Developing Environmental Flows for Fish and Wildlife:

A Mesohabitat Study on the Niobrara River

Revised Final Report

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A Mesohabitat Study on the Niobrara River

by

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and

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for

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Glossary

ACTogram	Analysis of Continuous Threshold: a graphical tool developed to capture the habitat variability and help to trigger management actions based on the durations of low flow events.
Allowable duration of habitat event	Typical duration for which habitat can be lower than a threshold without causing persistent habitat limitations. It is defined as the lowermost inflection point on the appropriate UCUT curve.
Akal	Medium to fine gravel (0.2 - 2 cm or 0.08 - 0.8 in).
Attribute	The physical components of a stream that are mapped in the MesoHABSIM models as *present*, *absent* or *abundant*. They include: Boulders, Riprap (manufactured concrete erosion control), Overhanging Vegetation, Submerged Vegetation, Canopy Shading, Undercut Bank, Woody Debris and Shallow Margin.
Backwater	Slack area along a channel margin caused by eddies behind obstructions, the development of sandbars during flood events, or through the abandonment of older channels.
Base flow	The flow corresponding to the common habitat threshold.
Bioperiod	Critical times in a year when particular habitat conditions (i.e., flow) are required by a species to complete a life stage.
CA	Channel area.
Cascade	Stepped rapids with very small pools behind boulders and small waterfalls.
Catastrophic duration of habitat event	Pulse stressor by an event of unusually long duration, for which habitat is lower than a threshold causing severe habitat limitations. It is identified as the highest most inflection point on the appropriate UCUT curve. Catastrophic events occur naturally at decadal frequency.
Cfs	Flow in cubic feet per second.
Cfsm	Runoff in cubic feet per second per square mile.
Choriotop	A substrate classification system based on the Austrian Standard ONORM 6232.
Community Habitat	A sum of habitat available for the fish community, where habitat for each species is weighted by the expected proportions of the species in the community. Hence, Community Habitat reflects how well habitat structure corresponds with expected community structure.
Common habitat threshold	The habitat magnitude occurring with regular frequency on a seasonal basis. Commonly the habitat magnitude is lower than common threshold. Habitat limitations occur only with extended duration of these events.
CPOM	Coarse particulate organic matter (e.g., fallen leaves).

Critical habitat threshold	A habitat magnitude that occurs more frequently than *rare event*, below which the habitat circumstances rapidly decrease to the rare level. If habitat is lower than critical threshold, it is a warning that management actions are needed.
Debris	Organic and inorganic matter deposited within the splash zone area by wave motion and changing water levels (e.g., mussel and snail shells).
Detritus	Deposits of particulate organic matter. Different types are CPOM (coarse particulate organic matter) and FPOM (fine particulate organic matter).
EPA	Environmental Protection Agency.
Exceedance probability	The probability that a reference level will be exceeded for a given amount of time.
Fast run	Uniformly fast-flowing stream channel.
Fluvial dependent fish	Fish species that need flowing water to complete a portion of their life history.
Fluvial specialist fish	Fish species that need flowing water throughout the year to complete their life history.
FSA	Farm Security Administration.
Gaining stream	A stream that obtains water from groundwater or submerged spring inputs.
Gigalithal	Bedrock substrate.
GIS	Geographic information system.
Glide	Moderately shallow stream channel with laminar flow. Lacks pronounced turbulence and exhibits flat streambed morphology.
GPS	Global positioning system.
GRAF	Generic resident adult fish.
Generic Fish habitat	The total amount of habitat available for the fish community. It is independent from the expected community structure.
Habitat event	Continuous period in which the quantity of habitat (relative habitat area) stays under a predefined threshold.
Habitograph	A diagram of daily habitat time series.
HMU	Hydromorphological unit.
HST	Habitat stressor threshold. A magnitude of habitat demarcating changes in frequency of occurrence of levels higher and lower than the threshold.
IHA	Indicators of hydrologic alteration.
LWD	Large woody debris.
Macrohabitat generalist fish	Fish species capable of living in various systems including lakes, reservoirs, and streams.

Macrolithal	Coarse blocks, head-sized cobbles, mix of cobbles, gravel and sand (20 – 40 cm or 7.9 - 15.8 in).
Megalithal	Large cobbles, blocks and bedrock (>40 cm or >15.8 in).
MesoHABSIM	A computer simulation of meso-scale habitat.
Mesolithal	Fist- to hand-sized cobbles with a mixture of medium to fine gravel (6.3 - 20 cm or 2.5 - 7.9 in).
Microlithal	Coarse gravel with a mixture of medium to fine gravel (2 - 6.3 cm or 0.8 - 2.5 in).
NDEQ	Nebraska Department of Environmental Quality.
NGPC	Nebraska Game and Parks Commission.
NHI	Natural heritage inventory.
NPPD	Nebraska Public Power District.
NPS	National Park Service.
NRD	Nebraska Department of Natural Resources.
NSD	Number of stress days.
PAE	Prepositioned area electrofisher grid units are used to collect fish within a predetermined and constant area.
Pelal	Silt, loam, clay and sludge (<0.063 mm or 0.002 in).
Persistent habitat event	Ramp disturbance for which habitat is lower than a threshold. The disturbance is longer than allowable yet shorter than catastrophic. They can occur with annual frequency, but four consecutive persistent events are considered catastrophic.
Phytal	Submerged plants, floating stands or mats.
Plunge pool	Area where main flow passes over a complete channel obstruction and drops vertically to scour the streambed.
Pool	Deep water impounded by a channel blockage or partial channel obstruction. Slow velocities with a concave streambed shape.
Ramp disturbance	Habitat limitation that through continuous duration causes an increased alteration of species composition.
Psammal	Sand (0.063 - 2 mm or 0.002 - 0.08 in).
Pulse stressor	Habitat limitation that causes an instantaneous alteration in fish community structure.
R&G	Rearing and growth bioperiod.
Rapid	Higher gradient reach than a riffle, with faster current velocity, coarser choriotop, more surface turbulence, and convex streambed morphology.
Rare habitat event	Habitat magnitude that happens infrequently and for only a short period of time.

River region	The Niobrara River is categorized into three broad river regions based on sinuosity, channel width, canyon constriction, island presence and braidedness.
RFC	Reference Fish Community. A model representing expected proportions of fish species that would naturally occur in the river.
Riffle	Shallow stream reach with moderate current velocity, some surface turbulence, high gradient and convex streambed morphology.
RRI	Rushing Rivers Institute.
RTE	Rare, threatened and endangered species.
Ruffle	De-watered rapid in transition to either run or riffle.
Run	Deeper stream reach with moderate current velocity, but no surface turbulence (laminar flow). The streambed is longitudinally flat and laterally concave.
Runoff	Flow per drainage area at the measurement's location.
Sapropel	Organic sludge.
Section	Sub-divisions of the large-scale river regions based on in-channel morphological characteristics.
Segment	The Niobrara River Study Area is comprised of three segments. Segment 1 (Sections/Sites 1-3); Segment 2 (Sections/Sites 4-5); Segment 3 (Sections/Sites 6-16).
Shallow margin	River areas less than 30 cm deep with velocities under 10 cm/sec; juvenile fish can find refuge here.
Side arm	Channel around an island, smaller than half the width of the river, frequently at a different elevation than the main channel.
Site	Each section is represented by a site.
Subsistence flow	Flow corresponding with rare habitat magnitude.
Tolerance	The ability of certain aquatic species to withstand or survive pollution or temperature changes in the river ecosystem.
TNC	The Nature Conservancy.
TFC	Target Fish Community. A model representing expected proportions of native fish species, which often serves as a restoration target (Bain and Meixler, 2008).
UCUT	Uniform Continuous Under Threshold. A method for analyzing frequency and duration of low flow (or habitat) events. Represents the frequency of habitat events for which habitat is below a threshold for a continuous duration of time.
Undercut bank	A river bank that has been eroded beneath the surface by the current; serves as habitat for certain fish species.
USEPA	United States Environmental Protection Agency.
USFWS	United States Fish and Wildlife Service

USGS	United States Geological Survey.
Wetted area	The area of a river channel that is in contact with water.
WPA	Works Progress Administration.
XFC	Expected fish community.
YoY	(Young of Year). This term is used to describe captured fish, or modeled habitat for fish that are in their first year of life.
Zone	The fishing survey is delineated into four zones. Zones are based on variations in geomorphic characteristics, hydraulic features and community assemblages. Zone 1 - Missouri Confluence to Spencer Hydro Dam; Zone 2 - Spencer Hydro Dam to Norden Chute; Zone 3 - Norden Chute to Cornell Dam; and Zone 4 - Cornell Dam to Box Butte Dam.

Executive Summary

Introduction

This report details the process utilized in developing a scientific basis for determining protected instream flows for the Niobrara River in Nebraska. The goals of the project are to document the current conditions, as well as to identify the instream flows and specific flow regimes needed to provide adequate habitat diversity for species and guilds presently found within the Niobrara River.

The Niobrara watershed, a sub-basin of the Missouri watershed, covers approximately 32,600 km^2, of which 90% lies within northern Nebraska. The remaining portions extend into eastern Wyoming and southern South Dakota (Chapman *et al.*, 2001; Schnieder *et al.*, 2005). The river is of an alluvial type that can be divided into three broadly defined river regions: a braided region extending from the confluence with the Missouri River upstream approximately to the Norden Chute; a canyon-restricted region extending from Norden Chute to Box Butte Creek; and a region with wider valleys and increased sinuosity extending from Box Butte Creek to the Dunlap Diversion Dam at Box Butte Reservoir (Alexander, 2009).

The Niobrara River's water source is primarily ground water seepage from underlying geological formations, but seasonal precipitation patterns are also a vital component to the hydrography (Istanbulluoglu, 2008). The dominant land use in the basin today is cattle ranching (>70%), but row crops account for 20% of the watershed and are concentrated in areas where adequate water sources are currently available (Peters, 2000). Anthropogenic diversions within the basin include dams and irrigation reservoirs along with groundwater wells. All of these uses have the ability to change the river and the surrounding ecosystem.

Two long term USGS discharge gaging stations are currently available on the mainstem of the Niobrara River. These are the Verdel gage, located near the Niobrara's confluence with the Missouri River, and the Sparks gage, located downstream of Valentine, Nebraska (**Figure 1**). The data recorded by these two gages are used throughout the report for referencing survey flows and for use in flow time series analysis.

Methods

MesoHABSIM model and surveys

In determining the riverine habitat characteristics and the habitat required for various faunal species within the basin, we utilized the Mesohabitat Simulation Model (MesoHABSIM) (Parasiewicz, 2007). The changing spatial distributions of physical habitat as a result of variations in flow and cover, as well as the biological responses by aquatic species to these changes, provide the basis for simulating the consequences of ecosystem alteration. The method collects data at the mesohabitat level as defined by discrete hydromorphological units (HMUs, such as pools and rapids) where hydraulics, fish cover and other hydrological characteristics are recorded. Mesohabitats are mapped in representative sites under multiple flow conditions and evaluated with the help of fish habitat preference functions.

Sixteen representative sites were chosen as a surrogate for each of the project's 16 sections **(Figure 1).** These sites and sections were chosen after reviewing the extensive USGS data set, and by conducting a reconnaissance survey. Due to expected differences in fish communities, the 16 sections were grouped into three study segments based in part on the similarity of their fish communities. Segment 1 (Sections 1 -3) includes the lower Niobrara and delta region up to Spencer Dam **(Figure 1)**. Segment 2 (Sections 4 and 5) includes the braided sites between the Spencer Dam and the Norden Chute. Segment 3 (Sections 6 through 16) includes the remainder of the study area, where fish can migrate freely with the exception of Site 6 on the downstream side of Cornell Dam. In our project, we use the Verdel gage flow record to analyze Segments 1 and 2, and the Sparks gage to analyze Segment 3. Daily average discharge data for the Sparks and Verdel gages for the record between June 1966 and September 2010 were used in the modeling.

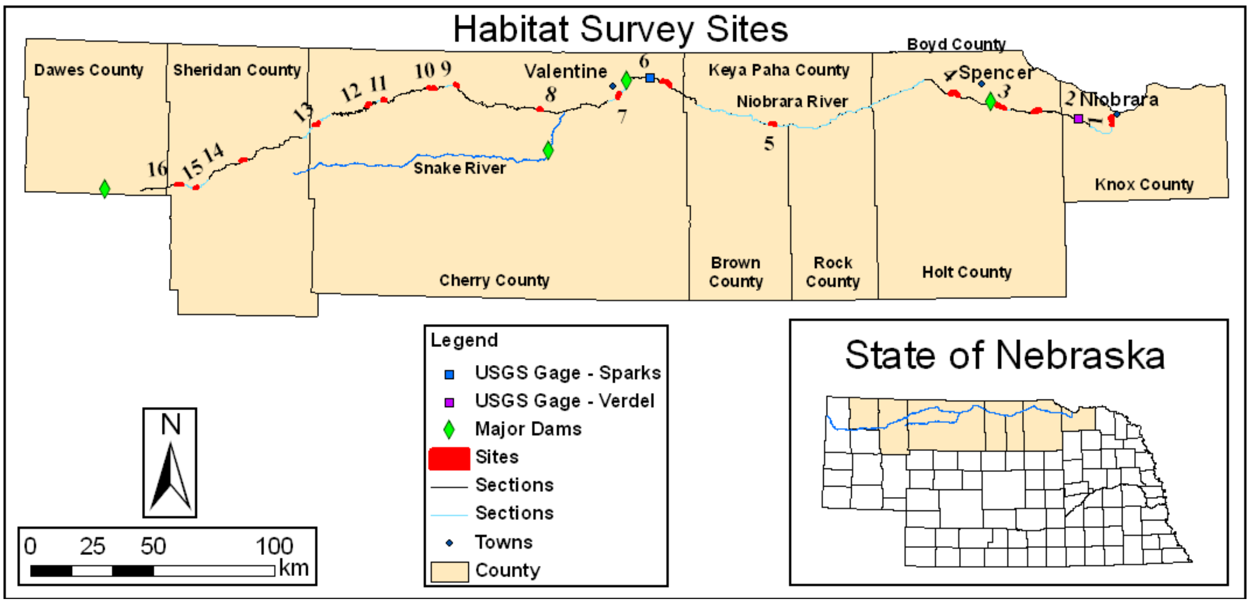

Figure 1: Study area for the Niobrara River. Map shows section and site locations.

Habitat mapping surveys were completed at three target flows chosen after examining the historical annual hydrographs for the Sparks and Verdel USGS gages. The flows can be thought of as approximating a typical sustained spring high flow, a summertime low flow and an intermediate flow.

Modeled fauna

We modeled habitat availability for species of interest within the Niobrara River Basin. Using historical data, concurrent surveys, and input from biologists from participating agencies, we identified target fauna species (Table 1) that could serve as indicators of habitat conditions necessary for protection of aquatic communities. Thirteen of the geologically, hydraulically, and geographically distinct study sites were sampled to develop the Expected Fish Community (XFC) as a starting point to model habitat availability for target species. Data for some species within the XFC were limited due to low catches. We therefore developed five guilds (e.g., groupings of similar habitat uses) to further characterize the habitat needs of fish in the Niobrara River.

We named the five guilds based on common habitat measures (e.g., depth, velocity, etc.): Lobate Margin, Run, Riffle, Slackwater, and Habitat Generalist. In addition to the guilds, the habitat availability of individual species of interest was investigated (**Table 1**). Furthermore, three avian species (Whooping Crane, Piping Plover, and Interior Least Tern) were also species of interest and therefore considered target species.

Table 1: Species modeled for the Rearing and Growth bioperiod in the five habitat use guilds, along with the species of special interest modeled in the project. YOY is for young-of-the-year fish.

Species included in Guilds		Species of Special Interest
Bigmouth Shiner	Bluegill	Paddlefish
Red Shiner	Brassy Minnow	Pallid Sturgeon
Plains Topminnow	Central Stone Roller	Shovelnose Sturgeon
Largemouth Bass	Longnose Dace	Sauger
Fathead Minnow	River Shiner	Adult Channel Catfish
Brook Stickleback	Green Sunfish	Interior Least Tern
YOY Channel Catfish	Yellow Perch	Piping Plover
River Carpsucker	Creek Chub	Whooping Crane
Emerald Shiner	White Sucker	
Sand Shiner	Shorthead Redhorse	

Faunal habitat needs vary seasonally due to different life stages (e.g., spawning or over-wintering) as well as changing environmental conditions. This is captured in the concept of bioperiods (Parasiewicz, 2008). Bioperiods are seasons characterized by the habitat requirements of the fauna and by the flow regime as each varies through the course of a calendar year. Protective instream flows can be developed for each of these periods. **Table 2** shows the bioperiods for the Niobrara Study area used for this project.

Table 2: Bioperiods for the Niobrara River study area and the indicated target community.

Bioperiod	Start Date	End Date	Indicator
Early Spawning	March 1st	May 14th	Generic Resident Adult Fish
Late Spawning	May 15th	June 30th	Generic Resident Adult Fish
Summer Rearing and Growth	July 1st	September 30th	Generic Resident Adult Fish
Overwintering Early	October 1st	December 31st	Flows
Overwintering Late	January 1st	February 28th	Flows

Habitat suitability

Habitat suitability criteria models were created for fish guilds and individual targeted species during the reproductive and the rearing and growth bioperiods periods for the Niobrara River. The model criteria were used to evaluate the habitat quality in the mapped areas of the river. Species and guild-based habitat model criteria were established from empirical data collected in the Niobrara River, as well as through literature review and the input of expert opinion. Habitat suitability for all investigated species were calculated for each mapped HMU. Subsequently, HMUs were assigned to unsuitable, suitable, or optimal categories and depicted in suitability maps. The amount of habitat determined to be suitable in the river was quantified for each flow as a proportion of the river channel area. The change of suitable habitat area across the range of flows was represented in habitat rating curves. In addition to curves for individual species, rating curves for Community Habitat, Generic Fish, and Generic Fish Plus were calculated (Parasiewicz, 2007). Rating curves for Community Habitat are constructed by weighing the suitable habitat area of each species by its expected proportion in the community, while Generic Fish Habitat curves represent the total amount of habitat area that is suitable for all of the species in the investigated community. Generic Fish Plus Habitat includes habitat for the additional species of special concern that were not included in the XFC.

We also analyzed the correspondence between the distribution of habitat at surveyed flows and the proportions of guilds in the community, illustrated with stacked bar diagrams. The similarity between the habitat structure and the guild community structure can be measured with the help of an affinity index (AI) model (Novak and Bode, 1992). Higher percent model affinity values indicate higher degrees of similarity between the community and available habitat. This information was used to determine the habitat status of the Niobrara River and to identify species/guilds that may have profound lack of habitat, and which should be investigated in more detail.

To investigate habitat availability over time, we analyzed the temporal flow and consequently, habitat patterns occurring in the historical time series. Specifically, we identified habitat levels that, because of their rare occurrence in the past, can be considered habitat stressor thresholds (HST) to substandard conditions. The HST describes the habitat availability as well as the durations for which the habitat area needs to be less than a chosen magnitude before creating conditions that are unremitting and can cause damage to the fauna. We identified *rare, critical and common* HSTs. There are specific flows that provide the habitat magnitudes defined by HST. Hence, we calculated seasonal flow thresholds enveloping *rare* and *common* HST for two project gaging locations, Sparks and Verdel, where we used the data to determine *base* flow, which corresponds to the *common* HST, and *subsistence* flow with the *rare* HST Trigger flow values correspond with the *critical* HST magnitude and are intended to “trigger” more closely durations of low flows followed by reactive management actions if HST durations are exceeded. The absolute minimum flow represents the lowest flow in the simulated time series. Ideally, this flow should never occur for longer than 1 day. The seasonal rules are presented in tables for each gage, for fish and avian fauna separately in the results section below.

The results of the modeling effort that estimate habitat availability in response to flows provide the ability to monitor habitat conditions using ACTograms. The ACTogram approach attempts to capture all essential parameters (flow, habitat, duration and function) in a single set of graphs that provides real-time functionality in an easy to understand and actionable figure.

Results

The habitat models documented a substantial amount of habitat for aquatic fauna in the Niobrara River. As demonstrated by the habitat rating curves for the Generic Fish Plus community (**Figure 2**), almost the entire wetted area can be utilized by the extended fish community. However, there are areas in the river that are not used by Generic Fish. The key difference between the two Generic Fish curves is the inclusion of the special interest fish species in the Generic Fish Plus analysis. These fish typically utilize the deeper river habitats where observational fish catch data is often lacking, therefore the Plus community curve is much closer to the available wetted area.

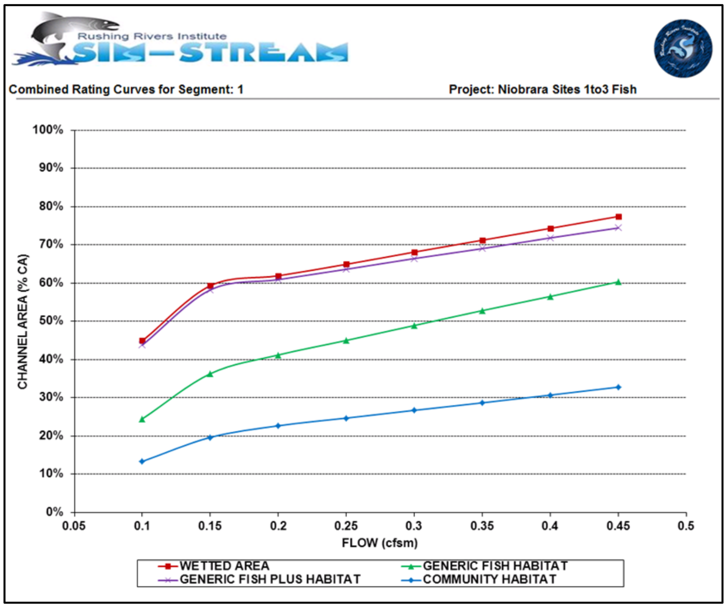

Figure 2: Community rating curves for Segment 1 (Sites 1-3) in the Niobrara River.

Figure 3 demonstrates the relationship between habitat that should be available in proportion to the expected fish community and the modeled habitat availability at selected flows in Segment 1. In Segment 1, the habitat for the Lobate Margin Guild seems to be underrepresented, and at flows of 0.1 cfsm, Run Guild habitat is in greater than expected proportions (**Figure 3**). In Segment 2, the Lobate Margin Guild habitat is abundant at the cost of habitat for the Habitat Generalist Guild. In Segment 3, there is a shift from Lobate Margin Guild habitats into Run Guild habitats and there is a slight increase in Habitat Generalist Guild habitat.

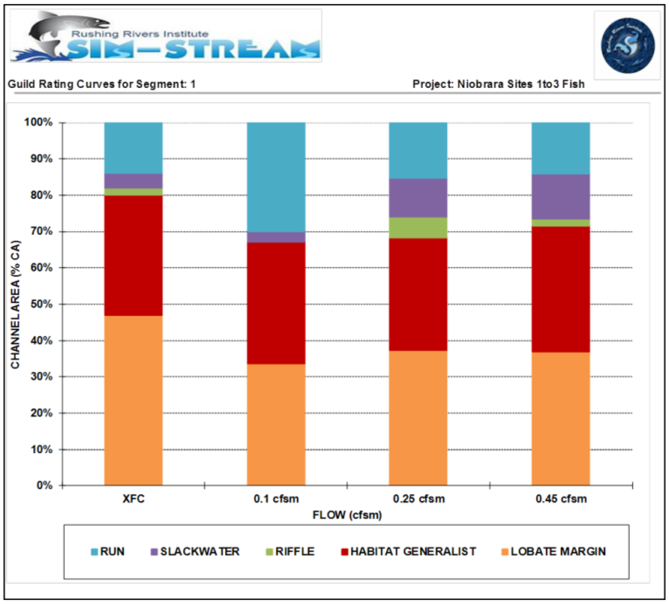

Figure 3: A comparison of the expected fish community (XFC) for Segment 1 with the model results at three flow levels.

The affinity index calculation for the three segments is presented in **Table 3** below.

Table 3: The affinity between the XFC and habitat structure at three selected flows. The values at the top of each column indicate the chosen flow threshold in cfsm combined for the two gages used in the study.

Segment	0.1/0.04 cfsm	0.25/0.01 cfsm	0.45/0.16 cfsm	Average
1	71%	83%	89%	81%
2	77%	66%	57%	67%
3	75%	86%	71%	77%

The study's affinity index values are mostly high, and AI's above 70% are usually observed in healthy rivers. The only exception is for Segment 2, which is a transition area between the fish communities of the other two segments. We can therefore conclude that the overall habitat distribution is appropriate to support the expected fish community and the observed discrepancies are the consequence of natural hydromorphological and biological variability of the river that may not be captured by snapshot observations of a single survey.

Habitat time series analysis

Analysis of the habitat time series documented typical habitat fluctuations that fish fauna would expect to experience in the river. The seasonal flow thresholds enveloping rare and common conditions for fish and avian species are presented in **Tables 4 and 5** for the Verdel gage and for fish in **Table 6** for the Sparks gage.

Table 4: Selected flow thresholds for fish in Segments 1 and 2 of the Niobrara River using the Verdel USGS gage.

Bioperiod **Approximate dates**	**Rearing & Growth** **July 1 - Sept. 30**	**R & G Generic Plus** **July 1 - Sept. 30**	**Overwintering Early** **Oct. 1 - Dec. 31**
Location Verdel Gage	**Threshold flows**	**Threshold flows**	**Threshold flows**
Base flow (cfs)	1725	1806	1969
Allowable duration under (days)	32	32	45
Catastrophic duration (days)	92	92	92
Trigger flow (cfs)	718	695	1158
Allowable duration under (days)	8	7	9
Catastrophic duration (days)	16	11	18
Subsistence flow (cfs)	625	637	926
Allowable duration under (days)	5	4	6
Catastrophic duration (days)	8	8	10
Minimum flow (cfs)	338	338	200
Bioperiod **Approximate dates**	**Overwintering Late** **January 1 - February 28**	**Early Spawning** **March 1 - May 14**	**Late Spawning** **May 15 - June 30**
Location Verdel Gage	**Threshold flows**	**Threshold flows**	**Threshold flows**
Base flow (cfs)	2084	2270	2270
Allowable duration under (days)	21	18	20
Catastrophic duration (days)	59	55	47
Trigger flow (cfs)	926	1390	1204
Allowable duration under (days)	7	7	7
Catastrophic duration (days)	8	11	11
Subsistence flow (cfs)	695	1297	1100
Allowable duration under (days)	4	3	6
Catastrophic duration (days)	5	8	9
Minimum flow (cfs)	240	430	646

Table 5: Selected flow thresholds for the modeled bird species in the Niobrara River using the Verdel USGS gage.

Bioperiod Approximate dates	Crane April 1 - April 30	Plover May 1 - August 31	Tern May 1 - August 31	Crane Oct. 1 - Oct. 31
Location: Verdel Gage	**Threshold flows**	**Threshold flows**	**Threshold flows**	**Threshold flows**
Base flow (cfs)	1806	1424	1818	1714
Allowable duration under (days)	11	24	34	18
Catastrophic duration (days)	17	68	81	31
Trigger flow (cfs)	1552	961	695	1540
Allowable duration under (days)	6	15	9	5
Catastrophic duration (days)	11	35	11	9
Subsistence flow (cfs)	1332	903	591	1332
Allowable duration under (days)	3	14	6	4
Catastrophic duration (days)	5	28	8	6
Minimum flow (cfs)	705	338	338	683

Table 6: Selected flow thresholds for fish in Segment 3 of the Niobrara River using the Sparks USGS gage.

Bioperiod Approximate dates	Rearing & Growth July 1 - Sept. 30	R & G Generic Plus July 1 - Sept. 30	Overwintering Early Oct. 1 - Dec. 31
Location Sparks Gage	**Threshold flows**	**Threshold flows**	**Threshold flows**
Base flow (cfs)	665	N/A	894
Allowable duration under (days)	47	N/A	46
Catastrophic duration (days)	92	N/A	92
Trigger flow (cfs)	465	N/A	536
Allowable duration under (days)	11	N/A	8
Catastrophic duration (days)	30	N/A	25
Subsistence flow (cfs)	436	N/A	465
Allowable duration under (days)	10	N/A	4
Catastrophic duration (days)	21	N/A	6
Minimum flow (cfs)	317	N/A	200
Bioperiod Approximate dates	**Overwintering Late January 1 - February 28**	**Early Spawning March 1 - May 14**	**Late Spawning May 15 - June 30**
Location Sparks Gage	**Threshold flows**	**Threshold flows**	**Threshold flows**
Base flow (cfs)	965	701	701
Allowable duration under (days)	22	39	12
Catastrophic duration (days)	59	54	29
Trigger flow (cfs)	608	515	515
Allowable duration under (days)	7	6	4
Catastrophic duration (days)	12	9	6
Subsistence flow (cfs)	536	493	493
Allowable duration under (days)	4	3	3
Catastrophic duration (days)	7	6	5
Minimum flow (cfs)	240	200	360

An example of the ACTograms developed with the help of tables 4 and 6 for specific bioperiods at the Verdel and Sparks USGS gages are presented below in **Figures 4 and 5**.

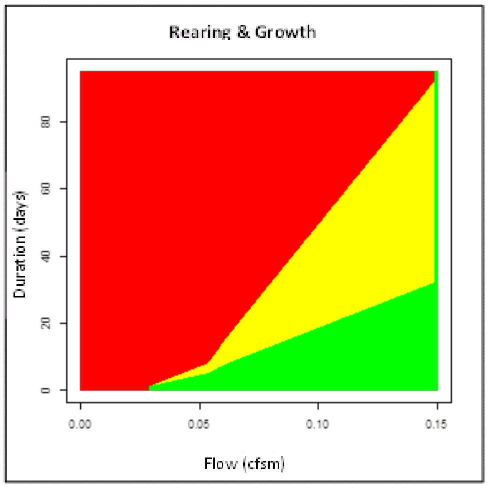

Figure 4: ACTogram for the Rearing & Growth bioperiod relevant to the Verdel Gage.

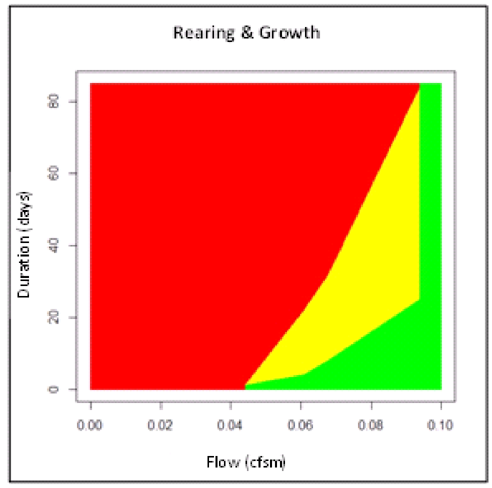

Figure 5: ACTogram for the Rearing & Growth bioperiod relevant to the Sparks Gage.

Discussion

Our study documented that the Community Habitat availability is lower than Generic Fish habitat. This indicates that the habitat structure potentially deviates from the fish community structure, i.e., guilds that are expected to represent the community in low numbers actually have a higher proportion of suitable habitat. This also means that guilds that were expected to represent the community in high numbers in turn have a lower proportion of suitable habitat.

However, the affinity values are generally high and document a relatively healthy river. The only exception is in Segment 2, which is a transition area between the fish communities of the other two segments. We can therefore conclude that the overall habitat distribution is appropriate to support the expected fish community, and the observed discrepancies are the consequence of natural hydromorphological and biological variability of the river.

The selected flow criteria for avian fauna do not always fall below the flows necessary to protect fish communities. Therefore, it needs to be considered whether for some periods dual criteria (fish and birds) should be applied. This means that, for example, during July the violation of criteria for fish as well as for plovers needs to be observed and reacted to.

The flow guidelines that would protect the current status of the Niobrara River should reflect the intra- and inter-annual variability of flow patterns. The purpose is therefore not to eliminate *persistent* and *catastrophic* conditions but to limit their frequency to the currently occurring level. Consequently, we propose as a general principle to maintain historical frequency of low flow events. This means that in one bioperiod the *catastrophic* conditions should not occur more often than once every 10 years and the *persistent* conditions should not occur more often than three times during three consecutive years. Therefore, action is required only if these frequencies are exceeded.

Each bioperiod should be monitored according to separate seasonally specific rules. The durations of each under-threshold event will be counted as they occur. To better reflect the natural variation at the border between bioperiods, a five day transition period can be considered, during which the rules for both neighboring bioperiods apply. This will assure that the prolonged durations of under-threshold events from one bioperiod season will continue to be recorded in the one that follows, instead of being ignored.

The above rule would allow mimicking natural habitat variability. Analysis of past flow time series reveals that preventive actions such as reducing water withdrawals would occur very sporadically, if at all, under current water use and management practices. However, additional water appropriations would cause increases in the frequency of such events and reduce the reliability of the current water supply at a cost to the present human and faunal water users dependent upon the Niobrara River.

Chapter 1.0: Project Introduction

Purpose, Objectives and Content

Through this project, we quantify the habitat availability for several habitat use guilds and species of interest in study sections of the Niobrara River. Our research investigated the river from Box Butte Reservoir to the confluence with the Missouri River using data collected over three flow conditions (i.e., summer low, intermediate, high) for use in further data extrapolation and model development. The relationship of hydromorphologic features to fish/wildlife presence and abundance is used to evaluate critical flow thresholds in the study area to ensure that adequate biological habitat needs are met under today's river conditions.

Accomplishing the above objectives requires the accumulation of existing data on geomorphology, hydrology, and habitat quality to identify homogenous segments; fish data to establish a target species list; a reconnaissance survey to validate the existing data; the identification of focus sections and sampling locations; habitat data collection and ultimately model development.

Terrestrial and aquatic ecosystems are intimately related to the hydro-geomorphic behavior of river basins under a given climate. Climate and human intervention control the hydrological variability of river flows (e.g., frequency, magnitude, duration, timing and rate of change). Physical stream processes, biological resources, and recreational values of a stream depend on the hydrologic regime. Many examples in the literature document that geomorphic organization in rivers takes place during rare, short-duration and high-magnitude floods, which are hard to forecast and control (Hooke, 1986). Flows less than these high-magnitude events, on the other hand, may be critical for maintaining fish and wildlife populations, in-stream vegetation, and recreational use (e.g., Gordon *et al.*, 2004). Our research focuses on, but is not limited to, summer low flows that may be most sensitive to human use.

Scope of Work

The Niobrara River is primarily a groundwater-fed stream that drains approximately 32,600 km^2, mostly from the Nebraska Sandhills. The headwaters of the Niobrara River begin near Lusk, WY, and the main stem of the river runs east across northern Nebraska. There are four major structures in the Niobrara River basin that modify the natural flow patterns: the Mirage Flats Project; Merritt Dam and Reservoir; Cornell Dam and Spencer Dam. Given these structures, the Niobrara still remains relatively intact hydrologically and is thus an important ecosystem for maintaining fish and wildlife resources in Nebraska. This project has been initiated to assess the current aquatic habitat availability across a range of flows to ensure that critical habitat is available for fish and wildlife species.

This report describes the current hydromorphological and habitat character of the study area, as well as quantifies the habitat available to selected fish guilds, individual fish and avian species of interest.

The text below presents the scope of work for this study, and summarizes how each task was completed.

Goals

The goal of the Niobrara River instream flow assessment is to determine instream flow quantities necessary for designated reaches to maintain habitat abundance and diversity for riverine fish and wildlife populations. Specific information on the following questions is lacking:

- What river flow is needed to provide adequate habitat for specific species/guilds?
- What flow regime is needed to provide habitat diversity for species/guilds?
- What are the flows needed to provide maintenance habitat diversity for species/guilds?
- Are there different flow requirements across fauna life-stages?

Objectives and Tasks

1) Quantify existing habitats and develop a model of habitat availability related to flow in the Niobrara River.
2) Identify and model available habitat used by target species, life-stages, and/or guilds in the Niobrara River over a range of flows.
3) Recommend flows needed (i.e., magnitude, frequency, duration, timing and rate of change of flows) in the Niobrara River to sustain the existing fish and wildlife community composition (presence/absence) and structure (abundance). The model will identify, to the extent possible, the specific flow requirements necessary to meet the needs of these species and communities throughout their various life stages.

MesoHABSIM

This project utilized the Mesohabitat Simulation Model (MesoHABSIM) approach (**Figure 6**), which will be presented throughout the report. In brief, MesoHABSIM assesses the status quo of river habitat availability and defines the requirements of watershed-based management of running waters. It builds upon earlier physical habitat simulation models (e.g., PHABSIM (Milhous et al., 1989)) to present the habitat availability for species at varying flows and in the case of simulations, predicts an aquatic community's response to habitat modification. The changing spatial distributions of physical attributes of a river provide the basis for presenting the current ecological status of the river because of variations in flow and the biological responses of aquatic species to these changes. In some cases, this approach can be used to simulate the consequences of ecosystem alteration and consequently provide justification for restoration measures.

MesoHABSIM modifies the data acquisition technique and analytical approach of other habitat assessment models by changing the scale of resolution from micro- to meso-scale. Due to this increase in scale, the model takes into account the variations in stream morphology along the river and is more applicable to large-scale issues. Habitat and fish measurements at larger spatial units are more practical, more relevant to river management, and more conducive to habitat modeling.

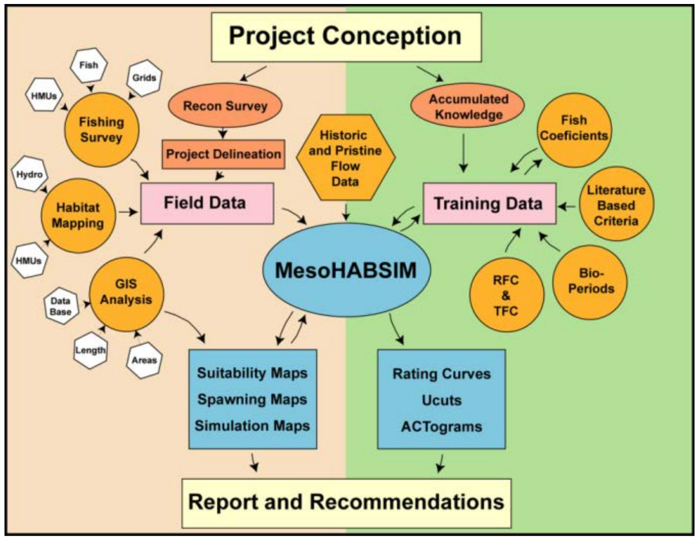

Figure 6: A simplified schematic illustrating the key components of the MesoHABSIM approach. Field collected data (left side) is filtered using weighted coefficients through Sim-Stream software (right) to develop a number of outputs and products.

Mesohabitat types are defined by their hydromorphological units (HMUs). HMUs are areas of similar habitat such as pools and rapids. Each HMU contains a unique combination of hydraulic conditions, substrate, physical structure that provides cover for aquatic animals,and bank properties. Mesohabitats are mapped under multiple flow conditions at extensive sites along the river. Fish or invertebrate data are collected in randomly distributed mesohabitats where habitat surveys are also conducted. These data are used for developing mathematical models that describe which mesohabitats are used by animals more frequently. It is important to note that the relationship between the physical habitat and animals' responses is determined by HMU type only. Other habitat descriptors such as distribution of depth and velocity or cover play the same or sometimes stronger role in mesohabitat habitat use. There may be a substantial difference between fast flowing and slow flowing *run*, or *run* with woody debris in terms of the suitability value of the unit. The models allow evaluating habitat availability at a range of flows.

Rating curves are developed to represent the relative changes in suitable habitat area in response to flow and allow for the determination of habitat quantity at any given flow within the range of surveys. These rating curves can be developed for river units of any size, making them useful for drawing conclusions about the suitability of channel patterns or habitat structures for various species of fish for specific sections or for the entire river. Rating curves can also be used to evaluate the benefits of various restoration measures on the entire fish community.

In combination with hydrologic time series, rating curves are used to create habitographs that can be analyzed with the help of Uniform Continuous-Under-Threshold (UCUT) curves for the frequency, magnitude and duration of significant habitat events (Parasiewicz, 2007b). The UCUT curves evaluate continuous durations of unsuitable habitat under a specified threshold. UCUT curves serve as a basis for the development of ACTograms that managers can use to determine how long a given species can tolerate unsuitable conditions depending on its life stage. These curves will be developed and explained throughout the report.

MesoHABSIM is designed to assess habitat availability not only for individual species but also for guilds or an entire aquatic community in order to analyze and predict ecosystem potential. For this purpose, we determine the composition of the native fish using the Target Fish Community approach, described by Bain and Meixler (2000). A comprehensive list of species is generated from literature sources and available regional data collected on relatively intact river reaches. The species are ranked on the basis of abundance in the long-term fish collection data and expected proportions of each species are calculated. Community structure may change seasonally, therefore requiring the development of models for each critical season (i.e., bioperiod). Bioperiods account for specific habitat needs for aquatic and terrestrial organisms to complete required life-cycle stages at a given time of year (e.g., spawning, rearing and growth, over-winter, etc.)

The results of MesoHABSIM create the framework for integrative analyses of many aspects of the ecosystem. In some projects, MesoHABSIM also allows managers to recreate reference habitat conditions and evaluate possible instream and watershed restoration measures or alterations, such as dam removals or changes in water withdrawals.

Principal benefits of the MesoHABSIM approach are:

- It offers a quantitative assessment of the current ecological status and planned actions.
- It operates on a scale that is relevant for data collection and river management.
- The model produces quantitative status snapshots and restoration endpoints.
- The model is established on a solid ecological background.
- It is designed to address habitat needs of entire aquatic communities (fish, avifauna and macroinvertebrates).
- It offers the ability for trade-offs between habitat structure and flow quantity.
- Through GIS framework, it has effective simulation capabilities.
- The outputs are designed to be comprehensible to non-scientists.
- The validation of the meso-scale model is less affected by coincidence in snapshot observations then micro-scale models.
- Flexibility and open architecture.

While this is a brief introduction to the MesoHABSIM method, there are many papers and projects around the world that will provide more information on the theory behind the technique. Additionally, if new to the method we recommend Parasiewicz 2007, Parasiewicz 2008 and Parasiewicz *et al.*, 2013 for more about the MesoHABSIM technique and its application.

Data Sources

In developing this project, part of our responsibility was to review existing literature, research historical information, and identify any ongoing studies concerning the Niobrara River and its watershed. The search centered around the historic land usage of the watershed, the change in ecological systems over time due to flow alteration and the current state of the watershed with a focus on riverine ecology. Key data sources will be highlighted below.

Reports

A literature survey was conducted to evaluate current knowledge regarding the Niobrara River and basin. We researched peer reviewed journal articles, published books, surveys, and unpublished work. Much of the grey literature obtained was in the form of government reports or informative data, such as fact sheets. Many of the literature sources were obtained directly from government agencies, the University of Nebraska-Lincoln (UNL), and the Nebraska Library Council. All data pertaining to biological, ecological, historical, geological and economical sources were considered applicable.

Historic data were primarily obtained from graduate work and can be found at UNL's Love library. However, other historical sources included published works that are widely available. Literature pertaining to ecology and biology of fishes and other organisms and their communities has primarily been furnished by agencies directly involved with the Niobrara River (Nebraska Game and Parks Commission [NGPC], Nebraska Department of Natural Resources [NRD], National Park Service [NPS], Nebraska Department of Environmental Quality [NDEQ], and the US Fish and Wildlife Service [USFWS]). When available, raw data from these reports were obtained and used. Unpublished biological and ecological literature was mostly in the form of graduate dissertations and theses. Graduate work often investigated specific components of the Niobrara River at a limited but precise scale.

Notable Resources

Simonds' (1999) research on historic reclamation projects gave a comprehensive historical setting for the importance of providing a continuous and reliable water resource for local residents, ranchers and farmers.

The US Department of the Interior, Bureau of Reclamation website provided a wealth of information (physical dimensions, usage, recreational opportunities, etc.) on the four main diversions outlined in the background section of the report.

A USGS report by Alexander *et al.* (2009) was utilized extensively to describe various characteristics of each of the segments, sections and sites in the study area.

Research by Wanner *et al.* (2009, 2010, 2011) provided the most up-to-date and in-depth examination of the fish communities in the Niobrara River. This information provided baseline data on species distributions, which, among other things, minimized the time required for field identification and processing.

GIS Data

Reports and files regarding geologic and geographic information (GIS) were provided by UNL and its respective departments. Data were obtained through UNL's GIS Data site (http://snr.unl.edu/data/geographygis/NebrGISdata.asp), the Nebraska Government website (http://www.dnr.state.ne.us/databank/spat.html), South Dakota Department of Environment and the Department of Natural Resources (http://denr.sd.gov/), the USGS National Map Seamless Server (http://seamless.usgs.gov/index.php) and directly from collaborators with the USGS. Data from these sources were compiled to create a base map of the study area.

The USDA's Geospatial Gateway (http://datagateway.nrcs.usda.gov/) provides various geospatial data ranging from census figures to National Hydrography datasets. By obtaining information from Geospatial Gateway we were able to analyze spatial data without having to heavily invest in the actual data acquisition, making geospatial calculations easier and less labor intensive.

Data on the geomorphic segmentation of the Niobrara River provided by the USGS was heavily referenced when developing study sections and choosing representative sites.

In-house development of maps and the collection of GIS ready data allowed us to utilize online resources and create the array of maps seen in this report and its appendices.

Chapter 1.1: Watershed Description

Geographical Settings of the Niobrara River

Understanding the Niobrara River and the habitat requirements of its aquatic and avian fauna requires a study of the past as well as the present. In this study, our goal is to develop a comprehensive understanding of the Niobrara River, which includes the terrestrial as well as the aquatic components that make up its unique character. The river, which is a vital economic, ecological and scenic component of northern Nebraska, needs to be understood as fully as possible to protect and ensure the common welfare of the flora, fauna and the elements of society that thrive upon or near its flowing reaches.

The Niobrara watershed, a sub-basin of the Missouri watershed, covers approximately 32,600 km^2 of which 90% lies within northern Nebraska and the remaining portions extend into eastern Wyoming and southern South Dakota. The Nebraska Legacy Project has identified eight Biologically Unique Landscapes within the basin's three distinct ecoregions (Chapman, 2001; Schnieder, 2005). The basin has four major tributary river systems (Verdige Creek, Long Pine Creek, Keya Paha River, and Snake River) that contribute to Nebraska's longest river, at approximately 568 miles (914 km) (Peters, 2000). The Niobrara River is used in many different ways to meet the needs of those living in the watershed, including: hydropower generation, irrigation of agricultural crops, water supply for ranches, water for domestic and recreational purposes and as a resource for native flora and fauna. Along with these the Niobrara River is also an integral part of the ecological processes that have been slowly evolving for millions of years to make this region the unique meeting spot for the diverse ecological zones found within the Great Plains.

Most of the land in the region is privately held, however, several large tracts of land are held in a conservation status, including the Niobrara National Scenic River, the Fort Niobrara National Wildlife Refuge, and The Nature Conservancy's Niobrara River Valley Preserve. A variety of floral eco-types exist within these conservation areas and in areas where development is limited. The Niobrara River borders the northern limits of the Nebraska Sandhills and in segments bisects its north-central portion. The Nebraska Sandhills are the largest intact sand dune complex in the Western Hemisphere (Bleed and Flowerday, 1998). The Sandhills grasslands begin in the western basin; proceeding east, the Sandhills give way to mixed-prairie grassland consisting of more mesic floral varieties (Kantak, 1995). The central stretch of the Niobrara River lies in an area considered to be a biological meeting place of the Great Plains. This area has been recognized by the US government for its unique characteristics. Along the riparian zone and active channel, deciduous and coniferous plants become the primary vegetation type. It is important to note that in many areas along the Niobrara, refugia for a variety of species can be found. For example, the north facing canyons, where cold ground water emerges, white birch *Betula papyrifera*, a primarily Rocky Mountain species, has established a foothold (Kaul *et al*., 1988).

Human History of the Watershed

Prior to the creation of the state of Nebraska, the area was home to numerous tribes such as the Sioux or Oceti Sakowin and the Ponca. These tribes also ranged into the Black Hills of South Dakota. The Ponca people called the river "Ní Ubthátha khe" meaning water spread out horizontally, and in the late 1800s the French named it "L'Eau qui Court" which means running water. The Nebraska territory was derived from a small portion of the Louisiana Purchase, a transaction with France completed in 1803. Around this time, colonial traders begin to arrive to the area, trapping and trading along the river near its confluence with the Missouri River. In the mid-1800s, people began moving west through this region in greater numbers on what became the Oregon Trail which ran along the Platte River. When gold was discovered in 1849, once again people surged through to seek their fortunes. The rapid migration to the area caused intense pressure on the native population and interactions became increasingly violent. By the late 1800s, most of the indigenous tribes were removed from their native lands and placed on distant reservations. Pioneer expansion and infrastructure modernization throughout Nebraska quickly followed this period. The Fremont, Elkhorn and Missouri Valley Railroad Company built several lines of tracks, some near the Niobrara River, thus improving access and encouraging settlement. The railroad also opened the rich soils and grasslands of western Nebraska to farmers. With the passing of the Homestead Act in 1862, the grasslands were divided and made available for farming and ranches within the Niobrara Watershed. From the onset, farmers in this region saw the need for augmenting the region's natural precipitation with an irrigation system to supply their crops on a regular basis. Irrigation has been an integral part of the history of Nebraska and critical to the people farming in this arid portion of the country. See **Appendix 1** for more detail.

Status Quo of Water Uses

Today, the uses of the Niobrara River are similar to those in the mid twentieth century, only now technology has allowed for greater utilization of the same finite resources of the river. The dominant land use in the basin today is cattle ranching (>70%), but row crops account for 20% of the watershed land use and are concentrated in areas where adequate water sources are available (Peters, 2000). The Niobrara River reached a critical point in 2007 when the Nebraska Department of Natural Resources labeled most of the river as "fully appropriated". However, in June 2011, the Nebraska Supreme Court reversed the January 2008 determination regarding a fully appropriated designation based on concerns regarding methodology (Schnieder, 2011).

The Niobrara River's water source is primarily derived through ground water seepage from underlying geological formations. Originating from the impermeability of the Pierre Shale and the proximity of the riverbed to bedrock, the two main aquifers supplying water for the Niobrara River Basin are the Arikaree and the Ogallala. The Arikaree lies on the western portion of the basin and beneath the immense Ogallala Aquifer (**Figure 7**), which underlies portions of eight different states. Most of Nebraska sits on top of the two to six million year old Ogallala Aquifer. The Arikaree is comprised predominantly of sandstone, siltstone, shale, and silty clay. The Ogallala consists of fine to medium sandstone and silty clay material (Long *et al.*, 2003). The gradual erosion of the Rocky Mountains provided the base material for the aquifer, which was then covered by windblown and alluvial sediment that filled the ancient valleys and channels of the present Niobrara River Basin. In the western portion of the Niobrara River, a majority of tributaries begin as seeps and result in many cold-water streams. Further east, within the National Scenic portion of the Niobrara River, these seeps create nearly 230 waterfalls. Water level fluctuations in the river are somewhat limited in the west because of the consistent aquifer discharge. In the east, however, water fluctuations increase with changes in soil type, precipitation, and distance in relation to the aquifer (Conservation and Survey Division, 1995; Istanbulluoglu, 2008).

Precipitation and groundwater contribution are vital components to the hydrography of the Niobrara River. Anthropogenic diversions within the basin include irrigation reservoirs and groundwater wells, and these uses have the ability to change the river and the surrounding ecosystem.

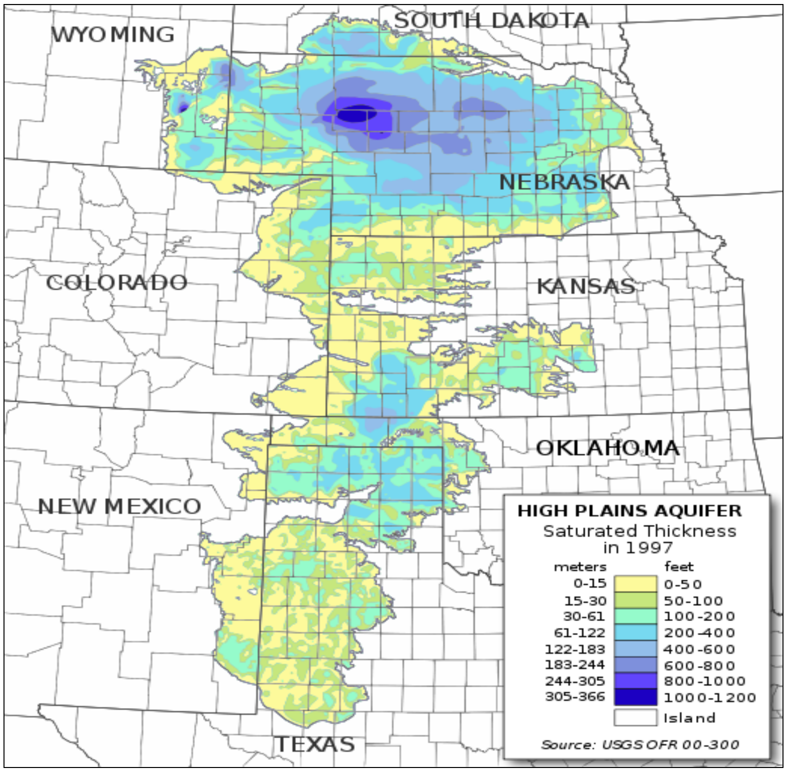

Figure 7: Shape and size of the Ogallala Aquifer system. Figure produced from GIS data by the USGS and published in Open File Report 00-300 (USGS OFR 00-300).

Chapter 1.2: Project Setup

Spatial Scale Terminology

Due to the size of the Niobrara River Study Area (>500 km), habitat surveying methods, and modeling techniques, specific terms referencing various spatial scales are used extensively throughout this report and associated appendices. These are described in **Table 7** below.

Table 7: Spatial scale terms and their usage within this report.

TERM	USAGE
River Region	The Niobrara River is categorized into three broad river regions based on sinuosity, channel width, canyon constriction, island presence, and braidedness.
Segment	The Niobrara River Study Area is comprised of three segments. Segment 1 (Sections/Sites 1-3), Segment 2 (Sections/Sites 4-5), Segment 3 (Sections/Sites 6-16). These Segments each have their own fish community assemblages.
Section	Sections are sub-divisions of large-scale river regions based on in-channel morphological characteristics. Cumulatively they cover the study area.
Site	Each Section is represented by an intensely studied Site that is determined by its morphometric similarity to the section as a whole. The Site or Representative Site is only a portion of the section that it represents.

Zone	The fishing survey is comprised of four zones. Zones are based on variations in geomorphic characteristics, hydraulic features and community assemblages. Zone 1 - Missouri Confluence to Spencer Hydro Dam; Zone 2 - Spencer Hydro Dam to Norden Chute; Zone 3 - Norden Chute to Cornell Dam; and Zone 4 - Cornell Dam to Box Butte Dam.

Study Area and Section Delineation

Several authors have described the Niobrara River's morphologic features differently, though each has consistently underscored the variety between and within sections. The Niobrara River is an alluvial river that provides a consistent amount of sediment transport due to geological and hydrological sources upstream. The river can be divided into three broadly defined categories (river regions) based on sinuosity, channel width, canyon constriction, island presence, and braidedness (Alexander *et al*., 2009). The braided river region begins at the confluence with the Missouri River and extends upstream approximately to the Norden Chute. It is exemplified by wide valleys, ephemeral and established islands, and braided channels. The braided channels range from 60 to 550 m with channel depths of <1.5 m (Alexander *et al.*, 2009). While it is described as braided, the area does consist of reaches that are singularly channeled along with a delta at the confluence of the Missouri River. The largest geomorphic river region of the Niobrara River study area begins upstream of the Norden Chute. This canyon-restricted portion of the river extends to Box Butte Creek (Alexander *et al*., 2009). The channel restrictions are a result of the close contact of bedrock on outside bends, a stair-step sloping pattern, and tributary sediments that form consistent channels. Generally, channel width for this portion of the river is approximately 30 m, yet some sections are similar in width to braided portions downstream. Within this river region, a consistent channel and thalweg is formed and lateral migration is limited due to the close association with the bedrock. The final river region of the Niobrara River includes the area between Box Butte Creek and the Dunlap Diversion Dam at Box Butte Reservoir. It exhibits wider valleys than the previous regions and increases in sinuosity (Alexander *et al*., 2009). Channel width progressively decreases upstream and depth is less than 1 m in most reaches.

The channel gradient of the Niobrara River fluctuates depending upon the region. Within the canyon-restricted region, channel slope is the greatest and contains the highest variation. Closer examination of the river allows further sub-divisions from the large-scale river regions into similar in-channel morphological characteristic sections. In-channel morphologic characteristics have been classified based on five general geomorphic units consisting of unique sediment properties and bed forms. Ripples, dunes, sand waves, plane beds, and anti-dunes can all be identified in the field and from aerial observations. Other geomorphic units may exist, yet these five classifications identify nearly all of the in-channel geomorphology. Additionally, it is important to note that all of these units vary both spatially and temporally, due to changes in discharge at any given time.

The study area was delineated after a reconnaissance survey was conducted consisting of aerial and ground surveys. Flight reconnaissance was utilized to view the entirety of the proposed project area of the Niobrara River. During the flight, a tablet computer loaded with aerial photos and available GIS data was used to annotate observed points of interest on the ground.

A point-based shapefile was created using a small Bluetooth GPS and ArcPad software, where the coordinates and observational notes could be recorded. In this manner, perceived changes in river structure and geomorphic character were identified. Dams, major tributaries and other points of interest were also recorded. After the aerial reconnaissance was completed, a ground survey was performed to validate the aerial imagery with what was actually observed on the ground. Still photos captured during the reconnaissance survey can be found in **Appendix 18**.

Section Development

With the completion of the reconnaissance survey, the collected data were compared to previously collected GIS data. Combining all these data allowed team members to begin the process of delineating sections within the study area. Major considerations for the development of section breaks were related to morphological changes, including presence/absence of sandbars and islands, diversity of hydromorphologic units, sinuosity and bank characteristics as well as the location of dams and major tributaries. For a more detailed description of this process, see the Phase 1 Report (**Appendix 19**, Parasiewicz *et al*., 2010).

With these morphological feature characteristics in mind, sections were roughly fitted to the wetted area of the river and were compared to the USGS geomorphic sections to understand where the similarities between the two existed. In many cases, the boundaries were very close (within 500 m) and in these instances, the proposed Rushing Rivers Institute (RRI) section was modified to match the location chosen through the USGS analysis. Other differences in section boundary locations were a function of lumping or splitting portions of either the RRI assessment or those of the USGS work. The splitting of USGS sections by RRI were mostly related to river features viewed as either an obstacle to fish passage (dams and falls) and therefore marked a transition in possible fish community, or were related to a rapid change in contributing watershed area at the confluence of large tributaries.

Section 1 marks the eastern boundary of the RRI study area where it begins at the confluence of the Niobrara and Missouri Rivers. Section 16 forms the western boundary of the RRI study area and begins roughly 18.4 km (11.4 mi) east of the Box Butte Dam/Reservoir located in Dawes County. Each of the 16 sections of the study area was chosen to represent a unique and/or representative characteristic of the Niobrara River.

Selection of Representative Sites

The MesoHABSIM approach often relies on the use of representative sites as intensive study areas that approximate their section's habitat characteristics and therefore can be upscaled to quantify section and segment habitat. One representative site is chosen for each study section. The process of determining project sections was described above and in the Niobrara Phase I report (Parasiewicz *et al.,* 2010). Here, we will outline the thought process and methodology used to define the representative sites used for this study.

Defining representative sites and their affinity to the sections that they represent can be done in a number of ways depending on the project's resources. For the Niobrara River project, our greatest obstacle was the length of the study area. It was not economically feasible to perform a detailed survey on the entire length of the study area. A reconnaissance fly-over aided in the development of section breaks, but did not provide enough detail as to where to place study sites. Therefore, we referenced the work of the USGS and their geomorphic segmentation report (Alexander *et al.*, 2009).

When developing their segmentation of the Niobrara River, the USGS created a catalogue of cross-section information using digitally-derived data at the equivalent of river width intervals over the length of the project area. A coordinate was given to each cross section and approximately 36 measurements were made. These included variables such as channel and valley widths, number of islands, ratios of related measurements, slopes and more. This wealth of data provided an excellent opportunity to find representative sites with characteristics that are statistically similar to the study sections. **Table 8** describes the variables that were used in our analysis.

Table 8: Variables used to define and assess representation of sites for their respective sections on the Niobrara River (data from Alexander *et al.* 2009).

Variable	Definition
Slope_10ch_wind	Slope over a 10 channel window (5 upstream and 5 downstream, centered on sampling point), and using centerline distance
Slope_100ch_wind	Slope over a 100 channel window (50 upstream and 50 downstream, centered on sampling point), and using centerline distance
Sin_100Chw	Sinuosity over a 100 point sampling window centered on the sampling point
Sin_50Chw	Sinuosity over a 50 point sampling window centered on the sampling point
Chan_Width_trans_feet	Channel width (feet) not adjusted for island widths
Wetted/Chan_Ratio	The ratio of wetted width of the channel to the total channel width (includes island width)
100Ch_COV	Coefficient of variation of channel width (standard deviation divided by the mean over a 100 channel width window centered on the sampling point)
30Ch_COV	Coefficient of variation of channel width (standard deviation divided by the mean over a 30 channel width window centered on the sampling point)
Chann_Vall_Ratio	Ratio of channel width to valley width
B.I. (#Channels)	Number of islands plus 1 equals the number of channel threads
B.I._avg_30ch	Braided index averaged over 30 channel widths centered on sampling point
Mean_SP	Mean daily stream power=mean q_100 channel*slope*weight of water
90_perc_SP	The 90th percentile stream power= 90percentile Q_100channel*slope*weight of water

The work performed by the USGS provides a strong statistical justification for surveying at the study site level, however several additional factors needed to be considered for successful site selection. First, we needed access to the site, both from a landowner permission perspective and for ease of equipment use, preferably at both the upstream and downstream end. Our on-foot surveys covered between two and six river kilometers depending on the river width, complexity of the geomorphology, access conditions and length of daylight.

Our first step in identifying suitable representative sites was to digitize a GIS layer for the study area using orthophotos as the background. All river access locations (bridges, boat launches, nearby roads) were marked and categorized as explained in the Phase I report (**Appendix 19**, Parasiewicz *et al.* 2010). Using this information, we were able to make the first attempt at selecting possible sites. We looked for areas with more than one access location in a 10 km window for each of the 16 study sections. In some sections where access was more prevalent, we identified multiple areas that appeared to be possible representative sites. In other sections, two access locations were not available in the 10 km window, and a site was chosen around a single access point.

Using the access locations as a guide, a box was digitized along the river to indicate the possible representative site. Each preliminary site contained up to 200 USGS cross-section location points with their associated morphometric data. To evaluate the representativeness of each study site, we developed a box-and-whisker diagram of the minimum value, the lower quartile (Q1), the median, the upper quartile (Q3) and the maximum value for each of the sections and the proposed representative sites. The section and site box plots were each evaluated to ensure that the median, Q1 and Q3 were approximately the same. If a proposed representative site differed greatly from the section box plot, the start or end morphometric point was extended or reduced to try and find a better representation. If this technique failed to provide a satisfying result, or if the survey length needed to achieve a representative site exceeded six km, an alternative site within the section was considered. This iterative process continued until a best possible fit of representativeness was achieved for each study site. The final step in the process was to verify land access permission from each of the landowners in the chosen survey areas. The box-and-whisker diagrams used in this analysis can be seen in **Appendix 3**.

While not every one of the 13 chosen indices shows an exact fit in the section and site comparison graphs, we feel that this technique gave us the strongest ability to choose sites to serve as surrogates for each study section.

Ultimately, sixteen sites were chosen to represent each of the sixteen sections Rushing Rivers Institute developed in Phase 1 of this project. These sites will be used to provide qualitative and quantitative descriptions of the ecological conditions in the Niobrara River. The final section delineation and representative site locations utilized for this report are shown in **Figure 8**. The lengths of each site and section can be found in **Table 9**.

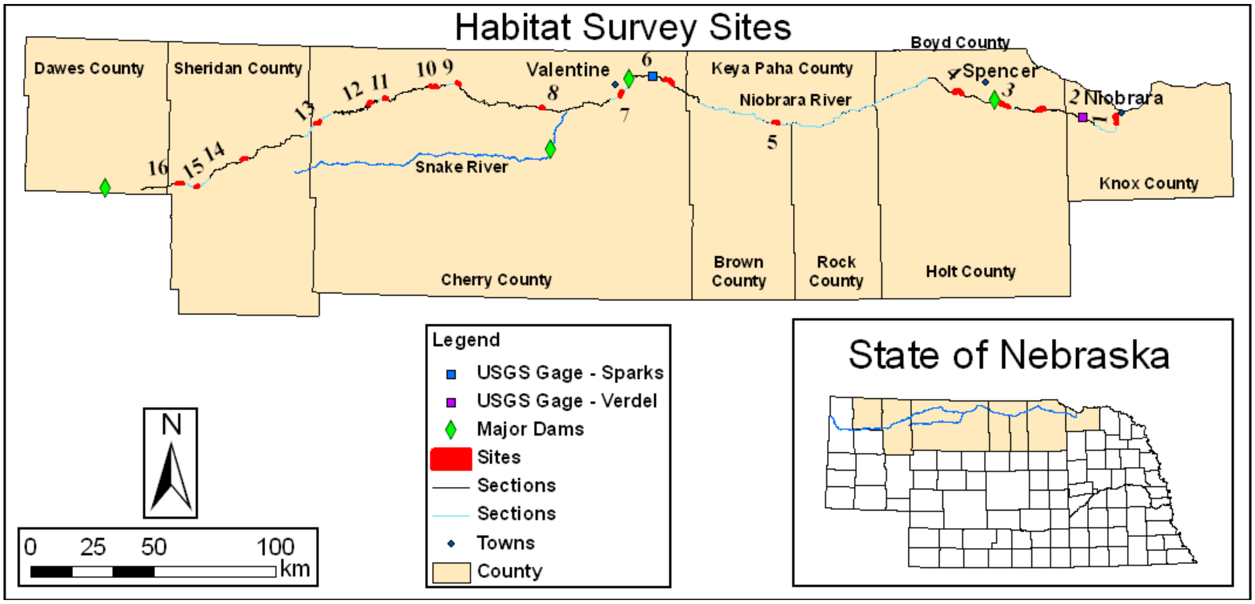

Figure 8: Study area for the Niobrara River. Map shows the location of project sections as well as site locations.

Table 9: This table details the bankfull wetted area of each site as well as the lengths for each of the final sections/sites chosen to represent the Niobrara study area.

Section		Site	Site Area
Number	**Length (m)**	**Length (m)**	**Area (m²)**
1	18,793	3,539	1,104,886
2	36,171	3,186	1,028,657
3	8,663	5,022	736,598
4	32,757	4,119	1,607,857
5	105,934	2,430	602,864
6	40,874	5,312	276,444
7	14,590	2,566	276,371
8	78,018	1,794	67,523
9	8,068	1,912	70,734
10	29,554	3,293	250,067
11	7,407	2,170	37,258
12	41,169	3,248	67,903
13	20,193	3,486	147,142
14	51,734	2,165	62,852
15	12,973	1,795	12,150
16	21,477	3,591	18,506

CFS and CFSM

Discharge recorded in cubic feet per second (cfs) is a standard unit of measure used by river scientists to describe conditions at a gaging station or those taken at a cross section. This measurement is very useful when describing river conditions at a known location, but can quickly become meaningless to someone who isn't familiar with the climate, watershed area, and other contributing factors present at the location where that measurement is taken. This is also true for the aquatic species within the system. A discharge measurement of 1000 cfs can signify a catastrophic drought in one system and represent a 500-year flood in another. A fish is dependent on the flow conditions as they relate to the bankfull capacity, and bankfull is determined by the upstream contributing drainage area combined with local geomorphic conditions.

To better describe flow conditions in a way that can be both regionally compared and relevant to their influence on aquatic species, we find the use of cubic feet per second per square mile of drainage area (cfsm) to be a very helpful unit. Cfsm divides a discharge measurement by the contributing upstream drainage at the location of that measurement. The result is a unit that not only describes the flow at a particular location, but also describes a river condition that can easily be applied up or downstream to evaluate the cfs needed to achieve a similar condition.

As a transferable scale, the use of cfsm allows the researcher as well as the reader to visualize the flow as it would appear from standing on the river bank. A flow of 1490 cfs at Site 2 and 440 cfs at Site 13 seem like drastically different flows. Without the context of contributing drainage area, the reader would not know that these are both flows of approximately 0.13 cfsm. River conditions at each site would both have low wetted area to bank full ratios and may feel very similar to the organisms present.

Throughout this report, we will use both cfs and cfsm. The cfs value will typically be used when describing conditions at a specific location (e.g., the USGS gaging station), whereas cfsm is used to describe a flow condition (e.g., target for measuring habitat at a site or a flow prescription). **Table 10** provides a look at cfs values for each study site at the three targeted survey flows (cfsm).

Table 10: Table of watershed areas and cfs values at the three target survey flows for each of the study sites. Watershed area * cfsm = cfs.

Study Site	Watershed Area	0.1 CFSM	0.2 CFSM	0.35 CFSM
Site 1	12080	1208	2416	4228
Site 2	11341	1134	2268	3969
Site 3	10944	1094	2189	3830
Site 4	10783	1078	2157	3774
Site 5	8214	821	1643	2875
Study Site	**Watershed Area**	**0.05 CFSM**	**0.1 CFSM**	**0.15 CFSM**
Site 6	7170	359	717	1076
Site 7	6708	335	671	1006
Site 8	4790	240	479	719
Site 9	4270	214	427	641
Site 10	3888	194	389	583
Site 11	3584	179	358	538
Site 12	3508	175	351	526
Site 13	3318	166	332	498
Site 14	2796	140	280	419
Site 15	2071	104	207	311
Site 16	2050	103	205	308

Habitat Mapping Surveys

The purpose of the habitat survey was to determine spatial proportions of the mesohabitat units in selected river sections. Mesohabitat units or hydromorphological units (HMUs) are portions of the river with similar morphologic, hydraulic and cover attributes (i.e., pools, riffles, runs). For each HMU, the location and size was determined with GPS and ArcPad software in conjunction with high-resolution aerial photographs, creating a detailed map of selected sites on the river. The outlines of each HMU were drawn as geo-referenced polygons on a Hewlett-Packard iPAQ or Trimble Nomad palmtop computer running ArcPad software.

In the wide braided sites (Sites 1 through 5), aerial photos were acquired one to five days before the start of the survey. The images were geo-referenced and mosaicked together and then clipped for use on our ArcPad enabled handheld computers. The HMU units in these sites were pre-annotated based on their appearance using a laptop computer the night before the survey. The survey crew would then investigate each HMU to validate the annotation, collect information on cover and hydraulic conditions, and make any necessary changes to the HMU boundaries.

Habitat mapping surveys were completed at the three target flows chosen after examining the historical annual hydrographs for the Sparks and Verdel USGS gages. The flows can be thought of as approximating a typical sustained spring high flow, a summertime low flow and an intermediate flow. Collecting habitat information at these three flows will allow for the development of habitat rating curves.

- **Survey 1** (8 May to 21 May and 2 June to 8 June, 2010) targeted the high spring flows of approximately 0.35 cfsm at the Verdel gage and 0.14 cfsm at the Sparks USGS gage. During this first survey, Sites 1, 2 and 4 were each surveyed on consecutive days due to their size and the adaptation of our mapping approach. Site 6 was surveyed on two days due to equipment failure and poor weather conditions. Approximately 49.6 km (30.8 mi) of river was mapped and divided into HMUs during each of the three surveys. The mapping of Survey 1 contained approximately 791 HMUs and 6959 hydraulic measurements.
- **Survey 2** (8 to 19 July and 27 to 29 July, 2010; 18 to 22 July, 2011) was conducted at a target flow of approximately 0.17 cfsm at the Verdel gage and 0.095 cfsm at the Sparks USGS gage. The study area was mapped fully during the 2010 field season. However, after reviewing our initial models it was decided to re-survey four sites in 2011 to confirm the accuracy of the collected data. The mapping contained approximately 820 HMUs and 7286 hydraulic measurements.
- **Survey 3** (19 to 23 August, 2 September and 7 to 9 September, 2010) was conducted at a target flow of approximately 0.12 cfsm at the Verdel gage and 0.065 cfsm at the Sparks USGS gage. The mapping followed the representative site division developed for the previous surveys. The mapping contained 711 HMUs and 6742 hydraulic measurements.

Within each HMU, mean column velocity, depth and estimated substrate were measured in stratified random fashion. This means that the unit was first visually divided into hydraulically uniform strata (e.g., slow-shallow) and at least 10 measurements were distributed among the strata according to their proportion within the HMU. The measurement locations within the strata are chosen randomly. Based on observations of previous studies, the total number of measurements was empirically determined as the smallest statistically relevant quantity. Measurements for depth and mean column velocity were taken with a Dipping Bar (Jens, 1968) or wading rod and Marsh-McBirney Flo-Mate 2000. Physical cover attributes were estimated for each unit (using three categories: absent (<5% of the area), present, and abundant (>50% of the area)) and entered into a GIS table associated with the corresponding polygon. For substrate definitions, we referred to the choriotop classification system according to Austrian Standard ÖNORM 6232 (1995). Please see **Appendix 2** for more detail on the survey methods and substrate definitions.

The mesohabitat distribution at three target flows was surveyed over multiple days during the 2010 and 2011 field season. The dates and flows at the time of each survey are shown in **Table 11** below and the locations are shown in **Figure 8**.

Table 11: Field survey dates for each site and corresponding flows in cubic feet per second (cfs) at the Verdel (Red) or Sparks (Blue) USGS gaging station (Gage cfs), estimated flow at the survey site (Site cfs) and flow as a function of contributing square mile of watershed (cfsm).

Study Site	Survey 1 Date	Gage cfs	Site cfs	cfsm	Survey 2 Date	Gage cfs	Site cfs	cfsm	Survey 3 Date	Gage cfs	Site cfs	cfsm	Watershed Area
1	05/20/10	4825	5033	0.417	07/17/10	2004	2091	0.173	09/09/10	1581	1649	0.137	12080
2	06/07/10	4506	4413	0.389	07/15/10	1992	1951	0.172	09/08/10	1386	1357	0.120	11341
3	05/19/10	4314	4077	0.373	07/14/10	2144	2026	0.185	09/08/10	1582	1495	0.137	10944
4	05/17/10	3884	3617	0.335	07/16/10	1978	1842	0.171	09/07/10	1452	1352	0.125	10783
5	05/09/10	3282	2328	0.283	07/13/10	1928	1368	0.166	09/02/10	1305	926	0.113	8214
6	05/08/10	929	931	0.130	07/19/11	566	680	0.095	08/23/10	449	450	0.063	7170
7	05/11/10	942	884	0.132	07/18/11	645	650	0.097	08/23/10	454	426	0.064	6708
8	05/14/10	999	669	0.140	07/22/11	589	415	0.087	08/23/10	463	310	0.065	4790
9	05/15/10	973	581	0.136	07/29/10	665	397	0.093	08/22/10	454	271	0.063	4270
10	05/13/10	934	508	0.131	07/21/11	540	337	0.087	08/22/10	463	252	0.065	3888
11	05/16/10	1002	502	0.140	07/12/10	680	341	0.095	08/21/10	458	230	0.064	3584
12	05/16/10	987	484	0.138	07/12/10	681	334	0.095	08/21/10	454	223	0.064	3508
13	06/04/10	950	441	0.133	07/10/10	682	316	0.095	08/19/10	453	210	0.063	3318
14	06/03/10	961	376	0.134	07/09/10	694	271	0.097	08/19/10	457	179	0.064	2796
15	06/02/10	972	282	0.136	07/08/10	696	202	0.097	08/20/10	465	135	0.065	2071
16	06/02/10	975	280	0.136	07/08/10	695	199	0.097	08/20/10	460	132	0.064	2050

Avifauna Habitat Surveys

For the purpose of this project, we adapted the traditional mesohabitat survey used for modeling fish stabilities and applied it when developing avian literature models. By collecting additional measurements relevant to bird habitat use using our field sampling protocol, we were able to collect model input data for fish and birds simultaneously.

Our modification of the data collection protocol included adding terrestrial habitat mapping units like High and Low Sandbars along with established Channel Islands to the aquatic survey ArcPad form. We used the MesoHABSIM digital mapping template to collect habitat variables that may be relevant to bird nesting suitability. This included substituting the estimated height above water level instead of water depth, while still collecting grain size information at ten or more stratified random locations within each HMU polygon. Information about the presence of vegetation and other cover attributes were also collected in a similar fashion to how we would collect data within aquatic habitat units. By digitally collecting this information, we were able to examine these features within a GIS framework and import the information directly into a SIM-Stream model. Additional data fields, like line of sight to banks or distance from roads/homes, were developed using GIS measurements based on information gathered through literature reviews. This approach allowed us to simultaneously collect fish and bird relevant habitat information and streamlined both the data collection and modeling effort.

Study Sections

Here we will provide a brief description of the Niobrara River's study sections. Distances and noteworthy location descriptions are included, as well as information on the prevalence of cover and river attributes. Definitions of terms may also be found in the Glossary at the beginning of this document. More detailed descriptions and locations of study sections may be found in **Appendix 3**. See **Figure 8** for approximate study site locations.

Section 1

Section 1 was derived from USGS Section 1 and is 18.8 km (11.7 mi) long. It begins 16.1 km (10 mi) southwest of the intersection of State Highway 12 with the Niobrara River and ends at the same intersection. Large islands are a dominant feature as the river nears its confluence with the Missouri River. Site 1 begins approximately 35.3 km (21.9 mi) downstream of Site 2 and flows north, paralleling State Highway 14 for 3.5 km (2.2 mi) where it ends on the south side of East Main Street (Route 12) in the town of Niobrara, NE. Main lobes and side arms were the dominant HMUs found in this section with high complexes, high bars, secondary lobes, backwaters and two runs comprising the rest of this site. Shrub brush was the most common land use type along the banks of this site. Woody debris was present in approximately one third of the HMUs surveyed. The dominate substrate was psammal, with some side arms and backwaters having a more organic pelal type of substrate. Extensive side arms were present along the west side of the site, forming large vegetated islands that often contained large backwaters at their centers.

Section 2

Section 2 is 36.2 km (22.5 mi) long and corresponds to USGS Section 2. It begins 8.3 km (5.2 mi) east of US Highway 281 and ends 16.1 km (10 mi) southwest of the intersection of State Highway 12 with the Niobrara River. Permanent islands are a prominent feature in this section. Site 2 begins 12.1 km (7.5 mi) downstream of Site 3 and continues for approximately 3.2 km (2.0 mi). Shrub brush was the primary land use type found along the banks of this site, with forests intermixed predominantly on the right bank. The HMU types were mixed and included slightly more high bars than in sites to the west. The substrate was mostly psammal with a small percentage of organic material found in the backwaters. Wood debris was present in approximately one quarter of the HMUs surveyed.

Section 3

Section 3 was developed from USGS Section 3 and is 8.7 km (5.4 mi) long. It begins 400 m west of US Highway 281 and ends 8.3 km (5.2 mi) east of US Highway 281. The river in this section possesses open valleys and varying channel width but is missing the permanent islands that were present in the previous sections. Site 3 begins 16 km (9.9 mi) downstream of Site 4 and 646 m east of US Highway 281. The site is just over 5 km (3.1 mi) in length and flows southeast along a series of hills on the right bank. Shrub brush was the dominant land use type along the site's shorelines. The river at this site abruptly narrowed and widened along its course and large changes in wetted area were also observed over the course of the study period. The HMU types observed were distributed between high and low complexes, main and secondary lobes, high bars, runs, side arms and backwaters that varied in distribution depending on the level of water present. The substrate was primarily psammal with occasional large rocks and boulders, with the exception of a section of bedrock exposed below Spencer Dam after a flooding event. There is not much canopy shading at this section and there was very little submerged vegetation, woody debris or boulders.

Section 4

Section 4 begins 14.6 km (9.1 mi) west of State Highway 11 and ends 400 m west of US Highway 281. It is 32.8 km (20.4 mi) in length, corresponds to USGS Section 4 and has numerous permanent islands with mature forest occurring regularly throughout its length. Site 4 starts 81.3 km (50.5 mi) from the end of Site 5 and continues for 4.1 km (2.5 mi) downstream. The site is crossed by State Highway 11 in the first half of its length and is approximately 6.6 km (4.1 mi) south from the town of Butte, NE. Shrub brush was the predominant shoreline land use type found in this area with little forest or fields. This site had a mix of extensive backwaters and side arms, which changed between the surveys due to sedimentation processes after flow increase. Main lobe HMUs formed a continuous channel through the entire site at most flows and was most prominent during the period of lowest surveyed flows (Survey 3). Cover for fauna was virtually nonexistent with not much woody debris or boulders and only 9% of the HMUs listed having any submerged vegetation. Psammal substrates were again dominant with only a few instances of other substrates occurring.

Section 5

Developed from USGS Section 5, **Section 5** is the longest section measuring 105.9 km (65.8 mi) in length. It begins 50.9 km (31.6 mi) east of State Highway 20 and ends 14.6 km (9.1 mi) west of State Highway 11. Site 5 begins 50.1 km (31.1 mi) downstream of Site 6 and flows east for 2.4 km (1.5 mi). This site includes part of the Niobrara National Scenic River area. Site 5 crosses US Highway 183 approximately 237 m before it ends. The river here is > 400 m wide in places, is shallow, fast flowing and has a large floodplain. This site was sparsely forested with only 8% forest noted along its banks. The dominant land use in this site was shrub brush. The HMU types in this section were split between high and low complexes, main and secondary lobes and high bars. There were two large vegetated islands present during all three surveyed flows. Woody debris was present and scattered throughout the site in at least 25% of the HMUs. The site’s substrate was almost entirely psammal.

Section 6

Section 6 was formed through a combination of USGS Sections 6 and 7 and marks the first of the canyon restricted sections. The section begins 10 km (6.2 mi) east of State Highway 20 and extends 40.9 km (25.4 mi) before ending 50.9 km (31.6 mi) east of State Highway 20. The river narrows down to a single channel that does not exhibit much variation in its width. The section and site lie completely within the central portion of the Niobrara’s National Scenic River region. Located in the northeastern corner of Cherry County the site begins 25.7 km (16 mi) downstream of Site 7 and continues for 5.3 km (3.3 mi). This is also the first site that does not exhibit the sandy braided channel characteristics observed on the previous five sites. The site is extensively forested with the remaining land use types split between shrub brush, pasture and fields. This site alternated between riffles, ruffles, glides, with runs being the most prevalent throughout. While the most frequently observed substrate category was psammal, the site also contained a considerable amount of cobble to fractured bedrock. There were some boulders and woody debris infrequently present throughout the site. Despite the high presence of forested banks, there was not much shading on the river.

Section 7

Section 7 is 14.6 km (9.1 mi) long and coincides with USGS Section 8. It begins 4.5 km (2.8 mi) west of US Highway 20 and ends in the Fort Niobrara National Wildlife Refuge, approximately 10 km (6.2 mi) east of US Highway 20. Site 7 is located 26.3 km (16.3 mi) downstream of the Snake River's confluence with the Niobrara. The site begins on the east side of State Highway 20 and extends for 2.6 km (1.6 mi) where it ends at the Borman Bridge on Road 220. The site is approximately 36.5 km (22.7 mi) downstream from Site 8 and is easily accessed due to the numerous roads and bridges heading south out of Valentine, NE. This site is roughly 2 km (1.2 mi) southeast of Valentine, NE and is located at the western edge of the Fort Niobrara National Wildlife Refuge. The end of this site is at the start of the Niobrara National Scenic River region, roughly 7 km (4.3 mi) upstream from the Cornell Dam. The river at this site varies in width between 280 m in the braided area below the old Route 20 Bridge and 30 m at its narrowest point further downstream. The land use types bordering Site 7 were evenly split between forests and shrub brush with a few fields and islands filling out the balance. There was some canopy shading along with some overhanging vegetation, especially on the downstream half of the site. The braided section of the site is made up of high complexes, main and secondary lobes while the remainder of the site is comprised of runs, riffles and glides. Boulders and woody debris were present throughout the site providing cover opportunities for fauna. The main channel of the river had a dominantly psammal substrate with some organic material found in the backwaters.

Section 8

Section 8 is comprised of USGS Sections 9 -13 and is 78 km (48.5 mi) long. It begins 23.9 km (14.9 mi) west of State Highway 97 and ends 4.5 km (2.8 mi) west of US Highway 20, near Valentine, NE. The river exhibits some sinuosity and the channel width fluctuates. Site 8 lies just to the north of the Samuel McKelvie National Forest and is in the approximate center of the section. This site is the first located upstream of the Niobrara's confluence with the Snake River, which occurs approximately 10.2 km (6.3 mi) downstream. The site begins 44 km (27.3 mi) down river from Site 9 and 19.1 km (11.9 mi) east of State Highway 97. The site is 1.8 km (1.1 mi) in length and is accessed near Andersen Bridge Wildlife Management Area crossing to the National Forest from the north. This site was chosen for its combination of braided and unbraided characteristics. The upper and lower portions of the site contain riffle/ruffle habitat in a narrow channel, while the middle of the site contains a wide braided complex. The HMU types were well mixed in this section. The substrate on this site was of mixture of psammal, mesolithal, macrolithal and gigalithal. Shrub brush dominated the adjacent land use for this area.

Section 9

Section 9 begins 29.6 km (18.4 mi) east of State Highway 61 and extends downstream for 8.1 km (5 mi) before ending 23.9 km (14.9 mi) west of State Highway 97. This section is derived from USGS Section 14 and exemplifies the transition between open and restrictive valleys. Site 9 starts 9.7 km (6 mi) downstream of Site 10 and is 1.9 km (1.2 mi) in length. This site is mostly a single channel with several established islands located in the downstream end. Shrub brush and forests are the main land use types with only a few fields and pastures located adjacent to the banks of this site. Despite the presence of trees in the site, there is very little canopy cover to provide shading for the river. There are four large permanent islands in the final third of Site 9. Just under half of this site was comprised of runs followed by glides and then riffles. Boulders were present, but scattered throughout the site. Psammal was the dominant substrate type and was intermixed with bedrock and large cobble in a few places.

Section 10

Section 10 coincides with USGS Section 15. It begins at the intersection of the Niobrara River and State Highway 61 and ends 29.6 km (18.4 mi) downstream. Moving downstream the valley widens and the channel width begins to show greater variability as it spreads out and narrows quickly. Site 10 begins 23.4 km (14.5 mi) down river from the end of Site 11 and 22.2 km (13.8 mi) east of State Highway 61. This site is 3.3 km (2.1 mi) in length and has no roads providing direct access to it. This site transitions from the single, narrow, sinuous, channel characteristics of Sites 11 and 12 to a wider braided type of river. Shrub brush was the most abundant land use type along the river, fields and pastures comprised the bulk of the rest with some forests present. Main lobes and high complexes were the most common HMU types. Runs, secondary lobes, glides and low complexes were distributed throughout the site with a few side arms, backwaters, and high bars. Once again, psammal was the dominant substrate covering > 90% of the HMUs, and organic material covered the bottom of both backwaters. Woody debris was observed throughout the site, providing ample cover opportunities for fish. Submerged vegetation was found scattered throughout the site, especially during the high flow survey.

Section 11

Section 11 was the shortest RRI section measuring only 7.4 km (4.6 mi) in length; it begins 6.2 km (3.9 mi) west of State Highway 61 and ends at the intersection of the Niobrara River and State Highway 61. This section is a combination of USGS Sections 16 and 17 and highlights the single narrow channel characteristics of this canyon-restricted portion of the river. Site 11 begins 7.9 km (4.9 mi) downstream from the end of Site 12 and 1.2 km (0.7 mi) west of State Highway 61. The site length is 2.2 km (1.4 mi) and is bordered by shrub brush for more than 60% of the area on both banks. Trees were much more abundant on the right bank than they were on the left. The river does not get much shading; only one HMU had canopy cover present, and overhanging vegetation was present on just two of the units surveyed. Runs and riffles dominated the site, with the runs making up the majority of HMUs on the downstream half. The remaining HMUs consisted of fast runs, glides, main lobes, pools, ruffles, and side arms. Rocky substrates make up more than half of the HMUs mapped, with the rest of the study area covered by sandy material.

Section 12

Section 12 corresponds with USGS Section 18 and provides an example of the highly sinuous nature of the Niobrara River in some of its reaches. From beginning to end, the section is 41.2 river km (25.6 mi) in length but in straight-line distance it is only 19.5 km (12.1 mi). The section begins 47.4 km (29.5 mi) west of State Highway 61 and ends 6.2 km (3.9 mi) west of State

Highway 61. A single narrow channel is evident again in this section and does not show much variation as the river flows through the restrictive boundaries imposed by canyon walls. The eastern portion of this section was chosen as the location for Site 12 because of access and similarity to the rest of the section. Site 12 starts 41.5 km (25.8 mi) downstream of Site 13 and continues for 3.2 km (2.0 mi). Runs and riffles dominate the HMU types in this section, followed by glides. The substrate for the site is sandy with some coarser material scattered throughout. Site 12 has some shading provided by trees and the presence of high canyon walls confining the river. The land use along the banks included forests (> 20%), shrub brush, pasture, and fields. Again, submerged vegetation was scattered throughout the site.

Section 13

Section 13 begins 10.5 km (6.5 mi) east of State Highway 27 and extends for 20.2 km (12.6 mi) before ending 30.7 km (19.1 mi) east of State Highway 27 at an unnamed road. This section corresponds to USGS Section 19 and the single channel characteristics of this section widen and narrow abruptly around islands dotted with standing vegetation. Site 13, situated in the center of the section, is located along the western boundary of Cherry County. It begins approximately 19 km (11.8 mi) east of State Highway 27 and 39 km (24.2 mi) east of the downstream end of Site 14. It is roughly 3.5 km (2.2 mi) in length. There are some forests found at this site predominantly on the south side of the river, but pastures and shrub brush comprise the bulk of the other land use types. This section contains some braided river characteristics as well as a widening of the channel width to as much as 60 m. Main lobes dominated this site, followed by side arms and high complexes. Low complexes, glides, riffles, runs, secondary lobes and backwaters make up the rest of the HMU types found within this site. The site was chosen because of the number of islands it contained. Psammal substrate is observed most frequently (89%) at this site, although there are areas of bedrock and large boulders present. Canopy shading was more evident with 17% of the site having some canopy cover. Approximately a quarter of the site had submerged vegetation.

Section 14

The Rushing Rivers Institute combined USGS Sections 20 and 21 to form **Section 14**. It is located in the eastern section of Sheridan County and begins 11.9 km (7.4 mi) west of State Highway 250 and extends 51.7 km (32.1 mi) to where it ends, 10.5 km (6.5 mi) east of State Highway 27. The valley constraints begin to widen, allowing the river to move more freely and relaxing channel width restrictions. In this section, the channel width is capable of doubling its width and narrowing again within short distances. Site 14 begins 24.4 km (15.2 mi) down river from Site 15 and 6.3 km (3.9 mi) east of State Highway 250. The site ends approximately 20 km (12.4 mi) west of State Highway 27 and is 2.2 km (1.4 mi) in length. The site is dominated by pasture and shrub brush land use types. The river is broad here measuring as much as 30 m across in some spots. Main lobes comprise 43% of the site followed by secondary lobes and high complexes, at 16% and 15%, respectively. The rest of the site is made up of backwaters, low complexes, glides, pools, runs, and side arms. Psammal is the dominant substrate covering almost the entire site. There is some organic substrate found in the few backwaters that were recorded. Canopy shading and overhanging vegetation were not common at this site. There was some scattered presence of submerged vegetation.

Section 15

Section 15 is 13 km (8.1 mi) long and derived from USGS Section 22. The section begins 980 m east of State Highway 87 and ends 11.9 km (7.4 mi) west of State Highway 250. It ends just 1.3 km (0.8 mi) past the point where the Niobrara River is crossed by an unnamed road. This section of the river flows as a narrow single channel with little variation due to valley boundaries exerting influence on the channel direction. Site 15 begins roughly 5.5 km (3.4 mi) downstream of where Site 16 ends. The site starts 40 m downstream of an unnamed road and continues in a northeastern direction for 1.8 km (1.1 mi) downstream. This site ends 18.1 km (11.2 mi) west of State Highway 250. It lies between two roads: #420 on the west and #390 on the east. Both banks of the river in this section are pastured with some shrub brush found in various places. The site was dominated by runs, which made up more than half of the HMUs observed. Walking the site from west to east, glides and riffles can be found scattered over the survey area but were much more evident in the lower half of the site. Psammal is again the dominant substrate at 73%, with akal, mesolithal and microlithal found is some HMUs. Pelal was only found in the two backwater HMUs. Submerged vegetation was present in more than half of the HMUs and for all flows.

Section 16

Section 16 includes USGS Sections 23 - 25 and is a total of 21.5 km (13.4 mi) in length. This section begins 2.9 km (1.8 mi) east of Old Dunlap Rd in Dawes County and ends 980 m east of State Highway 87 in Sheridan County. There are some highly sinuous channel forms in the beginning of this section and channel width variation is minimal. The study site chosen to represent this section is situated near the eastern boundary just 980 m from Section 15. The upstream boundary for Site 16 is 3.6 km (2.2 mi) west of the intersection of the Niobrara River and State Highway 87 in the western portion of Sheridan County, it is 200 m south of an unnamed farm road and was chosen due to the access opportunities provided by the roads and landscape of the immediate area surrounding the river. The end of the site is at the intersection of the Niobrara River and State Highway 87. This site exhibits a narrow, single channel with a limited floodplain. We find that 59% of the site is dominated by runs, followed by glides, which make up 22% of this site. There are a few plunge pools, pools, riffles, rapids, fast runs, cascades, and backwaters scattered the length of the site. The first half of the site has a land use of pasture with little to no shrub brush; this changes around the halfway point where the amount of shrub brush increases and continues for the remainder of the site. For the surveys conducted, we found that the dominant substrate was psammal with some gravel and bedrock interspersed throughout.

Chapter 1.3: Hydrology

Hydrology and Time Series Development

In this chapter, we will take a brief look at the hydrology and time series records that were used in developing the Niobrara River mesohabitat models. Time series data are records of discharge recorded at specific time intervals over a number of years. They provide us with information on how the river at a particular point behaves throughout the year and over a number of years. We use time series data from the Niobrara River in conjunction with our developed rating curves of habitat quantity at specific discharge levels to analyze habitat limitations over time.

Introduction

Natural river flow patterns are important to fish and macro-invertebrate habitat availability, oftentimes signaling the beginning or end of various life stages for river fauna. Natural flow variability needs to be preserved to help prevent harmful changes in the physical, chemical, and biological conditions and functions of natural ecosystems (Richter *et al.*, 2003). River managers and stakeholders have come to a consensus that establishing a more naturalized flow regime should be a priority in today's changing environmental climate (Poff *et al.*, 1997). Of particular importance are the durations and frequencies of various flow events, which can have chemical and physical consequences for aquatic habitat.

Methods

For this project, we are interested in a continuous record of historical flows throughout the study area. Flow record data was available from three USGS gages for use in our analysis, and the gages are located near Gordon, Sparks and Verdel, NE. Verdel and Gordon began recording in 1928, although the former did not record continuously until 1958 and the latter until 1945. Sparks started recording data in 1945. Unfortunately, the Gordon gage was deactivated in 1991. While we considered using the Gordon gage, ultimately we decided that it would be better to use the continuous records and not introduce potential error by developing rating curves to fill in off-line periods at other gage locations with shorter histories. Creating a rating curve to extrapolate the Gordon gage up to the current record could introduce unnecessary error. Additionally, we want to provide habitat recommendations tied to flows that can be monitored in real time as a product of this research. Also, the use of the two gages that are presently active is consistent with how the NDNR would regulate flows in the river.

Daily average discharge data from the two chosen gages was downloaded from the USGS surface water data site (http://waterdata.usgs.gov/ne/nwis/sw) for the Sparks and Verdel gages over the common period of record between June 1958 and September 2010. However, it was decided that we would use data from after the completion of the Merritt Dam and its associated Ainsworth Canal and Lateral System, the last component of which was completed in June of 1966. It is assumed that using data from after the completion of the last major flow altering structure in the system will best reflect the status quo of climate- and infrastructure-influenced flows for the past 44 years.

Due to the locations of these two gages and the change in watershed area and climate in the eastern sites, we decided to use the Verdel gage as a reference on Sites 1 through 5, and the Sparks gage for Sites 6 through 16.

Data Processing

Occasional missing daily average values from the time series were interpolated to complete the record and avoid potential errors associated with blanks. Otherwise, the time series data were uploaded directly to SimStream for use in the UCUT analysis to be described later.

Data recorded by the USGS gages measures discharge in cubic feet per second (cfs). The 15-minute flow records are then aggregated for each calendar day to create a daily average discharge value. Finally, the flow values are divided by the drainage area at the gauge location to obtain relative discharges, which presented throughout the report.

Data Development

In addition to the downloaded time series data, cross-section discharge measurements were made during field surveys when possible to provide a record of concurrent conditions at individual sites. This information could be used to develop a rating curve to adjust between the closest gage and an estimate of flow at each study site. While additional work would be needed to create a robust rating curve, our spot-check measurements indicated that developing a rating curve would be possible if desired in the future.

Chapter 1.4: Freshwater Ecology

Bioperiods and Flow Needs

Fish and other aquatic organisms have evolved along with the biological processes of seasonal variation in river flow (Bunn and Arthington, 2002; Poff *et al*., 1997). Timing, frequency, duration, and magnitude of river flow conditions are temporally variable components of the natural flow regime (Poff *et al.*, 1997). As part of our goal in providing a scientifically-based instream flow study for the Niobrara River, we identified fish species that could serve as indicators of habitat conditions necessary for protection of aquatic fauna.

Faunal habitat needs vary seasonally due to different life stages (e.g., spawning or over-wintering) as well as environmental conditions. This approach is captured in the concept of bioperiods (Parasiewicz, 2008). Bioperiods are seasons characterized by the habitat requirements of the fauna and of the flow regime itself as each vary through the course of a calendar year. When attempting to prescribe protective instream flows in a regulated river, it is necessary to take into consideration these flow and habitat fluctuations.

The timing and duration of these bioperiods were determined using a literature-based analysis of the life histories, review of the annualized hydrograph, and the biological needs of the resident target species identified in the Existing Fish Community. For the sake of simplicity, the end and the beginning of each bioperiod was set to coincide with the beginning, ending or middle dates of a calendar month (See below and **Table 12**).

1. **Early Spawning** – March 1 through May 14
    - Peak flow conditions associated with spring rise.
    - Important for fish spawning by species in the *Percidae, Acipenseridae, Centrarchidae, Cyprinidae,* and *Catastomidae* families that rely on an increase flows to initiate spawning.
    - Also important for Whooping Crane staging and migration.
2. **Late Spawning** – May 15 through June 30
    - Descending limb of the spring flow rise.

- Important for fish spawning by species in the *Centrarchidae, Cyprinidae, and Catastomidae*, and *Ictaluridae* families.
- Important for Interior Least Tern and Piping Plover Nesting.

3. **Summer Rearing and Growth** – July 1 through September 30
    - Relatively stable flows (lowest of annual cycle)
    - Critical bioperiod to ensure successful recruitment of fish and bird species. Sensitive to changes in historical flow regime.
4. **Overwintering Early** – October 1 through December 31
    - Stable flows that reflect a slight increase in flows from R&G period.
    - Primarily used by fish species to locate overwintering habitats.
5. **Overwintering Late** – January 1 through Feb 28
    - Stable flows very early in bioperiod that transition to spring rise.
    - Important for fish in spawning migrations from overwintering habitats.

Table 12: Selected bioperiods and indicators utilized for the Niobrara River assessment.

Bioperiod	Start Date	End Date	Indicator
Early Spawning	March 1st	May 14th	Generic Resident Adult Fish
Late Spawning	May 15th	June 30th	Generic Resident Adult Fish
Summer Rearing and Growth	July 1st	September 30th	Generic Resident Adult Fish
Overwintering Early	October 1st	December 31st	Flow
Overwintering Late	January 1st	February 28th	Flow

The two spawning periods imply that the timing of spawning-related habitat needs can be a critical point in the biology of a species/guild. Our review of life histories indicated that there are generally two windows of time that encompass spawning activities represented by different flow conditions, hence the separation. We do recognize that the bioperiods are not mutually exclusive because other aspects of a guild need or species life history requirement may occur in a bioperiod (i.e., Whooping Crane migrations through the basin during the fish spawning season). Nonetheless, these bioperiods reflect unique species assemblages or uses that separate themselves from other periods on an annual cycle and we can model them separately.

Targeted Species and Communities

The Niobrara River Basin supports one of the most biologically diverse regions in the Great Plains. The basin has been called the "crossroads of the Great Plains", with many taxa meeting their respective geographic limits (Bleed and Flowerday, 1998). Spatially, the river's length and intersection with differing ecoregions allow for a variety of species to occupy a variety of specific habitats. Temporally, the region is vital for migratory species that are cued to environmental changes. The Niobrara River basin also includes several threatened and endangered species (**Table 13**). Our goal was to identify and model habitat availability for fish and avian species of interest based on the input received from a stakeholders meeting after the completion of the phase 1 (Parasiewicz *et al,* 2010). Therefore, the subset of fish identified in **Table 1** as target species was identified from fish survey data, historical records, and input from biologists that attended project-related workshops to provide representative coverage of the entire community.

Table 13: Endangered and Threatened species of the Niobrara River Basin (Bold=Federal Status, Italics=State Status).

Species	***Status***
Whooping Crane	**Endangered**
Piping Plover	**Threatened**
Interior Least Tern	**Endangered**
River Otter	*Threatened*
Pallid Sturgeon	**Endangered**
Blacknose Shiner	*Endangered*
Northern Redbelly Dace	*Threatened*
Finescale Dace	*Threatened*
American Burying Beetle	*Endangered*
Blowout Penstemon	*Endangered*
White Prairie Fringed Orchid	**Threatened**
Ute Lady's Tresses	**Threatened**
Small White Lady's Slipper	*Threatened*

Fish Community

In total, 77 fish species have been historically documented in the Niobrara River basin. However, in the most recent surveys (1990-Present) of the Niobrara River, only 58 species have been identified (Gutzmer *et al.,* 1996; Mestl, 1993; Peters *et al.*, 2000; Gutzmer *et al,*. 2002; Bazata, 2005; Bazata, 2007; Dietsch, 2008; Wanner *et al.*, 2008; and Fischer and Paukert, 2009). Differences between basin wide surveys and mainstem river surveys are a result of the absence of rare coldwater fluvial specialist species, such as northern redbelly dace (*Phoxinus eos*), blacknose shiner (*Notropis heterolepis*), blacknose dace (*Rhinichthys atratus*), finescale dace (*Phoxinus neogaeus)*, and orangethroat darter (*Etheostoma spectabile*) (Schainost, 2008). However, other members of the fluvial specialist group are present and do make up a considerable portion in the Niobrara River fish biota (**Figure 9**). See **Appendix 4** for more details on the fish survey and the **Appendix 19** (Parasiewicz *et al.*, 2010) for more information on the historical background on fish in the Niobrara River.

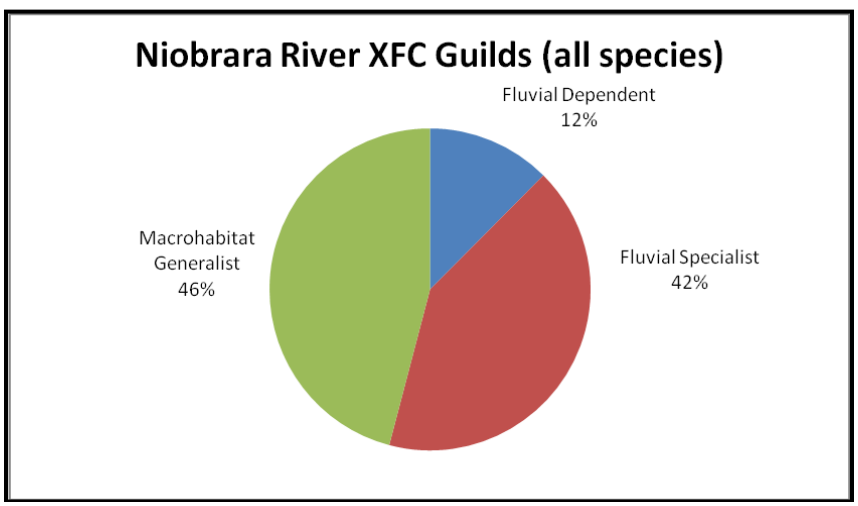

Figure 9: Proportion of fish species from the Niobrara River existing fish community (XFC) representing general habitat use guilds. Guild assignments from Hoagstrom and Berry (2006) and O'Hara, *et al.* (2007).

Cumulatively, the species within the Niobrara River constitute a diverse assemblage of communities between the headwaters in Wyoming and the confluence with the Missouri River. In addition to spatial differences, temporal variation also exists in the Niobrara River due to daily and annually changing depths, flows, turbidity, and temperatures. However, this aspect of community dynamics is less understood than those related to spatial variation.

In general, the most discernible communities of the Niobrara River lie in its eastern and western extremes. In the east, from Spencer Dam to the Niobrara River confluence, a predominately warm water and habitat generalist community exists. Habitat criteria and limits for species within this area are similar to those of the Lower Platte River in Nebraska (Peters *et al*, 1989). Fishes within this area prefer habitat consisting of turbid, warm waters with a variety of shallow and deep slow moving channels and pools. Furthermore, backwater areas, which are essential to many life stages, are also abundant.

In addition to the large river community component of the Niobrara River confluence, lentic prone species are found here due to the inter-dam area between Fort Randall Dam and Lewis and Clark Lake/Gavins Point Dam on the Missouri River. Examples of fish within the eastern portion include: Walleye (*Sander vitreus*), Largemouth Bass (*Micropterus salmoides*), Bigmouth Buffalo (*Ictiobus cyprinellus*) and Channel Catfish (Wanner *et al.*, 2008). However, within this area, the vast majority of species can be categorized as medium sized river fishes (Pflieger, 1997; O'Hara *et al.*, 2007; Schainost, 2008).

Beginning in the foothills of Wyoming and extending to Box Butte Reservoir, the western Niobrara River is vastly different from its eastern component. This is due to the contribution of cold groundwater-fed tributaries that establish conditions ideal for certain species. Representative species for the western Niobrara River are typical of cool and coldwater fisheries, with species such as federally endangered Blacknose Shiner and threatened Northern Redbelly Dace and Finescale Dace occurring in unimpacted streams (Schnieder, 2005; Peters, 2000). Recreationally, this portion of the Niobrara River supports a majority of Nebraska's trout fishery, with such species as Brook Trout (*Salvelinus fontinalis*) and Rainbow Trout (*Oncorhynchus mykiss*). However, tolerant fluvial dependent species, such as White Sucker (*Catostomus commersonii*) and Creek Chub (*Semotilus atromaculatus*) remain consistently present into the headwaters (Bazata, 2005; Schainost, 2008).

The central portion of the Niobrara River (Box Butte Dam-Spencer Dam) consists of a gradient between eastern and western fish communities. This gradient is not linear, however, as it is influenced by the defunct Cornell Dam near Valentine, NE. Habitat generalist species still make up the highest proportion within this area, but the large river and lentic species are reduced in number. The exception to this trend is Yellow Perch (*Perca flavescens*); a species stocked in Box Butte and Merritt Reservoirs. The headwater species make up a smaller percentage than in the west and are primarily restricted to the confluences of cool-water tributaries (Dietsch, 2008).

Generally, species within the central Niobrara River are tolerant of a variety of conditions and are likely pioneer species (Schainost, 2008). The variety and change of species is most likely due to the heterogeneity of habitat, which includes differences in tributary sources (groundwater runoff) and both natural and anthropogenic barriers (rapids and dams). In this study, we targeted habitat for the entire fish community. The assemblages vary between the three segments and are represented by a composition of habitat use guilds. Habitat models are developed for each guild and subsequently for the community. The methodological details of identifying existing fish communities and habitat use guilds can be found below and in **Appendix 5**.

Fish Species of Special Interest

Through the review of our Phase 1 report (**Appendix 19**) and in the subsequent stakeholders meeting, nine species were identified as species of special concern. These include River Shiner, Sand Shiner, Red Shiner, Bigmouth Shiner, Shovelnose Sturgeon, Pallid Sturgeon, Sauger, adult Channel Catfish and Paddle Fish. Although they are not prominent members of the Niobrara fish community in numbers, we have developed habitat models to evaluate their potential habitat availability.

Avifauna

More than 250 avian species have been recorded to use some part of the Niobrara River basin during a portion of their life cycle (Ducey, 1989). This report focuses on three of these bird species (Interior Least Tern, Piping Plover, and Whooping Crane) because of their rarity and dependence on specific characteristics of the Niobrara River during part of their lives. Use of the Niobrara River by cranes, terns, and plovers is highly dependent on water depth, sandbar characteristics and winter high flows. High discharge events are needed to scour away vegetation and develop sandbars for tern and plover habitat during the winter and spring snowmelt, but stable flows are needed during nesting periods. Shallow and slow habitats are needed for crane roosting sites during the early spring and fall. The timing and magnitude of flows could greatly affect avian species as well as the life cycles of fish in the Niobrara River.

For the purposes of this report, we focused on the nesting and rearing phase for the avian species of interest. This is the period of time that is believed to be at potential risk under the current withdrawal/diversion conditions and could be impacted by any future changes. Higher flow events and ice scour, while important to the geomorphological arrangement of the river, typically occur outside of the nesting bioperiod. They also occur outside of the agricultural growing season during a time when the human demand for water is lower. Modeling for and predicting high flow events that form sand bars is a difficult task, their management is not often practical, and they are less likely to be affected under the current Niobrara Basin water uses. Should withdrawals, diversions or other activities in the watershed change in a way that would influence high/low events, those activities should be studied more carefully.

*Interior Least Tern (*Sternula antillarum athalassos*)*

The state and federally endangered Interior Least Tern (50 Federal Register 21784–21792: USFWS, 1985b) was listed in 1985. It is a migratory bird approximately eight inches tall with a white body, grey wings, a black skullcap, and a yellow beak. They typically lay their eggs and raise their young on sandbars that are surrounded by water rather than connected to the bank or a vegetated island (Dinan *et al*., 1985). Isolated sandbars provide protection from predators such as raccoons and coyotes, and the shoals provide habitat for minnows, the birds' primary source of food (Carreker, 1985). Terns prefer to nest in colonies and have been frequently observed sharing habitat with Piping Plovers (Adolf *et al.*, 2001). Nebraska supports one of the largest breeding populations of Least Terns (USFWS, 1990) and nesting and rearing sites in the study area can be found from the confluence of the Niobrara and Missouri Rivers upstream to the Norden Chute (Adolf *et al.*, 2001). Terns arrive to the Niobrara River between early April and early May and begin to nest between mid-May and mid-June (Faanes, 1983; Adolf *et al.*, 2001).

*Piping Plover (*Charadrius melodus*)*

The state and federally threatened Piping Plover (50 Federal Register 50726-50734; USFWS, 1985a) was listed in 1986 and is a migratory bird with similar habitat needs to those of the Interior Least Tern (Faanes, 1983). This bird is approximately seven inches tall and can live up to 11 years of age. Adults have a sand-colored upper body, white undersides and orange legs. During breeding season, adults have a black forehead and breast bands, with orange beaks (USFWS, 1988; Brown *et al*., 2011). Like the Interior Least Tern, they prefer to nest on sandbars surrounded by water with little or no vegetation and are found in the same geographical area (Faanes, 1983; Ducey, 1981). This species relies more on eating small invertebrates and less on fish than the Least Terns (USFWS, 2003).

*Whooping Crane (*Grus americana*)*

The endangered Whooping Crane is the tallest North American bird (> five feet tall) and can live for over 20 years (The Rare Ones, website). In 1941, there were only 15 wild cranes left in the western flock. Through the efforts of protection and breeding programs, 281 cranes were counted while at their Texas wintering grounds in the winter of 2010–2011 (Whooping Crane, website).

This western flock has utilized the same migration route for about the last 57 years (USFWS website). The route extends through Nebraska on what is called the Wood Buffalo–Aransas flyway extending from the Gulf coast in Texas (Aransas National Wildlife Refuge) where they spend the winter up to their northern breeding grounds in Canada (Wood Buffalo National Park).

The Platte River and Rainwater basin are primarily considered the major staging areas for this species in Nebraska and they are known to use the central portion of the Niobrara River Basin directly to the north (Austin and Richert, 2005). Whooping Crane arrival to the Niobrara River Valley in the spring varies, but on average, the beginning of March is considered peak activity (Austin and Richert, 2005).

In Nebraska, Whooping Cranes commonly use rivers as roosting sites (Austin and Richert, 2001). Whooping Crane roosting sites are typically shallow water areas with minimal vegetation (Lingle *et al.*, 1984; Richert, 1999). Potential roosting sites near established islands with dense large woody growth are avoided due to potentially increased risk of predation; feeding locations vary between cultivated agricultural fields and wetlands (Faanes *et al.*, 1992).

Chapter 1.5: Fish and Bird Habitat

Existing Fish Community (XFC) and Habitat Associations

Fish Sampling Methods

For this project, we focused on the existing conditions as a benchmark for evaluating any future modifications or remediation to the Niobrara system. To evaluate the fish-habitat relationship, a survey of the Niobrara River fish community was conducted using prepositioned area electrofisher grid units (PAEs). The goal of the survey was to develop an understanding of the current species distribution and their proportions within the Niobrara River as well as to investigate their habitat use preferences throughout the study areas. The primary use for PAEs has been for research regarding habitat preference or association (Bain *et al.*, 1985; Peters *et al.*, 1989; Fisher and Brown, 1993). The PAEs explicitly limit the area in which fish can be sampled, thus allowing microhabitat associations to be determined for fish captured within the grid (**Figure 10**). See **Appendix 4** for detailed information about the Niobrara River fishing survey.

Figure 10: Photograph of PAE deployed in the Niobrara River.

Sample site selection was based on the analysis of distinct river zones along the Niobrara River identified by Alexander *et al.* (2010). Thirteen sites were selected for fish sampling based on the USGS section study and RRI's river delineation (**Figure 11**). A minimum of 15 PAEs were used per site to collect fish data representative of each zone. Sampling for each site was based on the proportions of HMUs identified during earlier site mappings to reflect the types of habitat present in the section. The location of PAE placement within the HMU was random, as long as locations were accessible, in order to reduce the influence of human-biased fish sampling.

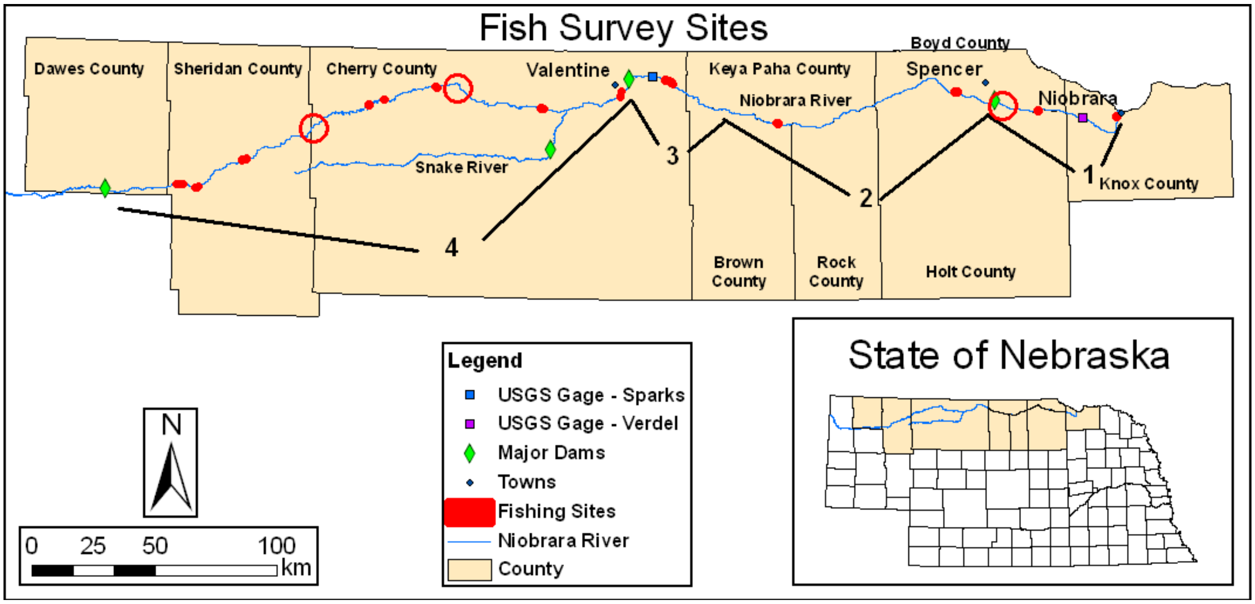

Figure 11: Fish survey study area for the Niobrara River.

Map shows beginning and ending site locations. Circled are sites 13, 9, and 3, where fish sampling did not occur due to inaccessibility or safety concerns. Brackets show zones delineated for fish community descriptions.

The top end of each PAE's two-meter PVC pipe was anchored to the river bed, allowing the cables of the PAE to run parallel with the river current (**Figure 10**). After the PAE was anchored, workers moved 10 meters downstream to affix the PAE to the electrofishing tote barge. We followed the recommendations of Bain *et al.* (1985), which indicated that catch efficiency was maximized by leaving the grid undisturbed in water for 10 minutes; efficiency increases only slightly thereafter when using a PAE. Before electrifying the PAE, two workers stationed themselves approximately two meters downstream to capture immobilized fish. Once the PAE was turned on, another worker moved upstream with a dip net to dislodge fish from substrate and to capture fish. In total, a team of three or four individuals was used to operate the PAE and capture fish.

Captured fish were identified to species, measured (total length) and enumerated. Fish that could not be readily identified in the field were preserved in 10% formalin for identification in the laboratory. Mean catch per unit effort (CPUE; the number of individuals of the species/total m^2) was calculated for each species.

Upon completion of fish sampling, habitat surveys were conducted within the grid. This habitat survey followed similar procedures to those identified in Appendix 2, with the exception of additional measurements for dissolved oxygen, temperature, and conductivity. The grid was first treated as though it were an isolated HMU. Hydraulic information was collected at each of the four grid corners and cover characteristics were described for the area within the grid. This data was used to identify habitat use guilds with the help of statistical analysis (see **Appendix 5** for more detail). We would typically sample several grids within a single HMU and that HMU would be mapped as described in the habitat survey section. Stratified randomly distributed samples of hydraulic data and HMU-wide cover attributes were also collected and used for generating the HMU-scale preference statistics for guilds during the Rearing and Growth

Bioperiod. The data also served as a validation/calibration database for literature-based habitat suitability models

Results

Total sampling effort of the Niobrara River consisted of 213 PAEs placed at 13 sites within our study area during late summer of 2010 (July, August, and September). The number of grids set per site ranged from 13 to 24, but averaged 17 per site. Zone 4 had the greatest number of samples, while Zone 3 had the least. Sampling was not conducted at Sites 3 (Spencer Hydro Dam), 9 (Southwest of Cody, NE), and 13 (Southeast of Gordon, NE) due to inaccessibility or safety concerns.

We collected 3345 fish representing 30 species (**Table 14**) and 8 families within the Niobrara River. The total catch differed between each site and ranged from 31 to 972, with an average of 16 fish per grid. Sand Shiners (32%) were the most abundant species, followed by Bigmouth Shiners (21%), Creek Chubs (8%), White Suckers (7%), Longnose Dace (6%), Red Shiners (6%), and Plains Topminnows (4%). The remaining species composed <18% of our total catch (**Figure 12**). An output table of sampled fish data within their grid and HMU along with collected MesoHABSIM data at each location can be found in **Appendix 6**. This data table can be used both within Sim-Stream and externally to run statistical models.

Table 14: Species name and total number of fish by species captured in the Niobrara River using PAEs during summer 2010.

Species Names	Total (% total capture)	Species Names	Total (% total capture)
Sand Shiner *Notropis stramineus*	1051 (31.6)	**YOY Channel Catfish** *Ictalurus punctatus*	58 (1.8)
Bigmouth Shiner *Notropis dorsalis*	706 (21.2)	**Brook Stickleback** *Culaea inconstans*	31 (0.9)
Creek Chub *Semotilus atromaculatus*	252 (7.6)	**Yellow Perch** *Perca flavescens*	24 (0.7)
White Sucker *Catostomus commersonii*	218 (6.6)	**Emerald Shiner** *Notropis atherinoides*	21 (0.6)
Longnose Dace *Rhinichthys cataractae*	196 (5.9)	**Shorthead Redhorse** *Moxostoma macrolepidotum*	18 (0.5)
Red Shiner *Cyprinella lutrensis*	186 (5.6)	**Green Sunfish** *Lepomis cyanellus*	18 (0.5)
Plains Topminnow *Fundulus sciadicus*	133 (4.0)	**Fathead Minnow** *Pimephales promelas*	18 (0.5)
River Shiner *Notropis blennius*	102 (3.1)	**Bluegill** *Lepomis macrochirus*	11 (0.3)
River Carpsucker *Carpoides carpio*	102 (3.1)	**Largemouth Bass** *Micropterus salmoides*	8 (0.2)
Brassy Minnow *Hybognathus hankinsoni*	86 (3.6)		
Central Stoneroller *Campostoma anomalum*	84 (3.5)	**Total**	**3323**

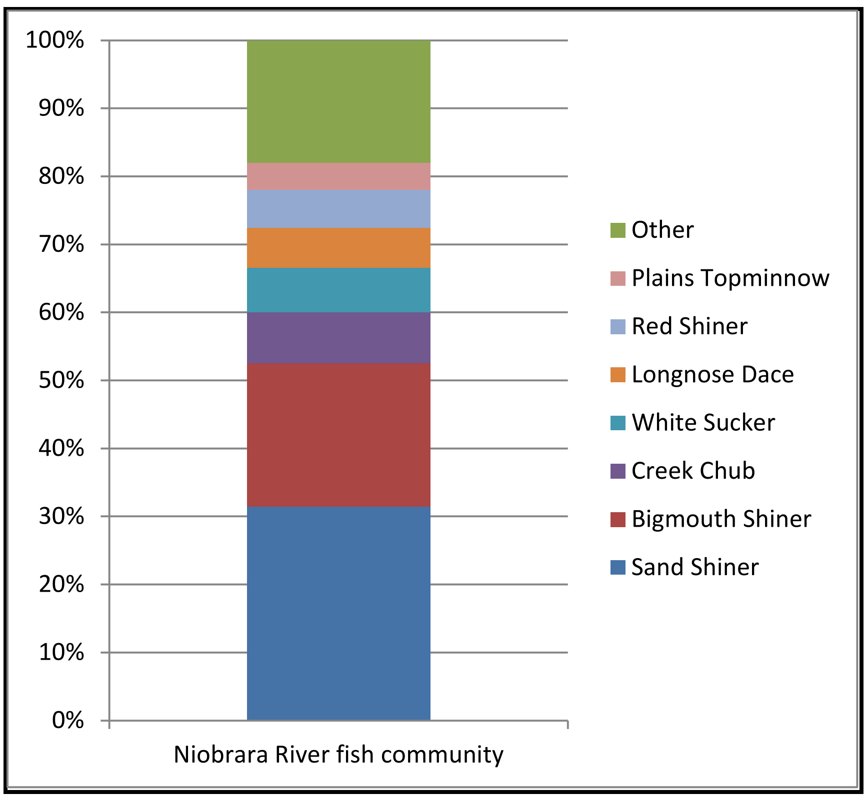

Figure 12: Niobrara River fish community captured by PAEs in summer of 2010 ("Other" includes 24 species that comprised <18% of total catch).

The fish community assemblage contained a variety of species, both native and introduced. However, the vast majority of our captures were native Nebraska species (N=27) with only three non-natives found. Species such as Largemouth Bass, Bluegill, White Crappie, and Black Crappie are most likely non-native to the Niobrara River, but are probably a result of stocking in the reservoirs within the Niobrara River drainage (Schainost, 2008). Macrohabitat generalist species were the largest proportion of the Niobrara River community (66%), though fluvial specialists, which are species that need flowing water throughout their life cycle, made up a large proportion also (27%) (Galat *et al.*, 2005). Fluvial dependents, which require flowing water for a part of their life cycle, were considerably less abundant than the other groups (Galat *et al.*, 2005). Environmental tolerance encompasses a broad range of changes to the environment and represents the ability of a species to withstand perturbation. The river fish community consisted primarily of moderately tolerant species (57%), while intolerant species were the least abundant (13%). Invertivores composed the greatest proportion of trophic association (36%), followed by carnivores (33%). The remaining species consisted of detritivores (17%), herbivores (7%), and planktivores (7%). See **Appendix 4** for more information. The resulting catch data and data from previous or concurrent sampling efforts on the Niobrara River (e.g., Wanner *et al.*, 2008; Behmer, unpublished data) were used to identify a targeted subset of the fish community that represented existing habitat needs for fish through a series of iterative meetings with project-related staff biologists and researchers. The iterative process included multiple agency input for prioritizing representation of habitat needs for rare species, species of concern, economically important sportfish and potential prey species. Of those captured in our survey, 20 species were chosen to represent the fish community in the subsequently developed habitat model.

Guild Structure Development

The guild approach identifies groupings within species assemblages based on environmental, biological, or other functional similarities (Leonard and Orth, 1988; Welcomme *et al.*, 2005; Persinger *et al.*, 2011). This approach accounts for multiple species responses and has been an appealing technique for ecologists and managers since its conception in the early 1900s (Kryhanovsky, 1948; Root, 1967). The formation of guilds allows for reduction in variability and is often used when investigating large scale responses by species. Often these guilds are formulated to either simplify explanations or used when data are insufficient or lacking (Austen *et al.*, 1994). Regardless of the reasoning, guild formation is often interpretative and thus subject to critique (Aarts and Nienhuis, 2003).

It was our goal to quantitatively apply the ecological guild approach within the Niobrara River and then evaluate guild habitat suitability. Our approach was to characterize assemblages using hierarchical cluster analysis based on microhabitat data. The guild approach allowed us to increase the number of individuals by combining species of similar habitat usage into guilds to generate regression coefficients that were then applied within the MesoHABSIM model. See **Appendix 5** for more details on our guild development strategy.

Data Analysis

We used hierarchical cluster analysis (CLA) to identify groups of species that were associated with similar physical habitat parameters recorded during the fish sampling survey. A total of 20 variables were used in guild development and were appropriately transformed prior to analysis (See **Appendix 5**). Ward's agglomerative hierarchical method and partial correlation were used to separate species into different clusters based on suggestions by McCune and Grace (2002). A partial correlation value of 0.025 was chosen as the point that would determine groups. Thus, species lying on the same branch at less than 0.025 would be grouped together within the same guild.

A discriminate analysis (DA) was used to assess species arrangement into the habitat guilds. We used the habitat parameters (depth, velocity, DO, pH and temperature) collected at the PAEs to classify each individual fish and assess its placement into the identified guilds. We examined the linear discriminant's function for each guild to determine relative importance of the habitat variables and a misclassification matrix to estimate the percent of incorrectly classified individuals based on the CLA (See **Appendix 5**).

Based on CLA and subsequent DA we evaluated and rearranged clusters in an ad hoc fashion. We then reevaluated the new guilds using the same DA procedures and a Mahalanobis squared distance at the significance level of 0.05 to determine whether or not our guilds were significantly different. This reevaluation allowed us to discern whether our original arrangement, based on quantitative means, was supported by reducing the misclassification error rate (See **Appendix 5**).

Results

The cluster analysis of the habitat variables initially identified seven clusters below the 0.025 partial R^2 cutoff (**Figure 13**). Four major splits occurred prior to the cutoff value, the first occurring at 0.46 semi-partial R^2. Consequently, the largest cluster had six species, while the smallest cluster consisted of just one species. We reclassified six species to: 1) reduce the overall number of guilds, and 2) associate perceived lentic- and lotic-prone species with other similar species (**Table 15**). For example, Bluegill was the sole species within a guild, so was added to Guild 4, which contained Yellow Perch and Green Sunfish that had similar macro-habitat requirements. Largemouth Bass was added to this group due to taxonomic and habitat use similarities. The result of the reclassification effort reduced the number of guilds to five (**Table 15**).

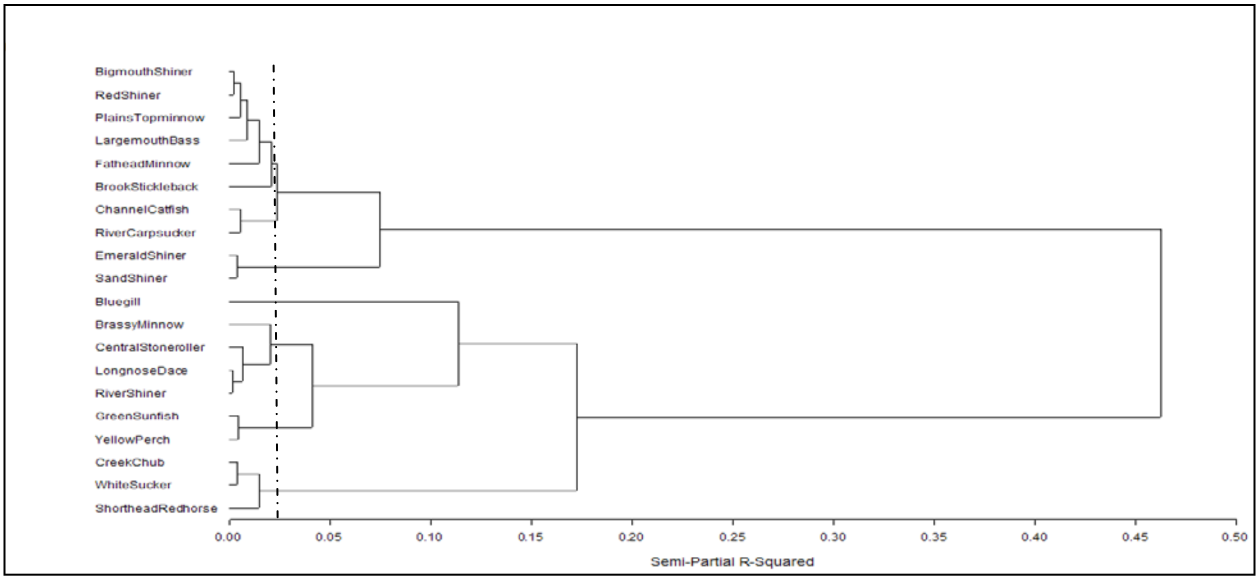

Figure 13: Results of the hierarchical cluster analysis showing similarities in habitat between 20 fish species in the Niobrara River.
A semi-partial R^2 value of 0.025 was used to split groups and determine guilds for use in the discriminant analysis (dashed vertical line). A total of seven guilds were defined, ranging in composition from a maximum of six individual species, to a low of one individual within a guild.

The linear discriminant function identified temperature, dissolved oxygen, and velocity as the most influential variables when assigning species into guilds. Temperature was either the first or second most important variable for all of the guilds, while dissolved oxygen was only important to Guilds 1 and 2. When identified, velocity was always the most important variable for guild determination.

Table 15: Reclassified guilds with species composition and characteristics observed from field collections. Guild names are derived from mesohabitat classifications and general habitat characteristics associated with species in each guild.

Guild Number	Guild Members	Guild Name	Characteristics
1	Bigmouth Shiner, Red Shiner, Plains Topminnow, Fathead Minnow, Brook Stickleback, YOY Channel Catfish	Lobate Margin	Inhabit areas of low velocity and shallow depths on the margin of channels. May include areas with lower dissolved oxygen and fluctuating temperatures.
2	Sand Shiner, Emerald Shiner	Run	May include main channel areas with greater velocities and depths.
3	Brassy Minnow, Central Stoneroller, Longnose Dace, River Shiner	Riffle	Typically found in clearer water with lower velocity main channel habitats. Often areas include coarse substrate and aquatic vegetation.
4	Largemouth Bass, Bluegill, Green Sunfish, Yellow Perch	Slackwater	Inhabits near off-channel pools or backwaters near stream edges. Inhabited areas are often lower in velocity and have greater depths.

5	White Sucker, Creek Chub, Shorthead Redhorse, YOY River Carpsucker	Habitat Generalist	Inhabit areas of low velocity and shallow depths within secondary lobate channels. May include areas with lower dissolved oxygen and fluctuating temperatures.

For the sake of consistency, the species captured during our fishing survey of the Niobrara River were further analyzed at the segment level (i.e., data from Zone 3 was grouped with Zone 4). The species proportions for each segment are shown on the left side of the figure below (**Figure 14**). The observed species were then categorized into a guild structure and their proportion within the community for each segment was determined (**Figure 14**).

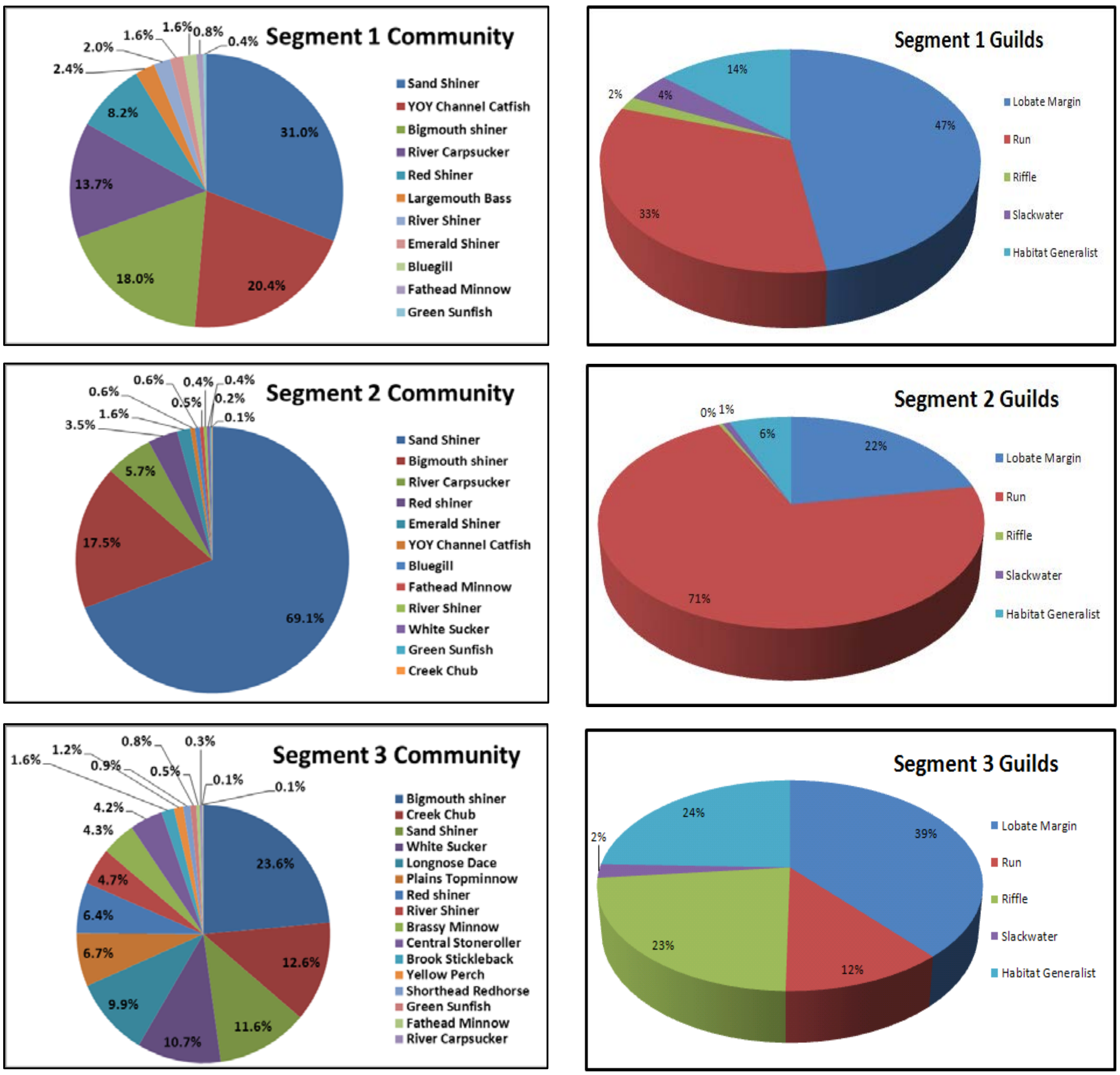

Figure 14: Proportion of fish species (left) and guilds (right) in each segment of the Niobrara River based on our fishing survey data.

Suitability Models

Introduction

Habitat suitability criteria models were created for fish guilds, avian species, and other targeted species during reproductive and rearing and growth periods in the Niobrara River. These models were identified in **Appendix 5, 8, and 14** (Parasiewicz *et al.,* 2010) and presented at the stakeholders meeting in March 2010. The model criteria were used to evaluate habitat quality in the mapped areas of the river. Species- and guild-specific habitat model criteria were established based on empirical data collected from the Niobrara River, as well as literature review and expert opinion. When sufficient empirical data were available we used multivariate statistical analysis to develop algorithms predicting probability of species presence or high abundance in an HMU. Models also define probability thresholds allowing for the distinction between not suitable (low probability of presence), suitable (high probability of presence) and optimal (high probability of high abundance) habitats. The literature-based models define ranges of physical attribute values that are utilized by fish and use a fuzzy logic approach to identify not suitable, suitable and optimal habitat. The empirical data were used for models dealing with the rearing and growth bioperiod for select species and guilds only. For spawning guilds and all other individual species the criteria were developed using literature. The reproductive guilds provided an additional level of detail on habitat suitability modeling during critical life-stage events that may be affected by water withdrawals. These literature-based criteria were then validated using data collected from the Niobrara River and are detailed in **Appendix 8**.

Methods

Empirical data-based habitat suitability model

We used a multivariate statistical model (logistic regression) to compute the habitat selection criteria for select species and guilds. We used the physical attributes recorded within HMUs where an electrofishing grid was located with the number of individuals captured within the grids to calculate the response functions for the species and guilds. The environmental attributes such as distribution of depth, velocity, substrate and cover were the independent variables, and the species and guilds presence or high abundance were the dependent variables in regression models describing habitat preference. It must be noted again that the HMU type is just one of the attributes investigated here and is not solely responsible for the value of dependent variables, but in combination with the remaining attributes. Therefore, the habitat types are not predefined here by HMU types but by the combination of all of these variables. We employed a stepwise forward logistic regression model (using R software) to identify the characteristics of habitat used versus habitat that is not used by each species and guild. The model uses Akaike Information Criteria (AIC) to determine which parameters should be included in the regression formula (Akaike, 1981).

The mathematical formula (**Appendix 8**) is based on proportions of occupied/non-occupied areas observed during the survey and does not capture all the possible circumstances or represent mechanisms of fish behavior. Furthermore, since fish presence is caused by a combination of environmental factors, interpreting the influence of individual parameters is limited. To distinguish suitable habitat, we used binary dependent variables indicating presence and absence and, in a second model, high and low abundances. The species and guild data were separated into low and high abundance classes. The cutoff value between high and low abundance was calculated from observed abundances per grid and was different for each species and guild depending on their behavior (solitary vs. gregarious) and results of fish sampling. We used all the available data for the presence model, and for the abundance model, we used only data from grids in which fish were caught.

For each mesohabitat mapped during the biological survey, we calculated the probability of species and guild presence using computed regression equations. To define the threshold probability value best corresponding with species presence/abundance, we used a relative operating characteristic (ROC) technique (Metz, 1978). The observed presence and abundance value at each grid was associated with the calculated probability for the HMU where the grid was located. The ROC examines the discrimination performance of the model over a range of threshold levels by plotting proportion of grids correctly predicted to be occupied (sensitivity or true positive rate), and the proportion of grids incorrectly predicted to be occupied (false positive rate). Best performing threshold is chosen by observing the critical point on the ROC curve. The area under the ROC curve defines the discrimination capacity of the model based on Mann-Whitney statistics (Pearce & Ferrier 2000).

The model was then applied to the data from the mapping survey to identify “suitable” (high probability of presence) and “optimal” (high probability of high abundance) habitat areas.

Literature based habitat suitability model

When empirical data were insufficient or lacking a literature review was used to determine habitat suitability criteria. Data for this model were based on peer reviewed literature, species reports, and expert review. A range of habitat rules that defined usable habitat (i.e., ranges of physical conditions under which species occurred) were entered into SimStream 7.0 and used to categorize the HMUs from our mapping survey (**Appendix 7 and 16**). In this model, we identified five physical attributes (depth [cm], velocity [cm/s], choriotop, HMU type and cover type) for which criteria can be developed that will then assess the suitability of an HMU. Additional rules defined how many of these criteria must be fulfilled in order for HMU to be determined suitable or optimal. For those species captured in sufficient numbers, model outputs were then validated using abundance data for fish collected from HMUs in the Niobrara River (**Appendices 4 and 8**).

Habitat use criteria for the rearing and growth and reproductive periods of target species and reproductive guilds were also reviewed with regard to their compatibility with the Niobrara River. Habitat suitability criteria from the Lower Platte River, along with expert opinion, were referenced for the empirical models created for the rearing and growth period as listed in **Table 16** (Peters *et al.*, 1989; Peters and Parham, 2008; Jennings, and Zigler. 2009; Bozek, *et al*., 2011). Criteria for the species reproductive period and reproductive guilds were evaluated with expert opinion (**Table 17**).

Table 16: Literature model habitat criteria developed for rearing and growth periods in the Niobrara River (* Peters *et al.*, 1989; ** Peters and Parham, 2008; *** Expert opinion). Critical characteristics are in bold.

Target Fish Species	Seasonal Period	HMU Type	Water Depth (cm)	Current Velocity (cm/s)	Choriotop (substrate)	Cover type
Red Shiner*, ***	May-September	Backwaters, Pools, Sidearm, Glide	< 10	10-30	Psammal, Akal	Stable bank, Overhanging vegetation, Low gradient
River Shiner*	May-September		< 30	20-30	Psammal, Akal, Pelal	
Sand Shiner*, ***	May-September	Low complex High complex, Secondary lobe, Glide	10-20	10-30	Psammal, Akal	Shallow flats
YOY Channel Catfish*	May-September		60-70	10-80*	Psammal, Akal, Pelal	
Adult Channel Catfish*, ***	May-September	Main lobe, Secondary lobe, Run, Deep run, Sidearm, Riffle	> 60	0-40	Psammal, Pelal	Undercut banks, Woody debris
River Carpsucker*, ***	May-September	Deep run, Run, Main lobe	> 50	< 10	Psammal, Pelal, Microlithal, Mesolithal	
Pallid Sturgeon**, ***	May-September	Main lobe, Deep run, High complex	> 36	37-121	Psammal, Akal, Microlithal	
Shovelnose Sturgeon**, ***	May-September	Main Lobe, Deep run, Fast run, Run, Pools	52-180	20-80	Psammal, Pelal, Akal, Microlithal	Shallow flats
Bigmouth Shiner	May-September	Run, Glide, High complex	< 40	10-40	Psammal, Akal	Shallow flats
Sauger***	May-September	Deep run, Run, Pool	100-500	10-30	Psammal, Pelal, Akal, Microlithal	Rip rap
Paddlefish***	May-September	Backwaters	150-450	0-30		

Table 17: Table of literature-reviewed spawning habitat features for species and guilds modeled in the Niobrara River. *Expert Opinion; **Jennings and Zigler, 2009; ***Bozek *et al.*, 2011.

Target Fish Species	Seasonal Period	HMU Type	Water Depth (cm)	Current Velocity (cm/s)	Choriotop (substrate)	Cover type
River Shiner	May-July	High complex, Low complex, Run, Riffle	< 40	30-60	Psammal, Akal	
Sand Shiner	May-August	High complex, Low complex, Run, Riffle	< 40	30-60	Psammal, Akal, Phytal	
Red Shiner	May-July	High complex, Low complex, Run, Riffle	< 40	< 20	Psammal, Akal	Submerged vegetation, Overhanging vegetation, Woody debris
Bigmouth Shiner	May-July	High complex, Low complex, Run, Riffle	< 40	30-60	Psammal, Akal	
Pallid Sturgeon*	April-June	Main lobe, Run, Deep run			Psammal, Pelal, Akal, Microlithal, Macrolithal	
Shovelnose Sturgeon*	April-June	Main lobe, Run, Deep run			Psammal, Pelal, Akal, Microlithal, Macrolithal	
Sauger***	March-April	Deep run, Run, Pools	> 60	33-98	Akal, Microlithal, Mesolithal, Macrolithal, Megalithal, Gigalithal	Low gradient
Paddlefish**	March-June	Deep run	> 100	> 30	Akal, Microlithal, Mesolithal, Macrolithal, Megalithal, Gigalithal	
Channel Catfish	May-July	Pools, Backwaters	< 500	< 15	Psammal, Pelal, Macrolithal	Undercut banks, Woody debris
River Carpsucker	June-July				Psammal, Pelal, Akal, Phytal	Submerged vegetation
Brood Hider Guild	April-July	Backwater, Pools, Riffle	< 100	< 30	Psammal, Akal, Macrolithal	Submerged vegetation, Overhanging vegetation, Woody debris
Nest Spawner Guild	April-July	Backwater, Pools	40-200	< 10	Psammal, Pelal, Akal, Phytal, Microlithal, Mesolithal, Macrolithal	Submerged vegetation, Overhanging vegetation, Woody debris, Undercut banks
Open Substratum Guild	May-July	Backwater, Pools, Run, Riffle, Secondary lobe, Sidearm	<150	30-60	Psammal, Akal, Microlithal, Mesolithal, Macrolithal, Phytal	Submerged vegetation, Overhanging vegetation

Final Species Modeling Plan

To summarize the final modeling plan for the Niobrara River, we have included **Table 18** below. We attempted to develop logistic regression models for all of the species sampled using electrofishing grids during our summer fishing survey. However, due to limited observations we were able to develop presence models for six species and abundance models for only four of those species. All of the species were assigned to habitat use guilds and logistic regression models were developed for five rearing and growth guilds. Literature-based models were developed for the top seven species observed in the Niobrara fish community plus an additional five species of special interest.

Table 18: Model types developed for species and guilds for analysis in this project.

Rearing and Growth				Reproductive Periods		
Species	**Presence**	**Abundance**	**Literature**	**Species**	**Literature**	**Date Range**
Lobate Margin Guild*	Yes	Yes	No	Brood Hider Guild	Yes	2 periods early/late
Run Guild*	Yes	Yes	No	Nest Spawner Guild	Yes	2 periods early/late
Riffle Guild*	Yes	Yes	No	Open Substratum Guild	Yes	2 periods early/late
Slackwater Guild*	Yes	Yes	No			
Habitat Generalist Guild*	Yes	Yes	No			
Red Shiner*	Yes	Yes	Yes	Red Shiner	Yes	5/15 to 6/30
River Shiner*	Yes	Yes	Yes	River Shiner	Yes	5/15 to 6/30
Sand Shiner*	Yes	Yes	Yes	Sand Shiner	Yes	5/15 to 6/30
Bigmouth Shiner*	Yes	No	Yes	Bigmouth Shiner	Yes	5/15 to 6/30
White Sucker*	Yes	Yes	Yes			
YOY Channel Catfish*	Yes	No	Yes			
River Carpsucker	No	No	Yes	River Carpsucker	Yes	3/01 to 5/15
Pallid Sturgeon	No	No	Yes	Pallid Sturgeon	Yes	3/01 to 5/14
Shovelnose Sturgeon	No	No	Yes	Shovelnose Sturgeon	Yes	3/01 to 5/14
Sauger	No	No	Yes	Sauger	Yes	3/01 to 5/14
Paddlefish	No	No	Yes	Paddlefish	Yes	3/01 to 5/14
Channel Catfish	No	No	Yes	Channel Catfish	Yes	5/15 to 6/30
				Piping Plover	Yes	5/01 to 8/31
				Least Tern	Yes	5/01 to 8/31
				Whooping Crane	Yes	May/October
* Coefficients generated from Niobrara PAE data collection.						

For the reproductive bioperiod, ten literature-based individual species models were developed for the project, including for all of the species of special interest. Guild-based spawning literature models were also developed for three spawning classes (**Table 17**). In addition, three avian models were developed for nesting or roosting birds of special interest.

Fish and Bird Habitat Rating Curve Results by Segment

Segment 1 Rearing and Growth

The Wetted Area and the Generic Fish Plus curves are very similar (**Figure 15**). Wetted Area is 44% of the channel area (CA) for a flow of 0.1 cfsm. Wetted Area rises sharply to 59% CA for 0.15 cfsm and then begins to climb at a more moderate pace to a peak of 77% CA for 0.45 cfsm. At 24% CA for 0.1 cfsm, Generic Fish Habitat climbs rapidly to 36% CA by 0.15 cfsm. Generic Fish habitat expands steadily as flow increases, reaching 60% CA for a flow of 0.45 cfsm. Generic Fish Plus Habitat is 43% CA for 0.1 cfsm and rises quickly to 58% CA for 0.15 cfsm, after which the purple curve continues to rise as flow increases, peaking at 74% CA for 0.45 cfsm. Community Habitat 1 is 13% CA for the lowest flow of 0.1 cfsm. It increases quickly to 19% CA for 0.15 cfsm, and at this point habitat area continues to increase but at a slightly slower rate, reaching a high of 32% CA for 0.45 cfsm.

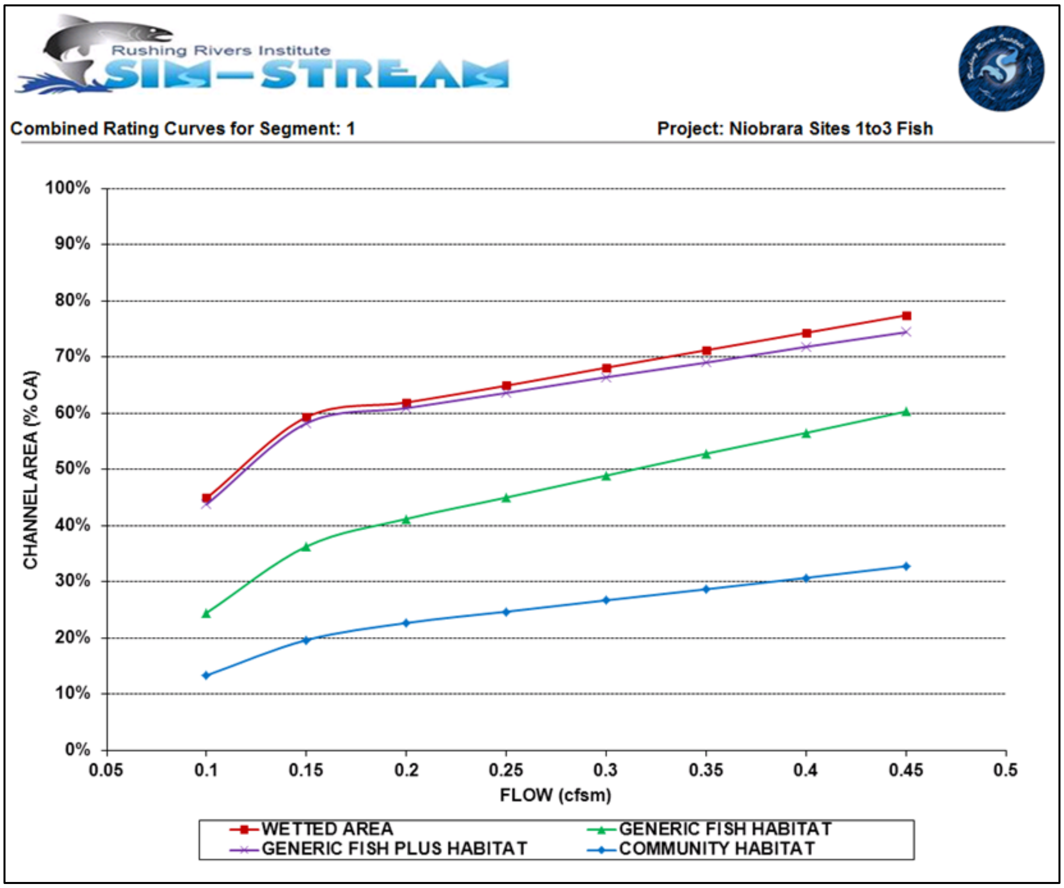

Figure 15: Community rating curves for Segment 1 (Sites 1-3) in the Niobrara River.

Segment 1 Spawning

Figure 16 shows Generic Fish Habitat near 28% CA for 0.1 cfsm and increasing to 45% CA by 0.2 cfsm. The curve continues to rise but at a slower rate until it peaks at 49% CA for a velocity of 0.45 cfsm. Community Habitat starts with 8% for 0.1 cfsm, rises to a peak value of 17% for 0.2 cfsm, then declines gradually to 10% for 0.45 cfsm.

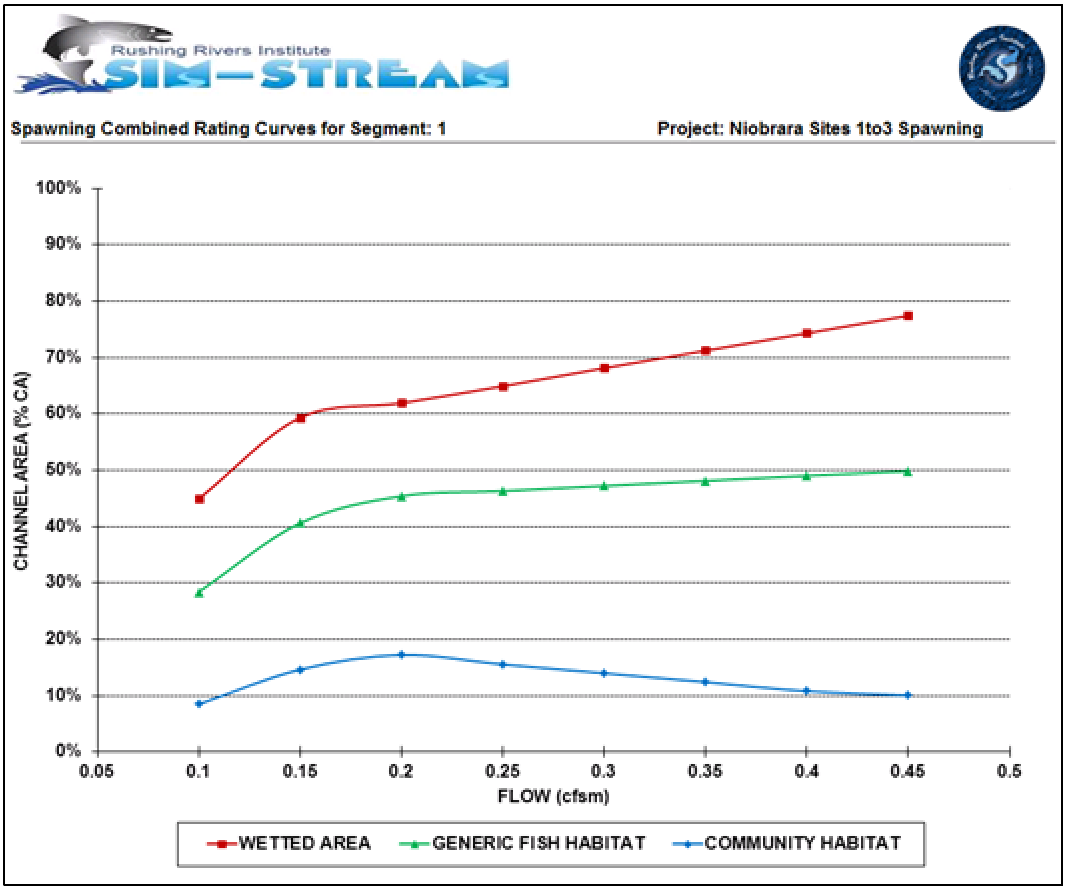

Figure 16: Spawning community rating curves for Segment 1 (Sites 1-3) in the Niobrara River.

Habitat Rating Curves

The amount of habitat suitable for each guild or species was assessed by applying suitability criteria to each surveyed HMU. The HMUs were assigned to unsuitable, suitable, or optimal categories and depicted in the maps of **Appendices 12 and 13**. The detailed results of the habitat suitability assessment for each HMU are presented in **Appendix 9**. The total area of suitable and optimal habitat was quantified for each site over the measured flows as a proportion of channel area at each site. The change of this relative habitat area across the range of flows is then represented as habitat rating curves (one for suitable and one for optimal habitat).

Effective habitat is an agglomerate of suitable and optimal habitat that is needed to support the species under investigation. We computed effective habitat by weighting the calculated suitable habitat by 25% and optimal by 75% and adding the resulting values. HMUs determined to be optimal for a species are by default also considered suitable. By making this calculation, we are preferentially favoring areas with optimal available habitat while still accounting for habitat determined to be suitable. This is a pragmatic way of underscoring the need of documenting more than just substandard conditions. We chose the 75% weighting value based on arithmetical experiments and concluded that a smaller value could cause arithmetical confusion. Large values, like 90%, will limit the spread of the results making interpretation difficult, and using larger values could be interpreted as a suggestion that optimal habitat is imperative for survival, which may not necessarily be true. The rationale here is to assure that a large proportion of optimal habitat will be represented in the river and therefore secure more than substandard habitat conditions needed for healthy fish populations. This calculation is made consistently throughout the HMUs to produce the weighted effective habitat curves.

Effective habitat rating curves were constructed for every species as well as generalized into a whole community index. The latter is modeled in two ways: 1) using a Generic Fish model where the habitat level is expressed as an area of habitats suitable for one or more of the investigated fish species/guilds, and 2) by using a Community Habitat model, where the habitat level is expressed as the sum of habitats suitable for investigated guilds weighted by their expected proportions in the existing fish community. For each segment, these proportions are taken from adding the expected proportions of species belonging to each guild (as presented in **Figure 14**, for example) for non-reproductive guilds. For reproductive guilds, analog methodology is applied. We also created a Generic Fish Plus Habitat model that is similar to the Generic Fish model, but also considers the five species of special interest.

The rating curves presented below are generalized to the three study segments. (Segment 1: Sites 1-3; Segment 2: Sites 4-5; Segment 3: Sites 6-16). Figures for individual species or guilds at both the site and segment resolution can be found in **Appendices 10 and 11**. The charts show wetted area and effective habitat for the Generic Fish Habitat model, Generic Fish Plus Habitat model and the Community Habitat model. The habitat models for Generic Fish Plus community were developed only for Segment 1 and 2. A more detailed presentation of this material can be found in **Appendix 10 and 11.**

Segment 1 Avian Roosting and Rearing and Growth

For the avian species models (**Appendix 14**), Segment 1 includes study sections 1 through 5, because unlike for the fish species, the presence of Spencer Dam does not inhibit the birds' up and downstream movement. Of course, the presence of a dam could have an influence on the quality of available habitat by altering sandbar development and disrupting normal instream flow patterns.

Figure 17 represents the rating curves for the three avian species of interest. Additional avian rating curves can be found in **Appendix 15**. Wetted plus high bar area includes both the wetted area of the channel potentially used as crane roosting habitat as well as the high bar portion of the channel potentially used for nesting and rearing by terns and plovers. The wetted plus high bar area is 72.6% CA for 0.1 cfsm and rises to 87.1% CA by 0.2 cfsm, and then levels off for the remainder of modeled flows. High bar area increases 14.6% CA at 0.1 cfsm to 18% CA at 0.15 cfsm and then continues to increase gradually, peaking at 20.1% CA at 0.45 cfsm. Interior Least Tern habitat makes up 5.8% CA at 0.1 cfsm and increases steadily with increasing flows to 16.2% CA at 0.45 cfsm. Piping Plover habitat makes up 9% CA at 0.1 cfsm and slowly increases to 11.5% CA at 0.25 cfsm before increasing slightly more rapidly to 15.6% CA at 0.45 cfsm. Whooping Crane habitat is available in 2.7% CA at 0.1 cfsm and increases slowly to 9.2 % CA at 0.45 cfsm.

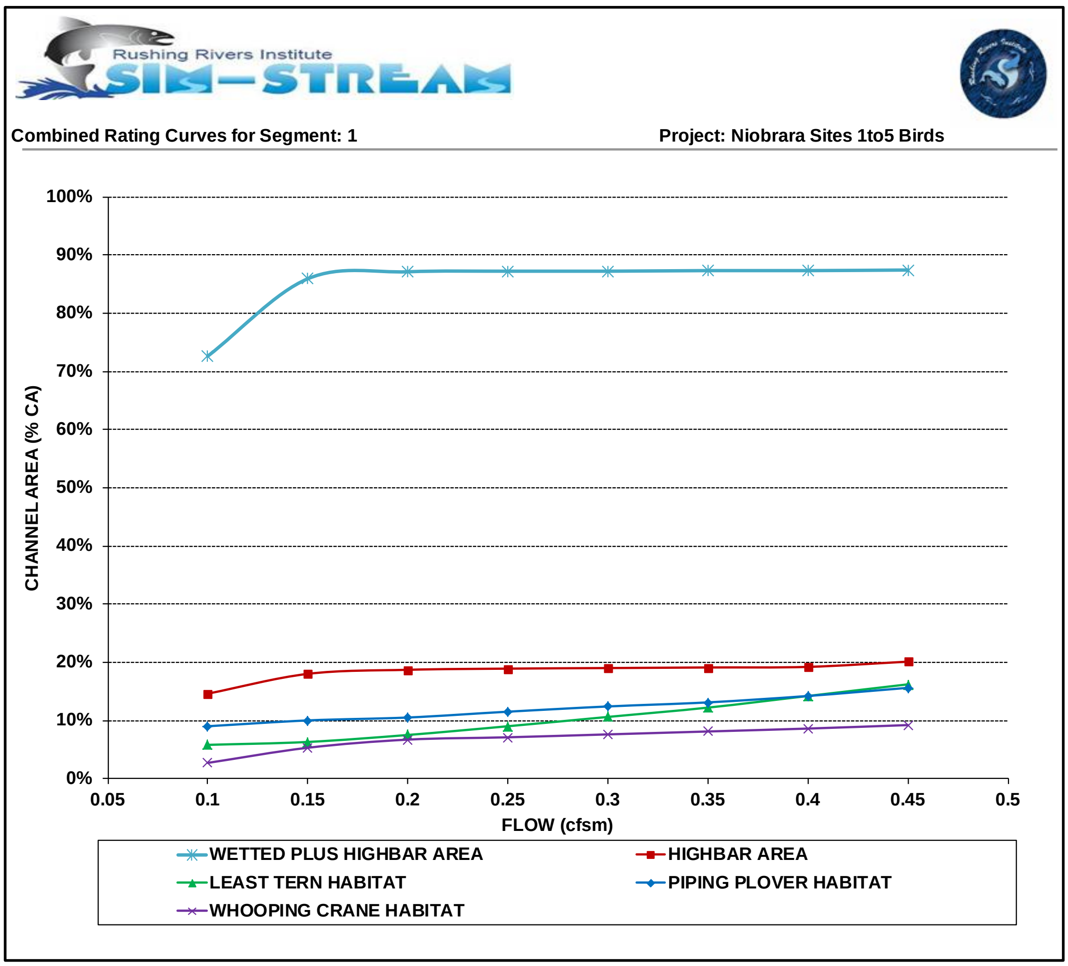

Figure 17: Combined rating curves of effective habitat for each of the three special interest avian species for Segment 1 and the change in high bar and wetted plus high bar area across the studied flows.

Segment 2 Rearing and Growth

Wetted Area for Segment 2 is 63% CA (0.1 cfsm) and quickly rises to 73% CA for 0.13 cfsm before declining continuously to 65% CA for 0.37 cfsm (**Figure 18**). This unusual trend is related to the large volumes of sand in the segment and the ability of the river to cut downward into its bed at higher velocities. At some point above the highest surveyed flow, we would expect the channel area to increase once again. Generic Fish Habitat is 36% CA for the lowest flow and climbs to 43% CA by 0.13 cfsm. The curve continues to increase moderately, culminating to more than 63% for the highest flow of 0.37 cfsm. The Generic Fish Plus Habitat curve closely matches the shape of the Wetted Area curve. Generic Fish Plus Habitat is 60% CA (0.1 cfsm) and, like Wetted Area, rises quickly, to a peak value of 70% CA for 0.16 cfsm before dropping to 65% CA for the highest flow. Community Habitat is 28% CA at 0.1 cfsm and rises to 30% CA for 0.13 cfsm. Habitat area dips between 0.13 and 0.16 cfsm before starting a rising trend that reaches a maximum of 45% for the highest flow.

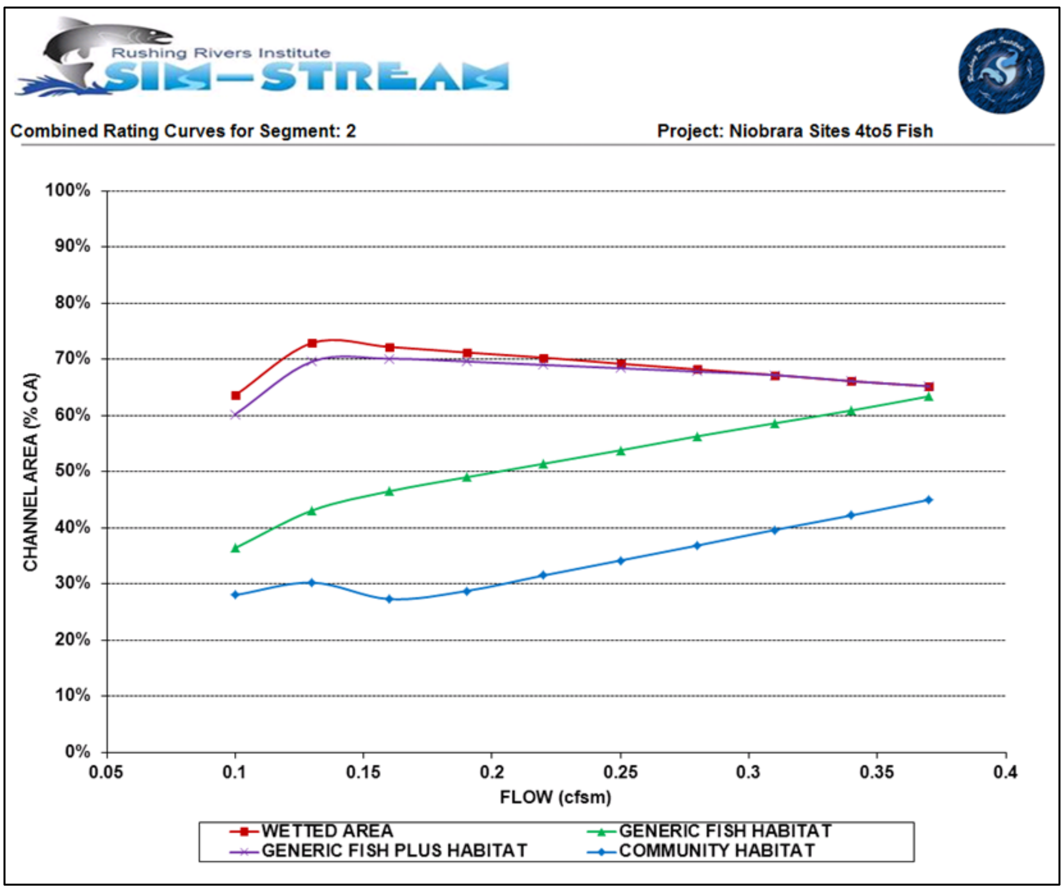

Figure 18: Community rating curves for Segment 2 (Sites 4-5) in the Niobrara River.

Segment 2 Spawning

The habitat rating curves for Segment 2 do not show any gains with increasing flows (**Figure 19**). Generic Fish Habitat loses more than 20% CA for the range of flows; it is at 62% CA for 0.1 cfsm, peaks at 69% CA for 0.13 cfsm and sinks to a low of 41% CA for 0.37cfsm. Community Habitat is nearly 25% CA for the first flow and peaks at 28% CA for 0.13 cfsm. Community Habitat drops moderately from 0.13 cfsm to 0.37 cfsm to a low of 15% CA.

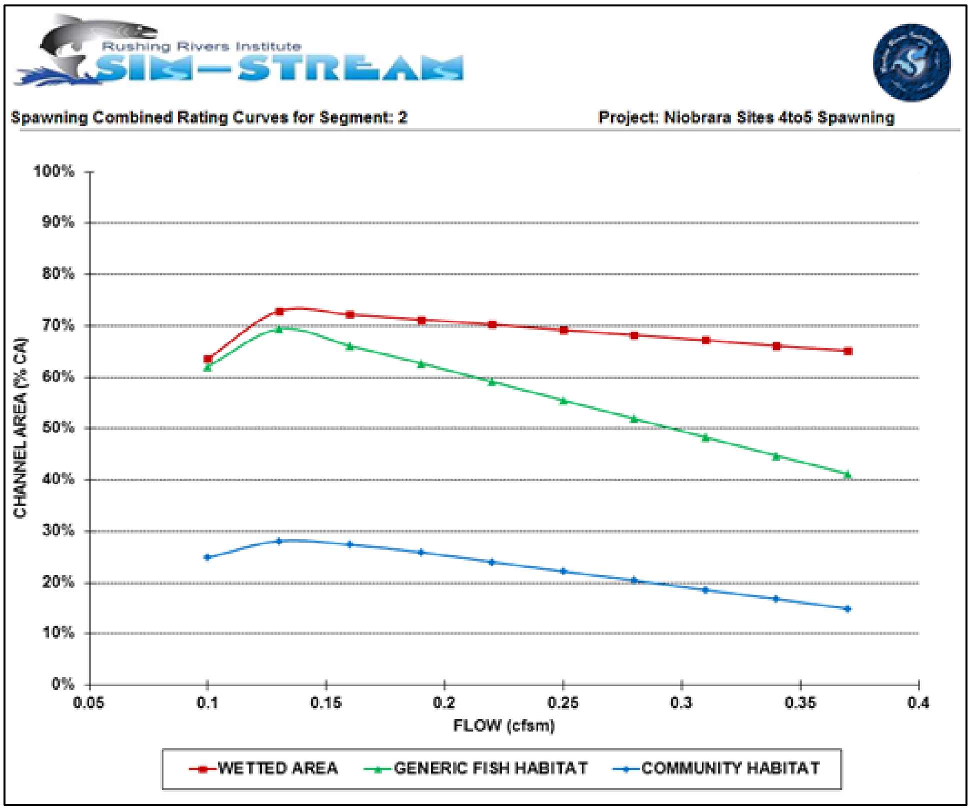

Figure 19: Spawning community rating curves for Segment 2 (Sites 4-5) in the Niobrara River.

Segment 3 Rearing and Growth

Figure 20 shows that the community curves all gain channel area as flows increase within the river comprising Segment 3. Wetted Area is 47% CA for 0.04 cfsm. It shoots up to 75% by 0.07 cfsm and then continues to climb at a slower pace as flows increase. For the last flow of 0.16 cfsm, Wetted Area is more than 86% CA. Generic Fish Habitat is 34% CA for the first flow and increases rapidly, reaching 54% CA for 0.07 cfsm before dipping down to 53% CA for 0.09 cfsm. As flows increase above 0.09 cfsm, habitat area continuously rises, reaching a maximum of 76% for the highest flow. Community Habitat is 12% CA for 0.04 cfsm and slowly rises to 20% CA for 0.07 cfsm. Habitat area dips slightly until 0.09 cfsm when it begins to trends upward, reaching 38% for 0.16 cfsm.

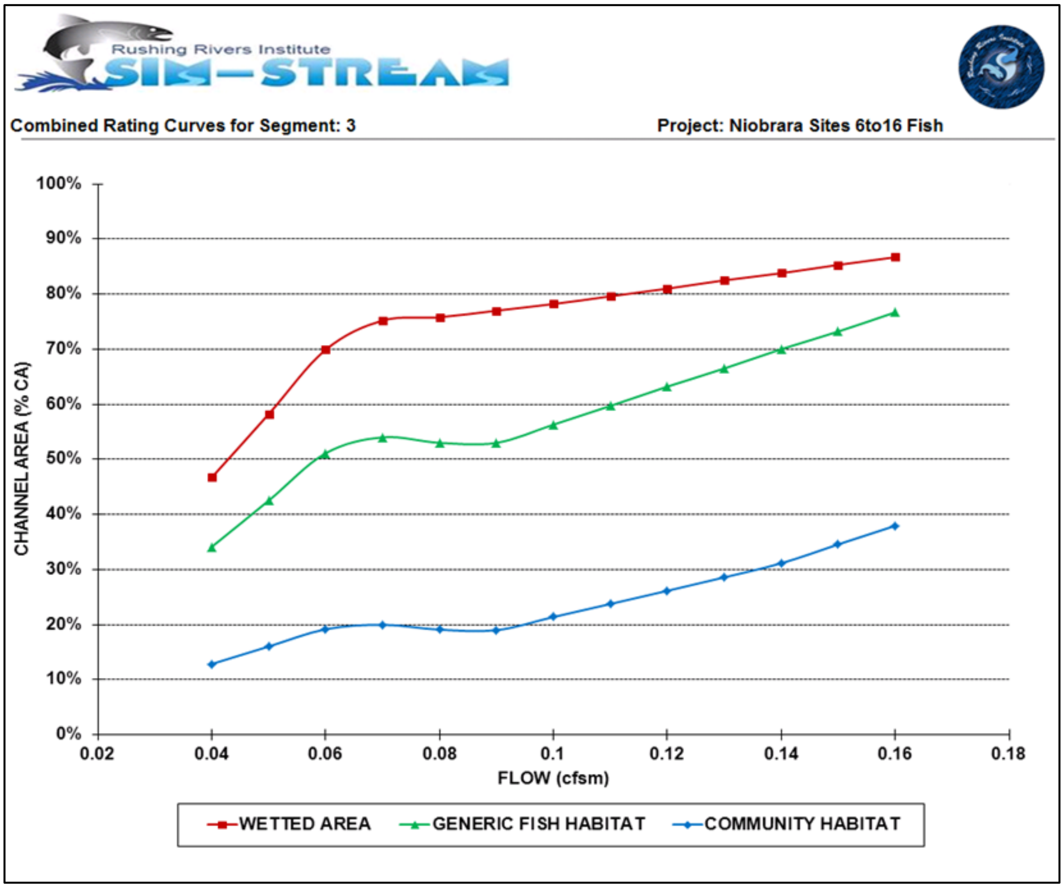

Figure 20: Community rating curves for Segment 3 (Sites 6-16) in the Niobrara River.

Segment 3 Spawning

Wetted Area is 46% CA for 0.04 cfsm, rises rapidly to 75% CA by 0.07 cfsm and then continues to trend upward slowly, reaching a high of 86% CA for 0.16 cfsm (**Figure 21**). Generic Fish Habitat is 40% CA for 0.04 cfsm and peaks at 68% CA for a flow of 0.09 cfsm. After reaching its high, the green curve gently falls to 65% CA for the highest flow. Community Habitat is 15% CA for 0.04 cfsm and rises to 23% CA by 0.07 cfsm, from here habitat area decreases slightly as flow continues to go up, dropping to 18% for 0.16 cfsm.

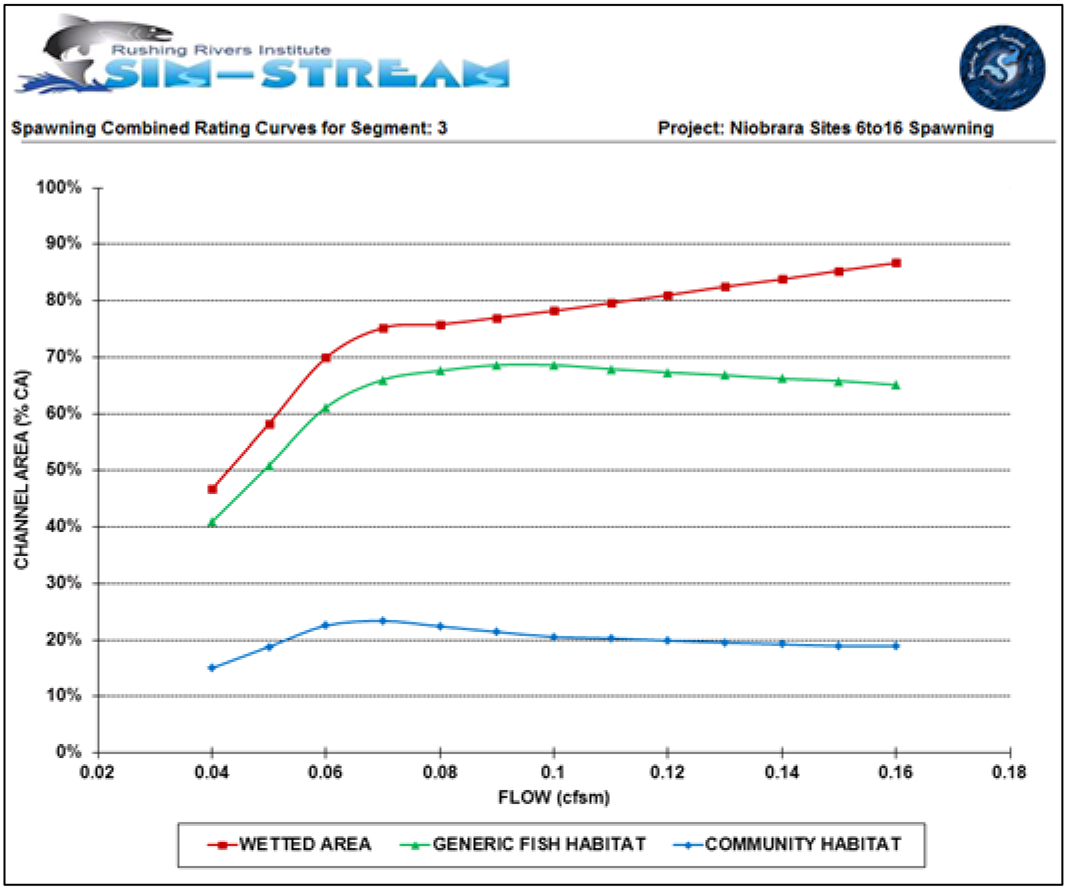

Figure 21: Spawning community rating curves for Segment 3 (Sites 6-16) in the Niobrara River.

Chapter 1.6: Habitat Time Series Analysis

Introduction

One of the most important underlying characteristics of any riverine environment is its continuous change over time. Different flow rates when combined with present cover attributes create different amounts of habitat availability each day; therefore, habitat availability is in flux and fauna are shaped by the varying environment rather than by static conditions. Ecosystems are driven by a combination of numerous and predictable events and much more rarely happening disturbances, creating habitat deficits. The disturbances may be created either by severe lack of habitat (pulse disturbance) or long continuous durations of low habitat magnitude as well as frequent occurrence of persistent habitat deficits (ramp disturbance). Pulse disturbances cause rapid impact, while the impact of ramp disturbances increases with their duration or frequency. Ramp disturbances lead to slow and continuous worsening of the physical condition of the animals through permanent stress. Drought is a typical example of ramp disturbance (Lake 2003).

Aquatic life is well adapted to this cycle of typical and rare conditions and can be mostly affected by changing the frequency patterns of disturbances (Poff 1992). Therefore, in instream flow management and conservation it is imperative that the disturbance frequency not be increased, or in other words, that despite human interventions rare events will remain rare. Consequently, to investigate habitat availability and the relationship to flows, we need to analyze temporal habitat patterns occurring throughout a time series and identify the disturbance thresholds. The purpose of such analysis should be to quantify parameters (magnitude, duration and frequency) of typical, transitional and catastrophic habitat conditions. This can be conducted by investigating the habitat time series with the help of the UCUT technique as described in detail in **Appendix 17**.

UCUT curves evaluate the duration and frequency of continuous events where habitat is lower than a specified threshold. The curves evaluate a portion of the flow record by analyzing all of the days within each bioperiod separately. As documented by Capra *et al.* (1995), the curves are good predictors of biological conditions. In interpreting the UCUTs, we assume that in natural systems fauna are adapted to the conditions that are most common and the occurrence of low probability (i.e., rare) events (e.g., long duration of low habitat availability caused by drought, flooding or channel modifications) creates stress. The increase in low probability events can lead to damaging conditions for the aquatic community. Analysis of the historical frequency of habitat patterns with the help of UCUTs allows us to separate the rare and common conditions in terms of habitat availability and the continuous durations of habitat deficits (Parasiewicz 2007, 2008).

Approximations of the habitat threshold within the habitat template of the Niobrara River were developed from the long-term hydrograph and habitat rating curves. For each bioperiod, we analyzed all habitat events occurring in the bioperiod over the period of the study record (mean daily flows of the last 44 years) and at multiple incremental habitat thresholds. A habitat event is defined as a continuous period in which the quantity of habitat stays under any predefined threshold. The frequency and cumulative duration of these events for a given bioperiod is represented with the help of duration curves through the UCUT curves diagram. The UCUT curve pattern for low habitat availability typically exhibits a "broken hockey stick" shape with a flat lower end. The increase of steepness indicates a reduction in event frequency caused by more persistent event durations. Typically, the steepness of the line increases towards the upper end of the curve. Aligning straight lines to the bottom part of the curves allows us to identify two regions of continuous duration, *typical* (flat end of the curve) and *persistent* (steep end of the curve).

Uncommonly long persistent events, which may have catastrophic effects on the fauna, can be considered severe disturbances. Such habitat deficits are commonly associated with droughts, for which those occurring at approximately decadal frequency are considered severe (McKee *et al.* 1993). Therefore, we chose the events of duration that happens approximately every ten years as a threshold to "catastrophic" disturbance. In our case, the demarcation points on the curves for catastrophic conditions are those representing events that did not happen more often than five times in the 44 year-long time series (**Figure 22**).

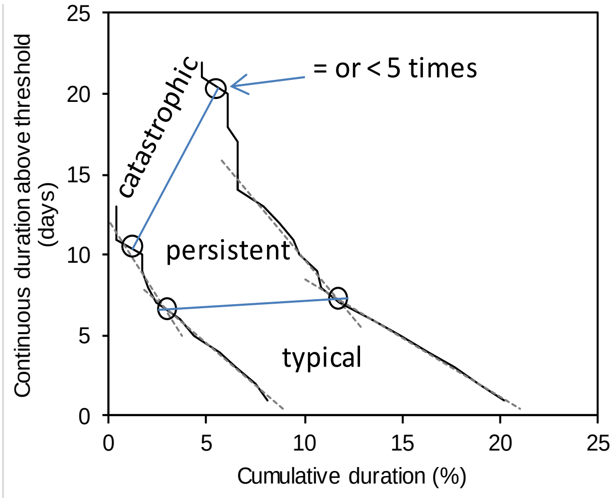

Figure 22: Example of inflection points identification by piece-wise linear regression. The two lines represent the UCUT curves selected as habitat thresholds. The dashed lines represent the broken-line linear relationships, while circles represent the inflection points (i.e., changes in slope of the linear function).

As the amount of habitat in the river reaches its carrying capacity, the influence of persistent duration on the population's conditions becomes less relevant. This quantity of habitat is commonly specified as the first critical point on the habitat rating curve. This habitat condition can also be approximated on the UCUT diagram as a curve that demarcates the first dramatic change in the pattern from the right hand side of the graph (e.g., strong increase or decrease of spacing between the UCUTs). The UCUT threshold chosen here represents the *common* events.

In situations where habitat availability is so low that it can't support the fish population, the event duration is of no consequence and catastrophic pulse stressor occurs. These conditions are very rare in natural systems and are represented by UCUT curves positioned in the left lower corner of the UCUT diagram. Typically, the UCUTs for rare habitat events are steep and very close to each other. The highest of these curves is selected as the threshold to *rare* conditions. Above this habitat level, the pattern rapidly changes. In our framework, the *rare* habitat should be exceeded most of the time and calls for the most immediate action. To prevent reaching this condition, we also identified the next highest UCUT line (the first that stands out) as a *critical* level, which often signals a need for action or vigilance.

Once the three threshold levels are identified, we search for the shortest persistent and catastrophic durations as described above on the three selected UCUT curves. The points allow for the construction of two lines separating typical and persistent events. The shortest persistent duration points on the UCUTs positioned in between the *critical* and *common* threshold curves should fall in the proximity of the created persistence demarcation line.

Figure 23 presents an example of UCUT curves for rearing and growth habitat for Generic Fish excluding all species of interest for Segment 1 of the Niobrara River. We chose 13% channel area as the highest magnitude for *rare* events, 15% for *critical* and 36% for *common*. A value of

13% channel area is equivalent to low flows of 0.054 cfsm, 15% channel area to 0.063 cfsm and 36% channel area to 0.15 cfsm at the USGS Verdel gage in this example.

For the determination of the shortest persistent duration for *rare* habitat events, the lowest of the two critical points corresponding with four days was selected. The catastrophic duration of decadal frequency was selected with six days as such, and longer events occurred in the time series only five times. For the *common* level, the critical points were estimated with 31 days for persistent durations and 91 days (entire bioperiod) for a catastrophic duration. See **Appendix 17** for descriptions of each UCUT curve.

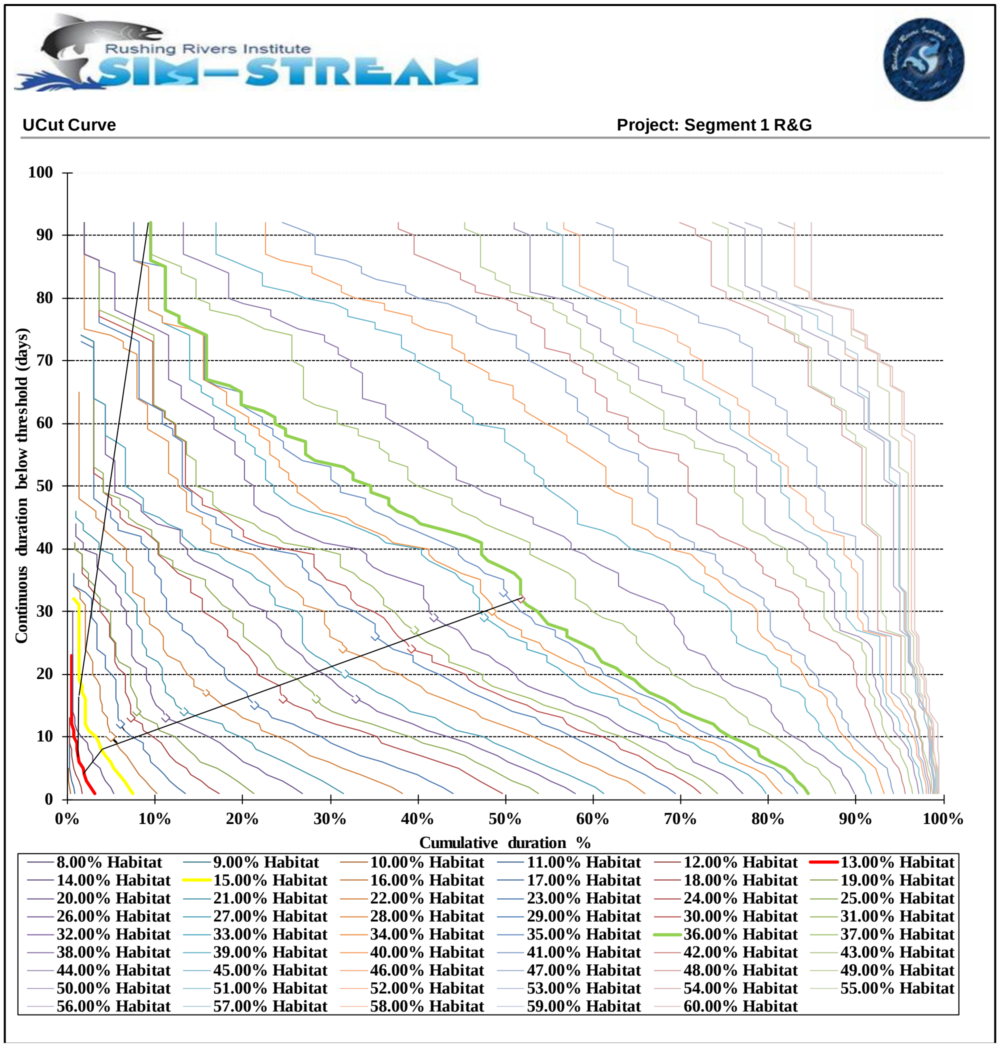

Figure 23: UCut curves for the Niobrara River Segment 1 R&G Generic Fish bioperiod. The markers on the lines between the critical and common threshold demonstrate the shortset persistent durations that could be selected on these curves.

Results

The results of our UCUT curve analysis can be seen in **Table 19** below. The table has been formatted to review the results for each section side-by-side within every bioperiod. It represents the parameters (magnitude and durations) of *rare, critical,* and *common* habitat stressor thresholds (HST). The information about the corresponding flows for each of these levels can be found in this table.

Table 19: Summarized results of the UCUT analysis.

Segments 1 and 2 use the Verdel Gage (11580 mi^2)	**Overwintering Late**		**Early Spawning**			**Late Spawning**			**Rearing and Growth**			**Rearing and Growth Plus**		**Overwintering Early**	
Segment 3 uses the Sparks Gage (7150 mi^2)	January 1 - February 28		March 1 - May 14			May 15 - June 30			July 1- September 30			July 1- September 30		October 1 - December 31	
Location (Segment)	**1/2**	**3**	**1**	**2**	**3**	1	2	3	1	2	3	1	2	1/2	3
Common habitat			**45%**	**68%**	**68.4%**	**45%**	**68%**	**68.4%**	**36%**	**43%**	**54%**	**58%**	**69%**		
Persistent duration (days)	21	22	18	14	39	20	14	12	32	26	47	32	25	45	46
Catastrophic duration (days)	59	59	55	58	54	47	38	29	92	75	92	92	75	92	92
Corresponding flow (cfsm)	0.180	0.135	0.196	0.146	0.098	0.196	0.146	0.098	0.149	0.132	0.093	0.156	0.129	0.170	0.125
Corresponding flow (cfs)	2084	965	2316	1691	701	2316	1691	701	1725	1529	665	1806	1494	1969	894
Critical habitat			**33%**	**50%**	**66%**	**29%**	**51%**	**66%**	**15%**	**21%**	**52%**	**26%**	**35%**		
Persistent duration (days)	7	7	7	4	6	7	4	4	8	6	11	7	7	9	8
Catastrophic duration (days)	8	12	11	7	9	11	7	6	16	10	30	11	10	18	25
Corresponding flow (cfsm)	0.080	0.085	0.120	0.081	0.072	0.104	0.083	0.072	0.062	0.058	0.065	0.06	0.059	0.100	0.075
Corresponding flow (cfs)	926	608	1390	938	515	1204	961	515	718	672	465	695	684	1158	536
Rare habitat			**31%**	**48%**	**65.8%**	**27%**	**49%**	**65.8%**	**13%**	**19%**	**51%**	**24%**	**33%**		
Persistent duration (days)	4	4	3	3	3	6	3	3	5	3	10	4	4	6	4
Catastrophic duration (days)	5	7	8	6	6	9	5	5	8	9	21	8	8	10	6
Corresponding flow (cfsm)	0.060	0.075	0.112	0.078	0.069	0.095	0.079	0.069	0.054	0.053	0.061	0.055	0.055	0.080	0.065
Corresponding flow (cfs)	695	536	1297	903	493	1100	915	493	625	614	436	637	637	926	465

Flow Guideline Criteria

The analysis of the habitat time series presented in **Appendix 17** allowed for the documentation of the typical habitat conditions that fish fauna would expect to experience in the river. Specifically, we identified habitat levels that, because of their rare occurrence in the past, can be considered HST to substandard conditions. There are specific flows that create the habitat magnitudes defined by HST. Hence, we could calculate seasonal flow thresholds enveloping rare and common conditions using the two gaging locations as presented in **Tables 20 and 21** for the Verdel gage and **Table 22** for the Sparks gage. The *base* flow corresponds with the *common* habitat levels and *subsistence* flow with the *rare* habitat conditions. The *trigger* is the flow value corresponding with *critical* habitat level and it is intended to trigger management actions, such as observing persistent durations of flows lower than trigger and subsistence. Since there may be more than one flow level that results in the same amount of available habitat, by applying the precautionary principle we select the highest of them. The absolute minimum flow represents the lowest flow in the simulated time series. Ideally this flow should never occur for longer than one day. To define the Verdel gage flows necessary to maintain adequate fish habitat, we chose the values computed for Segment 1 as they were consistently higher than those for Segment 2. This assures better protection of the species in the Niobrara River.

Table 20: Selected flow thresholds for fish in Segments 1 and 2 of the Niobrara River using the Verdel USGS gage.

Bioperiod **Approximate dates**	**Rearing & Growth** **July 1 - Sept. 30**	**R & G Generic Plus** **July 1 - Sept. 30**	**Overwintering Early** **Oct. 1 - Dec. 31**
Location Verdel Gage	**Threshold flows**	**Threshold flows**	**Threshold flows**
Base flow (cfs)	1725	1806	1969
Allowable duration under (days)	32	32	45
Catastrophic duration (days)	92	92	92
Trigger flow (cfs)	718	695	1158
Allowable duration under (days)	8	7	9
Catastrophic duration (days)	16	11	18
Subsistence flow (cfs)	625	637	926
Allowable duration under (days)	5	4	6
Catastrophic duration (days)	8	8	10
Minimum flow (cfs)	338	338	200
Bioperiod **Approximate dates**	**Overwintering Late** **January 1 - February 28**	**Early Spawning** **March 1 - May 14**	**Late Spawning** **May 15 - June 30**
Location Verdel Gage	**Threshold flows**	**Threshold flows**	**Threshold flows**
Base flow (cfs)	2084	2270	2270
Allowable duration under (days)	21	18	20
Catastrophic duration (days)	59	55	47
Trigger flow (cfs)	926	1390	1204
Allowable duration under (days)	7	7	7
Catastrophic duration (days)	8	11	11
Subsistence flow (cfs)	695	1297	1100
Allowable duration under (days)	4	3	6
Catastrophic duration (days)	5	8	9
Minimum flow (cfs)	240	430	646

Table 21: Selected flow thresholds for birds in the Niobrara River using the Verdel USGS gage.

Bioperiod Approximate dates	Crane April 1 - April 30	Plover May 1 - August 31	Tern May 1 - August 31	Crane Oct. 1 - Oct. 31
Location: Verdel Gage	**Threshold flows**	**Threshold flows**	**Threshold flows**	**Threshold flows**
Base flow (cfs)	1806	1424	1818	1714
Allowable duration under (days)	11	24	34	18
Catastrophic duration (days)	17	68	81	31
Trigger flow (cfs)	1552	961	695	1540
Allowable duration under (days)	6	15	9	5
Catastrophic duration (days)	11	35	11	9
Subsistence flow (cfs)	1332	903	591	1332
Allowable duration under (days)	3	14	6	4
Catastrophic duration (days)	5	28	8	6
Minimum flow (cfs)	705	338	338	683

Table 22: Selected flow thresholds for fish in Segment 3 of the Niobrara River using the Sparks USGS gage.

Bioperiod Approximate dates	Rearing & Growth July 1 - Sept. 30	R & G Generic Plus July 1 - Sept. 30	Overwintering Early Oct. 1 - Dec. 31
Location Sparks Gage	**Threshold flows**	**Threshold flows**	**Threshold flows**
Base flow (cfs)	665	N/A	894
Allowable duration under (days)	47	N/A	46
Catastrophic duration (days)	92	N/A	92
Trigger flow (cfs)	465	N/A	536
Allowable duration under (days)	11	N/A	8
Catastrophic duration (days)	30	N/A	25
Subsistence flow (cfs)	436	N/A	465
Allowable duration under (days)	10	N/A	4
Catastrophic duration (days)	21	N/A	6
Minimum flow (cfs)	317	N/A	200
Bioperiod Approximate dates	**Overwintering Late January 1 - February 28**	**Early Spawning March 1 - May 14**	**Late Spawning May 15 - June 30**
Location Sparks Gage	**Threshold flows**	**Threshold flows**	**Threshold flows**
Base flow (cfs)	965	701	701
Allowable duration under (days)	22	39	12
Catastrophic duration (days)	59	54	29
Trigger flow (cfs)	608	515	515
Allowable duration under (days)	7	6	4
Catastrophic duration (days)	12	9	6
Subsistence flow (cfs)	536	493	493
Allowable duration under (days)	4	3	3
Catastrophic duration (days)	7	6	5
Minimum flow (cfs)	240	200	360

Discussion

Our habitat models documented a substantial amount of habitat for aquatic fauna in the Niobrara River. As demonstrated by the habitat rating curves for Generic Fish and Generic Fish Plus communities, almost the entire wetted area can be utilized by the fish community. However, since there is a gap between the Community Habitat curve and Generic Fish curve, it indicates that the habitat structure deviates from the fish community structure, i.e., guilds that are expected to occur at low proportions within the community have a higher proportion of suitable habitat and vice-versa. **Figures 24-26** demonstrate this relationship in more detail. In Segment 1 at flows of 0.1 cfsm, habitat for the Lobate Margin Guild seems to be underrepresented, and habitat for the Run Guild is in greater than expected proportions. In Segment 2, the habitat for the Lobate Margin Guild is abundant at the cost of habitat for the Habitat Generalist Guild. In Segment 3, there is a shift from Lobate Margin Guild habitats into Run Guild habitats, and there is a slight increase in Habitat Generalist Guild habitat.

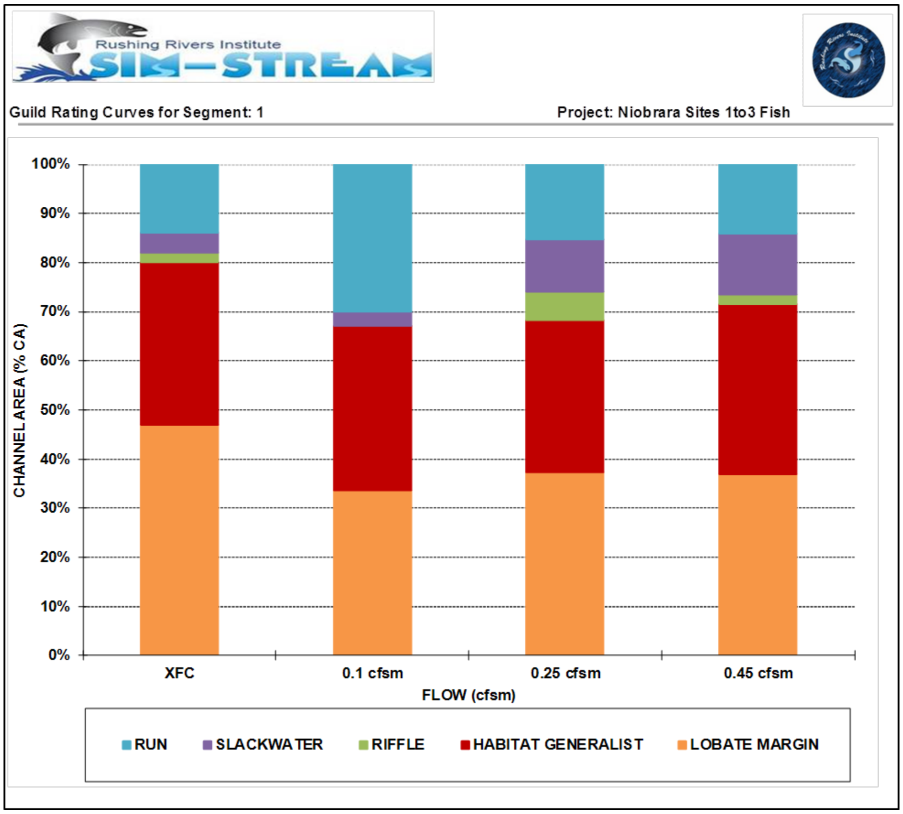

Figure 24: A comparison of the expected fish community (XFC) for Segment 1 with the model results at three flow levels.

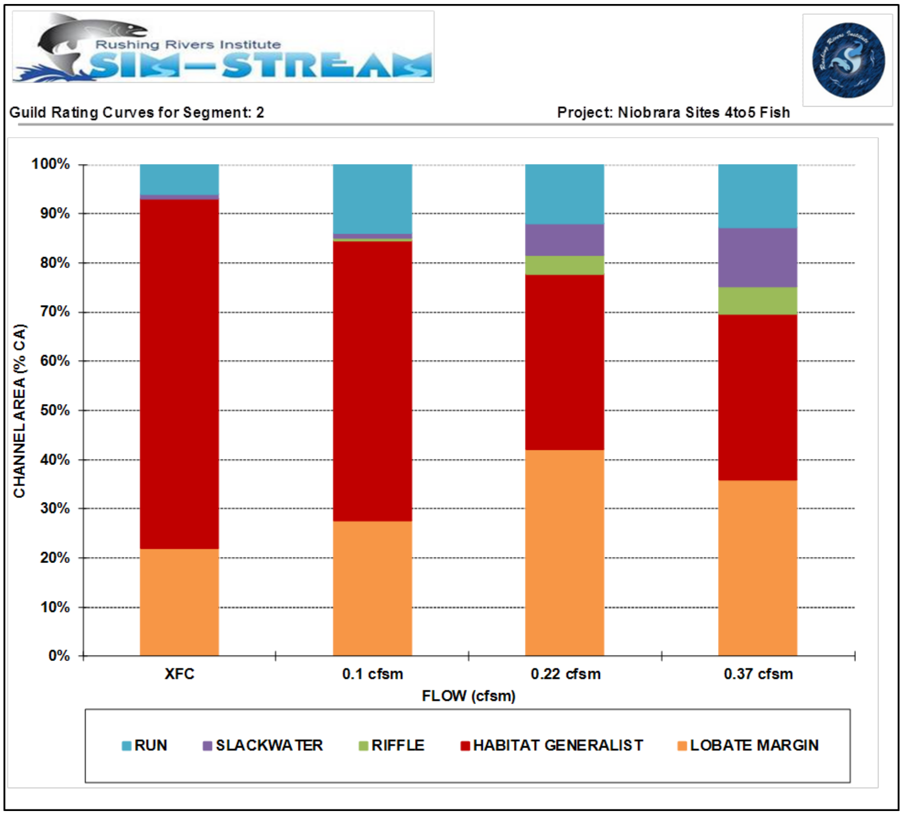

Figure 25: A comparison of the expected fish community (XFC) for Segment 2 with the model results at three flow levels.

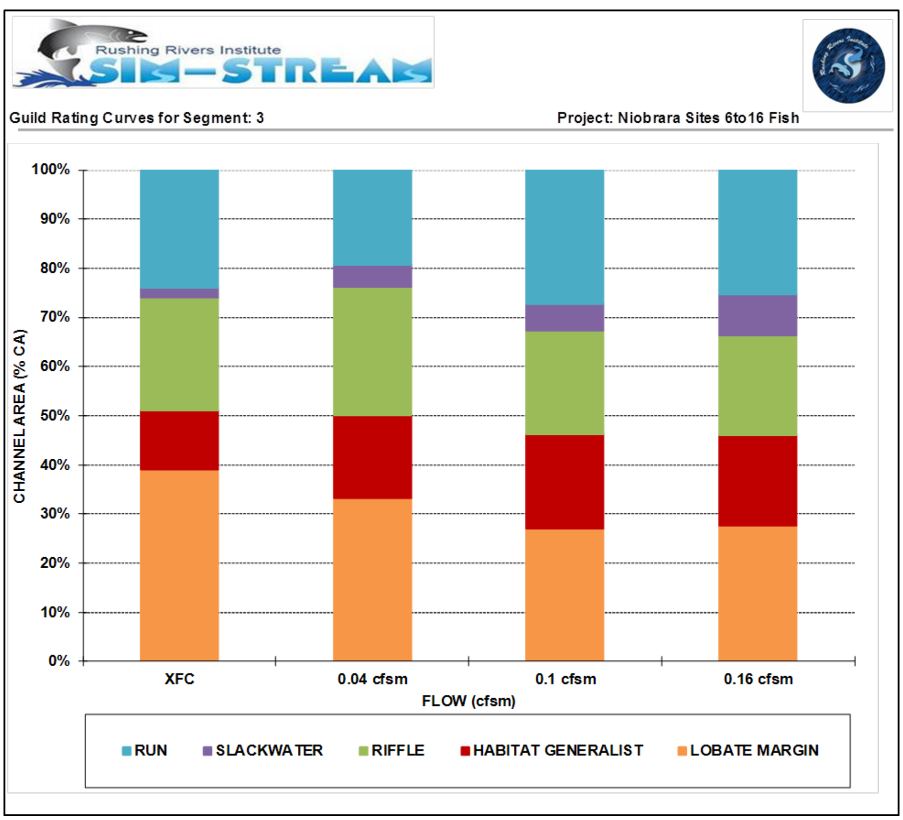

Figure 26: A comparison of the expected fish community (XFC) for Segment 3 with the model results at three flow levels.

The similarity between the distribution of guild proportions can also be measured with the help of an affinity index (AI) model (Novak and Bode, 1992). **Table 23** shows the expected fish proportion for each guild and the model results at three flow values for each study segment.

Table 23: The proportions of habitat use guilds in the XFC and habitat structure at three selected flows.

Segment 1	**XFC**	**0.1 cfsm**	**0.25 cfsm**	**0.45 cfsm**	**Average Departure from XFC**
LOBATE MARGIN	47.0%	14.4%	30.3%	38.6%	19%
HABITAT GENERALIST	33.0%	14.4%	25.1%	36.4%	10%
RIFFLE	2.0%	0.0%	4.7%	2.0%	2%
SLACKWATER	4.0%	1.2%	8.7%	12.9%	5%
RUN	14.0%	12.9%	12.4%	14.8%	1%
Segment 2					
LOBATE MARGIN	22.0%	16.4%	37.5%	49.2%	16%
HABITAT GENERALIST	71.0%	33.7%	31.8%	46.4%	34%
RIFFLE	0.0%	0.4%	3.4%	7.5%	4%
SLACKWATER	1.0%	0.5%	5.7%	16.5%	7%
RUN	6.0%	8.3%	10.7%	17.6%	6%
Segment 3					
LOBATE MARGIN	39.0%	16.6%	23.7%	43.8%	14%
HABITAT GENERALIST	12.0%	8.4%	16.8%	29.3%	9%
RIFFLE	23.0%	13.0%	18.6%	32.1%	8%
SLACKWATER	2.0%	2.2%	4.6%	13.2%	5%
RUN	24.0%	9.7%	24.0%	40.4%	10%

Higher percent model affinity values indicate higher degrees of similarity between the communities (**Table 24**). These values are calculated as:

Percentage similarity = 100%-0.5*∑|fish % – habitat %|

where *fish %* is the percentage of individuals of a particular guild in the XFC and *habitat %* is the percentage of the habitat for this guild in the Community Habitat.

Table 24: The affinity between the XFC and habitat structure at three selected flows

Segment	0.1/0.04 cfsm	0.25/0.10 cfsm	0.45/0.16 cfsm	Average
1	71%	83%	89%	81%
2	77%	66%	57%	67%
3	75%	86%	71%	77%

In comparison to other studies, the affinity values are mostly high and as a general rule, AIs above 70% are indicative of healthy rivers. Only Segment 2, a transition area between the fish communities of the other two segments, falls below this 70% threshold. We can therefore conclude that the overall habitat distribution is appropriate to support the expected fish community, and the observed discrepancies are the consequence of natural hydromorphological and biological variability of the river that may not be captured by snapshot observations of a single year survey. Therefore, for the habitat series analysis we chose habitat rating curves for Generic Fish rather than for the Community. Since our knowledge of the biological interactions between the species is very limited, this approach is more reflective of the model's accuracy.

Comparison of the rating curves between the sections demonstrates similarities where in each segment, there is a steep increase of the curves followed by decline in curve gradient. The critical point is at about 0.15 cfsm, 0.13 cfsm and 0.07 cfsm for segment 1, 2, and 3, respectively. Interestingly, the results are similar for both the spawning and R&G life stages. Even more notable is the fact that for avian fauna, the change in habitat availability is in the same flow range. These critical points correspond with the change in the wetted area apparently associated with maximizing channel area (Parasiewicz *et al.*, 1998).

As is visible in **Table 21,** the flows representing HST thresholds are slightly higher for Section 1 than for Section 2. The threshold's allowable and catastrophic durations are, in general shorter for Section 2 then what is logical since for lower habitat magnitudes the period duration is likely to be shorter. .Still, the choice of flow guideline criteria was made based on the precautionary principle by choosing the flow thresholds from Segment 1.

The flow thresholds for avian fauna fall within similar a range of magnitude as those for fish, and during the spawning season are lower than the threshold for fish. Although the thresholds for trigger and subsistence thresholds for the Whooping Crane in April are slightly lower than is the case for fish, the amounts are within the range of model accuracy. Furthermore, April is outside of the water withdrawal seasons, and not many management options are available. Hence, in these periods the fish needs-based flow guideline scheme for the Verdel Gage presented in **Table 20** will provide sufficient protection for avian fauna. The only notable exceptions are base and trigger flows for Plovers during the month of July, which is almost a third lower than those for fish. The same can be observed for Whooping Crane in October. For these months it needs to be considered whether dual criteria should be applied (i.e., both thresholds for fish and birds need to be observed), or whether to use just the criteria defined by fish. The reason may be that the fish suitability model is based on higher quality data than bird models and that the operation becomes more cumbersome for these months.

For the purpose of visualizing flow guidelines, the data in **Tables 20 and 22** are presented in the form of ACTograms. The ACTogram approach attempts to capture all essential parameters (flow, habitat, duration and function) in a single set of graphs. The boundaries demarcating the red, yellow and green areas (e.g., **Figure 27**) are defined by the flow-habitat relationship. Where boundary lines slope upward to the right, greater flows are indicative of greater habitat quantity. In such cases, persistent low flows may endanger ecological resources.

To plot flow data on the ACTogram, it is necessary to track the number of consecutive days that flows have remained below a threshold of interest. For example, in **Figure 27** two curves are presented, each representing flow-duration conditions on different days. The reference line indicates that the flow has been below 1 cfs for 0 days, below 4 cfs for 40 days, below 8 cfs for 50 days and below 14 cfs for 60 days. Note that these flow-duration conditions persist simultaneously on that calendar day. To complete the plot, each flow/consecutive-day data point is connected with a line. The result shows a flow-duration frontier that begins on an x-axis intercept at the left edge of the ACTogram and generally slopes higher to the right as flows increase. Intrusion of any part of the frontier into the yellow zone of the ACTogram is indicative of a stressed ecosystem. As dry days continue, the frontier will creep upwards. Upon entering the red zone, the ACTogram indicates that habitat quality has suffered critical damage and the bioperiod function has been seriously impaired. However, an increase in flow will break the consecutive day streak at all thresholds less than the new, higher flow. In this case, the frontier to the left of the new flow will be returned to zero, but remain high to the right of this flow. The flow/duration frontier is dynamic, and new flows must be plotted each day to accurately monitor the river condition.

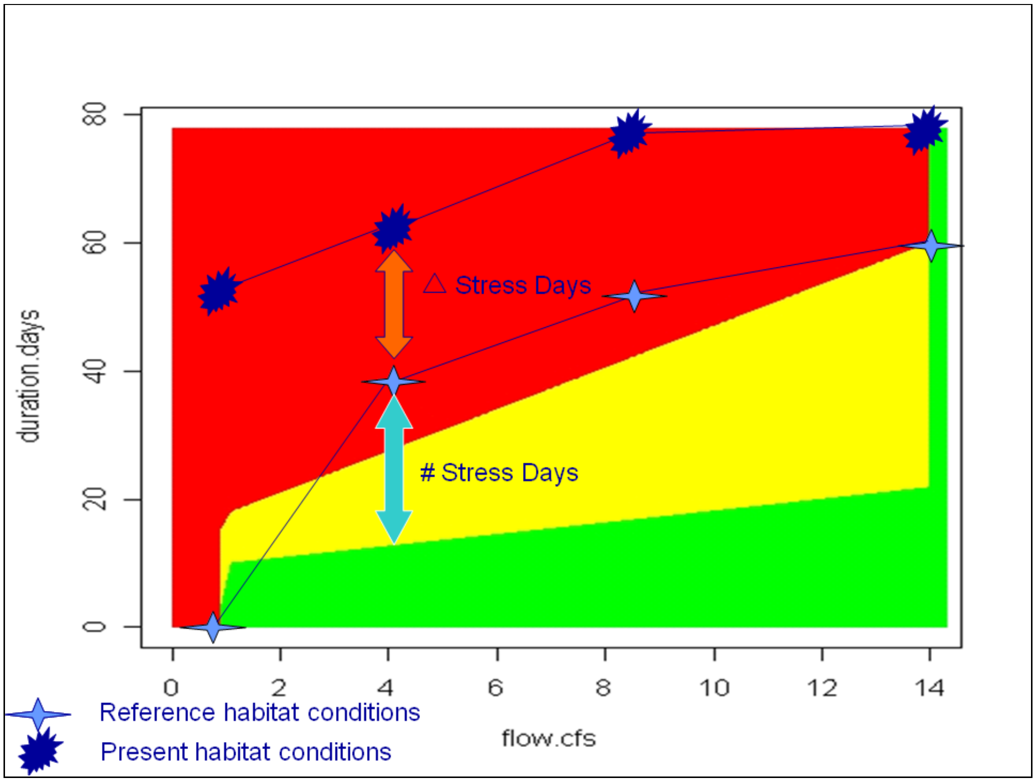

Figure 27: Example of an ACTogram.

The durations on the Y-axis represent time in days for which flows have been below the level indicated on the X-axis. The colored areas indicate if the event duration should be considered typical (green), persistent (yellow) or catastrophic (red). The squares and diamonds indicate the period that flows under a specific value (e.g., 4 cfs) on a chosen day for two different scenarios (reference and present conditions). The increase in number of stress days represents the impact to habitat at any given flow level.

The ACTograms developed for each bioperiod using the UCUTs for fish results at the Verdel and Sparks USGS gages are presented below in **Figures 28 and 29**. They serve as an example that can be modified once the final combination of thresholds for the Verdel gage is selected.

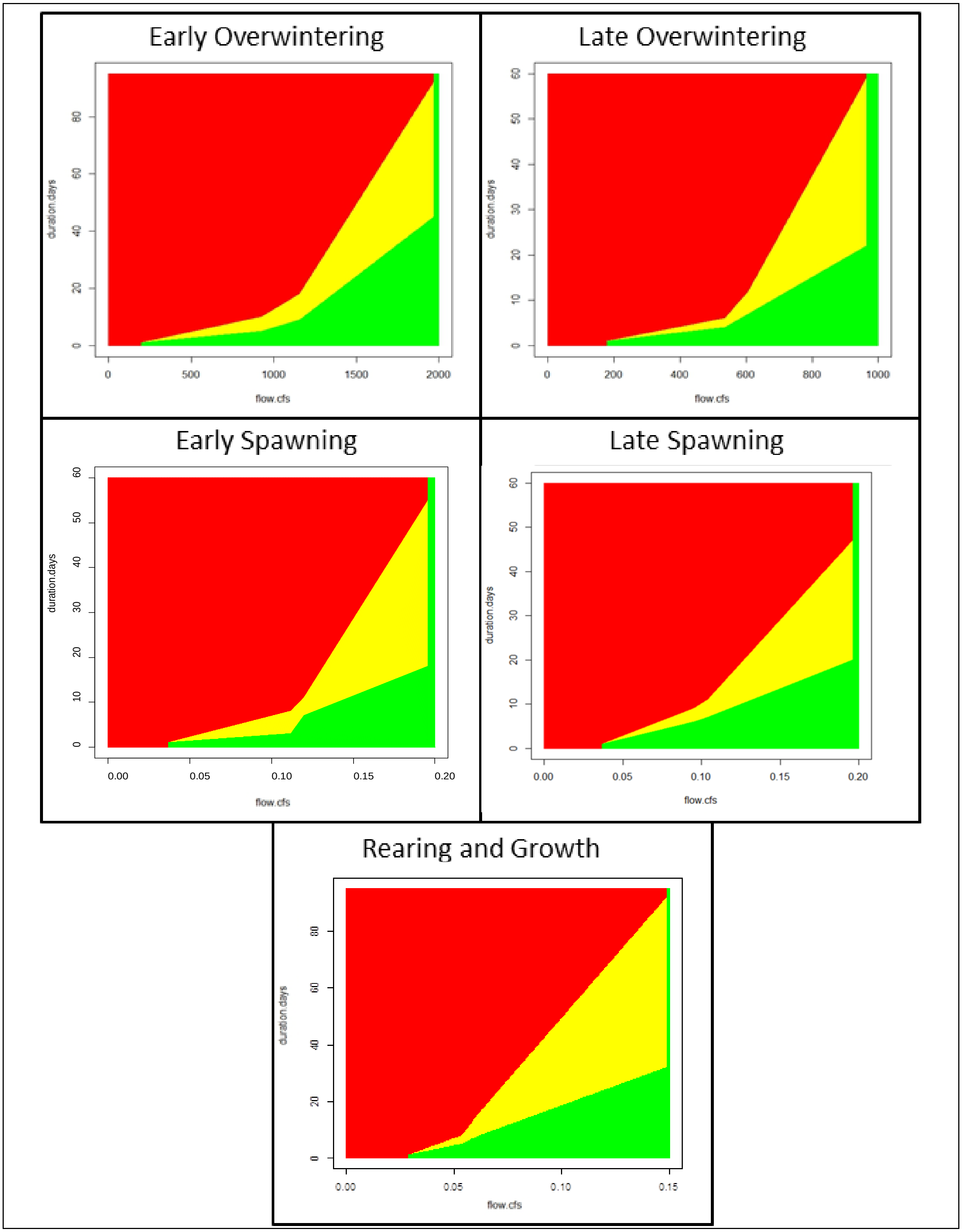

Figure 28: ACTograms for specific bioperiods relevant to the Verdel Gage.

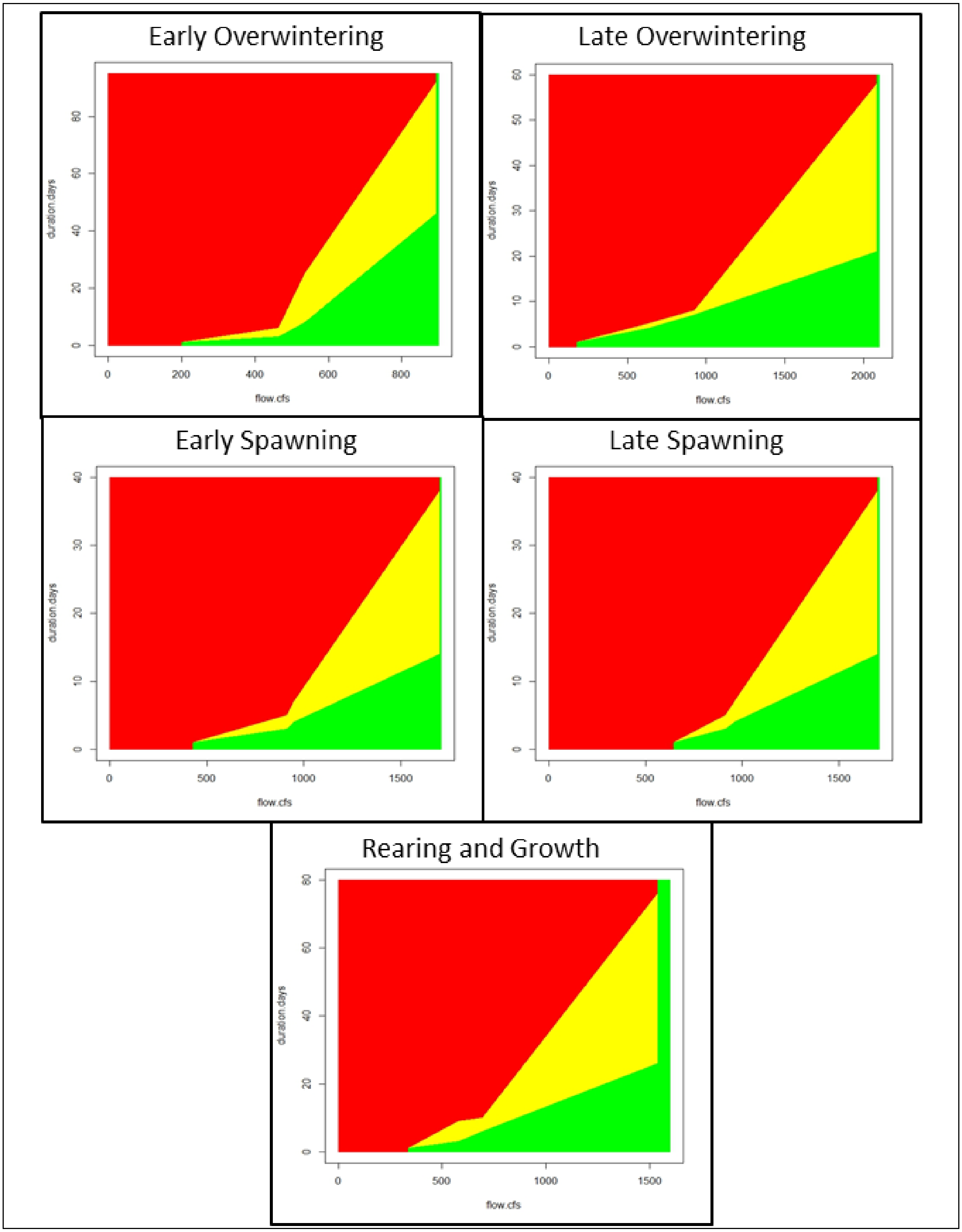

Figure 29: ACTograms for specific bioperiods relevant to the Sparks Gage.

Chapter 1.7: Flow Guideline Scheme

The flow guidelines that would protect the current status of the Niobrara River should reflect the intra- and inter-annual variability of flow patterns. To take into account intra-annual variability, we divided a year into bioperiods associated with hydrological trends and biological functions that occur annually. Each bioperiod can be managed according to separate seasonally-specific rules. Those rules are established by identifying habitat event thresholds based on the inter-annual frequency of those events. The durations of each under-threshold event will be counted as they occur. When allowable or catastrophic durations are exceeded, a management action may be necessary. Since the purpose of management actions is not to eliminate persistent and catastrophic conditions but to limit their frequency to the currently occurring level, such action will not happen every time the duration is exceeded. As a general principle, we propose that in one bioperiod the catastrophic conditions should not occur more often than once every ten years and the persistent conditions should not occur more often than three times during three consecutive years (similar to the EPA water quality rule). Hence, action is required only if these events happen more often.

To monitor habitat conditions, we propose the use of ACTograms (**Figures 28 and 29**). An ACTogram can be automated using data downloaded from the USGS gaging stations and the results from this study. After doing so, a river manager (or the general public) can easily see the habitat status of the Niobrara River and view the habitat history on the live ACTogram. When the ACTogram shows that the flow/duration frontier crosses into yellow (persistent) conditions or into red (catastrophic) conditions, the flow guidelines would suggest an action take place within the watershed. The action can be: no action, a flow reduction or the halt of withdrawals from part or all of the system, or the release of stored water. No action is needed when a catastrophic event occurs for the first time within the past 10 years and persistent events did not occur more often than twice during the past 3 years. Reductions in withdrawals could be introduced when the persistent/catastrophic durations and frequencies are exceeded for common and trigger flows and a complete stop is suggested when the subsistence flow level is reached.

To better reflect the natural variation at the border between bioperiods, a five-day transition period is considered, during which the rules for both neighboring bioperiods apply. This will assure that the prolonged durations of under-threshold events from one bioperiod season will continue to be recorded in the one that follows, instead of being ignored. The five days here is a suggestion and can be debated in its implementation by the stakeholders. The above rule would allow mimicking the natural habitat variability. Analysis of historical flow time series reveals that in the past, preventive actions of reducing water withdrawals would occur only very sporadically or not at all. However, more water appropriations would cause increases in the frequency of such events (hence the need for management actions) and reduce the reliability of the current water supply at a cost to the present water users, humans as well as avian and fish fauna.

The method presented here follows the recommendations of a natural flow paradigm upholding basic principles of ecology (Poff *et al.*, 1997), and requires little to no intervention in the natural processes that preserve hydrological variability. In contrast, methods typically using a minimum flow determination utilize a critical point on the habitat rating curve for defining minimum flows that are always maintained. Although such a system may be easier to implement, it not only requires more water but has also been criticized for creating a “flat-lined” flow regime, which can lead to shifts in fish fauna composition. In the system proposed here, the rating curve critical point corresponds with common HST, and the rule is permitting for flows to be lower than common HST, but only for allowable periods of time. This maintains flow regime variability and prevents substantial increases in bottleneck events. Therefore, the proposed flow guidelines are more protective to the fauna and also protect the interests of the water users. It must be noted that the model and rules proposed here incorporate the needs of the entire fish community as well as endangered avian fauna.

The aquatic ecosystem of the Niobrara River is a biologically unique and diverse assemblage, unequal to any in the state of Nebraska. Historically, a great deal of effort has been expended to understand this dynamic river system and its fishes. However, future studies must further this existing knowledge to understand how current resource demands affect the Niobrara River today. Particularly important is an increased awareness and understanding of how water demands impact the Niobrara and the surrounding landscape. With the increased demands for water, the potential exists to change habitat quantity and quality along the Niobrara River in a negative direction. However, by understanding the consequences of changing the natural flow cycle we may avert many negative impacts and allow the Niobrara River to remain a functioning ecosystem, while still allowing other appropriate uses of this resource.

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