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Identification of Most Probable Stressors to Aquatic Life in the Touchet River, Washington

National Center for Environmental Assessment
Office of Research and Development, Washington, DC 20460

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NOTICE

The Washington State Department of Ecology and the U.S. Environmental Protection Agency through its Office of Research and Development jointly prepared this report. It has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

The Washington State Department of Ecology (WSDE) currently practices "single-entry" total maximum daily load (TMDL) studies. A single-entry TMDL addresses multiple water quality impairments concurrently, which can reduce sampling costs, organize sampling group efforts, and provide an objective framework for basing management decisions in the regulatory process. The Touchet River, a subwatershed of the Walla Walla River in eastern Washington State, was listed for fecal coliform bacteria, temperature, and pH water quality impairments and slated for a single-entry TMDL. The U.S. Environmental Protection Agency (U.S. EPA)'s Stressor Identification procedures were used to identify and prioritize factors causing biological impairment and to develop effective restoration plans for this river. Six sites were sampled along the Touchet River over a two-year period; parameters measured included WSDE benthic macroinvertebrate assemblage metrics and physical habitat measures; chemical analysis of pesticides and other pollutants; and *in-situ* temperature and pH measurements. Nearly every measure of biological condition declined from upstream sites to downstream sites. A conceptual diagram was constructed to identify potential sources of stressors, pathways, stressors, and biological measures of effect.
Seven candidate causes of biological impairment were considered: toxics, low dissolved oxygen (DO), alkaline pH, water temperature, sedimentation, reduced detritus, and reduced habitat complexity. Toxic chemicals measured did not exceed aquatic life criteria, and the low levels of pesticides were not considered a stressor by toxicologists. Dissolved oxygen data rarely exceeded aquatic life criteria and were judged unlikely to cause the observed effects. The remaining candidate causes were evaluated based on multiple types of evidence from the case (spatial/temporal co-occurrence, stressor-response relationships from the field, and causal pathways) and from elsewhere (stressor-response from other field studies, mechanistically plausible cause) and consistency of evidence and consistency with other assessments. Evidence was qualitatively scored and the body of evidence was weighed based on consistency of the evidence and best professional judgment of the ecology of the region. Evidence corroborated temperature and sedimentation as highly probable causes of biological impairment. Alkaline pH was also implicated for some areas but was judged to be less severe than temperature and sediment. Reduced habitat complexity and cover were not directly causal, but could lead to sedimentation and warmer water.

This screening causal assessment of the Touchet River, a subwatershed of the Walla Walla River in eastern Washington State, is the first application of the United States Environmental Protection Agency (U.S. EPA) Stressor Identification (SI) process to a long stretch of river or to the Northwest. To do this, several physiographically matched reference sites were used for comparisons and evaluation of natural and cumulative stressor gradients. It is also the first U.S. EPA report of a case using the SI method in an arid system or for endangered salmonids. Thus, this case illustrates the range of applicability of the U.S. EPA methodology. The assessment identified probable causes of impairments to macroinvertebrates and by association, certain salmonids.

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Cover photo:
Mike Kuttel Washington State Conservation Commission. Touchet River at Pettyjohn Road. The riparian vegetation in the photo is representative of the reach from Coppei Creek to Hwy. 125. Photo taken October 2000.

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LIST OF ABBREVIATIONS

CPOM	Coarse particulate organic matter
DO	Dissolved oxygen
EPT	Ephemeroptera-Plecoptera-Trichoptera
NCEA	National Center for Environmental Assessment
SI	Stressor Identification
TLCS	The Lewis and Clark State Park
TMDL	Total maximum daily load
TSS	Total suspended solids
U.S. EPA	U.S. Environmental Protection Agency
WSDE	Washington State Department of Ecology
WWWPU	Walla Walla Watershed Planning Unit

PREFACE

This is a causal assessment of a biologically impaired river in the state of Washington. The assessment was done by the Washington State Department of the Ecology (WSDE) after they listed the Walla Walla Basin including the Touchet River on 303d list of impaired waters. A determination of the total maximum daily load (TMDL) to meet water quality standards was then required. The text was reorganized and formatted for the U.S. Environmental Protection Agency (U.S. EPA) publication during a workshop at Canaan Valley, West Virginia in May of 2005. The sampling, analysis, and conclusions are those of researchers who were employed by the WSDE at the time of the assessment. Only comments indicating alternative approaches and suggestions were prepared by the National Center for Environmental Assessment (NCEA). NCEA provided editorial and formatting assistance to make the original WSDE report similar to four other case studies that were solicited as examples for other practitioners of causal assessment.

The Touchet River case study is one of five causal assessments completed prior to 2005 by states that were selected to illustrate a causal assessment process. These cases were used to support state programs that required that the probable cause of a biological impairment be determined. Data for these cases are generally part of a monitoring program not necessarily designed for causal assessment, limited by resources, and often dependent on encountered data. And yet, some causes can be identified as: co-occurring with the biological impairment, part of a larger causal chain of events, occurring at sufficient levels known to cause the observed effects, and coherent with general ecological and scientific theory related to physical interactions that have occurred post-settlement. In some cases, manipulation of the cause altered the biological effect. Although none of the cases has evidence of similar quality for all candidate causes, evidence for some candidate causes is enough to identify probable causes or to suggest what additional, targeted data might greatly improve the confidence in the determination.

These cases, as all cases, could be improved with more resources, but represent the state of the capability and analysis that was available in 2005. Since then, additional analytical tools and databases have become more readily available and states, tribes and territories continue to reduce the uncertainty of the analysis. Many of these case studies use a biological index to define the impairment. The Touchet case differs since chemical criteria were used to list the River as impaired and the Washington State does not have a biological index for this region of the state. To demonstrate causal relationships, most of the case studies, including the Touchet River case study, used biological metrics. This practice diminishes the ability to detect associations because summing dampens the overall signal from individual taxa and species that are responding differently to environmental conditions or stressors. However, WSDE did use metrics in the analysis to good effect because metrics were developed using species with known effects to some of the candidate causes. This area of research continues to be very active in the Northwest.

To learn from these cases and continually improve assessors' ability to determine causes of biological impairments, text boxes have been inserted throughout the Touchet River case study to supply commentary or to suggest other approaches that could strengthen the case. The analyses in the case cannot be modified as they are already a part of the Washington State's public record. It is our intention to link the case studies to relevant tools and guidance on the U.S. EPA website: www.epa.gov/caddis.

The Touchet Case Study is a good example of several strategic techniques:

1. Integrated analyses of biotic metrics, habitat metrics, and chemical water quality measures can improve not just stressor identification, but also assessment, listing/delisting, and restoration activities.
2. Surrogate indicators contributing to stressor identification when primary indicators have not been monitored.
3. General species tolerance metrics for identifying stressors within specific water bodies.
4. Options for dealing with changing elevation and other factors that confound comparison within a watershed.
5. Analysis of an arid watershed.
6. Assessment of decline of a salmonid fishery.

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1. DEFINE THE CASE

1.1. REGULATORY CONTEXT FOR CASE

Total maximum daily loads (TMDLs), as required by the Federal Clean Water Act, are integral in determining pollution control plans for Washington state rivers and streams. TMDLs prescribe waste load allocations for surface water pollutants and set recommendations for implementing restoration work. The Washington State Department of Ecology (WSDE) conducts TMDLs using a "single-entry" approach, addressing all listed impairments in a watershed concurrently. This approach reduces expenses, enables rapid development of a TMDL, and has the advantage of allowing investigators to examine interactions of multiple stressors or pollutants within a system. Knowledge of stressor interactions provides opportunities for more effective management and restoration of aquatic resources compared to the pollutant-by-pollutant approach typically used in TMDLs and other regulatory programs. The "single-entry" approach attempts abatement of several water quality problems with fewer management actions.

Comment 1.
At various points in this document, the U.S. EPA editor provides comments. These are not meant to indicate that the causal analysis is in error. The Stressor Identification (SI) process does not address every possible option, nor does it provide details on implementation, so there are many opportunities for interpretation (U.S. EPA, 2000). The U.S. EPA encourages states and tribes to improve and interpret the methodology in ways that are appropriate to their circumstances. Hence, the inserted comments are meant to help other SI users by indicating alternative approaches that they might apply to their cases.

The U.S. Environmental Protection Agency (U.S. EPA) requires states to set priorities for restoring waters that have exceeded state water quality standards (i.e., 303(d) listings) and establish a TMDL for each listed waterbody. These water quality standards are intended to define the level of protection that is needed to support various beneficial uses. The Walla Walla River and Basin was placed on the 1998 303(d) list for concerns over fecal coliform bacteria, pH, and temperature; 4,4'-DDE, 4,4'-DDD, dieldrin, chlordane, hexachlorobenzene, and heptachlor epoxide; and PCB-1260 in edible fish tissue (WSDE, 2000; Swanson and Joy, 2002; LeMoine and Stohr, 2002; Johnson and Era-Miller, 2002). As a result, the Walla Walla River and tributaries were scheduled for a "single-entry" TMDL to address all of these water quality issues simultaneously. The Touchet River, a major tributary to the Walla Walla River and the focus of this study, was placed on the 1998 303(d) list for pH and bacteria (River Mile 0.5), pesticides (at the mouth), and temperature (River Mile 0.5 and 54). In addition to the water quality exceedences noted above, declining fish stocks in the watershed have also raised concerns (Kuttell, 2001; Mendel et al., 1999, 1999; Northrop, 1999).

Although WSDE has a well-established biological assessment program that has been used successfully to support various water quality programs throughout the state (e.g., 305(b) reporting, National Pollutant Discharge Elimination System stormwater permit monitoring), direct measures of aquatic community health are not currently included in TMDLs for listings based on conventional water quality variables. Like many other states, WSDE's approach to completing TMDLs uses state chemical water quality standards as surrogates for measuring attainment of the aquatic life beneficial use. In this study, we demonstrate the value of biological information in the Touchet River portion of the Walla Walla River "single-entry" TMDL and its development. We determine the status of aquatic assemblages in select reaches (benthic macroinvertebrates) and the stressors (i.e., "pollutants" in TMDL regulations) related to their impairment. We also consider the lack of salmonids from RM 50 to the mouth of the river. Inclusion of biological information sometimes reveals the primary stressors and sources of pollution so that effective restoration strategies can be developed and implemented.

1.2. DESCRIPTION OF THE WATERSHED

The 470,000-acre Touchet River watershed in southeast Washington State (see Figure 1) is a tributary to the Walla Walla River and part of the Columbia Basin. The headwaters of the Touchet River originate in the Blue Mountains, which have a maximum elevation of 6074 feet. The region is primarily forested with some small farms in the lower valleys. Three stream channels converge to form the mainstem Touchet River just upstream of the town of Dayton (see Figure 1). The bankfull river width along the mainstem ranges between 9 and 16 m just upstream of Dayton and the mouth. Water depth along the mainstem ranges between 0.4 and 1.1 m. These widths and depths are approximately 50% lower under normal flow.

Similar to other watersheds in the region, the Touchet River has been substantially modified by inhabitants since the early 1800s. The ecological history of the Touchet River watershed, while unique in its own right, is a typical example of historical land use changes in the region.

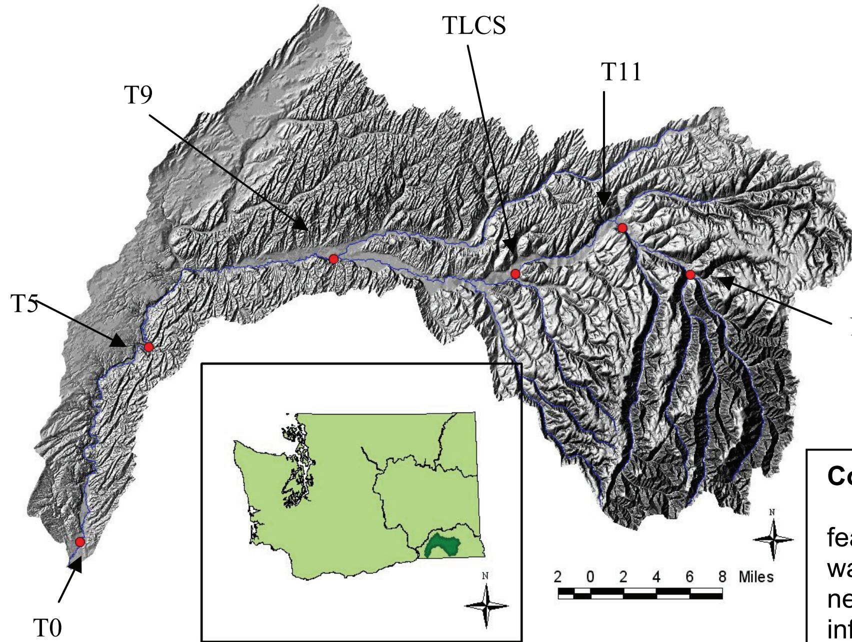
The Touchet River and greater Walla Walla River basins were originally inhabited by Native Americans. Passing through the valley in 1805, enroute to the Snake River, the Lewis and Clark expedition noted:

> *The hills of this creek (Touchet River) are generally abrupt and rocky, but the narrow bottom is very fertile, and both possess 20 times as much timber as the Columbia itself; indeed, we now find, for the first time since leaving Rock Fort [The Dalles], an abundance of firewood. The growth consists of cottonwood, birch, crimson haw, red and sweet willow, choke-cherry, yellow currants, gooseberry, the sumac, together with some corn-grass and rushes.*

The expedition also noted that farther up the Touchet River valley, near the present town of Prescott:

> *…the bottoms of the creek widened into a pleasant country, two or three miles in extent. The timber is now more abundant, and our guide tells us*

(A)



Comment 2.
In addition to maps of features relevant to the entire watershed, insets especially near sampling sites can be informative and helpful for orienting readers. Some landscape attributes to consider are roads, dams, pumps, irrigation, discharges, water withdrawals and returns.

(B)

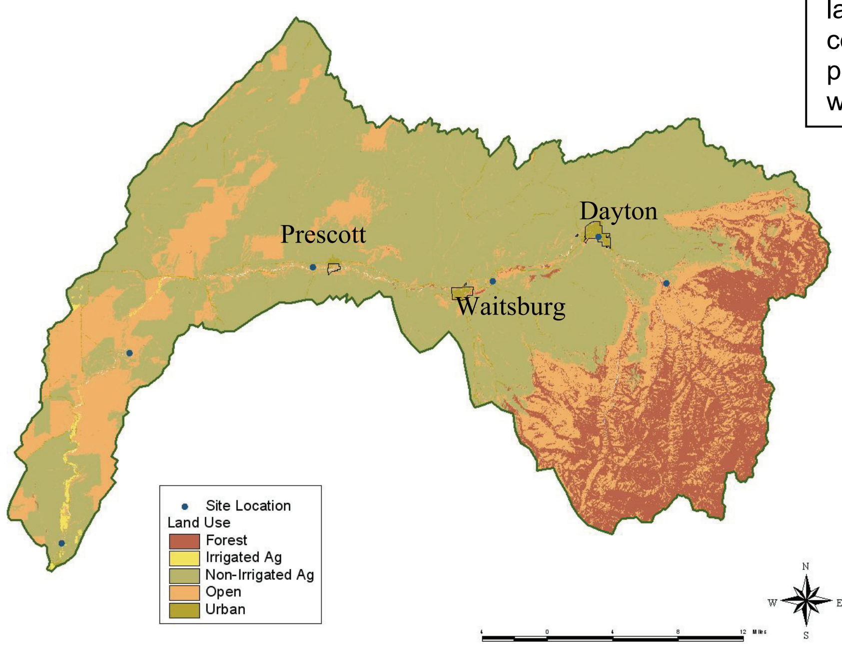


FIGURE 1

Relief (A) and Land-Use (B) Maps of the Touchet River Watershed. Locations identified in the relief map indicate sampling sites from which data were collected for this stressor identification study. River Mile (RM), Elevations (ft): NFTO (58.8, 1940), T11 (53.9, 1607), TLCS (47.3, 1383), T9 (34.2, 1000), T5 (17.8, 730) T0 (2, 450).

that we shall not want either wood or game from this place as far as the Kooskooskee (Moulton, 2003).

Modification of the Touchet River Basin began in the early 1800s when the Hudson's Bay Company started trapping beaver and other animals for pelts. By 1835, the populations of the most valuable fur-bearing animals had declined to the point where the Hudson's Bay Company decided to diversify operations by raising livestock (Meinig, 1968). This shift, along with increasing settlement, greatly intensified the clearing of riparian vegetation in this region for wood products, firewood, grazing, and agriculture. The discovery of gold in nearby Idaho in the 1840s caused a settlement boom that in turn increased the demand for cattle and sheep production in the Walla Walla region. By the 1860s, the bottom valleys had been settled and the uplands were beginning to be used for dry-land wheat production (Saul et al., 2000). The influx of settlers in the 1860s exacerbated the demand for wood. One result was more extensive logging in the valley riparian zones and in the Blue Mountains at the headwaters of the river. Logging near the headwaters resulted in stream modification, and in some cases, the destruction of salmonid spawning grounds (Van Cleve and Ting, 1960).

Today, land use is characterized by small farms at the headwaters of the river to dry-land wheat production and irrigated row crops just downstream of Dayton. Dayton (population 2655) is served by a waste-water treatment facility. The riparian corridor changes from large cottonwoods and Ponderosa pines to smaller cottonwoods and alders. Though the river is constrained by dikes that have been installed for flood control near Dayton, the channel remains wide and shallow. The riparian vegetation and channel morphology remain constant downstream to the town of Waitsburg. The only exception is Lewis and Clark State Park located roughly half way between Waitsburg and Dayton (see Figure 1; Lewis and Clark State Park station [TLCS]). The state park was created in 1933 with a small parcel of land and has increased to approximately 620 acres as of January 2006. The parklands support Ponderosa pines approximately 90 feet in height and a well-developed subcanopy of cottonwoods 60 feet in height. The park incorporates a camping ground that borders 1300 feet of Touchet River shoreline.

As the Touchet River flows past the town of Waitsburg (population 1212), the riparian conditions change to large cottonwoods dispersed among more dense underbrush. The floodplain increases in width, but the channel maintains its original characteristics. Annual precipitation decreases from approximately 30 inches per year in Dayton to approximately 15 inches per year in the lower parts of the river, making this area moderately arid. Most of the natural upland shrub-steppe vegetation has been converted to dry-land wheat. There is no municipal discharge from Waitsburg.

Prescott is the last town through which the Touchet River flows. Prescott has a population of 314 and does not discharge wastewater to the river. Although the channel width and depth are similar to the upstream reach at Waitsburg, smaller gravels dominate the substrate. The stream bank vegetation is similar to reaches near Waitsburg with large cottonwoods and dense underbrush of willow, sumac, and rushes.

Downstream of Prescott, the Touchet River flows through a wide canyon. The floodplain narrows but is still extensive enough to allow meandering. Dry-land wheat and irrigated agriculture are still prominent land uses.

One site in the lower Touchet River (T5) is free from agricultural and urban sources of impairment. This site is within a land trust established over 85 years ago. The nearby land was allowed to grow naturally, resulting in the reformation of shrub-steppe vegetation and a stream bank of locust, willows and cottonwoods, similar to vegetation observed at reference sites.

Comment 3.
The scale of the assessment, 70 miles, presents special challenges due to natural longitudinal changes in rivers that are further complicated by climate, geology, elevation, and land use. As more cases are performed and information is shared, it will become easier to distinguish natural changes from anthropogenic ones. In the meantime, analyses and appendices of chemical and physical parameters and any analyses to determine natural variation can strengthen a case.

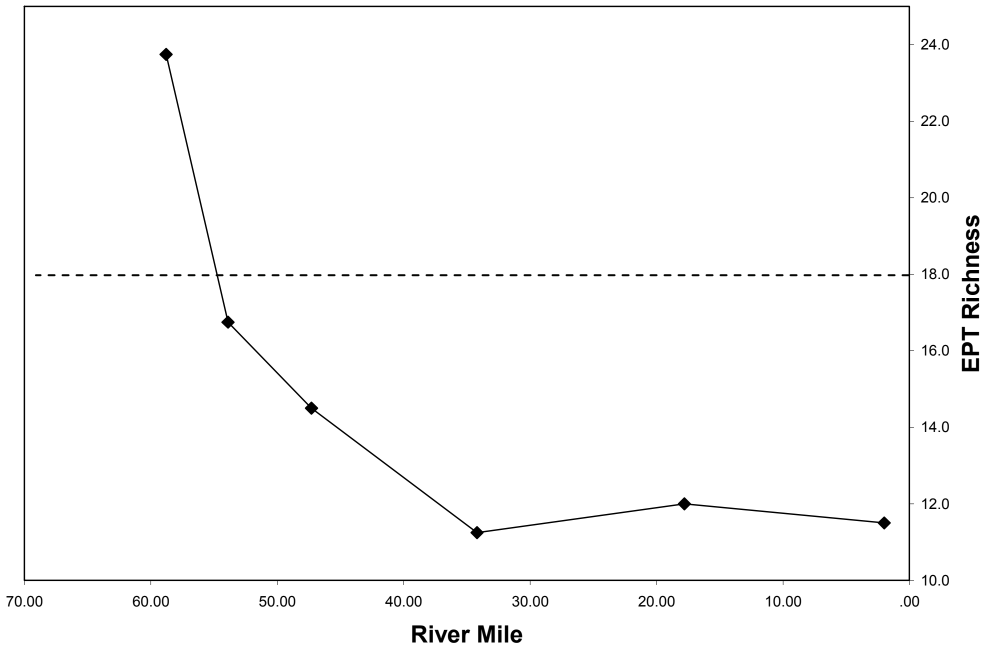
1.3. POTENTIAL SOURCES OF STRESSORS

Agricultural practices are the major sources of stress in the Touchet River basin. These include: (1) farming to the edges of the river and removal of much of the riparian vegetation, (2) filling of channel areas, (3) allowing livestock access to the river, (4) conversion of native perennial vegetation to annual crops, (5) water withdrawals for irrigation and (6) return of irrigation water to the river (Bureau of Reclamation, 1997; Kuttell, 2001; Mendel et al., 1999; Saul et al., 2000; U.S. Army Corps of Engineers, 1997). At the time of this study, there was only one permitted wastewater discharger to the Touchet River, the town of Dayton.

1.4. SPECIFIC BIOLOGICAL IMPAIRMENT

Two general types of biological impairment have been identified in the Touchet River: degradation of the macroinvertebrate assemblage and large decreases or absence of cold-water fish species, such as Bull trout, from the upper to lower reaches in the watershed.

Ephemeroptera-Plecoptera-Trichoptera (EPT) taxonomic richness in the Touchet River declines from upstream to downstream (see Figure 2). Although other macroinvertebrate indicators (e.g., % shredders, number of temperature intolerant species) show generally increasing impairment from upstream to downstream, EPT Richness changed the most. Based on data from references sites for the Touchet River, the average number of EPT taxa was 19.4 (range 16−29). For the purposes of this assessment, <18 EPT taxa were considered below expectations. The uppermost site in the North Fork of the Touchet River, near the town of Dayton, met reference expectation, all other sites did not. EPT diversity has generally co-occured with salmonid abundance in Columbia Plateau during recent years as noted in Figure 2.



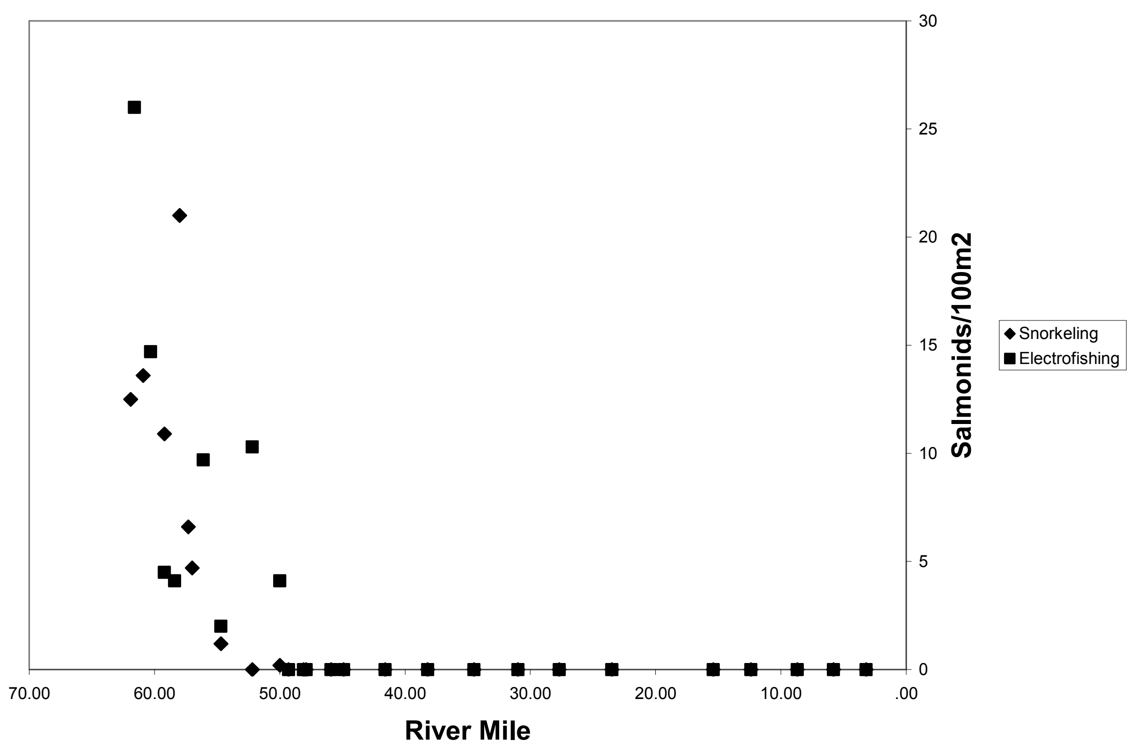


FIGURE 2

EPT Richness (top figure, line marks 18 EPT benchmark) and Salmonid Density (bottom figure) by river mile. Although no biological criteria exist for Washington, in this study, based on estimates from comparable drainages, an EPT Richness of ≥18 is judged within expectations for the region.

Historically, the Walla Walla River and its tributaries supported healthy stocks of Spring chinook (*Oncorhynchus tshawytscha*), however, Summer steelhead (*Oncorhynchus mykiss*) and Bull trout (*Salvelinus confluentus*). Spring chinook were extirpated from the system in the 1950s (Nielson, 1950, VanCleve and Ting, 1960; NMFS, 1999; WDFW, 2002). Summer steelhead and Bull trout remain in the basin in very low numbers and only a few stream reaches (Mendel et al., 1999). These species are listed under the Endangered Species Act (NMFS, 1999; U.S. Fish and Wildlife Service, 1998). Bull trout are currently limited to headwater reaches of the Touchet River. Summer steelhead, an anadromous form of rainbow trout, can migrate through the lower Touchet River and reproduce in limited portions of the upper river. Few salmonids now spawn below River Mile 54 (see Figure 2). The lower portion of the watershed functions primarily as migratory habitat during the winter and spring when flow and water quality conditions are optimal.

2. LIST THE CANDIDATE CAUSES

2.1. SELECTION OF CANDIDATE CAUSES

In accordance with U.S. EPA's Stressor Identification Framework (U.S. EPA, 2000), a conceptual model or diagram was developed that identifies sources of stressors associated with potential land-use, instream stressors, and biological effects. This diagram was used to guide data analyses and develop hypotheses regarding causes of observed biological condition in the Touchet River (see Figure 3). To be included in the model, land-uses that are sources of environmental stressors had to be present in the watershed and had to have a potential to cause biological responses. The list of watershed land uses were collected from: (1) literature focused on land uses and habitat degradation in the watershed (Kuttell, 2001; Mendel et al., 1999, 2000), (2) a land-use/land-cover map (USGS, 2005) and (3) information contributed by local biologists.[1] We verified land-use stressor sources by conducting reconnaissance surveys.

One candidate source of stressors in the study sites is the past logging that occurred upstream in the Blue Mountains. Currently, agriculture is the dominant land use in the watershed. Irrigated agriculture occurs primarily in or near the flood plain. Irrigation water drawn from the channel is then returned to the river and typically contain sediments, toxics, and nutrients, a form of nonpoint source pollution. Dry-land wheat farming practiced further from the stream still has the potential for contributing sediment and toxic chemicals to the river.

Urban influences, primarily from the town of Dayton, may be another source of stress in the lower Touchet River. The river channel is constrained through the town, which may reduce habitat complexity (Schueler, 1994; Walsh et al., 2005). Runoff from impervious surfaces could contribute fine sediments and nutrients to the river. The discharge from the wastewater plant in Dayton is a possible source of toxic chemicals, thermally heated water, and nutrients to the Touchet River. Municipal discharges to the river are relatively minor with respect to volume but continue year-round. The towns of Prescott and Waitsburg, located further downstream, may be sources of additional urban pollutants. Development in these towns did not appear to constrain or alter the river channel. The town of Waitsburg discharges municipal waste to a ditch where organic matter oxidizes. The effluent then flows into an infiltration lagoon. The lagoon does not have a surface connection to the Touchet River, but its contents enter the river via hyporheic flow (WSDE accessed 2006).

Livestock grazing occurs in the watershed in low densities. Historically, riparian areas were cleared for grazing, which has increased loadings of sediments and nutrients into the river.

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[1] Mendel (personal communication) and Bower (personal communication).

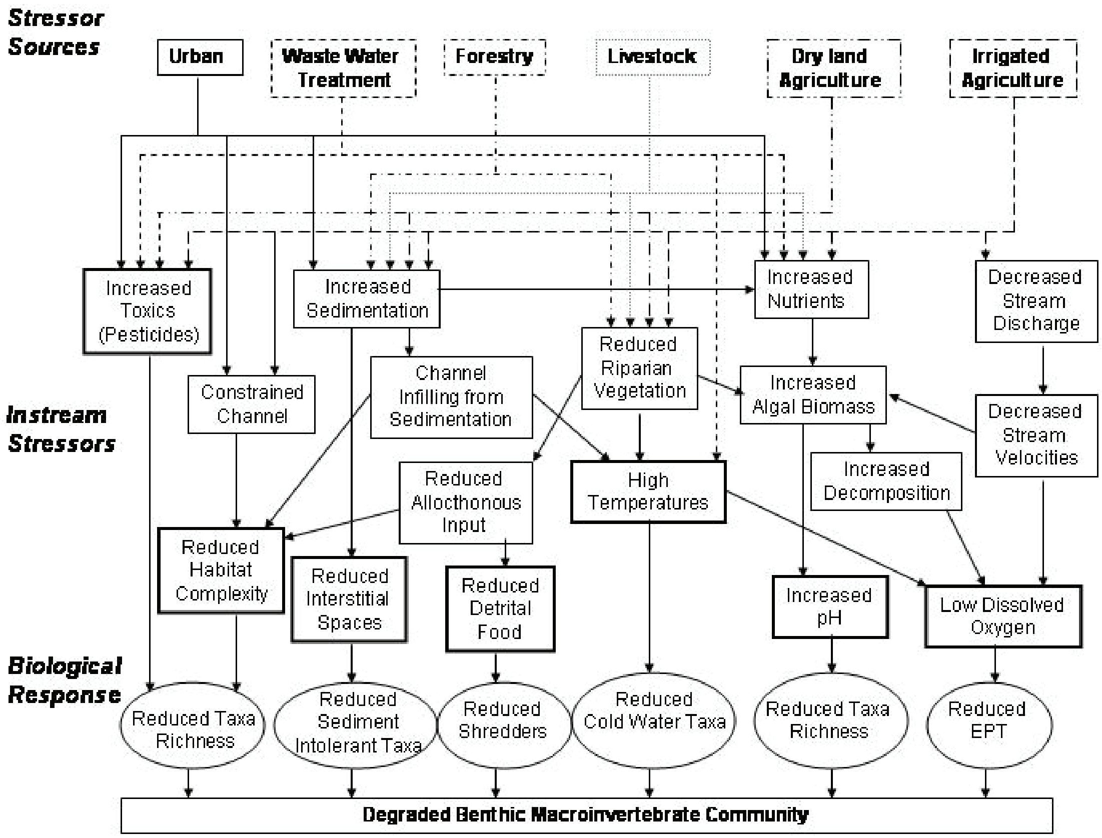

FIGURE 3

Conceptual Model of Potential Land-Use Sources, In-stream Stressors and Observed Biological Effects in the Touchet River, Washington

We hypothesized that the above land uses and human activities could result in the following proximate (direct) causes and biological responses:

- **Unspecified Toxicity**—Increased levels of toxic chemicals, such as pesticides, that could reduce taxonomic richness of benthic macroinvertebrates (e.g., EPT Richness and Total Taxa Richness)
- **Reduced Habitat Complexity**—Less diverse habitats from channel confinement, channel (pool) filling, and fewer inputs of leaves and wood reduce benthic macroinvertebrate taxa richness
- **Increased Sedimentation**—Reduced interstitial spaces from increased sedimentation reduces the abundance of sediment-intolerant macroinvertebrate taxa
- **Reduced Detrital Food**—Removal of riparian vegetation reduces the amount of allochthonous material potentially available as food for macroinvertebrates, particularly shredders
- **Warmer Temperature**—Reduced riparian shading and channel (pool) infilling increases water temperature and could result in the loss of cold-water obligate invertebrate taxa
- **Increased pH**—Nutrient enrichment increases algal production and increases pH which reduce macroinvertebrate taxa richness
- **Dissolved Oxygen**—Increased water temperatures and decomposition of excess periphyton biomass diminishes the dissolved oxygen concentration and reduces the abundance of *Ephemeroptera*, *Plecoptera* and *Trichoptera*

Note that the effects listed above focus on available macroinvertebrate assemblage data. Many of these proximate stressors are also detrimental to certain species of fish as well as other aquatic and semiaquatic biota.

2.2. DATA USED FOR CAUSAL ANALYSIS

The WSDE collected data on water quality, water quantity, and habitat parameters from June 2002 to June 2003 to complete TMDL allocations for temperature, pH, fecal coliform bacteria, and various toxic chemical pollutant loads (see Tables 1 and 2; Johnson and Era-Miller, 2002; LeMoine and Stohr, 2002; Swanson and Joy, 2002). In addition, diel measurements for pH, temperature, and dissolved oxygen were taken over several days at sites in the river during the summer of 2002. In the fall of 2002, benthic macroinvertebrates were sampled at six sites that were longitudinally distributed along the mainstem Touchet River (see Figure 1, Table 3); these samples were obtained using WSDE field protocols (Plotnikoff and Wiseman, 2001). All six sites or reaches were also TMDL

> **Comment 4.**
> A table listing when and where samples were taken is a useful communication tool that can be included as an appendix. If data sets are open for public access, Web links are also valued. You can access WSDE data.

TABLE 1 Water Quality Parameters Included in the 2002−2003 Single-Entry TMDL for the Touchet River, Washington	
Parameter	Method*
Temperature, continuous	Onset Temperature Probe
pH	150.1/4500H
Dissolved Oxygen	360.2/4500-OC
Chlorophyll *a*	/10200H(3)
Ammonia	350.1/4500-NH3D
Nitrate + Nitrate	353.2/4500-NO3F
Orthophosphorus	365.4/4500PF
Total Organic Carbon	415.1/5310B
Total Phosphorus	365.3/4500PF
Total Persulfate Nitrogen	/4500-NC
Total Suspended Solids	160.2/2540D

*U.S. EPA (1983), APHA et al. (1998, Standard Methods).

Sources: Swanson and Joy (2002) and LeMoine and Stohr (2002).

TABLE 2

Habitat Metrics Measured in the 2002−2003 Single-Entry TMDL for the Touchet River, Washington

Parameter	Method
River Mile	
Elevation	ArcView, Using Digital Elevation Model
Sinuosity	ArcView, using Rosgen (1996)
Slope	ArcView, using Digital Elevation Model
Median Substrate Size (pebble counts)	Wolman Pebble Counts (Wolman, 1954)
Dominant Substrate Size (pebble counts)	Wolman Pebble Counts (Wolman, 1954)
Percent Fine Sediment	Wolman Pebble Counts (Wolman, 1954)
Direct Sunlight	Solar Pathfinder, Center of Stream
Canopy Cover	Concave Densiometer, Center of Stream
Wetted Width	Tape Measure
Bankfull Width	Tape Measure
Wetted Depth	Average Depth, Stadia Rod
Bankfull Depth	Average Depth, Stadia Rod

Source: LeMoine and Stohr (2002).

TABLE 3

Geographical Information for Touchet Sites and Regional Reference Sites

Touchet Sites	EPT Richness[a]	Latitude	Longitude	Elevation (ft)	River Miles
NFT0	23.75	42.27	−117.89	1940	58.8
T11	16.75	46.31	−117.97	1607	53.9
TLCS	14.5	46.28	−118.11	1383	47.3
T9	11.25	46.29	−118.34	1000	34.2
T5	12	46.22	−118.58	730	17.8
T0	11.5	46.06	−118.67	450	2.0
Reference Sites	**EPT Richness[a]**	**Latitude**	**Longitude**	**Elevation (ft)**	**Description**
Cummings Creek at Wooten[b]	22.2	46.33	−117.67	2288	Watershed adjacent to the Touchet River
North Fork Asotin Creek[c]	18	46.24	−117.31	2120	Two watersheds to the east
Tucannon River at Marengo[c]	16	46.45	−117.75	1481	Watershed adjacent to the Touchet River
Quilomene Creek[d]	19	47.10	−120.09	1205	Western portion of the Columbia Plateau; very arid
Oak Creek[e]	24.25	46.73	−120.87	750	Western portion of the Columbia Plateau; low elevation
Entiat River near Entiat[c]	17	47.66	−120.25	660	Western portion of the Columbia Plateau; low elevation

[a]EPT richness mean of four replicates 2002.
[b]Cummings Creek at Wooten (1993, 2000, 2002, 2003, 2004).
[c]Tucannon River at Marengo (1993).
[d]Quilomene Creek (2002).
[e]Oak Creek (2000, 2002, 2003, 2004).

study reaches. Stressor data was not sampled where salmonid measurements were made and complete absence is dichotomous and intermediate responses could not be assessed; therefore, we used the macroinvertebrate results as primary biological response variables. Metrics are listed in Table 4. Occasionally, fish data from the Touchet River and other watersheds of the Columbia Plateau (Mendel et al., 1999, 2000, 2001, 2002, 2003, 2004) were incorporated to improve the evaluation of stressor pathways. Reference sites supported year round salmonid populations and the EPT richness range was 16−29 compared to 11−17 EPT taxa in the Touchet River. The ranges of per cent canopy cover were 44.5−92.5% at reference sites and 4−8.7% in the Touchet River.

Macroinvertebrates and fish are often limited by different stressors and affected at different scales (Brandt, 2001; Doudoroff and Warren, 1957; Stoddard et al., 2005). However, the inclusion of salmonid densities as biological endpoints offered important evidence from the Touchet and from the region. Salmonids also added cultural relevance to the analysis that is important to stakeholders. Hence, the effects of concern were the numbers of EPT taxa and salmonid densitiies.

The U.S. EPA’s SI procedure (U.S. EPA, 2007) was used to identify and compare candidate causes of biological impairment to this river. The first inferential step in SI is the elimination of inappropriate candidate causes. The list of candidate causes was reduced based on lack of co-occurrence of the stressor with the effect and sparse data. These causes were deferred because measured levels were not expected to cause a biological effect. They were not refuted due to the type of information or due to the small number of samples. The second inferential step is diagnosis, but symptoms were not available due to the nature of the impairment. However, the analysis used biological metrics that are somewhat specific to the candidate causes, for example sediment intolerant taxa to evaluate sedimentation. The probable cause was identified using the third and fourth inferential steps, evaluating weighted lines of evidence and weighing and comparing the bodies of evidence of the remaining candidate causes (U.S. EPA, 2000).

Comparison with reference sites was an important aspect of this study. It was necessary to demonstrate that the observed longitudinal degradation in macroinvertebrate assemblage condition (see Figure 2) did not result primarily from natural gradients in the stream setting, including physical and chemical conditions. Two types of evidence were used to evaluate this (1) a rank correlation analysis of biological metrics from reference sites and elevation and (2) the direct comparison of Touchet temperatures to temperatures in low elevation reference streams. WSDE reference sites included two low elevation sites (Oak Creek and Entiat River), a very arid site (Quilomene Creek), and three sites nearer to the Touchet River, (North Fork Asotin Creek, Cummings Creek, Tucannon River) (see Table 3). Detailed information regarding these streams can be found at WSDE Website.

The potential for confounding by elevation was of particular concern given that the study site encompassed nearly 60 miles of river and an elevation drop of

TABLE 4

Rank Correlation Between Biological Metrics from Columbia Plateau Reference Sites (*n* = 6) with Elevation

Biological Metric	Kendall's Tau	Significance (*p*)
Intolerant Richness	0.58	0.232
Clinger Richness	0.33	0.519
Cold-Water Richness	0.63	0.179
HBI	0.47	0.352
Plecoptera Richness	0.24	0.644
Sediment Intolerant Richness	0.26	0.621
Long-Lived Richness	–0.21	0.692
Total Richness	0.54	0.272
Trichoptera Richness	0.70	0.125
EPT Richness	0.62	0.190
Ephemeroptera Richness	0.47	0.350
% Intolerant	–0.35	0.501
% Chironomidae	0.61	0.202
% Clingers	–0.24	0.641
% Ephemeroptera	0.06	0.911
% EPT	–0.10	0.848
% Filterers	0.25	0.637
% Predators	–0.65	0.159
% Scrapers	–0.14	0.789
% Shredders	0.05	0.478
% Dominant Taxa	0.24	0.646

Collection protocols and methods can be found in Plotnikoff and Wiseman (2001). An explanation of the biological endpoints and their calculation methods can be found in Plotnikoff and Wiseman (2001); HBI, Hilsenhoff's Biotic Index (Hilsenhoff 1987); EPT, *Ephemeroptera*, *Plecoptera*, and *Trichoptera* approximately 1500 ft (see Figure 1 and Table 3). We found that none of the biological metrics of the Columbia Plateau reference sites were significantly correlated with elevation (see Table 4), but the power of the tests was low due to sample size. However, in the Touchet River, Trichoptera richness, % predators, EPT richness, cold water richness and % Chironomidae were somewhat correlated with elevation (absolute values of Tau greater than 0.6).

Temperature's relation to elevation was a particular concern. Temperatures ranged between 10.5 and 16.5°C in the reference sites compared to 17.7 to 24.5°C in the Touchet (see Table 5). Two low elevation sites, the Entiat River and Oak Creek, had elevations of 201 and 229 m, respectively, and had temperatures in the summer between 10.2 and 15.5°C. Quilomene Creek, a very arid stream in south central Washington, at 367 m, had summer temperatures of 16.5°C. Summer stream temperature was judged to be independent from elevation for this area. This is attributed to the hydrologic characteristics of these streams which have a short runoff season and then a longer base-flow period where the dominant contribution for surface flow is from groundwater sources (Marti, 2005). Similar findings with elevation were documented for benthic macroinvertebrate metrics in semiarid southern California (Ode et al., 2005).

Comment 5.
This case study evaluates the potential for strong confounding from elevation, an important consideration given that the study site encompasses 60 miles of river. Although the strength of the associations was deemed weak enough to ignore effects due to elevation, *Trichopteran* Richness (τ = 0.70) and Cold-Water Richness (τ = 0.63) were fairly strong. The synthesis of this correlation with knowledge about the reference sites was needed to assess the affects of elevation. The selection of reference sites matched for the case, rather for regional bioassessment method development, was strengthened by describing the characteristics used for selection of case specific reference locations.

WSDE collected data on water quality, water quantity, and habitat parameters from June 2002 to June 2003 to complete TMDL allocations for temperature, pH, fecal coliform bacteria, and various toxic chemical pollutant loads (see Tables 1 and 2; Johnson and Era-Miller, 2002; LeMoine and Stohr, 2002; Swanson and Joy, 2002). In addition, diel measurements for pH, temperature, and dissolved oxygen were taken over several days at sites in the river during summer 2002. In the fall of 2002, benthic macroinvertebrates were sampled at six sites that were longitudinally distributed along the mainstem Touchet River (see Figure 1); these samples were obtained using WSDE field protocols (Plotnikoff and Wiseman, 2001). All six sites or reaches were also TMDL study reaches. Due to discontinuity in available salmonid data from reaches where TMDL data were collected, we used the results of macroinvertebrate sampling to characterize biological impairment (see Table 3). Additionally, anadromous fishes such as salmon are migratory and influenced by stressors outside of the study area.

Macroinvertebrate data in this stressor identification study are used as surrogates for the fish assemblage because the habitat preferences of many of the benthic macroinvertebrate species (particularly EPT taxa) are reasonable indicators of the availability of cold-water fish species habitat in this region. When available, fish data from the Touchet River and other watersheds of the region (Mendel et al., 1999,

TABLE 5 Relevance of Candidate Causes of Biological Impairment to the Touchet River, Washington		
Candidate Cause	Reasoning	Relevance to Touchet
Increased Toxic Chemicals	Can result in reduced aquatic species richness	**Deferred.** Toxic chemicals measured did not exceed aquatic life criteria, and the Touchet River was noted to have low levels of pesticides and the levels were not considered a stressor by toxicologists
Reduced Habitat Complexity	Can reduce species richness via channel confinement, filling and reduced amount of detritus	Sedimentation was occurring, large woody debris counts were depressed, and diking was constraining some reaches
Sedimentation	Can smother existing aquatic plants and homogenize habitat reducing species richness	Decrease in substrate particle size class and increase in TSS suggested that sedimentation may result in reducing interstitial habitat spaces
Reduced Detrital Food	Can reduce available food and decrease species richness	Riparian canopy was reduced downstream possibly decreasing detritus inputs resulting in reduced abundance and taxa of shredders
Warm Temperatures	Can reduce or eliminate cold-water aquatic life	Temperatures increase to very warm levels and a decrease in cold-water obligate benthic macroinvertebrates and fish may occur
Increased pH	Can affect ion balance and ammonia excretion resulting in adverse effects to macroinvertebrates	pH levels come close to exceeding aquatic life criteria and may affect the biological community
Low Dissolved Oxygen	Can adversely affect the health of aquatic species	**Deferred.** Dissolved oxygen data rarely exceeded aquatic life criteria and were judged not at levels harmful to aquatic organisms

TSS = total suspended solids.

2000, 2001, 2002) were incorporated to improve the evaluation of stressor pathways. Fish distribution (based on presence/absence) data are relevant because fish have a direct value to people (consumption and recreation) and known responses to degraded water quality and habitat. We also used metrics based on macroinvertebrate habitat quality (see Table 2), as well as WSDE macroinvertebrate metrics to determine the status of aquatic life in the six study reaches.

Comment 6.
Focusing an assessment has many practical advantages but there is a risk that causes may be different for different assessment endpoints. For example, macroinvertebrates and fish often are limited by different stressor sand affected by different scales (Doudoroff and Warren, 1957; Stoddard et al., 2005).

Comparison with reference sites was an important aspect of this study to demonstrate that the observed longitudinal degradation in macroinvertebrate assemblage condition (see Figure 2) did not result primarily from natural changes in stream setting, including physical and chemical conditions. To address this issue, analyses incorporated relevant data from three different reference sites in the Columbia Plateau region: North Fork Asotin Creek, Cummings Creek and Tucannon River. Detailed information regarding these streams can be found on WSDE's web site (WSDE accessed 10/28/2008). We found that none of the biological metrics used in the Columbia Plateau Level III Ecoregion correlated with elevation based on the nonparametric analysis using Kendall's tau rank correlation method (see Table 4). Like the Touchet River, all of these regional reference streams originate in montane settings (Cascade Mountain foothills or the Blue Mountains). Although the reference data were comparable to the mid- and upper reaches of the Touchet River sites, biological indicators from the reference sites were expected to reflect the lower range of stream elevations in the Touchet River. The gradient of change is dramatic between montane origins of these streams and the lower reaches. They are strongly influenced by the transition of vegetation, climate, and water chemistry as the stream channels flow through the Columbia Basin ecoregion. Substrate type (e.g., angular basalt) and size distribution are dominant substrates in reference streams. Canopy cover is primarily deciduous (e.g., black cottonwood and willow) with understory dominated by red-osier dogwood and other low-growing vegetation. Hydrologic characteristics include a short runoff season and then a longer base-flow period where the dominant contribution for surface flow is from groundwater sources. Similar findings with elevation have been documented for benthic macroinvertebrate metrics in semiarid southern California (Ode et al., 2005).

Not all candidate causes could be directly measured in this analysis. In place of measuring the degree of sedimentation, samples were collected and measured for dominant particle size. It was assumed that increases in fine particle dominance correlated with increases in sedimentation. In addition,

Comment 7.
Direct measures are always preferred, however if only measures of surrogates or intermediate steps in the causal pathway are available, they may be used rather than ignore the information that they can provide. In the Touchet River case, the increased uncertainty is explicitly stated.

direct measurements of detrital standing stock were not made. Canopy cover was used as an indicator of the amount of potential for detritus at a site. Reduced habitat complexity was also estimated using surrogate metrics: river width to depth ratio and sinuosity of the stream. More direct methods for measuring habitat complexity would include channel constrainment, channel infilling, and sources of detritus. Finally, algal production was characterized using chlorophyll *a* measurements from samples taken in the water column. In this study, this measure indicates water column algal conditions and not necessarily periphyton production.

3. EVALUATE DATA FROM THE CASE

3.1. DEFERING OF CANDIDATE CAUSES

Potential proximate (direct) stressors were not considered when there was no evidence to demonstrate a relationship with the biological community. As such, impacts from toxic chemicals and low dissolved oxygen concentrations were excluded from the candidate list of potential stressors (see Table 5). Based on ten separate samplings events between May 2002 and May 2003, chlorinated pesticides and polychlorinated biphenyls were present at low concentrations, but did not exceed chronic aquatic life criteria anywhere in the Touchet River (Johnson et al., 2004). Dissolved oxygen (DO) measurements were taken over a 24-hour period at several sites in the river three times during the summer of 2002, as well as, 95 point measurements taken throughout the year. They indicated near-saturation concentrations and no large diel fluctuations (see Figures 4 and 5). These data were limited temporally, but are believed to represent near worst-case conditions for DO due to the warm temperatures and low-flow conditions under which they were taken. Super-saturation of DO (up to 110%) was recorded on several occasions; however, the diurnal range of DO was large at downstream sites (T0, T5, and T9) in the Touchet River during late spring (7.5−12.5 mg/L). The minimum DO was recorded at or less than the state standard supporting cold-water fish species (7 mg/L) on three occasions. Lowest DO concentrations observed were >6 mg/L and occurred infrequently and over very short durations (hours). However, it is was expected that the turbulence in riffle habitat in many parts of the river would abate the adverse effects of lower DO concentrations if they did occur.

Comment 8.
Defering candidate causes from consideration must proceed with great caution and is not the same as eliminating a cause based on evidence of impossibility or high improbability. In the Touchet River case, causes were not included in further analysis rather than logically eliminated. The decision to defer assumes that measurements were taken at their maximum, episodic events did not occur, and chronic criteria values would not cause effects to species that were absent from the impaired sites. The U.S. EPA SI Guidance does not recommend removing a cause using criteria values and recommends that stressors remain on the list of candidate causes, but analysis can be deferred until sufficient data is available. In essence, WSDE performed a tiered approach, and excluded what they viewed to be less likely causes.

Comment 9.
Swings from super-saturation to lower levels of DO can be indicative of eutrophication. At higher elevation and lower barometric pressure, supersaturation occurs at lower concentrations of gases, i.e., mg/L. Supersaturation is a serious problem for fish (see dissolved oxygen). Physiologically, insufficient oxygen is related to concentration rather than to saturation. WSDE wisely used concentration

3.2. SPATIAL/TEMPORAL CO-OCCURRENCE

Four of the five candidate stressors were analyzed for co-occurrence with established expectations for signal in biological indicators. This analysis relied, in part, on available information from various WSDE reference sites in the region. Habitat

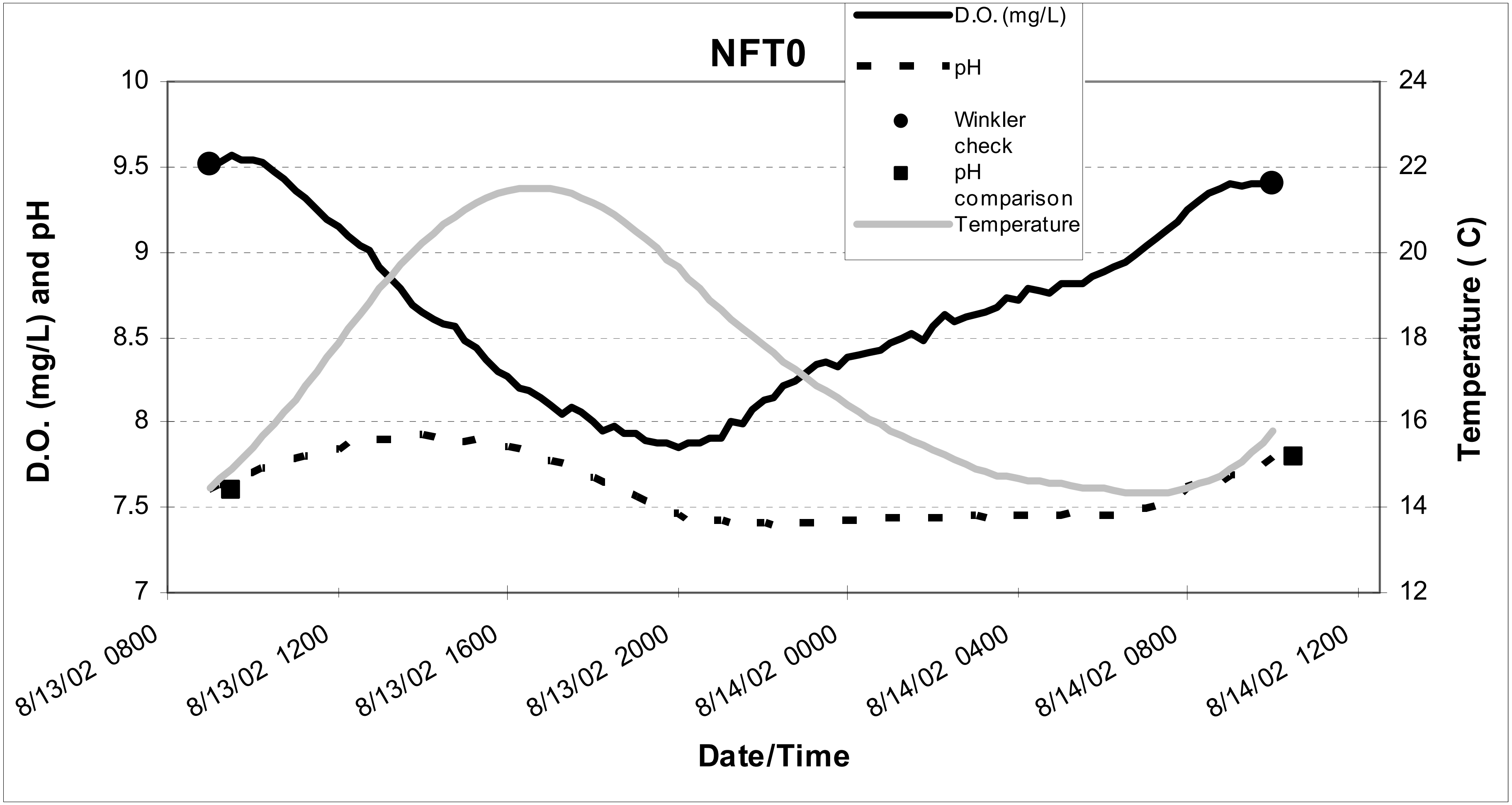

FIGURE 4

Diel pH and Dissolved Oxygen Measurements Taken at Site NFT0, Upstream of Dayton, in August 2002 (see Figure 1)

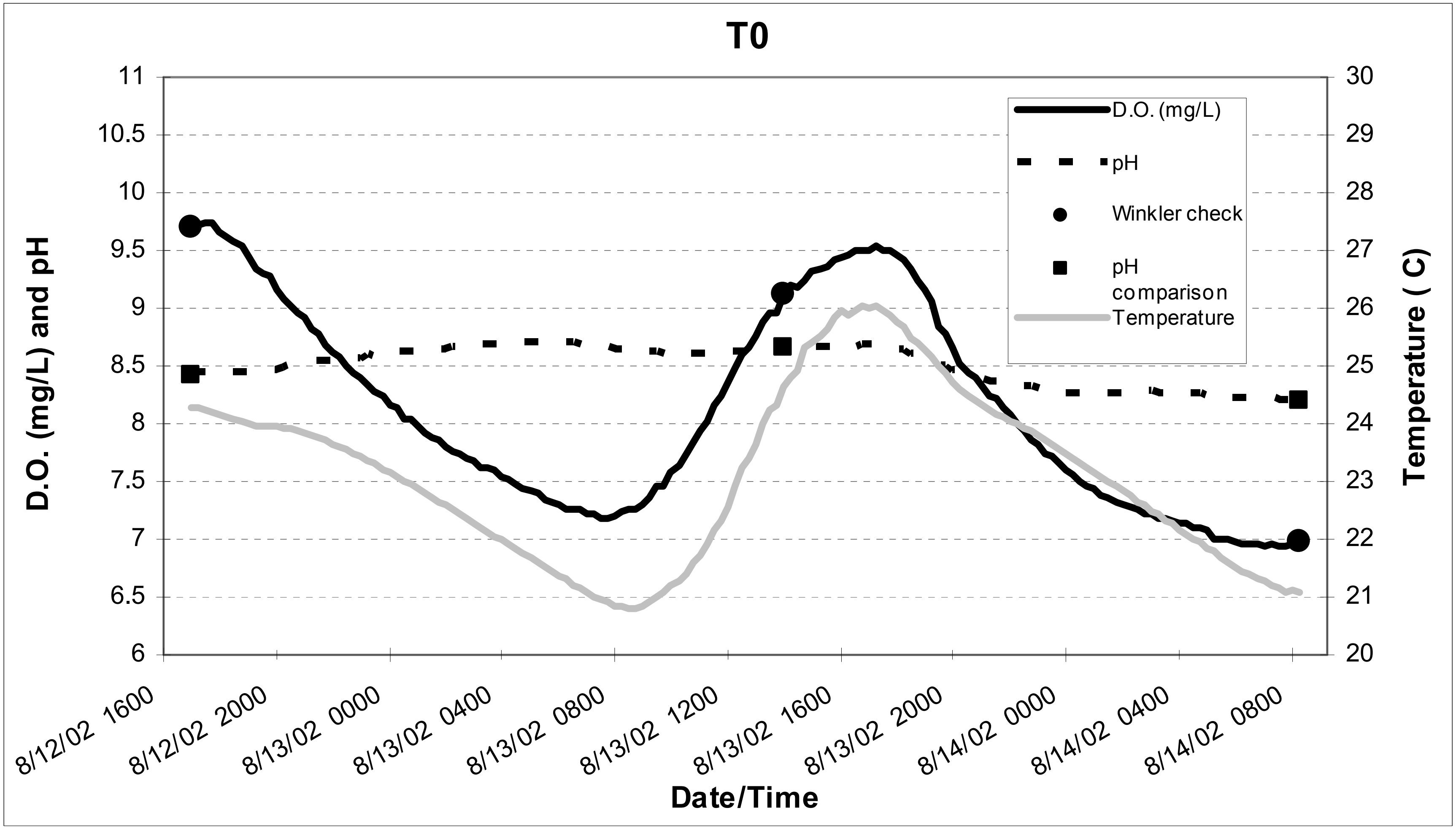

FIGURE 5

Diel pH and Concentrations of Dissolved Oxygen (DO) at Site T0, Downstream of Dayton, During August 12−14, 2002 complexity, described by channel sinuosity, pool/riffle ratio and depth to width ratio were not included in this analysis due to a lack of appropriate data from reference sites.

3.2.1. Temperature

Co-occurrence of heat stress (temperature) was analyzed by comparing the mean annual temperature observed at each site to the percentage of obligate cold-water macroinvertebrate taxa collected at nearby reference sites. Temperature effects on the biological assemblage were evaluated using existing temperature tolerance ratings for select macroinvertebrate taxa (Brandt, 2001). Although these tolerance ratings were developed for taxa in Idaho streams, the settings from which information was derived are similar to those in the Touchet River drainage. These temperature tolerance ratings reflected gradient affinities for each taxon based on frequency of occurrence in each predefined temperature category.

> **Comment 10.**
> Habitat complexity can be assessed without comparison to reference sites for many river systems. Rosgen (1996), Schumm et al. (1984), and Simons and Downs (1995) have developed river classification systems that provide insight into unstable stream reaches and sedimentation within the river system, without the need for comparison with other reference systems. Rosgen's system can be found on the U.S. EPA website (accessed 10/28/2008). GSTAR-M (Generalized Sediment Transport for Alluvial Rivers—Meandering Rivers) is a computer model that simulates the bed topography, flow field, and bank erosion rate in curved channel with an erodible bed. The model can be used to predict channel migration in meandering rivers. Ideally, these approaches complement the use of reference sites; this is not a recommendation to eliminate comparison with reference sites. The point is that assessments can still be made for sedimentation even if an alternative reference site is not available.

Instantaneous temperature measurements from reference sites were used for comparison rather than mean values, introducing some uncertainty as to whether the temperature-biological (percent obligate cold-water species) relationship observed truly reflected a response to the temperature gradient. All sites in the Touchet River had warmer mean annual temperatures than the reference sites for the same time period, although the warmest temperature at the uppermost site in the Touchet River (North Fork) was only slightly greater (+2.5°C) than the mean annual temperature measured at nearby reference sites (see Table 6). Site T11 (Dayton) had a similar percentage of obligate cold-water species as the reference sites although the mean annual temperature at the reference sites were 5.4 to 10.1°C less than at T11. Similar conclusions were made using the rolling 7-day average temperature, the monthly summer average, and the maximum temperatures for this site. Even though surface water temperatures were warm, the large number of obligate cold-water taxa in this reach may be due to the presence of strong groundwater influence in the Dayton area (Marti, 2005). Taxa may proliferate if available temperature refugia are available, but presence of these refugia is unusual and may be at risk if ambient temperatures increase further. At the remaining sites as compared to reference sites, warmer mean annual temperatures co-occurred with smaller numbers of obligate cold-water species.

TABLE 6 Spatial/Temporal Co-ocurrence in the Touchet River, Washington[a]			
Locations			Co-occurs and Score[b]
Temperature			
Reference[c]	10.5–15.2°C	5.9 Cold Water Richness	++
NFTO	17.7	4	yes
T11	20.6	6	no
TLCS	22.8	2	yes
T9	24.5	1	yes
T5	25.4	2	yes
T0	26.4	2	yes
Sedimentation			
Reference	Substrate Class[d] of 9	6−10 Sediment Intolerant Richness	+ +
NFTO	11	9	no
T11	11	8	no
TLCS	9	6	no
T9	3	4	yes
T5	1	3	yes
T0	7	3	yes
Alkaline pH			
Reference	pH 8.0−8.4	30−46 Total Richness	+
NFTO	7.8	44	no
T11	8.3	36	no
TLCS	8.5	27	yes
T9	8.7	27	yes
T5	8.8	33	yes
T0	8.6	28	yes
Lack of Detrital Food			
Reference	45.5−92.5% Canopy Cover[e]	1−8% Shredders	++
NFTO	18.7	1	no
T11	13.8	0	yes
TLCS	17	0	yes

TABLE 7 cont			
Locations			Co-occurs and Score[b]
T9	4	0	yes
T5	12.7	0	yes
T0	12.2	0	yes

[a]Locations of the Touchet River sites are shown in Figure 1.
[b] Co-occurrence at each site was noted by a "yes" if stressor is greater than regional reference and symptomatic taxa were indicative of the cause; ++, This biological alteration is somewhat specific of the candidate cause; +,
[c]Ranges for reference are based on data from regional reference sites.
[d]Sedimentation represents the dominant substrate particle size class (larger values represents less fine sediment).
[e]Percent canopy cover over the stream is used as a surrogate indicator for detrital food abundance.

Note: The Touchet River case study was prepared for publication using causal characteristics as an organizing framework (Wiseman et al, in press). In that manuscript, the information in Table 6 was split into evidence of co-occurrence and evidence of a specific biological alteration (macroinvertebrate symptomology). At the time of the original case study, the causal characteristics had not yet been developed (See Cormier, et al in press). Both manuscripts to be published in Human and Ecological Risk Assessment Volume 1 in February, 2010.

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Other biological assemblages indicated the persistence of warm water in lower reaches of the Touchet River. Although, smallmouth bass were found in the lower reaches of the drainage, the fish appeared sluggish during the summer months (LeMoine, personal observation). Warm temperatures suggest detrimental effects on local fish assemblage in the Touchet River.

3.2.2. Sedimentation

This stressor was analyzed by comparing the percentage of fine sediment intolerant macroinvertebrate taxa to the dominant substrate particle size observed at each site. Ranges for dominant substrate particle size were determined from measurements at reference sites. Sediment tolerance values for macroinvertebrates were derived from Reylea et al. (2000) and developed with biological and physical information for Idaho, Oregon, and Washington streams.

Comment 11.
Stream power can be a valuable explanatory mechanism for evaluating expected particle composition. One method is the Relative Bed Stability Method (Kaufmann et al., 1999).

Many of the lower Touchet River sites had a smaller dominant substrate particle size and a lower percentage of fine sediment intolerant species (see Table 6). The dominant substrate particle-size class of the northern-most site (North Fork) was similar to that of the reference sites and the percentage of species intolerant to fine sediments resembled reference conditions. Sites downstream of TLCS had finer benthic particle size than were observed either upstream or at reference sites. The number of sediment intolerant species was lower at the lower Touchet River sites where dominant particle sizes were smaller than at either reference or the North Fork Touchet River site (see Table 6). This result is unlikely to be due to factors other than differences in surrounding land cover and floodplain characteristics among sites. Stream size and gradient varied little (<5%) between sites downstream of TLCS and the North Fork site.

3.2.3. pH

Greater mean annual pH and lower taxa richness consistently co-occurred at Touchet River sites (see Table 6). However, the difference in mean annual pH observed in Touchet River sites was $\leq$0.4 pH units greater compared to the corresponding pH measured at the reference sites. This difference in average pH between the Touchet River and reference site was judged to be insufficient to affect individual species. Increased pH and fewer macroinvertebrate taxa did not co-occur. T5 had the greatest mean annual pH recorded among the Touchet River sites (pH = 8.8) and yet a similar number of taxa as at reference sites. Diel pH measurements determined that pH varied by less than one unit over 24-hour periods (e.g., North Fork Touchet site [NFT0], Figure 4). However, pH did exceed 8.5 (violation of state freshwater standards for the protection of aquatic life) repeatedly within 24-hour periods during the spring. Exceedance of pH >9.0 extended for a few hours a day for several days downstream of Dayton. Maximum pH values above 9.0 probably occurred for up to 6h per day during several weeks in the spring (Joe Joy, personal communication).

3.2.4. Detrital Food

Some co-occurrence between the surrogate measure for detrital presence (measured by canopy cover) and the percentage of shredders (a macroinvertebrate metric related to quantity and quality of detrital biomass) was calculated for sites within the Touchet drainage (see Table 6). All Touchet River sites had substantially less canopy cover than the reference sites and shredder species were not found at any of the Touchet River sites except for site NFT0. Canopy cover was substantially less at NFT0 than at reference sites; however, woody debris was prevalent in the stream at this site and may have entrained upstream detritus for longer periods of time. This would provide more suitable conditions for a diverse and functional shredder assemblage.

3.2.5. Summary of Co-occurrence Analysis

Co-occurrence analysis identified four stressors (temperature, sediment, pH, and allochthonous organic matter) that related to specific biological responses (see Table 7). One of these four potential stressors, pH, appeared to be only slightly elevated (a 0.2−0.4 pH difference on average) relative to reference sites. Effects of changes in habitat complexity are not addressed in this analysis because comparable information was not available from reference sites.

3.3. STRESSOR-RESPONSE RELATIONSHIPS FROM THE FIELD

Stressor-response relationships observed in the Touchet River were evaluated from longitudinal plots of individual stressors and biological effects for each candidate cause (Wiseman 2009) as well as results from rank correlation analysis (Kendall's Tau) (see Table 8) (see Comment 12).

Comment 12.
The evidence for stressor-response from the case was helpful in the Touchet case but deviates on a point of interpretation. The use of significance which implies hypothesis testing is discouraged from causal analysis for a number of reasons. However, the relative strength and the direction of the associations are valid and recommended forms for interpretation.

Temperature tolerance for macroinvertebrate taxa was used to determine cold water richness (Brandt, 2001). The relative strength and the direction of the associations were particularly strong for temperature and somewhat weaker for pH.

Sediment tolerance values for macroinvertebrates were derived from Relyea et al. (2000) and developed with biological and physical information for Idaho, Oregon, and Washington streams. The correlation of number of sediment tolerant taxa and dominant substrate particle size was strong, but not statistically significant (see Table 8). This may be partly due to the fact that the furthest downstream station consisted of two dominant types of substrate, small gravel and riprap, resulting in an unknown dominant size class.

TABLE 8 Summary of Co-occurrence and Macroinvertebrate Symptomology Analyses		
Candidate Cause	Score	Reasoning
Reduced Habitat Complexity	NE	No evidence available at reference sites for this stressor.
Warm Temperatures	++	Warmer temperatures co-occur with biological decrease at 5 of 6 sites, compared to reference sites. Cold-water stenothermic fishes also are absent at sites with temperatures warmer than reference. Sediment intolerant macroinvertebrate richness declined.
Sedimentation	++	Perhaps seasonal in nature, but increased sedimentation (as expressed by % fine sediments) co-occurred with a decrease in fine sediment tolerant taxa when compared to 6 regional reference sites. Upstream biological condition within range of reference condition. Sediment intolerant macroinvertebrate richness declined.
Increased pH	+	Steady increase in max pH measured related to biological degradation and co-occurred at 5 out of 6 sites when compared to regional reference sites. Non-specific macroinvertebrate richness declined.
Less Detrital Food	++	General evidence of co-occurrence of detrital material (as expressed by canopy cover) and the percentage of shredders where shredder taxa in the Touchet may be due to lack of riparian cover.

Reduced habitat complexity could not be analyzed as a prospective stressor due to lack of appropriate data from the reference sites (NE). Co-occurrence at each site was noted by a "yes" if stressor is greater than regional reference and symptomatic taxa were indicative of the cause; ++, This biological alteration is somewhat specific of the candidate cause; +, See Table 7 for details

TABLE 9

Rank Correlations Between Proximate Stressors and Biological Effects

Proximate Cause	Measure or Surrogate	Biological Effect	Kendall's Tau	*p* value	Plausible Stressor-Response[a]
Temperature	°C	% Temperature Intolerant	–0.85	0.0001	+ +
Sedimentation	Dominant Size Class	Sediment Intolerant Richness	0.87	0.24	+
pH	pH	Total Richness	–0.64	0.0026	+
Detrital Food	%Canopy Cover	Percent Shredders	–0.54	0.027	0
Habitat Complexity	Bankfull Width/Depth	Total Richness	–0.33	0.14	-
	Sinuosity	Total Richness	–0.25	0.14	-

[a] ++, $\tau > 0.7$, $p < .05$; This finding strongly supports the case for the candidate cause, but is not convincing due to potential confounding. A strong effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, and the gradient is in the expected direction; +, $\tau < 0.7$, $p > .05$ or $\tau > 0.7$, $p < .05$; This finding somewhat support the case for the candidate cause, but is not strongly supportive due to potential confounding or random error reflected in the weaker gradient; –, $\tau < 0.5$, $p > .05$; This finding somewhat weakens the case for the candidate cause, but is not strongly weakening due to potential confounding or random error; [b]Result inconclusive due to zero values at all sites except NFTO (see Table 6).- $\tau \leq 0.5$, $\rho > 0.05$.

Surrogate indicators of habitat complexity did not exhibit a clear relationship with biological response and the signs of the correlations were contrary to expectations (see Table 8).

The indicator of detritus (% canopy) was inversely related to percent shredders (see Table 8), contrary to mechanistic expectations (Cummins, 1989). Although there may have been more canopy to supply leaves, the detritus may not have been retained long enough to affect the invertebrate assemblage. Also, the sampling occurred before autumn leaf fall in August when leaf packs would be at a minimum.

Stressor-response relationships observed in the Touchet River were consistent with the hypothesis of increasing stress intensity on biological communities with distance downstream; i.e., cumulative impacts are expected to increase as land use practices upstream deliver pollutants to the stream and they are transported downstream. The potential longitudinal patterns between increasing stressors and biological effects were examined from longitudinal plots of an individual stressor and biological effect for each candidate cause, as well as from rank correlation (Kendall's Tau). Correlations with p values <0.05 were considered statistically significant and an indicator of potential association between stressor and biological indicator.

3.3.1. Temperature

Mean annual temperature increased steadily from upstream to downstream sites (see Figure 6). Obligate cold-water macroinvertebrate taxa richness was relatively diverse in the two sites furthest upstream but rapidly declined downstream (see Figure 6). Temperature-intolerant macroinvertebrate taxa were highly correlated with mean annual temperature (see Table 8). Bull trout distribution has been linked with the longitudinal temperature regime in the Touchet River (WDFW, 2002). Bull trout occupy the lower reaches of the Touchet River during winter months when temperatures are cold and migrate upstream with cold-water conditions as the seasons progress into spring and summer.[2]

3.3.2. Sedimentation

The dominant substrate particle size decreases from upstream to downstream sites. However, the furthest downstream station (site T0) has a larger dominant substrate particle size distribution (see Figure 7). The increase in sediment size was influenced by riprap in the channel just upstream of site T0, which constrained the reach width, increasing water energy and resulting in a lower sedimentation and greater transport rate. Although the number of fine sediment intolerant taxa generally decreased with increasing fine sediment, no significant correlation was observed (see Table 8). The similar number of fine sediment intolerant taxa at all sites suggests that changes in fine sediment among sites are inconsistent with expectations based on longitudinal changes.

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[2]Mendel (personal communication).

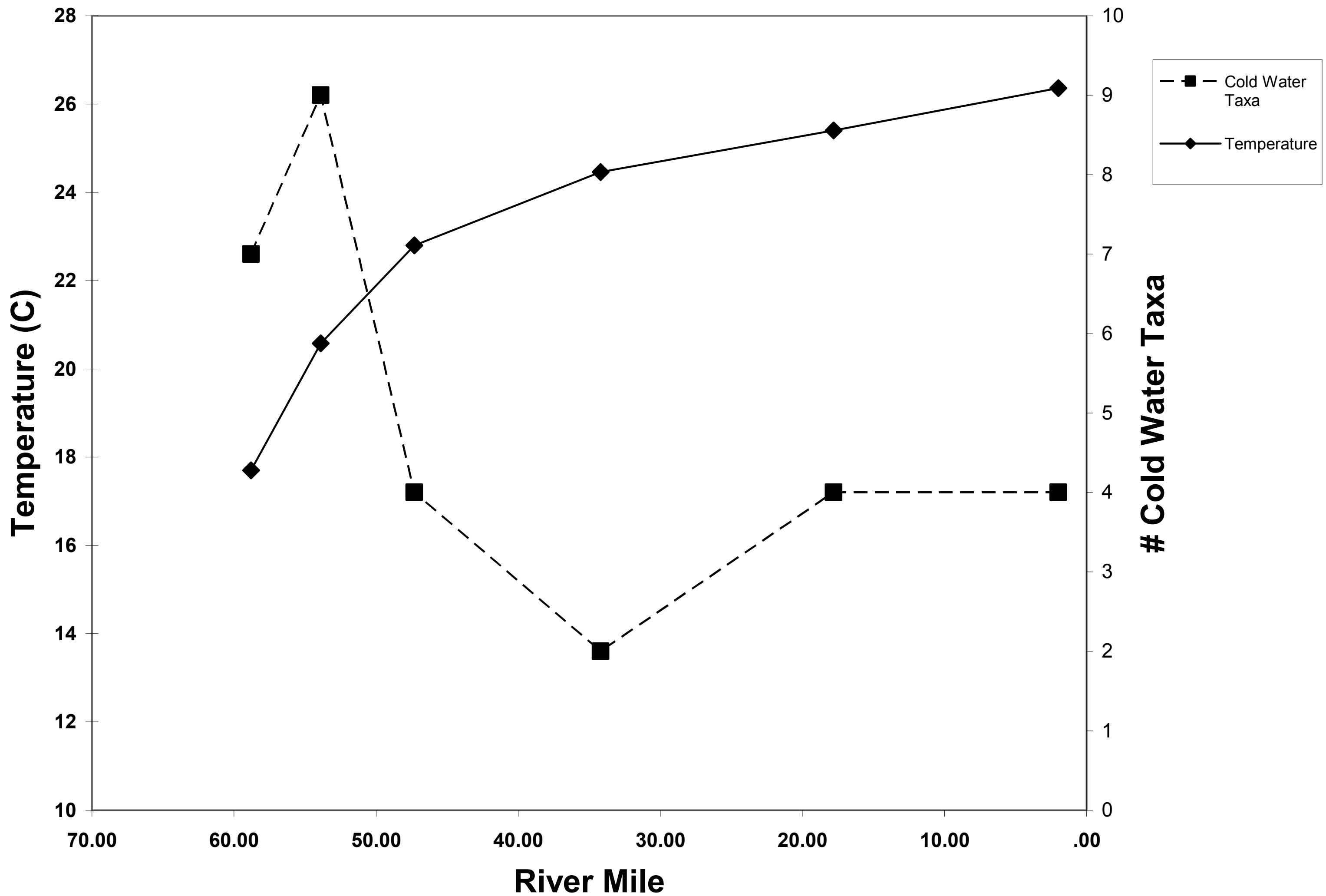

FIGURE 6

Mean Annual Stream Temperature (°C) and Number of Cold-Water Macroinvertebrate Taxa by River Mile (RM) in the Touchet River

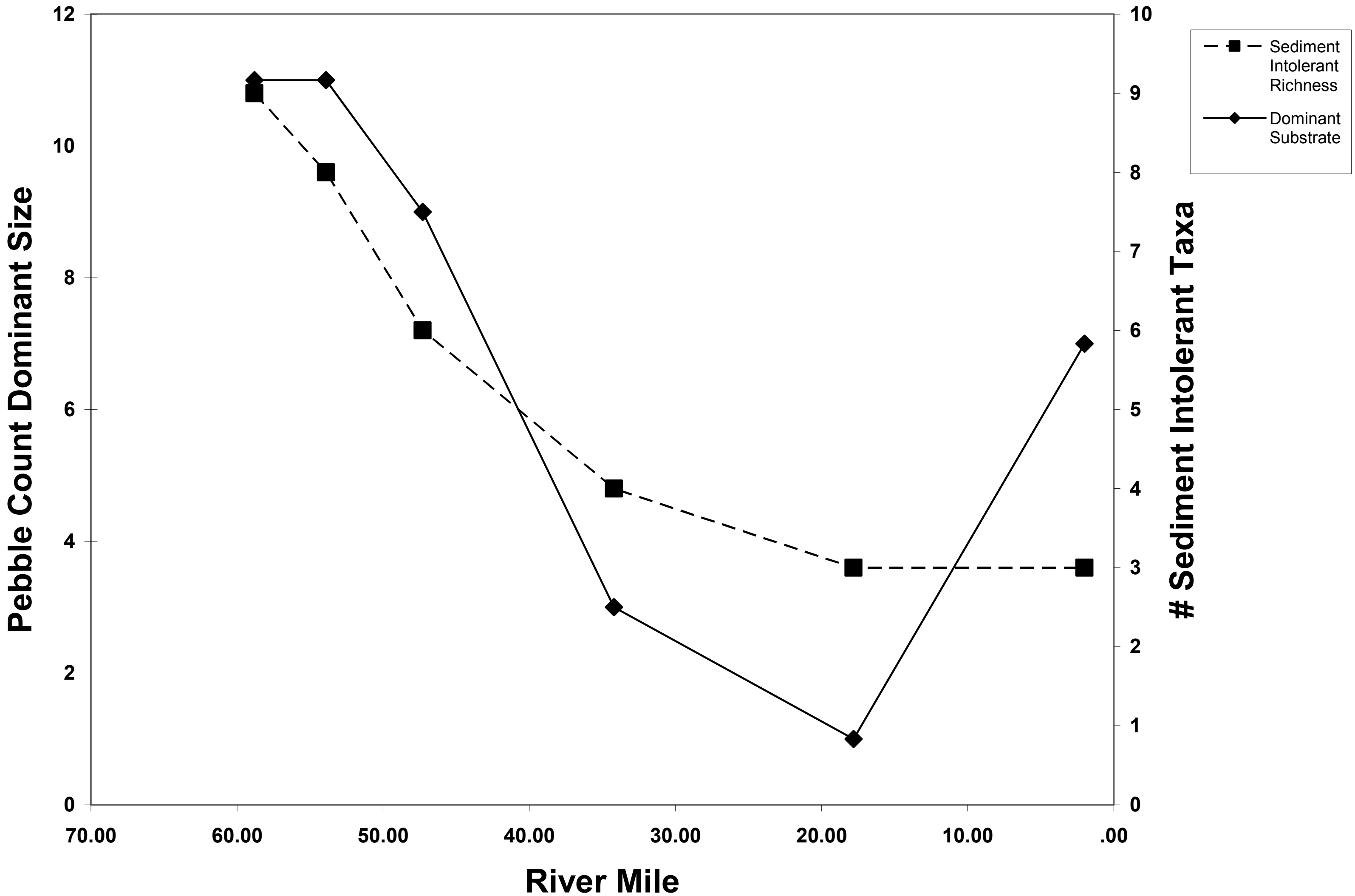

FIGURE 7

Dominant Substrate Particle Size Class and Macroinvertebrate Sediment Intolerant Taxa Richness by River Mile

3.3.3. pH

Comment 13.
WSDE points out that although there may have been more canopy to supply leaves, the detritus may not have been retained long enough to affect the invertebrate assemblage. One reviewer also pointed out that the sampling time occurred in August, before autumn leaf fall when leaf pack would be at their minimum.

Mean annual pH generally increased from upstream to downstream sites (see Figure 8); however, the change in pH observed was within a range generally tolerated by many taxa. In general, the abundance of macroinvertebrate was greater at sites with higher pH, which may indicate greater periphyton production in association with higher maximum pH.

3.3.4. Detrital Food

Canopy cover in the Touchet River drainage is sparse with relatively low cover at the upstream site and decreasing downstream (see Figure 9). The proportion of shredders in the benthic macroinvertebrate assemblage generally declined from upstream to downstream (see Figure 9). Contrary to expectations from the conceptual model, there was a significant negative correlation between percentage of shredders and the small changes measured in canopy cover (see Table 9), suggesting that canopy cover was not related biologically to this indicator, or that areas of detrital material retention in the stream were unrelated to canopy cover (see Comment 7).

3.3.5. Reduced Habitat Complexity

Macroinvertebrate taxa richness was not strongly related to either of the surrogate indicators used to estimate habitat complexity (see Table 8; Figures 10 and 11).

3.3.6. Summary of Stressor-Response Relationships

Biological indicators measured in this study responded to gradients of temperature and pH. Measures for sedimentation did not result in a significant rank correlation with the number of sediment intolerant taxa (see Table 8). The furthest downstream station consisted of two dominant types of substrate, small gravel and riprap, resulting in an unknown dominant size class. Surrogate indicators of habitat complexity did not exhibit a clear relationship with biological response and detrital food was inversely related to percent shredders, contrary to mechanistic expectations (see Table 8). Table 9 summarizes results of these analyses.

3.4. CAUSAL PATHWAYS

3.4.1. Temperature

Riparian vegetation provides important structure for moderating temperature in semiarid desert regions such as the setting for much of the lower Touchet River.

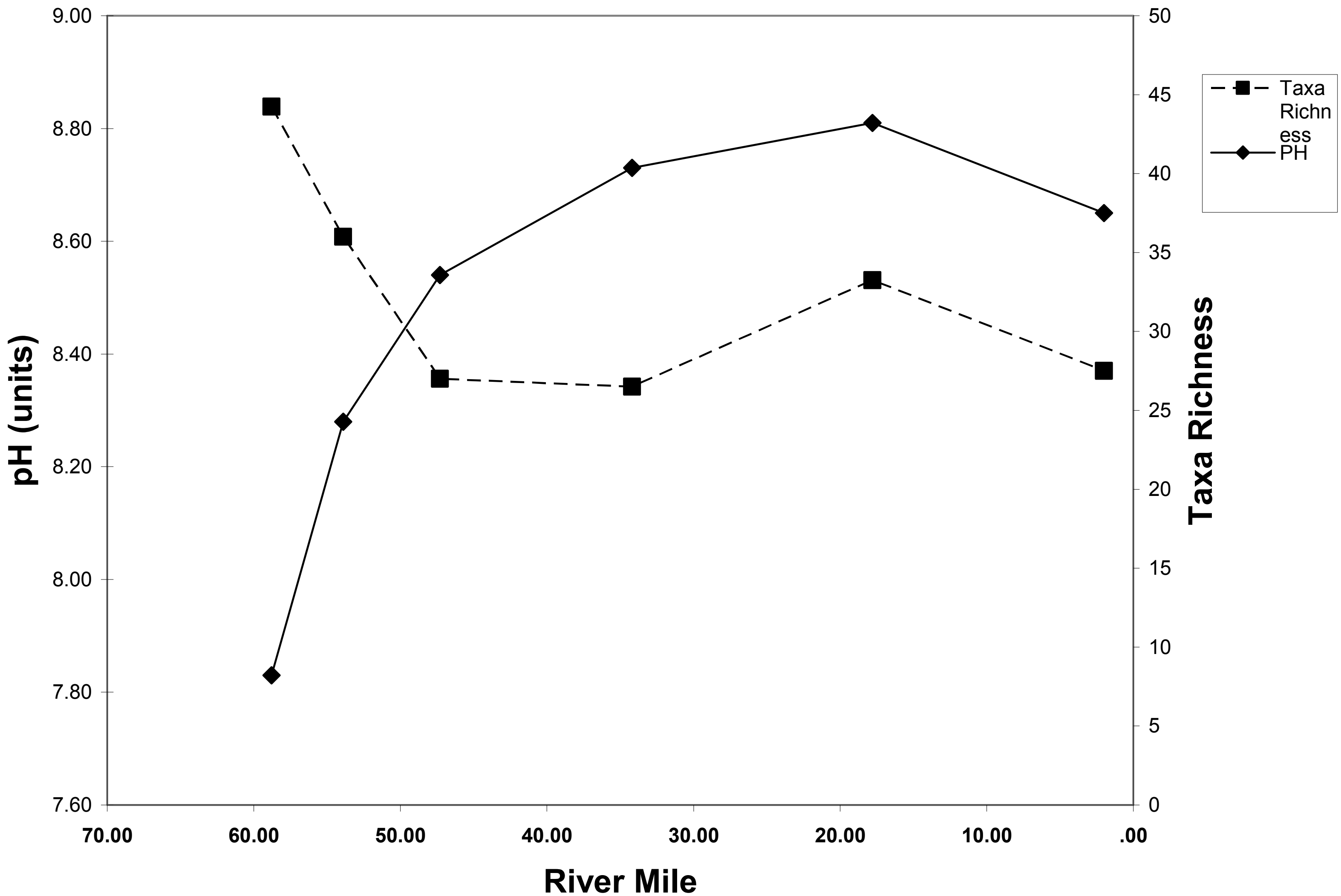

FIGURE 8

Mean Annual pH and Macroinvertebrate Taxa Richness by River Mile

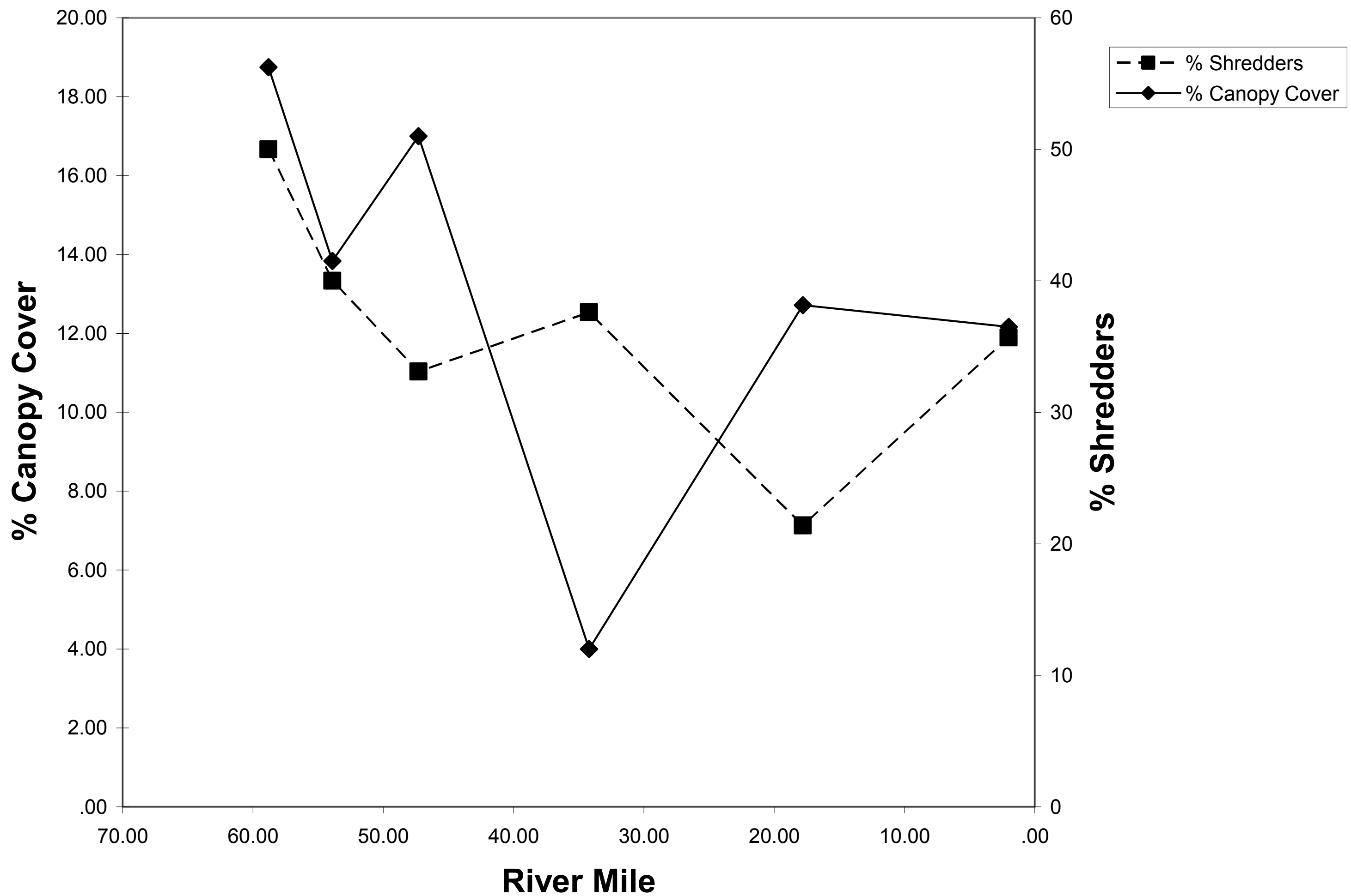

FIGURE 9

The Percent of the Riparian Canopy that is Closed by Vegetation and the Percent of Macroinvertebrates Collected in those Reaches that Shred the Leaf Material, Plotted by River Mile

TABLE 10

Summary of Stressor-Response Relationships in the Touchet River

Candidate Cause	Score	Reasoning
Reduced Habitat Complexity	–	No clear trend found between proximate cause and biological endpoint data
Sedimentation	+	Some indication that # of sediment intolerant taxa decreases as sediment size decreases; however correlation not significant
Warm Temperatures	++	A clear negative trend between temperature stress and cold-water taxa abundance
Increased pH	+	Inverse relationship between pH and total taxa with distance downstream
Reduced Detrital Food	0	A negative association between canopy and % shredders observed

++ $\tau \geq 0.7$, $\rho < 0.05$.
\+ $\tau \leq 0.7$, $\rho > 0.05$ or $\tau \geq 0.7$, $\rho < 0.05$.
\- - - $\tau \geq 0.5$ opposite direction, $\rho < 0.05$.
\- $\tau \leq 0.5$, $\rho > 0.05$.

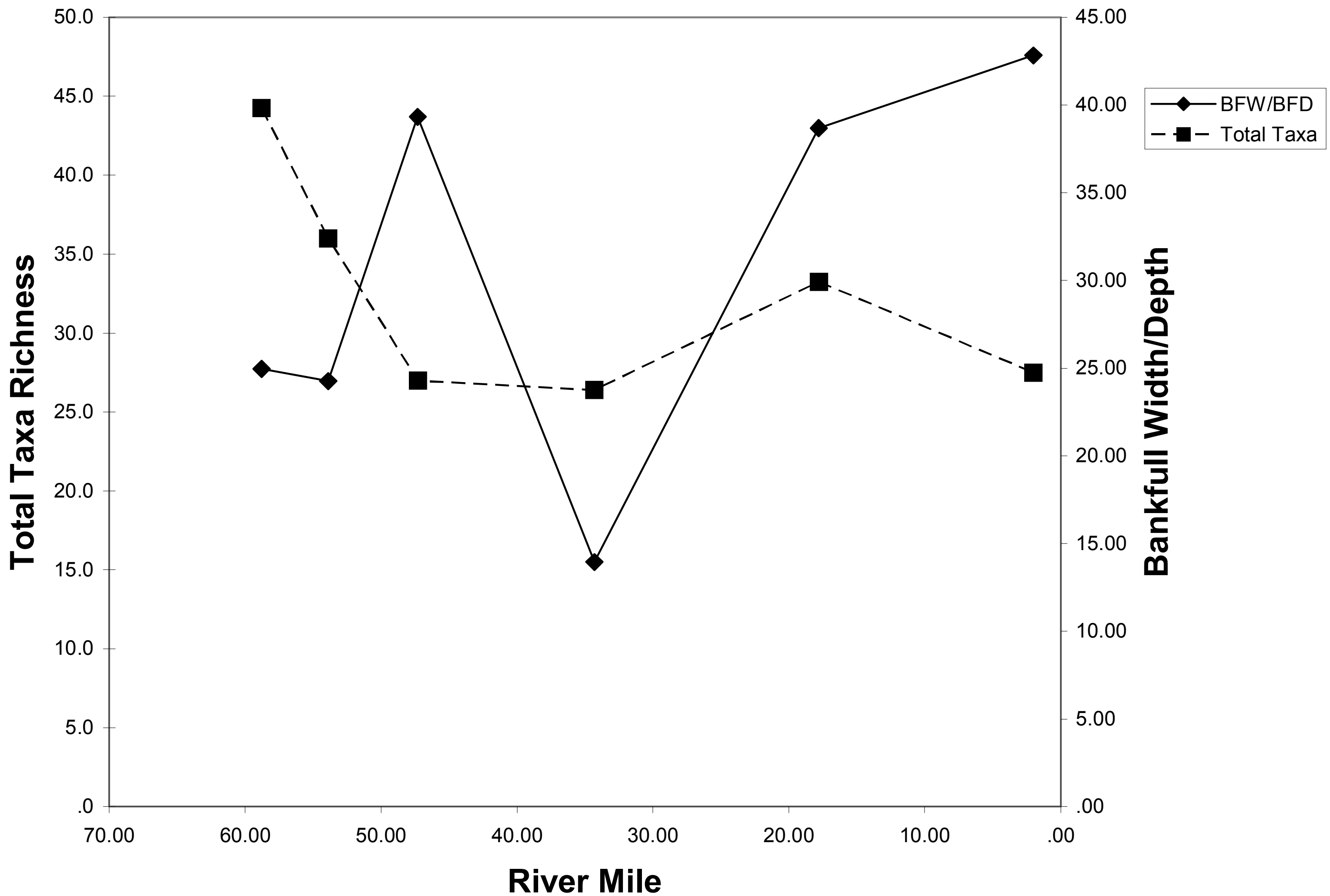

FIGURE 10

The Ratio of Bankfull Stream Width to Depth (BFW/BFD) and Total Taxa Richness, Plotted by River Mile

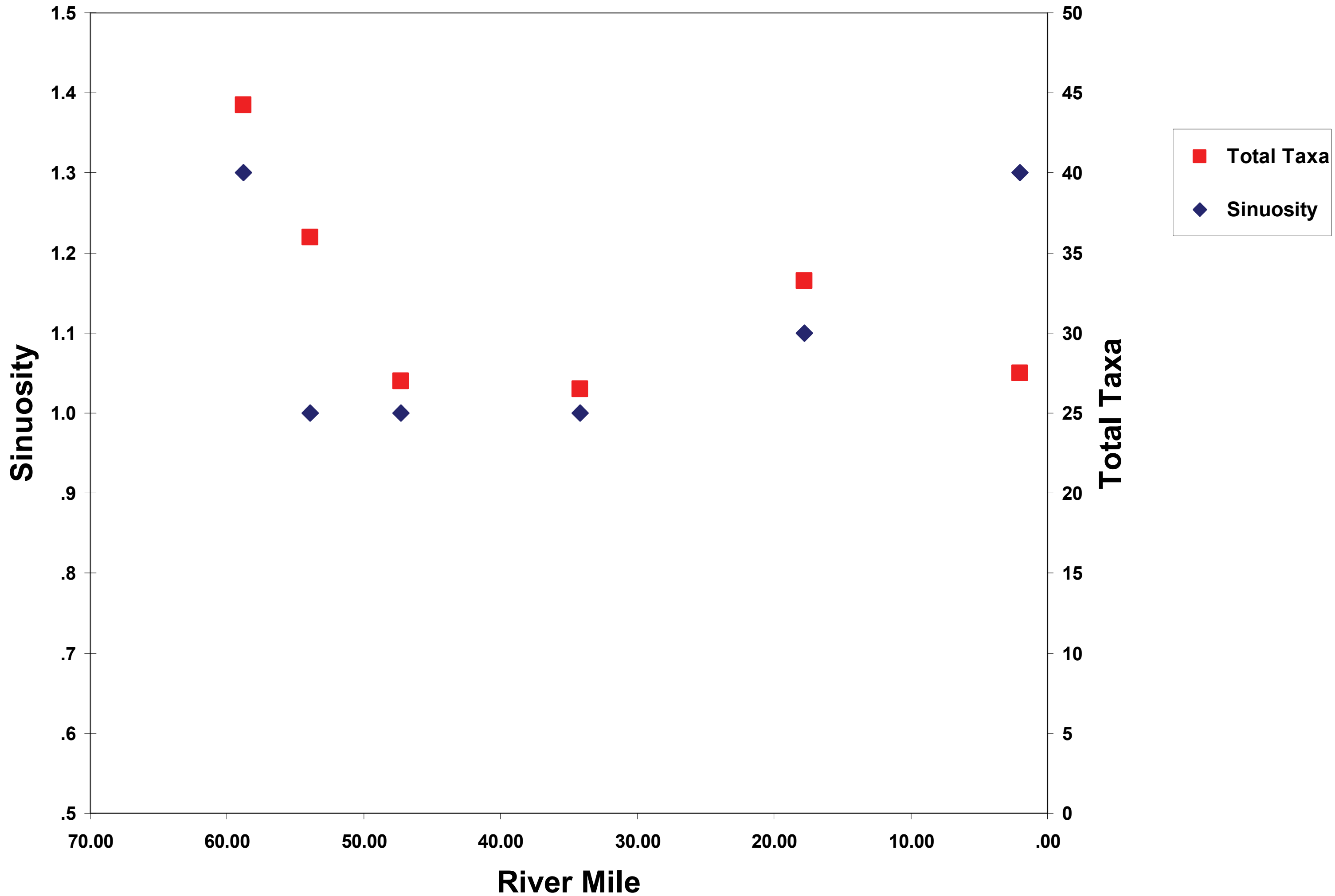

FIGURE 11

River Sinuosity and Total Taxa Plotted by River Mile

Historical accounts of riparian vegetation removal along the Touchet River are well documented. The quantitative measurements taken for riparian canopy cover and estimates for direct solar radiation reaching the wetted channel are reported in Table 10. With less shading of the stream channel and less evapotranspirative cooling by trees, temperatures of the water are expected to become warmer. There are no major tributaries to cool the Touchet River once it flows from the Blue Mountains ecoregion into the arid Columbia Plateau. The lack of moderating cool water from ground water inputs indicates that water will become increasingly warmer from upstream to downstream (see Table 10). The direct association between heat stress (warm temperature) and loss of salmonid abundance and diversity is documented in several studies in the region (Hicks, 1999, 2002, Kuttell, 2001; ODEQ, 2005; Spence et al., 1996).

TABLE 11

Summary of Complete Pathway Analysis for Increased Temperature Due to Reduced Canopy

Site	% Direct Radiation	% Canopy Cover	Maximum Temperature (°C)
Regional Reference sites	NE	44.5−92.5%	16.5°C
NFT0	82.7	18.8	23.46
T11	86.4	13.8	24.58
TLCS	87.3	17.0	30.39
T9	83.5	4.0	31.06
T5	76.3	12.7	NA
T0	90.1	12.2	30.87
Causal Pathway Score		+ +	

NE = no evidence; NA = data not available.
++, This finding strongly supports the case for the candidate cause, because it is improbable that all steps occurred by chance and the values seem sufficient to increase stream temperature.

3.4.2. Sedimentation

Previous studies have identified fine sediments as a serious threat to survival of aquatic life in the lower Touchet River (Kuttell, 2001; Mapes, 1969; USDA Soil Conservation Service et al., 1984). In a previous project, attempts were made to determine specific sources and mechanisms for sediment delivery to Washington's southeast rivers and streams. Results indicated that 88% of sediment delivery was from sheet and rill erosion of cropland. In the lower Touchet River, the vast majority of sediment came from cropland. Sediment is transported from the highly erodible upland and floodplain soils into the river channel following precipitation. The erosion rate has been greatly exacerbated by the transformation of native grasslands to tilled croplands (mostly dry-land wheat). The proposed mechanism of sediment mobilization following rain is supported by TMDL studies. The greatest total suspended solids (TSS) values recorded in the lower Touchet River were during high flow (see Figure 12) coincident with rain during the winter and with spring snowmelt (see Figure 13).

3.4.3. pH

High pH during daylight often results from increased periphyton or phytoplakton photosynthetic activity. Other studies in the region have determined that periphyton growth is limited by phosphorus and solar radiation (Saul et al., 2000). We previously reported that solar radiation can readily penetrate the riparian canopy along the majority of the mainstem Touchet River. Therefore, solar radiation is unlikely to be a limiting factor in algal production. Bioavailable phosphorus increased in a downstream direction, but water column chlorophyll *a* (a direct measure of phytoplankton, and a very indirect indicator of periphyton) did not show any clear trend (see Figure 14). This is contrary to our expectation of a direct relationship between phosphorous and algal production. However, this indeterminate relationship may be due to taking chlorophyll *a* measurements from water column samples and not benthic samples. Thus, our chlorophyll *a* measures may not reflect how phosphorus concentrations influence periphyton biomass and production near or on the bottom of the river. Although we observed little or no filamentous algal mats in the Touchet, the increased mean daily maximum pH observed in the spring at downstream sites (see Figure 15) is unlikely to be related to sources other than increased algal production. But, pH may also have been greatest in the spring when total suspended solids also were at a maximum (Joe Joy, personal communication). These sediments may have been more alkaline. For these reasons, evidence of a causal pathway for pH was scored as ambiguous.

Comment 14.

Phosphorous, light, temperature, algal productivity, pH, and dissolved oxygen are all associated with photosynthesis. Although not used in WSDE analysis, process models can be used to show that a mechanism involving these factors can explain observations. This is a beneficial analysis if there is sufficient data to run the model.

If a model is unavailable or data is insufficient, it is best to focus on the proximate cause. In the Touchet example, pH can be a proximate cause, a cofactor, or a byproduct.

Extremes of pH can (1) directly injure fish, (2) make certain compounds more toxic, such as ammonia, (3) be a byproduct of photosynthesis, or (4) be a natural phenomena, for example in karst topographies. One analytical strategy is to separate out functions and to describe the role of pH in conjunction with each proximate candidate cause, for example diel extremes of dissolved oxygen as a cause and high pH as an associated by product. Another option is to relate the factor to probable causes when comparing among candidate causes. For example, elevated levels of pH were unlikely to be the cause of reduced benthic invertebrate assemblages, but elevated pH coincided with observations of high dissolved oxygen levels, both of which are associated with algal productivity and nutrient enrichment.

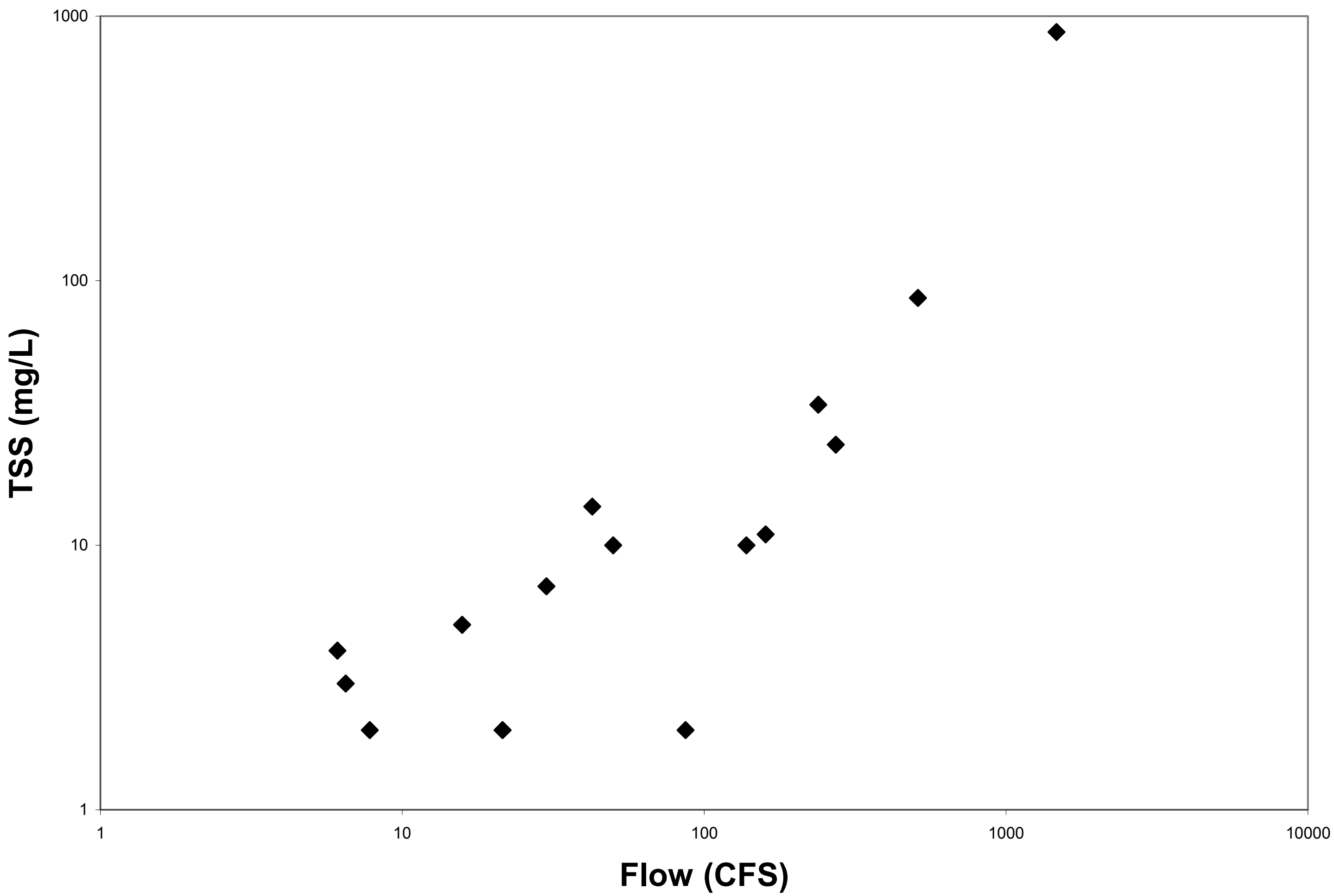

FIGURE 12

Total Suspended Solids (TSS) Measured in the Lower Touchet River as a Function of Stream Flow

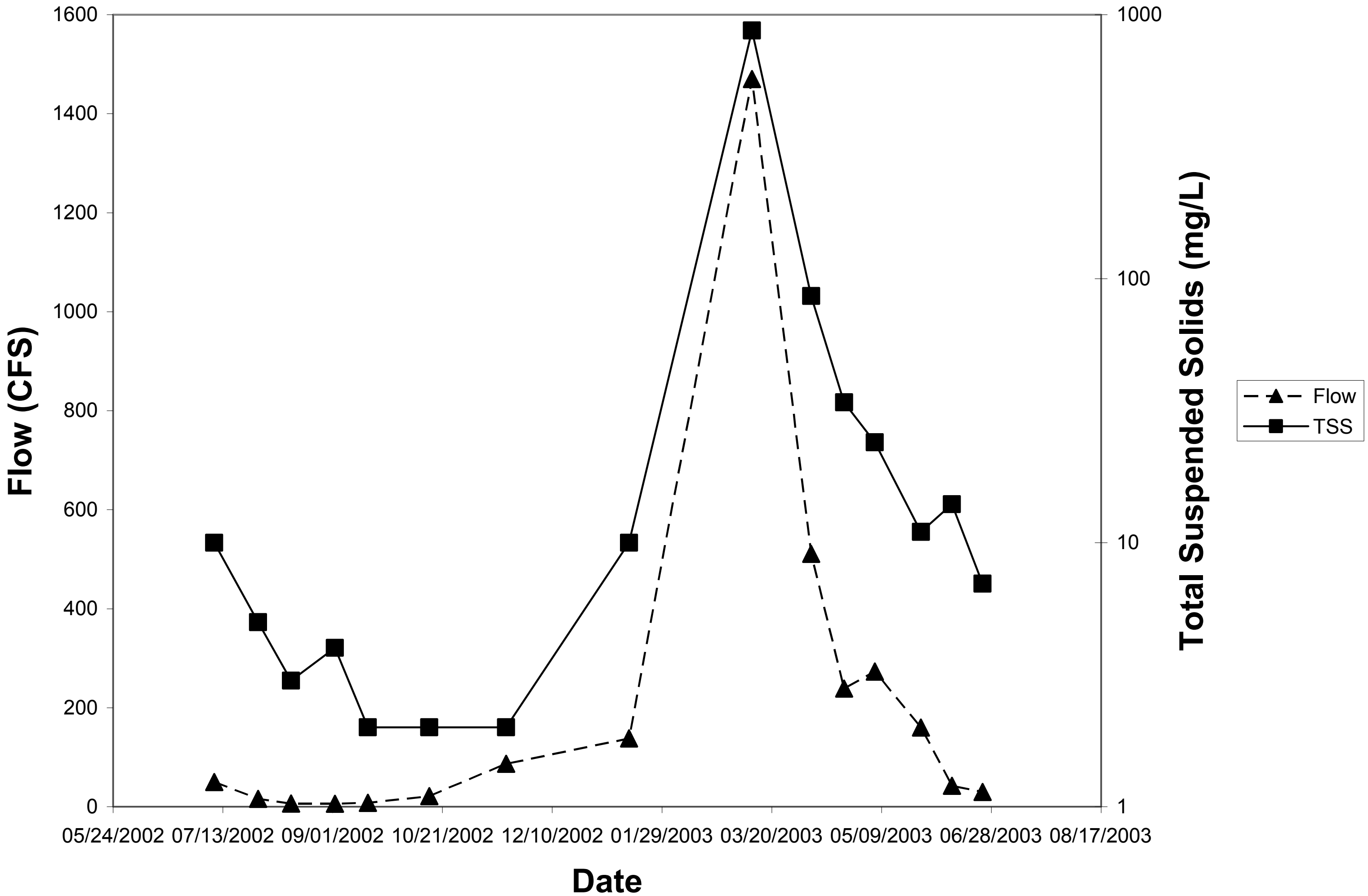

FIGURE 13

Flow and Total Suspended Solids in the Touchet River as a Function of Time of Year

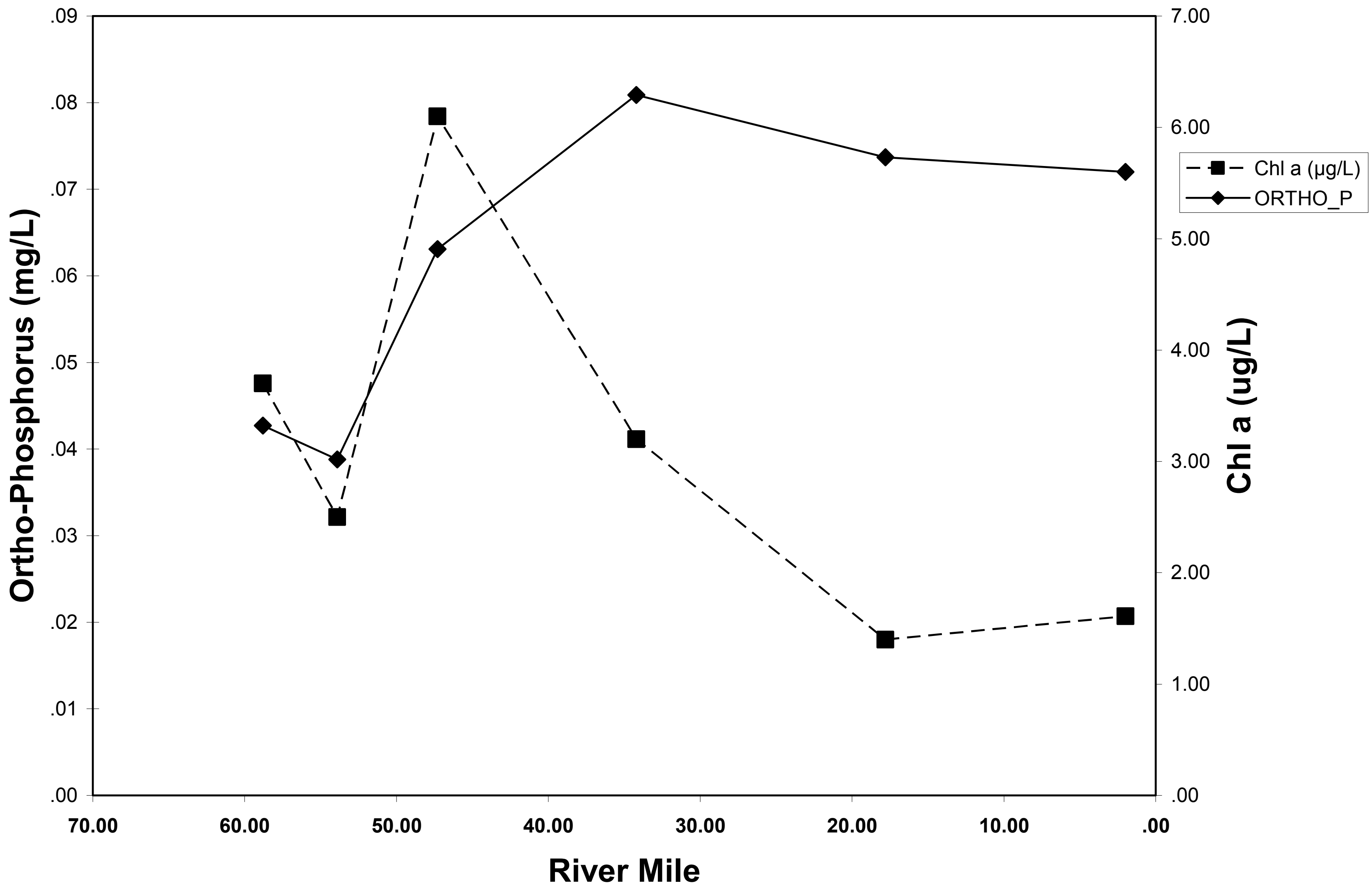

FIGURE 14

Chlorophyll *a* and Orthophosphorous Measurements in the Touchet River

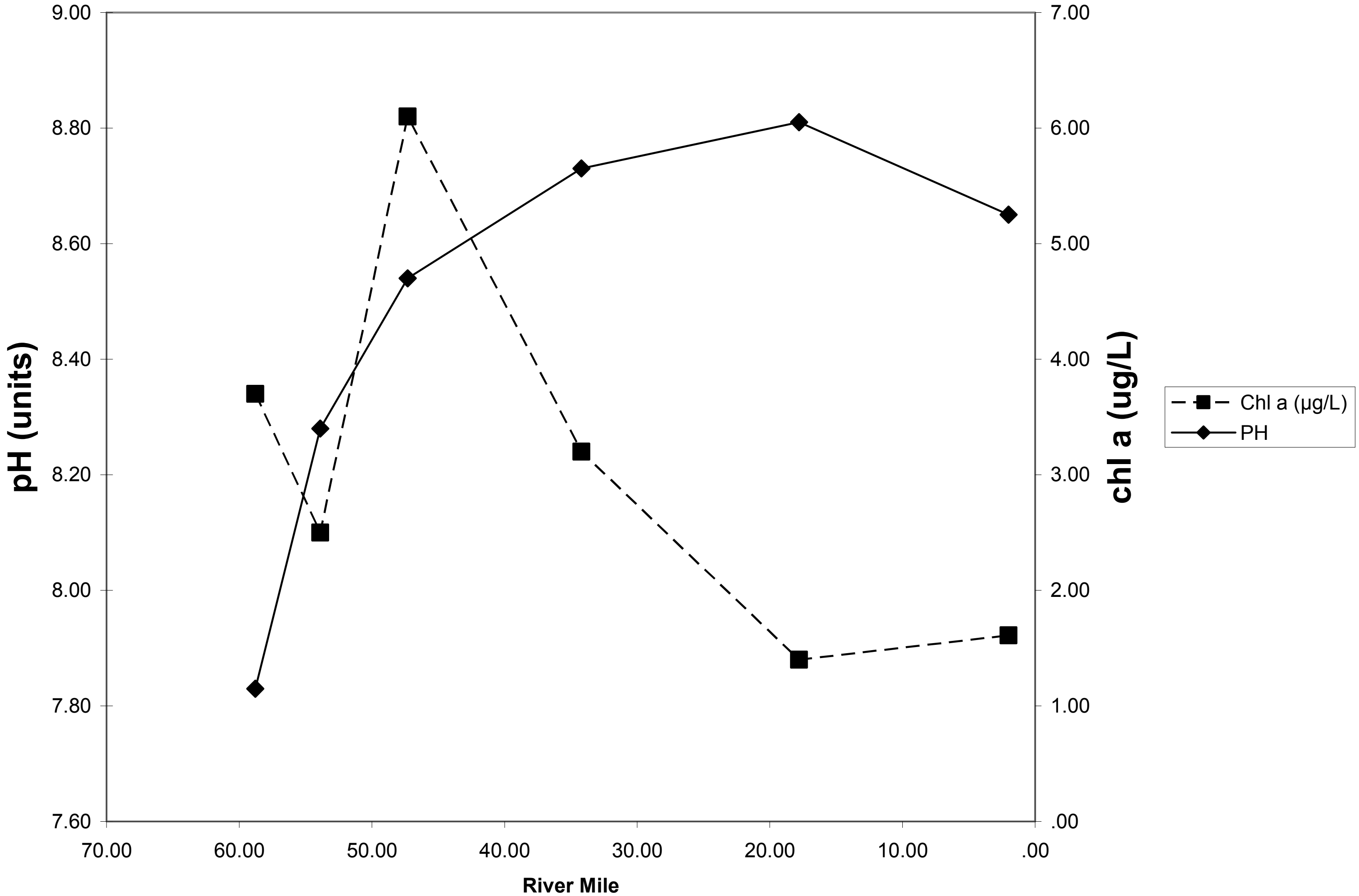

FIGURE 15

Chlorophyll *a* in Relation to Mean Daily Maximum pH Observed at Each Site in the Touchet River

3.4.4. Detrital Food

We did not directly measure detrital food sources. Canopy cover was used as a surrogate for direct measures of leaf litter inputs and standing biomass of detritus. To verify a complete causal pathway between riparian vegetation and use by macroinvertebrates, we would need to measure benthic coarse particulate organic matter (CPOM) and changes in available biomass with responses by the macroinvertebrate assemblage. This information was not collected and this pathway can therefore not be addressed further in the analysis.

3.4.5. Reduced Habitat Complexity

We did not directly measure the alterations in stream and riparian corridor that could result in reduced habitat complexity. Therefore, we have no evidence that any of the causal pathways lead to reduced habitat complexity. Three characteristics were proposed for measuring habitat complexity in future studies: channel constrainment, channel infilling from sedimentation and reduced large woody debris that would serve as habitat (also see Kaufmannet al, 1999).

3.4.6. Summary of Complete Causal Pathway

Possible causal pathways leading to warmer temperature and increased sediment were supported by the data generated by this study (see Table 11). The hypothesis that pH is greater in the spring due to increased periphyton production (chlorophyll *a*) was ambiguous because robust benthic periphyton measurements were lacking in this study. However, this pathway has some support based on examination of ortho-phosphorous data and the increase in macroinvertebrate scrapers at sites with greater maximum pH. Reduced detrital food and habitat complexity pathways could not be verified due to a lack of intermediate measures (see Table 11).

TABLE 12 Summary of Complete Pathway Analysis		
Candidate Cause	Score	Reasoning
Warm Temperatures	++	Riparian canopy is reduced and climate is arid and hot. The stream has little ground water inputs, resulting in warm summer temperatures.
Sedimentation	++	TSS increases with flow. Flow is high during winter rain events and spring runoff.
Reduced Detrital Food	NE	Measurements of intermediate steps were not taken.
Reduced Habitat Complexity	+	Measurements of intermediate steps were not taken.
Increased pH	0	pH increases downstream, so does ortho-phosphorous. There is some increase in scrapers; algal data not complete. pH highest in spring, may also be associated with runoff.

NE = no evidence.
+ + = intermediate measures met for sites that are impaired in the Touchet that could lead to biological impairment, + some evidence that a pathway was present.

4. EVALUATE DATA FROM ELSEWHERE

4.1. STRESSOR-RESPONSE FROM OTHER FIELD STUDIES

Temperature and pH were the only stressors that we were able to evaluate using available information from the region or other locations. Both temperature and pH were measured directly in the Touchet River and collected within a similar timeframe. The Touchet River watershed stressor-response levels were compared with other environmental studies that collected temperature, pH and habitat complexity data from settings similar to the Touchet River. Reduced detrital food and increased sedimentation were not evaluated when there were no studies from comparable physiographic characteristics.

4.1.1. pH

The pH in the Touchet River reached a maximum of 9.5 in spring sampling, which is believed to be at or close to the maximum pH that occurs in this river. Toxicological and other data derived from U.S. EPA's water quality criteria indicates that a pH of 9.5 may cause harm to aquatic life if it occurs over a long duration. A pH of 9.5 is not acutely toxic to many freshwater organisms (e.g., Rainbow trout), but it has been shown that such waters can inhibit ammonia excretion in fish (Laurent et al., 2000; Scott et al., 2005; Wilson et al., 1998). Furthermore, based on information from many regions of the U.S., U.S. EPA recommends an aquatic life pH criterion of 6.0−9.0. Habitat suitability indices derived for warm water and cold-water fish species by the U.S. Fish and Wildlife Service indicate less than satisfactory conditions when pH >9.0, particularly for cold-water fish species such as trout (Raleigh et al., 1984). It is possible that pH may be a stressor in this system since maximum pH values above 9.0 probably occurred for up to 6h per day during several weeks in the spring (Joe Joy, personal communication).

4.1.2. Temperature

Bull trout (*Salvelinus confluentus*) have a temperature preference of 9−13°C and are absent in waters above 19°C (ODEQ, 1995). These temperature affinities are much lower than the 30+°C temperatures measured in the lower sites of the Touchet River. Steelhead trout (*Onchorynchus mykiss*) distribution is also limited by warm in-stream temperatures. Returning steelhead will hold in the mainstem Columbia River until tributary temperatures are cooler before they migrate into the Walla Walla River and the upper-drainage tributary, Touchet River (Kuttell, 2001).

Stressor-response profiles based on habitat suitability models developed by U.S. Fish and Wildlife Service also suggest that temperature is a primary cause for lack of trout in the Touchet River. Table 12 summarizes temperature tolerances from published sources. Published information indicates that neither Bull trout nor Rainbow

TABLE 13

Temperature Tolerance Information for Rainbow and Bull Trout Compared With Temperature Range in Touchet (Grab Sample17.7−26.4°C, Maximum 30.8°C)

Species	Adult Preference	Upper Incipient Lethal Temperature	Spawning	Rearing	Reference
Rainbow Trout	10−13	21−22	13.3	5.6−11.1	Hicks, 1998; Bell, 1986; Smith et al., 1983
Bull Trout	10−12	19	4−10	<10	Spence et al., 1996; Temperature Subcommittee, DEQ
Plausible Stressor Response Score	+++	+++	+++	+++	

+++, This finding convincingly supports the case for the candidate cause of temperature. All benchmarks were exceeded including adult incipient lethal temperature. It is not definitive because the correspondence could be coincidental due to confounding or conditions between the case and the laboratory.

trout are likely to complete all life cycle stages in the portion of the Touchet River that was evaluated between June and September 2002 (Mendel et al., 1998). Figure 16 shows plots of both the monthly average and the 7-day monthly maximum temperatures for each site between June and September 2002. At nearly all sites, the 7-day maximum average temperature exceeded lethal levels reported for adult survival, spawning, and rearing. Monthly average temperatures often exceeded these thresholds except for the upper most site in the drainage (NFT0). When maximum temperatures were examined, incipient lethal conditions were exceeded during this time period for both fish species (maximum temperatures ranged between 23.46°C and 30.87°C for the Touchet River sites). Exceedence of lethal temperatures for both species during this time period further supports temperature as a likely cause for species absence in this drainage. The nearby Tucannon River, a reference stream in the region, is minimally influenced by agriculture and urbanization, has a natural riparian canopy, is much cooler than the Touchet at similar elevations in the upper drainage, and harbors salmonids for most of the year (Mendel et al., 1998).

Available information from fish surveys in the Walla Walla drainage provides support for detrimental effects of warm temperature on salmonid assemblages and their movement. Streams in northeast Oregon that had a greater thermal heterogeneity had more Rainbow trout (31%) and Chinook salmon (59%) (ODEQ, 2005) than in the Touchet River. Mendel et al. (1998, 2002) and Kuttell (2001) surveyed several streams that were similar in flow and elevation as the Touchet River and reported warm summer temperatures with a corresponding lack of riparian canopy and severely impaired salmonid assemblage. Streams identified by these authors include lower Coppei Creek, Dry Creek, and Cottonwood Creek (see Table 13).

Temperature effects on macroinvertebrates are less well known than for salmonids. Temperature tolerance ratings developed for Idaho streams did not always appear to apply to many of the species observed in the Touchet River. Some cool-water benthic invertebrate species were observed in warm water sites near the mouth of the Touchet River. Macroinvertebrate assemblage structure and function might not be strongly affected by the relatively small temperature changes observed among sites in the Touchet River. Ode et al. (2005) reported a similar result in southern California streams, finding little difference in metric values between higher elevation (>1000 ft) and low elevation streams. It seems probable that maximum temperatures observed in the Touchet River are neither lethal nor chronically detrimental to the types of macroinvertebrates that currently colonize the downstream reaches because many of these species have a broad tolerance range (eurythermic) or are able to complete life cycle stages in a timeframe that avoids the warmest time of the year (Sweeney, 1984). Given that warm water temperatures have occurred in this river for over 100 years, the benthic macroinvertebrate assemblage may have shifted to a temperature-tolerant assemblage.

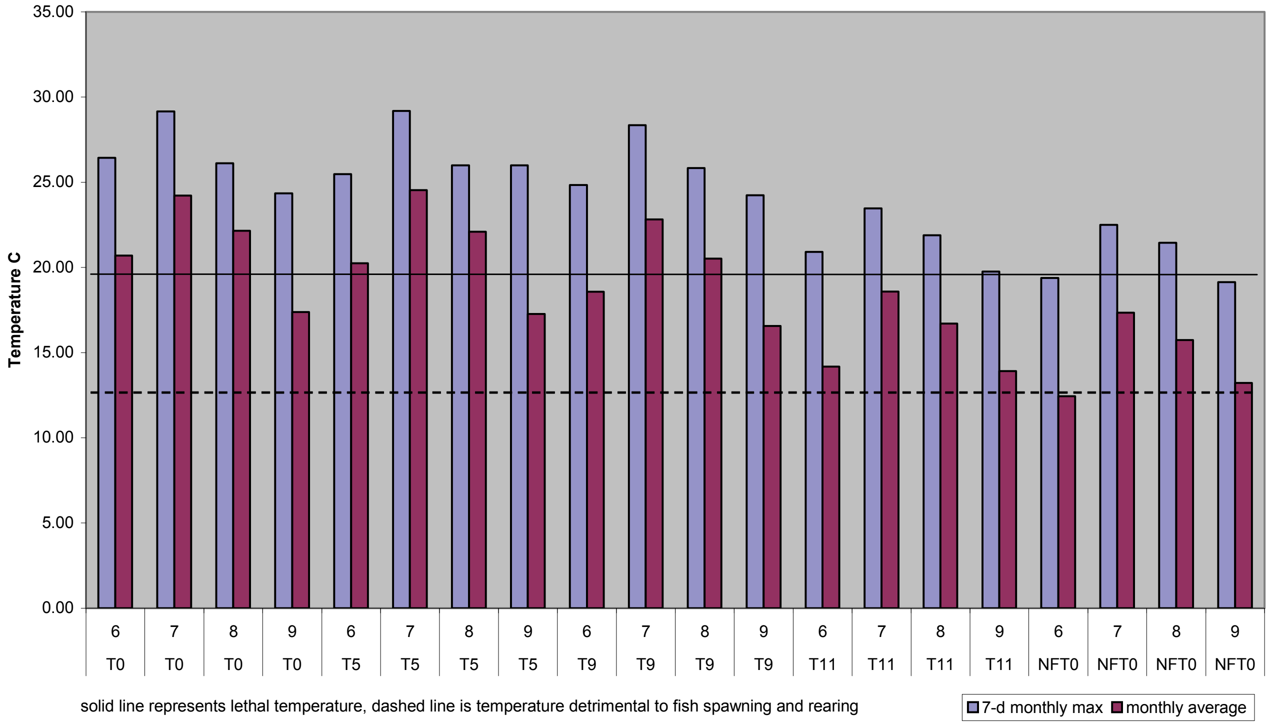

FIGURE 16

Seven-Day Monthly Maximum and Monthly Average Temperature (°C) Plotted by Site for June (6), July (7), August (8) and September (9), 2002. Solid line represents lethal temperature, dashed line is temperature detrimental to fish spawning and rearing.

TABLE 14

Average and Maximum Temperatures in Upstream and Downstream Reaches of Three Streams in the Walla Walla Region, all Similar in Size to the Touchet River and Recorded Presence of Salmonids

Stream	Average Summer Temperature	Maximum Summer Temperature	Salmonids Present	Salmonids in Upstream Reaches	Summer Temp <18°C Upstream
Lower Coppei Creek	>18°C	>21°C	No	Yes	Yes
Dry Creek	>18°C	>29°C	No	Yes	Yes
Cottonwood Creek	>21°C	Not reported	No	NA	NA
Touchet	>22°C	>30°C	No	Yes	Yes
Stressor response compared to other impaired streams and unimpaired upstream reaches			+		

Mendel *et al*. (1999, 2002); Kuttell (2001);
+,This finding somewhat supports the case for the candidate cause, but is not strongly supportive because the association could be coincidental and the conditions in other watersheds may be different from the Touchet River.

4.1.3. Sedimentation

Abundance of fine sediment in streams affects macroinvertebrate colonization as well as the occurrence and reproduction of many fish species (Jha, 2003). Agriculture is common in the Columbia Plateau and is the primary source for the sediment inputs into these streams (WDFW, 2002). Many states throughout the U.S. have identified sedimentation as one of the chief causes for biological impairment. Although detailed data are lacking for the Touchet River region, information from similar settings indicate that the sedimentation level observed in the Touchet River is consistently associated with impaired biological conditions (see Table 14). Historical changes throughout the Columbia River Basin suggest that increased sedimentation of stream channels has increased since the 1930s. Presumably, this change has affected endemic aquatic life in the basin.

TABLE 15

Summary of Regional Information Regarding Proximate Causes of Salmonid Decline in Streams in the Walla Walla Watershed

Study	Primary Proximate Causes	Secondary Proximate Causes
Current Study	Temperature, Sediment	pH, Habitat Complexity, Riparian/Detrital
Kuttell (2001)	Screens and Diversions, Riparian Condition, Floodplain Connectivity, Substrate Embeddedness, LWD, Pool Frequency, Off-Channel Habitat, Water Quality/Temperature, Biological Processes	Fish Passage, Streambank Condition, Pool Frequency, Pool Quality, Water Quantity/Dewatering, Change in Flow Regime
Mendel et al. (2003, 2004)	Temperature	Sediment, Flow, Cover, Pools, etc.
WWWPU (2004)[a]	Sediment	Habitat Quantity, Flow, Predation, Temperature, Channel Stability, Obstructions
WWWPU (2004)[b]	Habitat Diversity, Flow	Temperature, Sediment, Predation, Channel Stability

[a]Ecosystem Diagnosis and Treatment (EDT) Analysis for Steelhead and Spring Chinook, Mouth to Waitsburg.
[b]EDT Analysis for Steelhead and Spring Chinook, Waitsburg to Forks.
LWD = length:width:depth ratio.

4.1.4. Detrital Food Availability

Detritus availability is not consistently associated with biological response in semiarid stream settings. These streams naturally have sparse riparian vegetation and a small cache of available detritus available as a food base. For much of the year, fauna in these streams is supported by primary production (periphyton, macrophytes) and/or dissolved organic carbon originating from storm runoff and floods. While detrital availability was not directly measured in the Touchet River or other streams in the region to our knowledge, information from the arid west in general suggests that detrital availability does not relate in a consistent manner with biological condition.

5. IDENTIFY THE PROBABLE CAUSE

Scoring criteria for each causal consideration and from multiple lines of evidence (see Table 15) indicated that increased temperature and sediment inputs are the primary stressors impairing biotic communities in the Touchet River. Also identified as a minor concern was high pH at select locations.

TABLE 16

Strength of Evidence for Each Candidate Cause

Consideration	Temperature	Sedimentation	Reduced Detrital Food	Habitat Complexity	pH
Spatial Co-occurrence	++	++	++	NE	+
Biological Gradient	+++	+	0	–	+
Complete Exposure Pathway	++	++	NE	+	0
Mechanistically Plausible Causal Pathway	+++	NE	NE	NE	NE
Plausible Effect Given Stressor-Response Relationships	+++	NE	NE	NE	NE
Consistency of Evidence	++	++	+	–	+
Consistency of Assessments*	++	++	+	+	+
Overall Strength of Evidence	H	H	L	L	M

*See Table 14 for evidence. ++, all known assessment support; +, some assessments support.
H = High, M = Medium, L = Low, NE = No evidence. +++, convincingly supports; – – –, convincingly weakens; ++, strongly supports; – –, strongly weakens; +, somewhat supports; –, somewhat weakens; 0, neither supports nor weakens; NE, no evidence.

5.1. PROBABLE CAUSES

The temperature and sedimentation pathways were supported by evidence from this study and by information from other parts of the region. The proximate causes and biological impairments increased from upstream to downstream. Although elevation, gradient, and morphology change from upstream to downstream, it is unlikely that the temperature, sedimentation, and biological conditions are due to natural phenomenon because streams with similar natural features did not exhibit biological impairments or temperature or sediment characteristics that were observed in the Touchet River. Furthermore, several types of evidence suggested that observed biological data were inconsistent with expectations based on a natural gradient. Rather, the evidence compiled in this study strongly suggest that observed biological effects were related to changes in land use activity, which caused detrimental changes in temperature and sedimentation as one proceeded downstream in the Touchet River. This was demonstrated, by benthic macroinvertebrate metrics that are responsive to either temperature or sedimentation. Furthermore, the effects of temperature and sediment on salmonid health are well documented in the Touchet River drainage. These relationships are consistent throughout Pacific Northwest drainages, thereby increasing confidence in our description of the stressor-biological response relationships identified in this case study.

5.2. UNCERTAIN CAUSES

Comment 15.
As regional data bases become more accessible and more fully analyzed, empirical models of causal relationships will make it easier to provide stronger quantitative evidence for causal assessments. (See the stressor-response gallery in CADDIS for examples.)

Both the “Habitat Complexity” and “Reduced Detrital Food” pathways were inconclusive, largely due to a lack of data in some cases and lack of relationship when evidence was available. The two proximate measures of habitat complexity (sinuosity and width-to-depth ratio) used in the analyses are reasonable surrogates, but other habitat characteristics should be explored further (Kaufmann et al., 1999). Reduced detrital food availability was analyzed based on the presences of overhanging trees (percent canopy cover). The food base is an important characteristic to measure in semiarid landscape streams and any alterations of the food base can have dramatic impacts on existing biological communities. A direct measure, such as CPOM, would provide more credible evidence and increase confidence in a determination of this candidate cause. A complete analysis of a causal pathway for pH was not possible with available data. Modeling of periphyton production rates would improve a mechanistic understanding of the biological response, pH measurements, nutrients, temperature, and diel DO shifts.

Comment 16.
The U.S. EPA does not recommend elimination of a cause based on criteria which were developed for a different purpose. In fact, there was evidence to suggest that supersaturation and relatively low dissolved oxygen did occur and may have been associated with algal productivity, however, this cause was not analyzed in the Touchet example.

5.3. DEFERED CAUSES

Toxicity by any compound and low dissolved oxygen was not evaluated further as candidate causes because chemical concentrations of dissolved oxygen levels did not fall below state criteria.

6. COMPARISON OF CANDIDATE CAUSES

The evidence presented in this assessment is consistent with previous studies that identified anthropomorphically modified temperature and sediment regimes as the primary limiting environmental factors to salmonid survival in the Columbia Basin (Kuttell, 2001; Mendel et al., 2003, 2004; Walla Walla Watershed Planning Unit [WWWPU], 2004). Mendel et al. (2003, 2004) concluded that elevated temperatures in the lower Touchet River were the greatest limiting factor for a viable salmonid assemblage in the watershed. The warm lower reach in this drainage serves as a thermal impediment to migrating anadromous fisheries. Greater sediment yield, low water availability, absence of fish cover, and few pools were identified as secondary causes limiting salmonid survival (see Table 15). Water quantity, fish cover, and pools were not identified as proximate causes for biological impairment in the Mendel et al. 2003 and 2004 studies. However, these factors could indirectly be related to other causes. Reduced flow exacerbates water quality problems by concentrating pollutants and increasing the residence time of polluted “slugs” of water in reaches from headwaters to the mouth of the drainage. Also, reduced flow can affect temperature and pH. Cover and pools can be included as measures of habitat complexity, one of the proximate causes. Removal of riparian vegetation can also reduce the quantity of woody debris and reduce habitat complexity.

Kuttell (2001) identified a variety of primary and secondary salmonid habitat limiting factors and causes for biological impairment in the Walla Walla basin (see Table 15). Those factors, riparian condition, substrate embeddedness, large woody debris, water quality/temperature, and water quantity, were included in this causal pathway model. Obvious limiting factors for verification of improvement to salmonid habitat are screens and diversions. Floodplain connectivity, off-channel habitat, water quantity, and changes in the flow regime provide for the natural dynamics of the river prior to establishment of flood control barriers in this drainage. A properly functioning floodplain in the Touchet River drainage would alleviate many of the problems that reduce important salmonid refugia during the more stressful months of the year. Irrigated agriculture and other resource uses constrained the channel by changing the hydrologic patterns over the seasons and reduced habitat complexity. Kuttell (2001) identified pool frequency, pool quality, and streambank condition as important factors affecting salmonids in this region.

The WWWPU (2004) identified sediment, habitat diversity, and flow (water quantity) as the most important habitat factors limiting Spring chinook (*Oncorhynchus tshawytscha*) and steelhead survival in the lower Touchet River. Secondary factors that influence these fish assemblages include habitat loss, reduction in water quantity (flow), predation, temperature, channel stability, and channel barriers (see Table 15). All of the primary factors were considered for the causal analysis model.

At the outset of this stressor identification process, we recognized that data were limited to a particular year and season for some of the candidate causes (e.g., habitat factors, pH). While broader data (temporally and spatially) would reduce uncertainties about the degree to which these stressors actually cause identifiable biological impairments in the Touchet River, we are confident that temperature and sedimentation are important causes of biological impairment based on several types of evidence discussed in this study.

Other causes that may be important are detrital food availability, and causes related to changes in pH such as unusual algal productivity. Detrital food availability was not measured directly in the Touchet River or at reference sites used for comparison in this region. Instead, we relied on a surrogate measure for canopy cover to identify the relationship with biological endpoints. Canopy cover was an indirect measure of detritus availability and the evidence for other candidate causes was stronger. Furthermore, the type of restoration needed to address the two primary stressors, temperature and sedimentation (increased riparian vegetation, buffer), will also influence detrital food availability. So, although the importance of detrital food has not been demonstrated in the Touchet, restoration strategies for reducing temperature and sediment loads would include establishing trees along the stream banks thus providing a source of leaf material.

We were unable to eliminate increased pH as a cause, but it appears to be a factor related to another cause but a less likely direct cause for biological impairment. The increase in pH observed in downstream reaches of the Touchet River may be related to increased periphyton production given the greater dissolved phosphorous concentrations and evidence of substantial diel swings DO. The surrogate measure used to evaluate periphyton responses, chlorophyll *a*, has a weak relationship to periphyton production as these analyses are based on water column and not benthic samples. There is ample evidence from other stream restoration efforts that natural riparian vegetation buffers used for shading and decreasing stream temperature also reduce nutrient inputs into streams. Riparian buffers reduce loading of pollutants such as nutrients and transport of sediment to streams. In addition, restoration that reduces sediment loading to the Touchet (including better riparian buffers) will also reduce nutrient inputs from sediment runoff in this region.

A major challenge in this study was understanding confounding gradients, including elevation, temperature, stream size and agricultural land use. While some of these longitudinal stream changes are natural in the region, we are confident that changes in biological response were related to changes in temperature and sedimentation from anthropogenic sources. Cooler temperatures in lower elevation reference streams during the summer were attributed to shading which was lacking in the lower Touchet River. Several important macroinvertebrate metrics (e.g., EPT, number of taxa) as well as the number of salmonids and endemic fish species are more numerous in reference streams than in the Touchet River. Results of all types and pieces of evidence in this study strongly indicate that restoration of temperature and sedimentation regimes would improve biological conditions in this river.

Since sediments accumulate downstream, inputs are consistently present and aggregation of fine sediment would naturally form point bars and braided channels in a landscape that had naturally eroding soils. The pattern for increasing suspended sediment in a downstream direction along the mainstem Touchet River reflects continuous inputs from land-use sources. Natural features of the stream channel like gradient and sinuosity would normally have a greater effect on concentration and loads of suspended sediment. Physical stream characteristics like suspended sediment and temperature are frequently influenced by anthropogenic activity whereas stream gradient and other underlying natural features do not change appreciably from nonpoint sources of pollution. However, these underlying physical features modify the effect of introduced pollutants and pollution resulting from these introductions.

Stressor gradients appear to be clearly defined among several independent studies. The setting, anthropogenic alterations, and species of concern are affected by the same primary limiting factors based on a variety of assessment approaches. Temperature and increases in fine sediment delivery were identified as primary causes for biological impairment in these studies. Habitat complexity/diversity is an important broad-scale characteristic of the drainage and necessary for inclusion in further assessments. All biological communities rely on habitat diversity for completion of specific life stages as well as for escape under stressful aquatic conditions. Conclusions from this casual analysis should be used along with TMDL recommendations in order to reduce pollutant loads and to guide future restoration strategies. Future biological surveys in this watershed will determine the effectiveness of TMDL implementation efforts. This approach provides inexpensive and useful information for evaluating overall implementation effects and specific pollutant reductions.

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