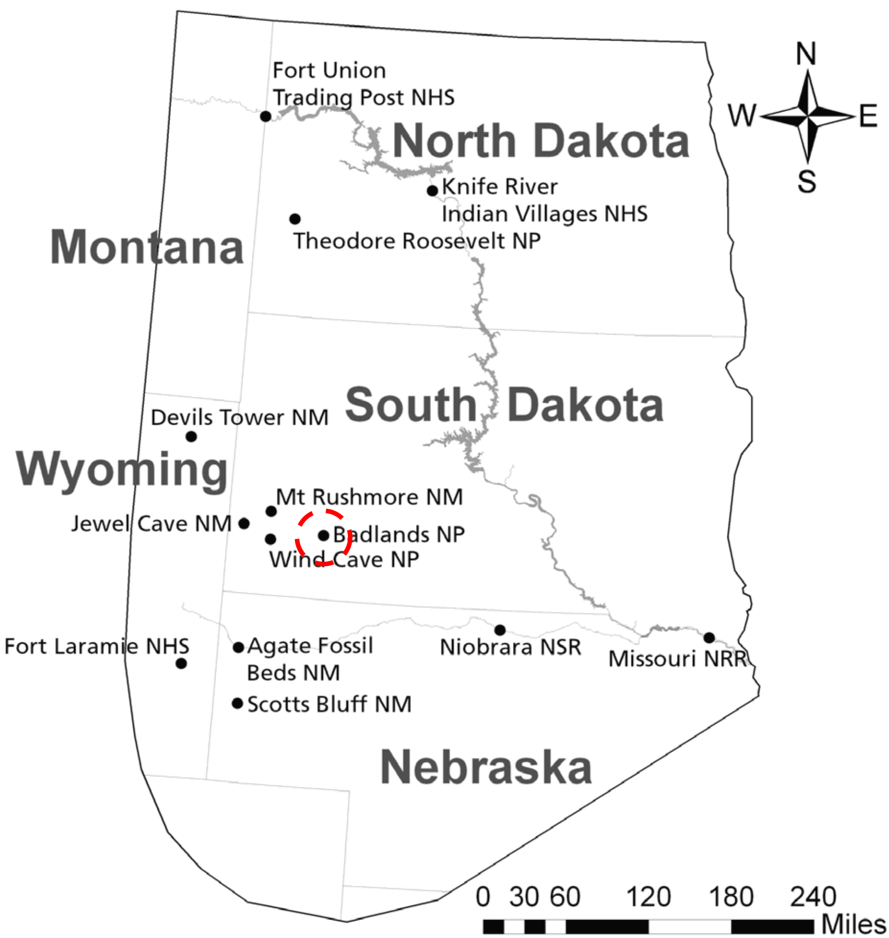

Figure 1. Location of national park areas within the Northern Great Plains Network of the National Park Service (Badlands National Park circled).

Water quality, stream habitat and benthic invertebrate data were collected from Sage Creek within the Sage Creek Unit of the Badlands Wilderness Area. Sage Creek is a tributary of the Cheyenne River which it enters near Wasta, SD. Drainage area is 239 km^2 and divided among three sub-basins (Sage Creek, Middle Fork Sage Creek and South Fork Sage Creek).

Two of our sample reaches were located upstream of the primitive camping unit on the South Fork of Sage Creek. The third sample reach was located below the confluence of the South Fork with Sage Creek and below the bridge of the Sage Creek Rim Road on the North extent of the Badlands Wilderness Area.

METHODS

Water chemistry, habitat and invertebrate assessments were completed twice during 2004 and once during 2005 over the period May 15 – August 1 from 10 cross-channel transects within each sampled reach (40x channel width). Water chemistry grab samples were collected from the most downstream transect of each reach. Water temperature, pH, conductance and dissolved oxygen were measured with a YSI model 556 multiparameter sonde from the center of the downstream transect (Table 1). Nitrate+Nitrite-N, ammonia-N and total phosphorus were collected as grab samples from the center of the channel at the downstream transect. These samples were acidified to pH<2 and refrigerated in the field prior to shipment to the South Dakota Department of Health laboratory for analysis. Total alkalinity was determined titrimetrically in the field (Hach 2003). Fecal coliform grab samples were collected alongside water chemistries and shipped in overnight mail to the South Dakota Department of Health Laboratory for analysis.

Stream habitat measurements were made from the channel, bank and riparian zone along each sampled reach (Peck et al. 2006). Stream reaches of 40x channel width were divided by 10 cross-sectional transects along their length. Wetted widths and depths were measured from each transect. Current velocities and stream flows were estimated using the 0.6x depth method at the downstream most transect on each reach. Median substrate particle size was noted at each of 10 locations along each transect. Stream bank angles were measured with a clinometer and riparian canopy cover estimated with a spherical densiometer on each bank at each transect location. The percentage of linear stream bank (left and right) displaying visible signs of erosion was also measured with a meter tape within each reach.

Table 1. Summary of methods used in data collection from Sage Creek, Badlands National Park, SD.

Test	Method*
Water Temperature (C)	EPA 170.1
Dissolved Oxygen (mg/L)	EPA 360.1
Specific Conductance (uS/cm)	EPA 120.1
pH	EPA 9040A
Alkalinity (mg/L as $CaCO_3$)	HACH 8203
Total Dissolved Solids (mg/L)	SM 2540C
Total Suspended Solids (mg/L)	SM 2540D
Ammonia-N (mg/L)	EPA 350.1
Nitrate+Nitrite-N (mg/L)	EPA 353.2
Total-P (mg/L)	EPA 365.2
Fecal Coliforms (#/100 ml)	SM 9222 B EC

*EPA (United States Environmental Protection Agency 1983); HACH (Hach 2003); SM (Cleseri et al. 1998)

A D-frame net (350 um mesh) was used to sample macroinvertebrates from five randomly chosen transects within each reach. These five net samples were pooled to generate one composite sample for each reach. Composite samples were preserved with 70% ethanol and transported to the laboratory for processing. Invertebrate samples were subsampled (Barbour et al. 1999) and identified to the lowest possible taxonomic level (genus, species) (Merritt and Cummins 1996, Thorp and Covich 2001, Wiggins 1977, Weiderholm 1983). Invertebrate identifications were randomly checked by capable staff and voucher specimens of each taxon were retained.

Water quality characteristics related to beneficial use assignments were evaluated against state water quality standards for Sage Creek (ARSD 2006a). The Shannon-Weiner diversity index (H') (Pielou 1966) was applied to abundances of functional feeding groups and habit guilds to examine feeding and habit guild diversities. Kruskal-Wallis ANOVA was used to compare Sage Creek water quality, habitat and invertebrate attributes with those from other similarly sized NGPN streams (Conover 1980).

RESULTS

Water Quality

Sage Creek displayed higher conductivity, total dissolved solids, total suspended solids, nitrate-N, alkalinity and fecal coliform concentrations than other streams within the NGPN (Table 2). Individual measurements of dissolved oxygen fell below those necessary to support a warmwater fishery. In addition, several fecal coliform results from Sage Creek fell above those necessary to support immersion contact recreation.

Table 2. Water quality characteristics of Sage Creek as compared to other streams within the Northern Great Plains Network.

Parameter	SAGE CREEK		OTHER NPS STREAMS	
	Median	Range	Median	Range
Water Temperature (C)	16.7	13.7-25.7	16.4	9.5-26.7
Conductance (uS/cm)	1465	636-5158	376	62-844
Dissolved Oxygen (mg/L)	7.6	0.6-13.2	9.2	0.2-18.4
pH	8.39	7.86-8.83	8.22	5.55-9.67
Alkalinity (mg/L)	177	127-420	135	8-280
Total Dissolved Solids (mg/L)	822	453-2354	273	5-7631
Total Suspended Solids (mg/L)	43	5-1067	8	1-1418
Nitrate-N (mg/L)	2.2	0.1-2.4	0.05	0.05-2.4
Ammonia-N (mg/L)	0.01	0.01-0.04	0.01	0.01-0.26
Total Phosphorus (mg/L)	0.08	0.05-18.80	0.06	0.01-4.31
Fecal Coliforms (#/100 ml)	5600	<5-8900	35	<5-1800

Stream Habitat

Sage Creek was wider and shallower than most other streams within the NGPN (Table 3). This stream displayed intermittent flow during both years of sampling, and median flows were much lower than those observed from other NGPN streams. Fine substrates dominated the channel bottom in all three sampled reaches. Riparian areas had little canopy cover, and stream banks were steep and highly eroded.

Table 3. Physical stream habitat of Sage Creek as compared to that of other streams within the Northern Great Plains Network.

Parameter	SAGE CREEK		OTHER NPS STREAMS	
	Median	Range	Median	Range
Wetted Width (m)	2.5	0-13.5	1.7	0.2-18.7
Depth (cm)	2	0-3.8	5.8	1.1-54.7
Current Velocity (m/s)	0.03	0-0.21	0.09	0-0.75
Stream Flow (cms)	0.0007	0-0.016	0.09	0-0.75
Fine Substrate (%)	100	0-100	0	0-100
Bank Angle (%)	55	9-100	29	1-100
Bank Erosion (%)	32.5	0-100	0	0-100
Canopy Cover (%)	0	0-50	47	0-100

Stream Invertebrate Community

Median total invertebrate abundance was lower from Sage Creek (250/sample) than other park network streams (407/sample). In addition, taxa richness was distinctly lower from Sage Creek (7.5 taxa/sample vs 14 taxa/sample; Figure 2), and true flies (Diptera) were noticeably more abundant from Sage Creek samples (99%) compared to other network streams (20%). The three most abundant invertebrate taxa comprised 98% of Sage Creek total invertebrate abundance as compared to 71% in other network streams (Figure 3).

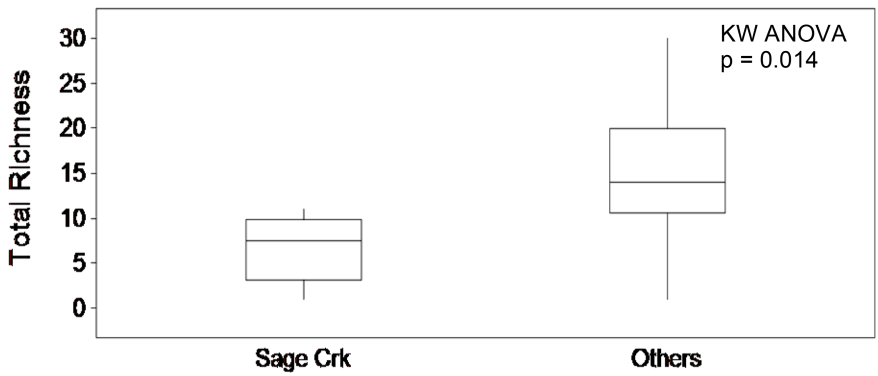

Figure 2. Macroinvertebrate taxa richness of Sage Creek stream sites as compared to other streams within the Northern Great Plains Network.

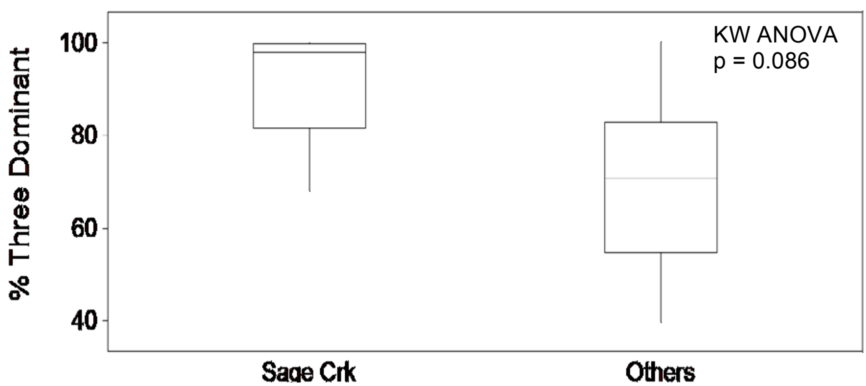

Figure 3. Percent contribution of the three dominant invertebrate taxa (by abundance) from Sage Creek stream sites as compared to other streams within the Northern Great Plains Network.

Most major invertebrate groups were noticeably absent or represented by only select genera from Sage Creek (Table 4). Of 219 genera recorded from all of our NPS sites (including Sage Creek), only 29 were found within Sage Creek, and 12 of these were not collected from the other network streams. These 12 genera belonged to the insect orders Coleoptera, Diptera and Hemiptera. Seven were predators, and all but one were moderately or extremely tolerant to low dissolved oxygen concentrations.

Ephemeroptera, Plecoptera and Trichoptera were found in significantly fewer numbers from Sage Creek than other network streams (Table 4; Figure 4). In fact, Trichoptera and Plecoptera were not collected from any of our Sage Creek samples. *Caenis* sp. was the only mayfly collected from Sage Creek, whereas up to four mayfly genera were collected from other network streams.

Feeding guild diversity (Shannon H') of Sage Creek averaged less than half of that observed from other network streams (Figure 5). Parasite and scraper feeding guilds were not collected from Sage Creek. A similar pattern was observed for habit guild diversity (Shannon H'), although differences between Sage Creek and other network streams were not statistically significant. The glider habit guild was absent from Sage Creek.

Table 4. Number of macroinvertebrate genera in samples collected from Sage Creek versus other streams of the Northern Great Plains Network.

Major Group	Sage Creek	Other NPS Streams
Annelida	0	13
Crustacea	0	5
Insecta	29	175
Coleoptera	8	27
Collembola	0	1
Diptera	17	71
Ephemeroptera	1	21
Hemiptera	5	15
Megaloptera	0	1
Odonata	1	12
Plecoptera	0	9
Trichoptera	0	18
Mollusca	0	13
Total	29	206

DISCUSSION

Sage Creek displayed many characteristics expected from the harsh, semi-arid Badlands landscape through which it drains. Flows were predictably intermittent, and total suspended and dissolved solids concentrations were high. Stream banks had little vegetative cover, and much of the stream bottom was comprised of fine substrate with little structural complexity. Aquatic invertebrate communities were dominated by those few taxa which were able to tolerate this

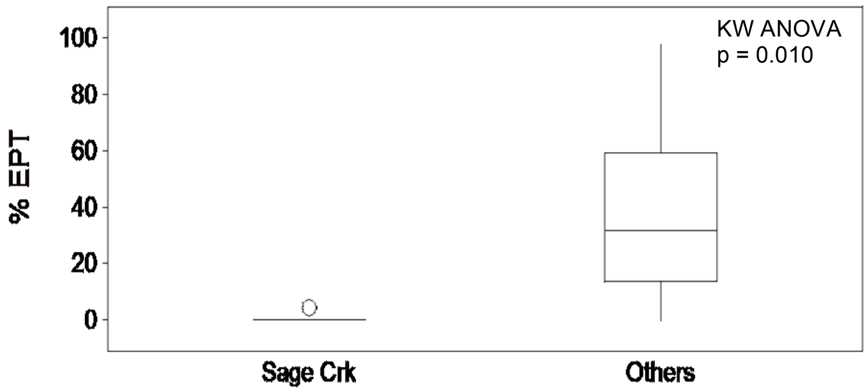

Figure 4. Percent Ephemeroptera, Plecoptera and Trichoptera collected from Sage Creek stream sites as compared to other streams within the Northern Great Plains Network.

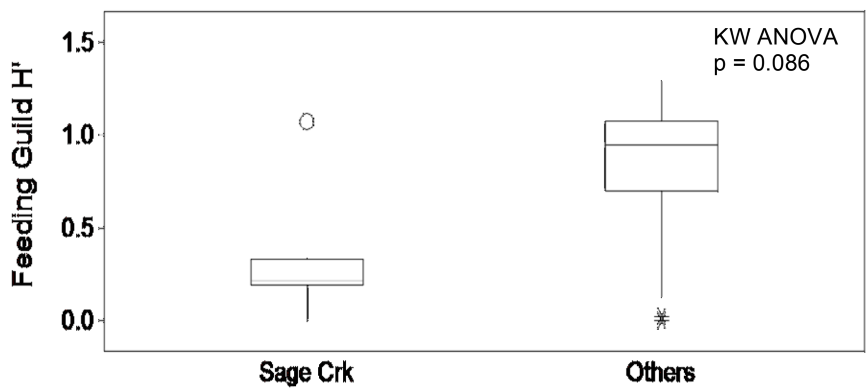

Figure 5. Feeding guild diversity (H') of Sage Creek stream invertebrates as compared to other streams within the Northern Great Plains Network.

harsh environment. By comparison with other similarly sized NPS streams, these characteristics might suggest a severely impaired stream.

In many respects, the conditions in Sage Creek resemble extremes of what we already know about prairie streams (Matthews 1988, Miller and Golladay 1996, Dodds et al. 2004, Fritz and Dodds 2004). Intermittent flow appears to be the rule for many prairie streams, increasing in prevalence as mean annual precipitation decreases. The wet-dry cycle of intermittent channels brings a seasonal succession of changing habitat conditions and biota within these channels (Williams 1996). Flowing water gives way to isolated pools which may eventually dry completely during the hot summer months. Reductions in water depth during the mid-summer drying phase reduce available habitat. Elevated temperatures and correspondingly lower dissolved oxygen concentrations place physiological stresses on ill-adapted aquatic species (Matthews 1988). Geologic history within the Badlands is also a strong determinant of water chemistries within streams of this region. Clay and silt soils with low vegetative cover are easily eroded during rainfall runoff events. This leads to high suspended and dissolved solids concentrations and channel habitats dominated by fine substrates.

Typically, these intermittent systems host communities with lower overall diversity than those of more permanent water bodies (Williams 1996). Well-adapted species demonstrate flexible life-cycles, diapausing stages during development to avoid desiccation and high powers of dispersal in some, allowing them to move from temporary to more permanent water bodies as conditions become stressful (Williams 1996). We observed an overwhelming prevalence of Diptera larvae within the invertebrate samples of Sage Creek. Williams (1996) noted that this insect order is particularly well represented in temporary water bodies. The only mayfly we observed from Sage Creek samples was *Caenis* sp. This mayfly genus has been noted to be a habitat generalist and is particularly well adapted to resist displacement by spates (Dodds et al. 2004).

Water quality data for a particular stream is evaluated against legislated standards defined to protect assigned beneficial uses (Lamb 1985). These standards provide the benchmarks against which chemical monitoring data are evaluated. However, habitat and biological characteristics of streams are evaluated against regional reference sites. These reference sites represent minimally disturbed water bodies with similar landscape characteristics (Hughes et al. 1994, Mrazik 1999). The drainage area above our sampling reaches on Sage Creek falls entirely within Badlands National Park. The national park arguably represents an area which is minimally disturbed by human activity relative to privately owned land around the park. Thus, we would argue that habitat and invertebrate community characteristics measured from Sage Creek are representative of reference conditions for other similar badlands stream systems. Furthermore, we would argue that reference conditions measured outside the badlands region are probably not representative of minimally disturbed badlands streams. Thus, habitat and invertebrate community benchmarks (Karr and Chu 1999, Rust and Troelstrup 2006, Troelstrup and Rust 2006) should be regionalized to account for the unique conditions found within the Badlands.

Sage Creek has been assigned the beneficial uses of irrigation, fish and wildlife propagation, recreation and stock watering (ARSD 2006a). Water quality criteria have been defined to protect these uses, and together, the criteria for each of these uses comprise the water quality standards for Sage Creek (ARSD 2006b). We observed no violations of water quality standards assigned to protect beneficial uses of Sage Creek. Our data suggest a simplified, yet well-adapted invertebrate community within this stream. In addition, despite intermittent flow and high solids concentrations, Sage Creek is capable of supporting at least two species of warmwater fish (Ahrens 2008). However, Sage Creek may contribute high loads of sediment downstream to the Cheyenne River. How are we to protect beneficial uses of downstream, receiving water bodies from naturally high loads of suspended sediment from Badlands streams? Should high sediment loads from upstream tributaries be regulated to protect more demanding beneficial uses downstream, or should beneficial uses in reaches of receiving waters downstream of those tributaries be changed to account for naturally high loads? These are challenging questions faced by water resource managers.

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