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Montana Prairie Wetlands and Intermittent/Ephemeral Streams: Hydrologic Needs Assessment for Healthy Watersheds

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US Environmental Protection Agency
Healthy Watersheds Program
William Jefferson Clinton Building
1200 Pennylvania Avenue, N.W.
Washington, DC 20460

Prepared by—

Jennifer Phelan, Phillip Jones, Kimberly Matthews
RTI International
3040 E. Cornwallis Road
Research Triangle Park, NC 27709

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1. Executive Summary

A project was conducted to address the hydrologic needs for healthy watersheds in Montana. Through a two-step process involving the development of hydrology–ecology hypotheses and a case study analysis of one of these hypotheses, it was demonstrated that precautionary limits of hydrologic alteration can be determined for the prairie wetlands of Montana. Twenty hydrology–ecology hypotheses addressing macroinvertebrates, fish, amphibians, and birds were identified for individual- and landscape-level wetlands and intermittent/ephemeral steams. One of the hypotheses was then selected for a case study analysis to develop a proof-of-concept model relationship that describes hydrological alteration and ecological condition and supports the development of precautionary limits of hydrologic alteration.

The selected hydrology–ecology hypothesis, "*altered hydrology of wetland and intermittent/ephemeral streams systems negatively impacts amphibian populations and communities,"* was tested through a review of available data and the development of hydrologic alteration–biological response relationships. The most significant relationship was found to be changes in amphibian diversity in response to human disturbances (expressed as Human Disturbance Index or HDI) across the landscape; as human disturbance increased, amphibian diversity decreased. Although the relationship was linear and did not clearly indicate a threshold of response to set a precautionary limit, the change in amphibian diversity associated with human disturbance at the watershed level could be used to inform precautionary limits of hydrologic alteration (as represented by mean HDI scores) and land management goals to reduce negative impacts on amphibians in the prairie wetlands region of Montana.

However, the human disturbance–amphibian diversity relationship does not directly relate hydrologic alteration to the condition of amphibian communities within wetland and intermittent/ephemeral streams, and should be interpreted and applied with caution. A series of next steps to further assess the hydrologic needs for healthy watersheds in the prairie wetland region of Montana is therefore recommended. Specifically, additional datalayers anticipated to become available in the near future, such as U.S. Geological Survey (USGS) Stream Stats, may allow the incorporation of hydrologic data for studies on non-isolated and riparian wetland habitats. In addition, grid-scale HDI values, which were not available at the time of the case study analysis, could be used to greatly increase the spatial resolution of the modeling results. With the availability of new data, it may be possible to conduct additional analyses that relate human disturbance to hydrologic alteration and hydrologic alteration to responses of different aquatic biota in the Montana prairie wetlands region.

2. Background

The north-central and eastern regions of Montana consist of unique and complex hydrologic systems of prairie wetland, lake, and stream features that vary in hydrologic permanence from ephemeral/intermittent to permanent (Vance et al., 2013). Land management and development and climate change have and will continue to alter the hydrology of the prairie wetlands and streams systems, potentially threatening their biology.

Ecological Limits of Hydrologic Alteration (ELOHA) developed by Poff et al. (2010) is a flexible framework to characterize appropriate environmental flows at a regional scale based on existing hydrologic and ecological knowledge and data. According to ELOHA, flow regimes, hydrology–ecology relationships, and water management goals are identified for each river type, with the ultimate objective of identifying ecological limits of hydrologic alteration that meet both ecological and societal water needs and priorities (Kendy et al., 2012).

Although ELOHA was originally developed for river systems, a modified version of the framework could potentially be applied to wetland/stream systems like those found in Montana; similar to rivers, "hydrology is probably the single most important determinant of the establishment and maintenance of specific types of wetlands and wetland processes" (Mitsch and Gosselink, 2000). Many wetland systems, including the Montana prairie wetlands and intermittent/ephemeral systems, do not have the hydrologic foundation datasets or models that describe the temporal, spatial, and typological hydrology and hydrologic foundation that are a necessary component of the ELOHA framework. However, Vance et al. (2013) conducted a comprehensive review of existing literature, studies, models, and local expert knowledge for the Montana prairie wetlands and ephemeral/intermittent streams to describe the hydrology–ecology relationships and to hypothesize ecological responses to hydrologic alteration. The hydrology–ecology, also termed hydrologic alteration–biological response, relationships are central to ELOHA and are often the most difficult component of the framework to establish or quantify.

The purpose of this project was to further the work of Vance et al. (2013) and develop and test specific hydrology–ecology hypotheses to determine precautionary limits of hydrologic alteration for Montana prairie wetlands and ephemeral/intermittent streams. Step 1 of the project involved developing the hypotheses and associated precautionary limits and identifying potential datasets to test the hypotheses. Step 2 included selecting one of the hydrology–ecology hypotheses and performing a case study analysis of hydrology–ecology relationships to test the hypothesis, develop a hydrologic alteration–biological response model, and support the determination of precautionary limits of hydrologic alteration. In this report, we present the methods and results of each step and conclude with a summary of the main findings and recommended next steps.

3. Hydrology–Ecology Hypotheses

This section describes identifying and developing hydrology–ecology hypotheses and associated precautionary limits of hydrology alteration for the Montana prairie wetlands and ephemeral/intermittent streams.

3.1 Methods and Results

Hydrology–ecology hypotheses and precautionary limits of hydrologic alteration for Montana prairie wetlands and ephemeral/intermittent streams were developed based on a review of Vance et al. (2013), supporting literature, and recommendations from the Montana Prairie Wetlands Technical Team (MTPWTT). The MTPWTT consists of seven expert scientists and resource managers (**Table 1**). Within this document, the hypotheses and precautionary limits are presented as hydrology–ecology cause-and-effect statements followed by a detailed hydrology–ecology framework that presents the hypotheses, biologic and hydrologic indicators, types of impact, and precautionary limits of hydrologic alteration. Both the cause-and-effect statements and hydrology–ecology framework acknowledge the complexity of the hydrological–ecological systems in the Montana prairie wetlands and are presented as relationships at the landscape- and individual hydrologic feature-levels. Landscape-level refers to the hydrology–ecology within the wetland complex and hydrologic alterations that impact biology on a landscape scale (e.g., migration, dispersal, large-scale habitat disruption). Individual hydrologic feature-level refers to hydrology–ecology relationships for specific wetland and intermittent/ephemeral stream types and the hydrologic alterations that impact biology within these specific wetland types or streams (e.g., water requirement for amphibian reproduction, freshwater habitats for macroinvertebrates, colonization of nonnative plant species).

Table 1. Members of the Montana Prairie Wetlands Technical Team (MTPWTT).

Name	Affiliation	Specialization
Lynda Saul	Montana Department of Environmental Quality (DEQ)	program coordinator
Eloise Kendy	The Nature Conservancy (TNC)	eco hydrologist
Linda Vance	Montana Natural Heritage Program (NHP)	wetland ecologist
Kathy Chase	U.S. Geological Survey (USGS)	hydrologist/civil engineer
Dave Stagliano	private consultant (formerly MT NHP)	senior aquatic ecologist
Abby Dresser	Ducks Unlimited/Natural Resource Conservation Service (NRCS)	wetland biologist
Michael Downey	Montana Department of Natural Resources and Conservation	water planner

Hydrology–ecology relationships for Montana prairie wetlands and intermittent/ephemeral streams are summarized in **Table 2**. These relationships are based on the framework presented by Vance et al. (2013) and identify the physical mechanisms (*Impact on Hydrology, Hydrologic Change*) and biological impacts (*Ecological Effect*) of altered hydrology and ecology at the landscape- and individual hydrologic feature-level. These general relationships summarize the direct connections between hydrologic alterations, hydrologic impacts (i.e., hydrologic change), and biological change.

Table 2. Hydrology-Ecology Cause (i.e., Hydrologic Change[s]) and Effect (i.e., Ecological Effect[s]) Relationships for the Montana Prairie Wetlands and Intermittent/Ephemeral Streams

Impact on Hydrology	Hydrologic Change(s)	Ecological Effect(s)
Upland conversion of native prairie	▪ Increased flow rate ▪ Increased flow volume ▪ Altered inundation period	▪ Decreased abundance and diversity of: – native plant communities – macroinvertebrates – amphibians – mammals
Drainage of wetlands	▪ Decreased wetland density and diversity ▪ Decreased wetland/stream connectivity ▪ Increased water level in receiving wetlands ▪ Decreased water level in drained wetlands ▪ Increased inundation period in receiving wetlands	▪ Loss of habitat ▪ Loss of dispersal pathways ▪ Decreased abundance and diversity of: – native plant communities – macroinvertebrates – amphibians – shorebirds – waterfowl
Consolidation of wetlands	▪ Decreased wetland density and diversity ▪ Decreased wetland/stream connectivity ▪ Increased water level ▪ Increased inundation period	▪ Loss of habitat ▪ Loss of dispersal pathways ▪ Decreased abundance and diversity of: – native plant communities – macroinvertebrates – amphibians – shorebirds
Excavation of wetlands	▪ Increased inundation period ▪ Increased water level	▪ Alteration of habitat ▪ Decreased abundance and diversity of: – macroinvertebrates – waterfowl – native plant communities ▪ amphibians

(continued)

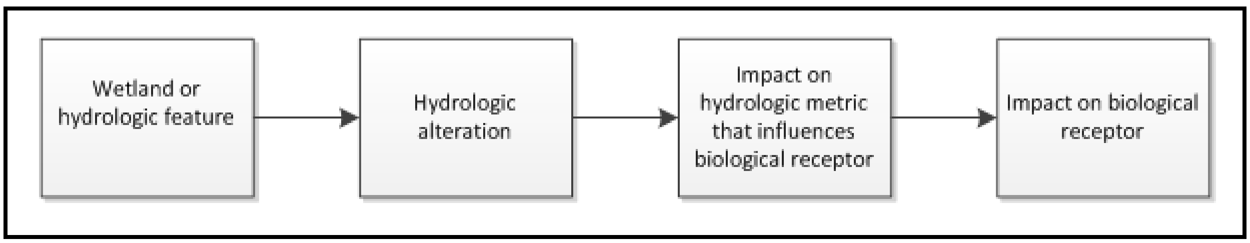
Table 2. Hydrology-Ecology Cause (i.e., Hydrologic Change[s]) and Effect (i.e., Ecological Effect[s]) Relationships for the Montana Prairie Wetlands and Intermittent/Ephemeral Streams (continued)

Impact on Hydrology	Hydrologic Change(s)	Ecological Effect(s)
Impoundment of streams (including springs and groundwater seeps)	▪ Decreased wetland/ stream connectivity ▪ Decreased flow volume ▪ Decreased water levels of receiving streams and wetlands	▪ Loss of habitat ▪ Loss of dispersal pathways ▪ Decreased abundance and diversity of: – macroinvertebrates – amphibians – fish – mammals
Diversion of streams (including springs and groundwater seeps)	▪ Decreased water level in receiving streams and wetlands	▪ Loss of habitat ▪ Decreased abundance and diversity of: – macroinvertebrates – amphibians – mammals
Alteration (excavation, widening, or straightening) of stream channels	▪ Increased flow rate	▪ Decreased abundance and diversity of: – native plant communities – macroinvertebrates
Groundwater withdrawal	▪ Decreased water level ▪ Decreased inundation period	▪ Decreased abundance and diversity of: – native plant communities – macroinvertebrates – fish

The hydrology–ecology cause-and-effect relationships were further developed into detailed Hydrology–Ecology Hypotheses and Precautionary Limits of Hydrologic Alteration (**Tables 4 and 5**). The focus of this step was on identifying literature-supported causal mechanisms between hydrologic alteration and biological/ecological change. These hypotheses, limits, and supporting information were presented in a modified version of a framework developed by The Nature Conservancy (TNC) to document flow-ecology hypotheses for river and stream systems in different regions of the United States (DePhilip and Moberg, 2010). TNC's framework was modified for application in the unique hydrologic conditions of the Montana prairie wetland and stream systems, to accommodate the low level of detail and information available to characterize the Montana prairie wetland hydrology–ecology relationships, and for consistency with project objectives and comments from the MTPWTT and U.S. Environmental Protection Agency (U.S. EPA). The landscape- and individual hydrologic feature-level hydrology–ecology frameworks are presented separately in **Tables 4** and **5**, respectively.

The hydrology–ecology framework consists of the following categories, each of which are represented as column headings in Tables 4 and 5: *Hydrology–Ecology Hypotheses, Biological Indicator, Biological Metric, Hydrologic Feature Type, Hydrologic Metric, Timing of Biological Impact, Impact; Hydrologic Alteration, Precautionary Limits of Hydrologic Alteration and Management Actions, Supporting Literature,* and *Potential Supporting Data*. The *Hydrology–Ecology Hypotheses* were constructed to follow a regular format (**Figure 1**) that connects hydrologic alteration with the wetland complex or hydrologic feature, altered hydrology, and biota that are potentially impacted by the altered hydrology. In the interest of efficiency and consistent with the limited availability of information and data regarding individual Montana prairie wetland hydrology–ecology relationships, multiple sources of hydrologic alteration, hydrologic features, and biota are included in each *Hydrology–Ecology Hypothesis*. Components of the hypotheses are grouped based on common hydrologic alteration, hydrologic metric, or biological response. If and when desired, and as more information becomes available, individual hypotheses that list single alterations, hydrologic features, and biota can be developed from the hypotheses outlined in Tables 4 and 5.

Figure 1. Format of Montana Hydrology–Ecology Hypotheses



Biological Indicator lists the biota that could be impacted by altered hydrology, and is consistent with the biota identified in the ecological effect of the hydrology–ecology cause-and-effect relationships. *Biological Metric* identifies metrics that could be used to characterize the response of the biological indicators to hydrologic alteration. Publications documenting the relationships between hydrology and biological metrics in Montana are limited. Therefore, the biological metrics listed in Tables 4 and 5 are predominantly based on the expertise and recommendations of the MTPWTT. *Hydrologic Feature Type* identifies the wetland complex or individual wetland or stream type impacted by the hydrologic alteration based on classifications developed by Stewart and Kantrud (1971), and *Hydrologic Metric* outlines the component of hydrology in the hydrologic feature being affected by the hydrologic alteration. *Timing of Biological Impact* refers to the time of year that the hydrologic alteration is hypothesized to impact the biology. The source of hydrologic alteration is indicated in the *Impact; Hydrologic Alteration* category. The *Hydrologic Metric* and *Impact*; *Hydrologic Alteration* categories are consistent with the metrics and alterations presented in the hydrology–ecology causes and effects, respectively.

Precautionary Limits of Hydrologic Alteration and Management Actions describe management actions and recommended limits to the amount of hydrologic alteration to reduce negative impacts on the dependent biology (i.e., biological indicator). These limits reflect the level of understanding of the relationships between hydrologic alteration and biological response/condition presented by Vance et al. (2013); in most cases, there was insufficient information to identify or quantify an amount of hydrologic alteration to a biological condition or amount of change in biology. General values for key biological and hydrologic fields are summarized in **Table 3**.

Table 3. Summary of Possible Values for Key Biological and Hydrologic Fields in Tables 4 and 5

Biological Indicator	Hydrologic Feature Type	Hydrologic Metric	Impact; Hydrologic Alteration
▪ Mammals ▪ Waterfowl ▪ Shorebirds ▪ Fish ▪ Amphibians ▪ Macroinvertebrates ▪ Native plant community	▪ Seasonal wetland ▪ Temporary wetland ▪ Ephemeral wetland ▪ Semipermanent wetland ▪ Permanent wetland ▪ Ephemeral stream ▪ Intermittent stream	▪ Inundation period ▪ Water level ▪ Flow rate ▪ Flow volume ▪ Wetland density and diversity ▪ Wetland/stream connectivity	▪ Agriculture ▪ Infrastructure ▪ Resource extraction ▪ Climate change ▪ Upland conversion of native prairie ▪ Excavation of wetlands ▪ Wetland consolidation ▪ Drainage ▪ Impoundment ▪ Flow diversion ▪ Groundwater extraction ▪ Channelization

Table 4. Precautionary Limits: Landscape-level Hydrology–Ecology Hypotheses to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetlands and Intermittent/Ephemeral Streams

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified by Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
1	Predicted increases in the number of days at or above the historical hottest summer temperatures in the northern Great Plains will increase evapotranspiration and decrease water levels and inundation periods[a] of shallow seasonal, temporary, and ephemeral wetlands and ephemeral and intermittent streams used as spring and summer refugia by mammals, rearing waterfowl, amphibians, and macroinvertebrates, thereby reducing the abundance and diversity of the biota	Mammals Waterfowl Amphibians Macroinvertebrates	Macroinvertebrates—Univoltine Index, Shannon Diversity Index (H) Amphibians—Abundance, Index of Biological Integrity (IBI)	Seasonal, temporary, and ephemeral, wetlands Ephemeral and intermittent streams	Inundation period Water level	Summer Fall	Climate change	Inundation period during the summer should remain within natural range to support shallow seasonal, temporary, and ephemeral wetlands and ephemeral and intermittent streams to prevent reductions in the abundance and diversity of dependent mammals, waterfowl, amphibians, and macroinvertebrates Water level during the summer should remain within natural range to support shallow seasonal, temporary, and ephemeral wetlands and ephemeral and intermittent streams to prevent reductions in the abundance and diversity of dependent mammals, waterfowl, amphibians, and macroinvertebrates	U.S. Global Change Research Program (USGCRP), 2014	www.globalchange.gov; Stagliano 2004–2013 (unpublished)

(continued)

Table 4. Precautionary Limits: Landscape-level Hydrology–Ecology Hypotheses to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetlands and Intermittent/Ephemeral Streams (continued)

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified By Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
2	Upland conversion of prairie to nonnative vegetative cover increases surface runoff volumes and rates and flashiness, and leads to the channelization of ephemeral and intermittent streams and concomitant loss of floodplain connectivity, which alters riparian habitats/native vegetation communities used by mammals, amphibians, and macroinvertebrates, thereby reducing the abundance and diversity of the biota	Mammals Amphibians Macroinvertebrates Native plant communities	Macroinvertebrates—IBI, Observed/Expected (O/E), Habits (locomotion type [e.g., burrowers, clingers, and swimmers]), Life cycle (i.e., univoltine vs. multivoltine), Shannon Diversity Index (H) Amphibians—Abundance, IBIs	Ephemeral and intermittent streams	Flow rate Flow volume	Spring Summer	Agriculture (row crops) Upland conversion of native prairie	Reduce upland conversion so that ephemeral and intermittent stream channels are not channelized and remain connected to floodplain, thereby maintaining riparian habitats/native vegetation communities and preventing reductions in the abundance and diversity of dependent mammals, amphibians, and macroinvertebrates Maintain sufficient natural buffers to maintain riparian habitats/native vegetation communities and prevent reductions in the abundance and diversity of dependent mammals, amphibians, and macroinvertebrates	Hubbard & Linder, 1986; Kantrud et al., 1989; Murkin, 1998; Voldseth et al., 2009; Winter 1989; Winter & Rosenberry 1998	Maxell Montana Natural Heritage Program (NHP) Amphibian Database

(continued)

Table 4. Precautionary Limits: Landscape-level Hydrology–Ecology Hypotheses to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetlands and Intermittent/Ephemeral Streams (continued)

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified by Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
3	Draining or consolidating seasonal, temporary, and ephemeral wetland complexes into semipermanent and permanent wetlands reduces wetland habitat density and diversity and macroinvertebrate abundance, which reduces critical early thaw and warm shallow water forage sites for migratory waterfowl and impedes waterfowl rearing success	Waterfowl Macroinvertebrates	Macroinvertebrates—IBIs, O/E, Habits, Life cycle	Seasonal, temporary, and ephemeral wetlands	Wetland density and diversity Inundation period Water level	Spring	Agriculture (row crops and pasture) Infrastructure[b] Drainage of wetlands Consolidation of wetlands	Reduce drainage of wetlands to maintain the characteristic natural density and diversity of the seasonal, temporary, and ephemeral wetlands across the landscape and prevent reductions in macroinvertebrate abundance and dependent waterfowl Reduce consolidation of wetlands to maintain the characteristic natural density and diversity of the seasonal, temporary, and ephemeral wetlands across the landscape to prevent reductions in macroinvertebrate abundance and dependent waterfowl	Anteau, 2011; Christensen & Crumpton, 2010; Euliss & Mushet, 2004; U.S. EPA, 2002	National Wetlands Inventory (NWI); North American Breeding Bird Survey; Montana Wetland and Riparian Geographical Information System (GIS)
4	Consolidation of seasonal, temporary, and ephemeral wetlands into permanent or semipermanent wetlands increases water levels and inundation periods and reduces shoreline habitat in the landscape, thereby reducing critical foraging and rearing sites and rearing success of shorebirds	Shorebirds		Seasonal, temporary, and ephemeral wetlands	Wetland density and diversity Inundation period Water level	Spring	Agriculture (row crops and pasture) Infrastructure Consolidation of wetlands	Minimize wetland consolidation and reductions in shoreline/wetland perimeter length to maintain critical habitat and prevent reductions in the shorebirds Maintain the characteristic natural density of seasonal, temporary, and ephemeral wetlands across the landscape to maintain critical habitat and prevent reductions in shorebirds	Anteau, 2011; De Leon & Smith, 2009; Niemuth et al., 2006	North American Breeding Bird Survey; NWI; Montana Wetland and Riparian GIS

(continued)

Table 4. Precautionary Limits: Landscape-level Hydrology–Ecology Hypotheses to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetlands and Intermittent/Ephemeral Streams (continued)

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified by Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
5	Draining permanent and semipermanent wetlands reduces the density and water level of deep water and open water habitats favored by diving, dabbling duck species, thereby reducing waterfowl abundance and diversity	Waterfowl		Permanent and semipermanent wetlands	Wetland density and diversity Water level	Spring Summer	Agriculture (row crops) Infrastructure Drainage of wetlands	Reduce wetland drainage to maintain density of deep and open water wetlands across the landscape to maintain habitat and prevent reductions in the abundance and diversity of waterfowl	Drever, 2006	North American Breeding Bird Survey; NWI; Montana Wetland and Riparian GIS
6	Predicted warmer winters and reduced snowpack will alter the timing and volume of snowmelt inflows to wetlands in the western prairie pothole region and reduce water levels and inundation periods such that the density of ephemeral, temporary, and seasonal wetlands favored by native and migratory shorebirds and waterfowl will be reduced or eliminated, thereby reducing bird abundance and diversity	Shorebirds; Waterfowl		Seasonal, temporary, and ephemeral wetlands	Wetland density and diversity Inundation period Water level	Spring Summer	Climate change	Focus restoration and mitigation efforts on long-term climate change resiliency by maintaining ecosystem form and structure, creating refugia for biota, aiding migration of habitats and species, and protecting wetlands and streams that show resilience to climate change	Johnson et al., 2005; USGCRP, 2014	www.globalchange.gov

(continued)

Table 4. Precautionary Limits: Landscape-level Hydrology–Ecology Hypotheses to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetlands and Intermittent/Ephemeral Streams (continued)

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified by Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
7	Predicted changes in the west-east rain gradient may lead to drier conditions in the west and wetter conditions in the east; these changes may shift western wetlands to drier states (i.e., eliminate seasonal, temporary, and ephemeral wetlands and shift semipermanent and permanent wetlands to temporary or seasonal status) and shift eastern wetlands to wetter states (i.e., move seasonal, temporary, and ephemeral wetlands to semipermanent or permanent status); these changes may alter or remove preferred habitats for shorebirds, waterfowl, amphibians, and macroinvertebrate species, thereby reducing the abundance and diversity of biota	Shorebirds Waterfowl Amphibians Macroinvertebrates	Macroinvertebrates—Voltinism, Traits, Shannon Diversity Index (H) Amphibians—Abundance, IBIs	Seasonal, temporary, and ephemeral wetlands	Inundation period Water level Wetland density	Spring Summer Fall	Climate change	Focus restoration and mitigation efforts on long-term climate change resiliency by maintaining ecosystem form and structure, creating refugia for biota, aiding migration of habitats and species, and protecting wetlands that show resilience to climate change	Clair and Ehrman, 1998; Johnson et al., 2005; Mortsch, 1998; Vance et al., 2013	Maxell Montana NHP Amphibian Database; Stagliano, 2008 and 2004–2013 (unpublished)

(continued)

Table 4. Precautionary Limits: Landscape-level Hydrology–Ecology Hypotheses to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetlands and Intermittent/Ephemeral Streams (continued)

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified by Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
8	Drainage and consolidation of seasonal, temporary, and ephemeral wetlands and impoundment of ephemeral and intermittent streams reduces the connectivity of habitats and disrupts the dispersal of native amphibian species, thereby decreasing reproductive success, abundance, and diversity of amphibians	Amphibians	Amphibians—Abundance, IBIs	Seasonal, temporary, and ephemeral wetlands Ephemeral and intermittent streams	Wetland density and diversity Wetland/stream connectivity	Spring Summer Fall	Agriculture (row crops and pasture) Infrastructure Drainage of wetlands and stream channels Consolidation of wetlands and stream channels Impoundment of wetlands and stream channels	Reduce wetland drainage to maintain habitat networks of ephemeral, temporary, and seasonal wetlands and ephemeral and intermittent streams in the landscape and prevent reductions in the abundance and diversity of amphibians Reduce wetland consolidation to maintain habitat networks of ephemeral, temporary, and seasonal wetlands and ephemeral and intermittent streams in the landscape and prevent reductions in the abundance and diversity of amphibians Reduce stream impoundment to maintain habitat networks of ephemeral, temporary, and seasonal wetlands and ephemeral and intermittent streams in the landscape and prevent reductions in the abundance and diversity of amphibians	Joyal et al., 2001; Semlitsch, 1998	Maxell Montana NHP Amphibian Database

(continued)

Table 4. Precautionary Limits: Landscape-level Hydrology–Ecology Hypotheses to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetlands and Intermittent/Ephemeral Streams (continued)

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified by Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
9	Impoundment of ephemeral and intermittent streams reduces downstream flow volume and eliminates connectivity to upstream habitat and deeper water channel pools required for fish migration during high flow periods, thereby reducing fish abundance and diversity	Fish	Fish—IBIs, O/E	Ephemeral and intermittent streams	Flow volume Water level	Spring Summer	Agriculture (row crops and pasture) Stream impoundment	Maintain seasonal connectivity of ephemeral and intermittent streams during spring and early summer high flow periods to allow for fish migration and prevent reductions in fish abundance and diversity	Franssen et al., 2006; Winston et al., 1991	Montana Fisheries Information System (M-FISH); Stagliano (unpublished); Bureau of Land Management (BLM) 2010–2012 (unpublished); U.S. Geological Survey (USGS) 2014 Fish dataset
10	Upland conversion of prairie to row crop agriculture increases surface runoff volumes and rates and associated sediment delivery, resulting in increased turbidity and sedimentation in receiving wetlands and stream channels, thereby reducing the abundance and diversity of macroinvertebrates and native plant diversity	Macroinvertebrates Native plant community	Macroinvertebrates—IBIs, O/E, Habits, Life cycle, Shannon Diversity Index (H)	All wetland types Ephemeral and intermittent streams	Flow volume Flow rate	Spring	Agriculture (row crops) Upland conversion of native prairie	Reduce upland conversion to maintain the characteristic natural range of surface runoff volumes into receiving wetlands and streams and prevent reductions in the abundance and diversity of macroinvertebrates and diversity of the native plant communities	Detenbeck et al., 2002; Dieter, 1990; Lavergne & Molofsky, 2004; McCabe & O'Brien, 2013; Neely & Baker, 1989; U.S. EPA, 2002; Voldseth et al., 2009; Werner & Zedler, 2002; Zimmer et al., 2003	National Land Cover Dataset (NLCD) Change 2006–2011; NWI; Montana Land Cover GIS; Montana Wetland and Riparian Framework

[a] "Inundation period" refers to the calendar period(s) during which the water body holds surface water.

[b] "Infrastructure" refers to road, ditch, pipeline, or other infrastructure construction.

Table 5. Hydrology–Ecology Hypotheses for Wetland and Intermittent/Ephemeral Streams to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetland and Stream Systems

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified by Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
11	Impoundment or diversion of spring flows away from ephemeral and intermittent streams decreases volume of channel pools used as refugia and water source by mammals and amphibians, thereby reducing mammal abundance and amphibian abundance and diversity	Mammals Amphibians	Amphibians—Abundance, IBIs	Ephemeral and intermittent streams	Water level	Spring Summer	Agriculture (row crops and pasture) Infrastructure Diversion of spring flow Impoundment of spring flow	Minimize diversion of spring flows to maintain the natural variation of inflow to ephemeral and intermittent streams and channel pools and prevent reductions in mammal and amphibian abundance and diversity Minimize impoundment of spring flows to maintain the natural variation of inflow to ephemeral and intermittent streams and channel pools and prevent reductions in mammal and amphibian abundance and diversity	Fritz & Dodds, 2004; Larivière & Messier, 2000; Vance, 2009; Wiewel et al., 2007	Maxell NHP Amphibian Database
12	Excavations of seasonal, temporary, and ephemeral wetlands increase water residency time, water level, and inundation period, and reduce macroinvertebrate productivity (abundance and diversity) bursts associated with wet-dry hydroperiod nutrient cycling and sediment oxidation; reductions in macroinvertebrates remove an important energy source for waterfowl, thereby causing reductions in bird abundance, diversity, and rearing success	Waterfowl Macroinvertebrates	Macroinvertebrates—IBIs, O/E, Habits, Life cycle, Shannon Diversity Index (H)	Seasonal, temporary, and ephemeral wetlands	Inundation period Water level	Spring Summer	Agriculture(row crops and pasture) Excavation of wetlands	Reduce wetland excavations to maintain water levels and inundation periods associated with natural wet-dry cycling of seasonal, temporary, and ephemeral wetlands to prevent reductions in the macroinvertebrate communities and waterfowl that depend on them	Anteau, 2011; Anteau & Afton, 2008; Euliss & Mushet, 2004; U.S. EPA, 2002	Stagliano 2004–2014 (unpublished)

(continued)

Table 5. Hydrology–Ecology Hypotheses for Wetland and Intermittent/Ephemeral Streams to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetland and Stream Systems

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified by Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
13	Excavations of seasonal, temporary, and ephemeral wetlands to increase water residency time reduce shallow water wetland habitat and encourages deep water predatory taxa (i.e., tiger salamander) that reduce reproductive success and abundance of native frog species (boreal chorus frogs and northern leopard frogs)	Amphibians	Amphibians—Abundance, IBIs	Seasonal, temporary, and ephemeral wetlands	Inundation period Water level	Spring	Agriculture(row crops and pasture) Excavation of wetlands	Reduce seasonal, temporary, and ephemeral wetland excavation so that water levels and inundation periods (and predatory taxa abundance and distribution) are maintained within the range of natural variation to prevent reductions in the abundance of native frog species	Benoy, 2008; Euliss & Mushet, 2004; Meyer et al., 2007	Maxell Montana NHP Amphibian Database
14	Upland conversion of prairie to nonnative land cover increases surface runoff and the rate and volume of inflows to seasonal, temporary, and ephemeral wetlands, thereby altering wetland habitat and reducing native amphibian abundance and diversity	Amphibians	Amphibians—Abundance, IBIs	Seasonal, temporary, and ephemeral wetlands	Inundation period Flow rate Flow volume	Spring Summer	Agriculture (row crops) Upland conversion of native prairie	Reduce upland conversions to maintain the characteristic natural range of surface runoff rates and volumes into receiving seasonal, temporary, and ephemeral wetlands and prevent reductions in habitat and amphibian abundance and diversity	Balas et al., 2012; Kantrud & Newton, 1996	Maxell Montana NHP Amphibian Database

(continued)

Table 5. Hydrology–Ecology Hypotheses for Wetland and Intermittent/Ephemeral Streams to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetland and Stream Systems

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified by Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
15	Impoundments and diversions of springs and groundwater seeps reduce or remove down-gradient flows into receiving wetlands or stream channels, thereby altering vital dry weather refugia and reducing the abundance and diversity of amphibians and macroinvertebrates	Amphibians Macroinvertebrates	Amphibians—Abundance, IBIs Macroinvertebrates—IBIs, O/E, Shannon Diversity Index (H)	Seasonal, temporary, and ephemeral wetlands Ephemeral and intermittent streams	Water level	Summer	Agriculture (row crop and pasture) Impoundments of springs Diversions of springs Impoundment of groundwater seeps Diversion of groundwater seeps	Reduce use (diversion and impoundment) of springs to maintain natural abundance and distribution of summer refugia in seasonal, temporary, and ephemeral wetlands and ephemeral and intermittent streams and prevent reduction in the abundance and diversity of amphibians and macroinvertebrates Reduce use (diversion and impoundment) of groundwater seeps to maintain natural abundance and distribution of summer refugia in seasonal, temporary, and ephemeral wetlands and ephemeral and intermittent streams and prevent reduction in the abundance and diversity of amphibians and macroinvertebrates	Dodds et al., 2004; Fritz & Dodds, 2004; Myers & Resh 1999; Stagliano, 2008; Stagliano et al., 2006	Maxell Montana NHP Amphibian Database; Stagliano, 2008 & 2004–2013 (unpublished)
16	Groundwater withdrawals lower water levels in intermittent streams and lead to higher temperatures and lower dissolved oxygen concentrations that can be lethal for stream biota, thereby resulting in reductions in intolerant fish and macroinvertebrate species	Fish Macroinvertebrates	Fish—IBIs, O/E, Tolerance Macroinvertebrates—IBIs, O/E, Habits, Life cycle, Shannon Diversity Index (H)	Intermittent streams	Water level	Spring Summer	Agriculture(row crops and pasture) Resource extraction (mining, oil, and gas) Groundwater withdrawal	Reduce groundwater extraction so that stream temperature and dissolved oxygen levels remain within range of natural variation during growing season and prevent reductions in fish and macroinvertebrate species	Dodds et al., 2004; Lake, 2003	Montana Fish, Wildlife and Parks (FWP) M-FISH; BLM 2010–2012 (unpublished); Stagliano 2008 & 2004–2013 (unpublished); USGS 2014 Fish dataset

(continued)

Table 5. Hydrology–Ecology Hypotheses for Wetland and Intermittent/Ephemeral Streams to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetland and Stream Systems

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified by Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
17	Excavation of semipermanent, seasonal, temporary, and ephemeral wetlands to increase water depth and inundation period alters wetland habitat and leads to reductions in the abundance and diversity of macroinvertebrates and diversity of emergent macrophytes	Macroinvertebrates Native plant community	Macroinvertebrates—IBIs, O/E, Habits, Life cycle, Shannon Diversity Index (H)	Semipermanent, seasonal, temporary, and ephemeral wetlands	Water level Inundation period	Spring Summer	Agriculture (row crops and pasture) Excavation of seasonal wetlands	Reduce excavation of semipermanent, seasonal, temporary, and ephemeral wetlands so that hydroperiod alteration does not result in reductions or loss of native plant and invertebrate communities	Euliss & Mushet, 2004; Rose & Crumpton, 1996; U.S. EPA 2002	Stagliano 2008 & 2004–2013 (unpublished)
18	Consolidation or excavation of seasonal, temporary, and ephemeral wetlands into permanent or semipermanent wetlands increases inundation periods and water levels, thereby promoting the growth of cattails, aggressive macrophytes, and nonnative plant species, which reduces native plant abundance and diversity	Native plant community		Seasonal, temporary, and ephemeral wetlands	Inundation period Water level	Spring Summer Fall	Agriculture (row crops and pasture) Infrastructure Consolidation of wetlands Excavation of wetlands	Minimize wetland consolidations and excavations to maintain density of seasonal, temporary, and ephemeral wetlands and prevent the in-growth of invasive macrophytes and reductions in native plant abundance and diversity	Shaffer et al., 2007; Voldseth et al., 2007	

(continued)

Table 5. Hydrology–Ecology Hypotheses for Wetland and Intermittent/Ephemeral Streams to Support the Determination of Precautionary Limits of Hydrologic Alteration in Montana Prairie Wetland and Stream Systems

Index	Hydrology–Ecology Hypotheses	Biological Indicator	Biological Metric (Identified by Vance et al., 2013 and/or Expert Opinion)	Hydrologic Feature Type (From Stewart and Kantrud, 1971)	Hydrologic Metric	Timing Of Biological Impact	Impact; Hydrologic Alteration	Precautionary Limits of Hydrologic Alteration and Management Actions	Supporting Literature (Hydrology–Ecology Hypothesis)	Potential Supporting Data
19	Groundwater withdrawals lower water levels in seasonal, temporary, and ephemeral wetlands and ephemeral and intermittent stream channels; lower water tables result in reductions in the abundance and diversity of native plant communities and provide a competitive advantage to nonnative species such as the invasive saltcedar (*Tamarix* spp.)	Native plant community		Seasonal, temporary and ephemeral wetlands Ephemeral and intermittent streams	Water level	Spring Summer Fall	Agriculture (row crops and pasture) Resource extraction Groundwater withdrawal	Reduce groundwater extraction to maintain sufficient water levels in stream and seasonal, temporary, and ephemeral wetlands to prevent reductions in native plant communities	Lesica & Miles, 2001; Ohrtman et al., 2011; Sexton et al., 2006; Stromberg et al., 2008	
20	Excavating, widening, or straightening ephemeral and intermittent stream channels leads to increased flow rates during spring thaw and storm events (especially when uplands have been converted to agriculture); the higher flow rates increase sediment delivery to downstream wetlands, which negatively impacts native plant seed emergence and macroinvertebrate egg survival, thereby resulting in decreased macroinvertebrate and native plant community abundance and diversity	Macroinvertebrates Native plant community	Macroinvertebrates—IBIs, Habits, Life cycle, Shannon Diversity Index (H)	Wetlands Ephemeral and intermittent streams	Flow rate	Spring Summer	Agriculture (row crops) Infrastructure Alteration of stream channels	Minimize alteration of stream channels to maintain the natural characteristic range in flow rates from runoff and thaw events and prevent reductions in macroinvertebrate and native plant community abundance and diversity	Euliss & Mushet, 1999; Gleason & Euliss, 1998; Jurik et al., 1994; Lenhart et al., 2012; Rosso & Fernández Cirelli, 2013; Schilling et al., 2011; van der Kamp et al., 2013	

4. Case Study Analysis

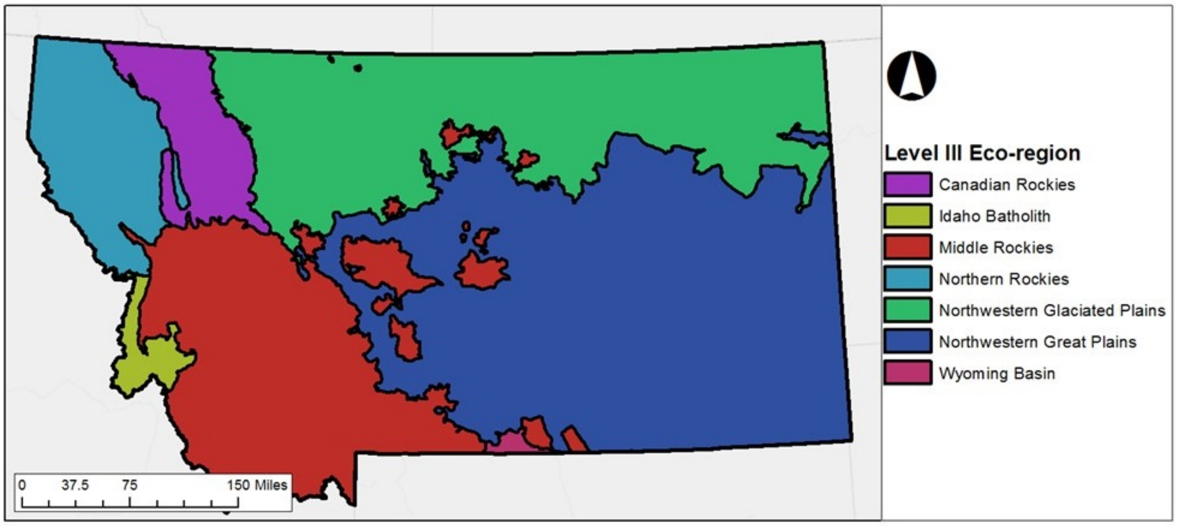
The goal of the work detailed in Section 3 was to develop a comprehensive set of hydrology–ecology relationships and associated precautionary limits of hydrological alteration that address current biological and hydrologic conditions in the Montana prairie wetlands and ephemeral/intermittent stream systems. Once assembled, these hypotheses were reviewed by the MTPWTT and U.S. EPA to select a hypothesis for evaluation and testing as a case study analysis. The overall goal of the case study analysis was to produce a proof-of-concept relationship that relates hydrological alteration to ecological response and supports the development of precautionary limits of hydrologic alteration for a defined landscape-level wetland system or individual hydrologic feature in Montana. This hydrologic alteration–ecological response relationship and the precautionary limit or limits determined by the relationship could serve as tools to support an evaluation of the current health of Montana aquatic ecosystems and aid water and ecological resource managers with current and future land and water use decisions. The following sections describe the methods and results of the case study analysis.

4.1 Hydrology–Ecology Hypothesis Selection

The selection of the hydrology–ecology hypothesis for the case study analysis involved multiple presentations of the hypotheses and discussions with the MTPWTT and U.S. EPA. The main criteria used in selecting the hypothesis included the management relevance of the Montana prairie wetland or intermittent/ephemeral stream system, the ecological significance of the impacted biology, and the availability and quality of supporting data. Due to its paucity, data availability played a central role in hypothesis selection. Criteria used to evaluate the quality and suitability of available hydrologic and ecological data included:

- Spatial distribution of relevant biological and hydrologic data in the prairie wetlands region of Montana. For the purposes of this project, the prairie wetland study area was defined as the U.S. EPA Level III Ecoregion Northwestern Glaciated Plains (Omernik, 1987) (**Figure 2**)
- Temporal distribution of data
- Number of samples by spatial unit (i.e., watershed, catchment, ecoregion)
- Variability of parameter values (e.g., mean, median, standard deviation, minimum value, maximum value)
- Relevance to environmental and ecological processes
- Standard Operating Procedures of collecting organization
- Professional judgment of MTPWTT

Figure 2.   Level III Ecoregions in Montana



Source: Omernik, 1987

The review and selection process for the hydrologic and biological data are described further in Sections 4.2.1.1 and 4.2.1.2, respectively.

Based on the selection criteria, thorough review of quality and suitability of currently available data, and communications with MTPWTT and U.S. EPA, landscape-level hydrology–ecology hypothesis #8 (Table 4) was selected for the case study analysis.

> *Drainage and consolidation of seasonal, temporary, and ephemeral wetlands and impoundment of ephemeral and intermittent streams reduce the connectivity of habitats and disrupt the dispersal of native amphibian species, thereby decreasing reproductive success, abundance, and diversity of amphibians.*

Comprehensive and spatially extensive studies that have specifically investigated the relationship between drainage and consolidation of wetlands and intermittent/ephemeral streams on the connectivity of amphibian habitat and amphibian dispersal were not readily available. Therefore, it was not possible to directly test the selected hydrology–ecology hypothesis. Instead the following surrogate hypothesis was adopted and evaluated in the case study analysis for the Montana prairie wetlands.

> *Altered hydrology of wetland and intermittent/ephemeral streams systems negatively impacts amphibian populations and communities.*

Although this hypothesis does not specify the mechanism, the influences of wetland and stream "drainage and consolidation" on amphibian habitat and dispersal are captured within the hypothesis. In addition, this hypothesis leads to an evaluation of the relationship between altered hydrology and biological condition, and the resulting relationship could be used to support precautionary limits of hydrological alteration.

4.2 Methods

4.2.1 Data Description

The following subsections describe the hydrologic and biological data that were considered and used in the case study analysis to test the hydrology–ecology hypothesis, evaluate the relationships between hydrologic alteration and ecological condition, and support the determination of precautionary limits of hydrologic alteration in the Montana prairie wetland study area.

4.2.1.1 Hydrologic Data

The Montana prairie wetland region and the Northwestern Glaciated Plains Ecoregion study area contained therein are characterized by a complex hydrologic regime governed by geomorphology, stratigraphy, surface water/groundwater interactions, and precipitation. Potential datasets to represent the hydrology of wetland and intermittent/ephemeral streams within the study area were identified through a review of the literature and consultation with the MTPWTT and federal, state, and nongovernmental sources familiar with the Montana prairie wetland region. Unfortunately, relevant hydrologic data with sufficient spatial coverage were not available. Therefore, for the purposes of the case study analysis, a variety of proxy or surrogate datasets and variables, including land use and cover, wetland inventory, groundwater information, and disturbance index data, were evaluated in an effort to characterize hydrology in the study area (**Table 6**).

Each of the datasets representing hydrology was mapped to the Montana prairie wetland study area to confirm spatial coverage. The temporal characteristics (permit date, image date, etc.) of these datasets were also recorded. Once mapped, the datasets listed in Table 6 were summarized at the USGS Watershed Boundary Dataset (WBD) HUC12 watershed spatial scale (USDA-NRCS, USGS, U.S. EPA, 2014). Other spatial scales were considered; however, the proxy hydrologic variables obtained for this study were characterized at the watershed scale due to mapping resolution, accuracy, and likely biological impact. For example, an individual wetland may be less important for biological response (breeding population, dispersal, forage behavior, etc.) than the number or diversity of wetlands at the landscape scale. The HUC12 watershed scale is also commonly used as a spatial unit for both land management decisions and biological sampling programs. In addition, at the time of analyses, human disturbance index (HDI) data were only available at the HUC12 scale. For these reasons, the HUC12 watershed scale was adopted as the basic analytical unit for the hydrologic variables.

A brief description of hydrologic data is provided below. Additional information on data sources, metadata, and availability can be found in **Appendix I**.

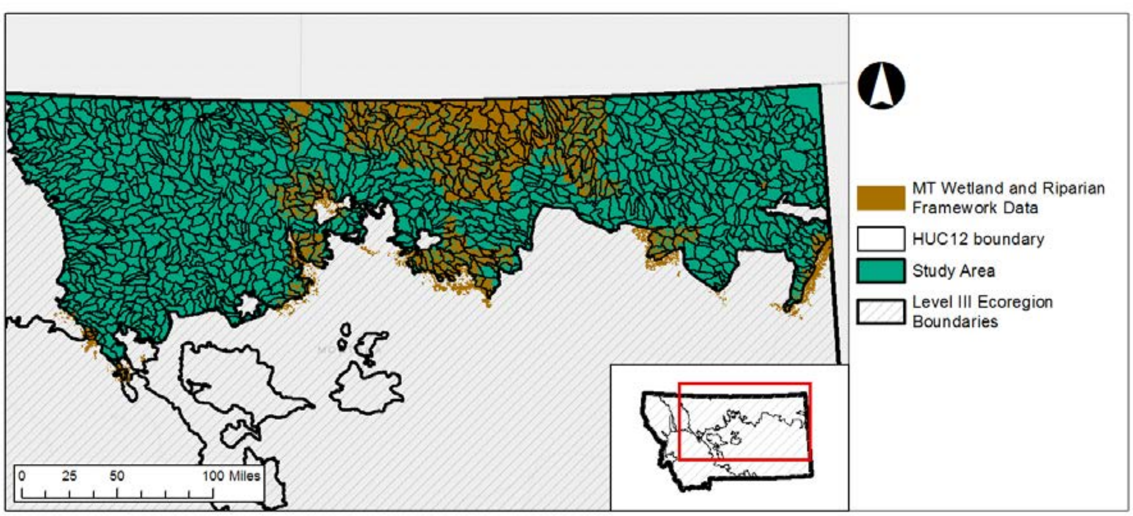
Table 6. Datasets Evaluated to Represent Hydrology for the Case Study Analysis in the Montana Prairie Wetland Region

Name	Description	Source
Montana Land Use/Land Cover Framework	Current land cover mapping; 2013 version	MT NHP
Montana Wetland and Riparian Framework (MTWRF)	Current wetland mapping; imagery dates: 2005, 2006, 2009, 2011, and 2013	MT NHP
National Wetlands Inventory (NWI) Mapping	'Historic' wetland mapping; imagery dates: 1980 to 1989.	U.S. Fish and Wildlife Service (U.S. FWS)
Human Disturbance Index (HDI)	Landscape disturbance index; inverse distance to 'human' land use, including agriculture, roads, oil and gas, etc.; based on 2014 Montana Land Use/Land Cover Framework	MT NHP
Groundwater Information Center (GWIC)	Groundwater withdrawal permit and general (quad) location; current and historical permits	MT Bureau of Mines and Geology
National Hydrography Dataset (NHD) Plus	Stream and waterbody locations; version 2, released 2012	U.S. Environmental Protection Agency (U.S. EPA)
National Inventory of Dams (NID)	Dam locations; 2013 database	U.S. Army Corps of Engineers (USACE)

Montana Land Cover/Land Use Framework. The Montana Land Cover/Land Use Framework (2013) is a 30-m raster datalayer derived from the Northwest ReGAP mapping project, which is based on satellite imagery obtained from 2002 to 2005. This base layer was modified by the Montana Natural Heritage Program (NHP) using information from the National Land Cover Dataset (NLCD), the National Wetlands Inventory (NWI), the National Hydrography Dataset (NHD), Montana Spatial Data Infrastructure (MSDI) Structures and Transportation themes, and the Montana Department of Revenue Final Land Unit classification. The Montana Land Use/Land Cover Framework contains three land-use categories: Level 1 (with 8 classes), Level 2 (with 27 classes), and Level 3 (which represents each unique Montana specific Ecological System Name). The Montana Ecological System Name is an ecosystem classification guide developed by Montana NHP (see http://fieldguide.mt.gov/helpES.aspx). For the purposes of this case study analysis, each of the three land-use levels was summarized at the HUC12 watershed scale to calculate total land-class area (acreage) and relative percent land-class area (%) in each HUC12 watershed unit.

Wetlands Data: National Wetlands Inventory and Montana Wetland and Riparian Framework. Two wetland mapping datasets, NWI and the Montana Wetland and Riparian Framework (MTWRF), were evaluated for this project. NWI is a statewide datalayer of wetland and deepwater habitat extent based on remotely sensed data; the dates for imagery used to derive the Montana NWI data range from 1980 to 1989. NWI data in Montana contain six unique habitat types: freshwater emergent wetland, freshwater forested/shrub wetland, freshwater pond, lake, riverine, and other. The MTWRF data were digitized from orthorectified aerial imagery collected in 2005, 2006, 2009, 2011, and 2013. This datalayer contains 10 unique habitat types: freshwater emergent wetland, freshwater forested wetland, freshwater pond, freshwater scrub-shrub wetland, lake, other, riparian emergent, riparian forested, riparian scrub-shrub, and river. NWI coverage is statewide, while the MTWRF data only covers portions of the prairie wetlands region (**Figure 3**). For the purposes of this project, several datalayers were produced from these wetland datasets: total wetland area and wetland count (i.e., the number of unique wetland features) and wetland diversity (i.e., the number of unique wetland types). All of these wetland values were calculated at the HUC12 watershed level. In addition, an attempt was made to characterize changes in wetlands over time, given that the temporal gap between the NWI and the MTWRF data is roughly 20–25 years. Change metrics were calculated as the value difference in wetland area, count, and diversity between the older NWI data and the more recent MTWRF data at the HUC12 watershed scale. However, because the NWI and MTWRF datasets use different imagery and classification methodologies and the MTWRF data also include more information on riparian habitats, it was necessary to modify the datasets to enable the comparisons. Habitat types associated with rivers and riverine ecosystems (identified through keywords including riparian, river, and riverine) were removed from both datasets, and the comparisons between wetland area, count, and diversity were focused on isolated upland wetlands.

Figure 3. Spatial Coverage of Montana Wetland and Riparian Framework (MTWRFP) Data within HUC 12 Watershed Boundaries for the Montana Prairie Wetlands Study Area (Northwestern Glaciated Plains Level III Ecoregion)

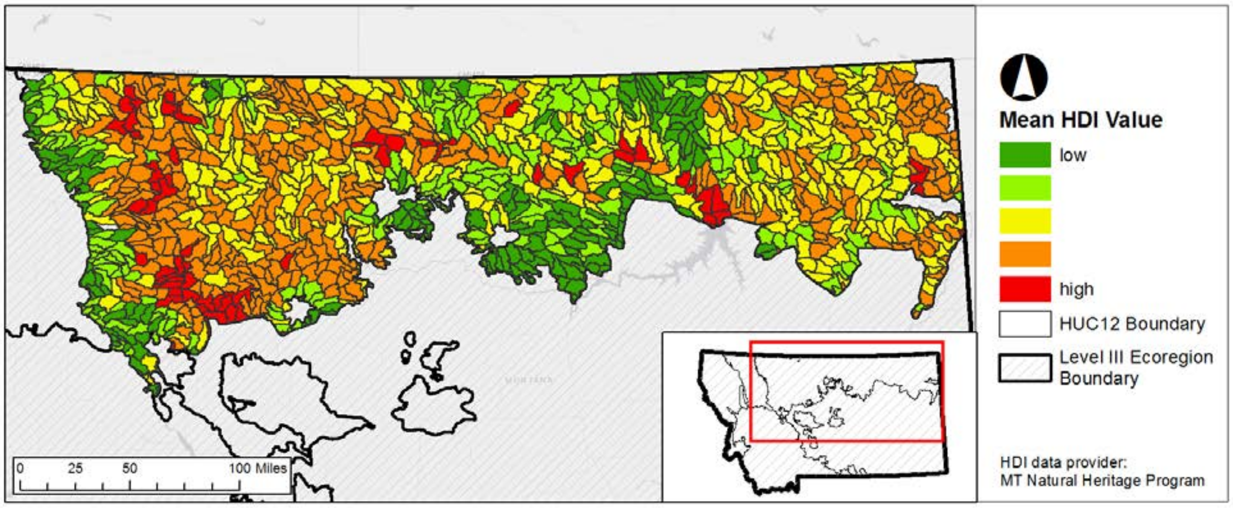


Human Disturbance Index. The Human Disturbance Index (HDI) is a Montana NHP datalayer that characterizes the degree of human disturbance for each pixel or grid cell in the Montana Land Use/Land Cover Framework datalayer. The original purpose of the HDI was to identify potentially restorable wetland areas in terms of local and regional human disturbance. In the development of the HDI by Montana NHP, six disturbance categories (Development, Transportation, Agriculture, Resource Extraction/Energy Development, Introduced Vegetation, and Forestry Practices) were derived from 24 land-use categories in the Montana Land Use/Land Cover Framework (**Table 7**). Each disturbance was assigned a weight and a distance-based decay curve. The HDI was then calculated as an inverse distance-weighted value based on the proximity of a given grid cell to disturbance categories (i.e., the distance each grid cell is from disturbance category grid cells). A lower HDI value indicates less human disturbance. The HDI was adopted for this project and case study analysis as a proxy variable for hydrologic change because the activities associated with disturbed land uses (e.g., agriculture, development, resource extraction) are often correlated with indicators of wetland disturbance, including drainage, consolidation, and changes in hydrologic regime. In addition, as previously mentioned, the original purpose of the HDI was to screen landscape disturbance for the purpose of wetland restoration. The HDI values can therefore be reasonably interpreted as a characterization of landscape change (i.e., departure from natural conditions) that is expected to negatively impact wetland health. Summary statistics (mean, median, minimum, maximum, and standard deviation) were calculated for HDI values at the HUC12 watershed scale within the study area of the Montana prairie wetland region (**Figure 4**). Note: After the completion on the analyses for this study, the Montana Natural Heritage Program released grid-scale HDI values which could be used to greatly increase the spatial resolution of the modeling results.

Table 7. Montana Land Use/Land Cover Framework (2013) Land-Use Categories Classed as "Disturbed" in the Human Disturbance Index (HDI) Datalayer

Montana Land Use/Land Cover Framework Land-Use Code	Description
21	Developed Open Space
22	Low Intensity Residential
23	High Intensity Residential
24	Commercial/Industrial
25	Railroad
26	Interstate
27	Major Roads
28	Other Roads
31	Mines
32	Coal Bed Methane
33	Gas and Gas Storage
34	Injection Well
35	Oil and Oil and Gas
40	Wind Turbines
81	Pasture and Hay
82	Cultivated Crops
8601	Harvested forest-tree regeneration
8602	Harvested forest-shrub regeneration
8603	Harvested forest-grass regeneration
8402	Introduced Upland Vegetation-Shrub
8403	Introduced Upland Vegetation-Annual and Biennial Forbland
8404	Introduced Upland Vegetation-Annual Grassland
8405	Introduced Upland Vegetation-Perennial Grassland and Forbland
8406	Introduced Riparian and Wetland Vegetation

Figure 4. Montana NHP Human Disturbance Index (HDI) Class Values within HUC12 Watershed Boundaries for the Montana Prairie Wetlands Study Area (Northwestern Glaciated Plains Level III Ecoregion)



Other Data. The remaining datasets identified in Table 6, Groundwater Information Center (GWIC), National Inventory of Dams (NID), and National Hydrography Dataset (NHD) Plus, were considered but ultimately rejected for use in the case study analysis. The following descriptions outline the main reasons for not including these data in the analyses:

- GWIC: Groundwater withdrawals for livestock, agriculture, oil and gas extraction, and other purposes can impact depressional wetlands and seeps by lowering the local water table. However, GWIC data are not consistently spatially referenced, and many withdrawal permits are arbitrarily assigned coordinates in the center of the host quadrangle. This spatial ambiguity meant that individual permits could not be accurately assigned to HUC12 watersheds.
- NID: Dams and impoundments can dramatically alter the hydrologic regimes of wetlands. However, inventory guidelines require that dams meet minimum height and storage capacity thresholds for inclusion in registries, and many of the impoundments related to agriculture and livestock do not meet registration requirements. For this reason, NID was judged to be an inconsistent record of hydrologic alteration in the study area.
- NHD Plus: Hydrography layers such as NHD Plus provide some information on lotic and deepwater habitats. However, many upland prairie wetlands are isolated from these systems and do not receive inputs from perennial channels. The application of NHD Plus datalayers to landscape scale hydrologic alteration and wetland change was therefore questionable.

In summary, hydrology for the case study analysis of the Montana prairie wetland region was represented by a total of 12 datalayers derived from 5 existing datasets summarized at the HUC12 watershed scale (**Table 8**). These data were identified through a review of the literature and consultation with the MTPWTT, and describe landscape and hydrologic alterations that are expected to negatively impact the wetland and intermittent/ephemeral stream systems in the study area. Wetland area, count, diversity, change in wetlands, land cover types, and degree of human disturbance are all captured by the data.

Table 8. Final Set of Hydrologic Datasets and Variables Summarized at the HUC12 Watershed Scale and Used in the Case Study Analysis

Dataset	Derived Datalayers	Methodology
Montana Wetland and Riparian Framework (MTWRF)	Area	Sum of nonriparian wetland area
	Count	Count of unique nonriparian wetland IDs
	Diversity	Count of unique nonriparian wetland type
Montana Land Cover	Area	Sum of each unique class within each classification system: Level 1, Level 2, and Level 3
	Percent Area	Percent cover of each unique class within each classification system: Level 1, Level 2, and Level 3
National Wetlands Inventory (NWI) Mapping	Area	Sum of nonriparian wetland area
	Count	Count of unique nonriparian wetland IDs
	Diversity	Count of unique nonriparian wetland type
Human Disturbance Index (HDI)	Mean, median, minimum, maximum, standard deviation	Summary statistics for all grid values within spatial unit
Wetland Change: NWI and MTWRF	Area	NWI wetland area—Montana Wetland and Riparian Framework area
	Count	NWI wetland count—Montana Wetland and Riparian Framework count
	Diversity	NWI wetland diversity—Montana Wetland and Riparian Framework diversity

4.2.1.2 Biological Data

Prior to the selection of the hydrology–ecology hypothesis for the case study analysis, biological datasets with coverage in the study area were identified and reviewed in the literature and during consultation with the MTPWTT (**Table 9**). The Montana prairie wetland region plays a vital role in the life cycles of migratory waterfowl and shorebirds. In addition, the prairie wetlands host year-round populations of native mammals, birds, amphibians, and fish. Different federal and state agencies and universities have developed monitoring programs to evaluate the presence and abundance of these different taxa in the Montana prairie wetland region.

Table 9. Biological Datasets with Coverage in the Study Area of the Montana Prairie Wetlands Region

Name	Description	Source
Montana Fisheries Information System (M-FISH)	Fish Population Survey	Montana Fish and Wildlife Division (FWD)
Montana Department of Environmental Quality (MDEQ) Stream Observed/Expected (O/E) and Index of Biological Integrity (IBI)	Fish and Macroinvertebrates	MDEQ
U.S. EPA Regional Environmental Monitoring and Assessment Program (REMAP)	Fish IBI; Macroinvertebrate abundance	U.S. EPA (Region 8 Office of Research and Development); USGS; Montana State University (MSU)
North American Breeding Bird Survey	Transect survey and range data on breeding birds in the Montana Prairie Wetlands Region	USGS
Maxell Amphibian Database	Amphibian and wetland survey	Montana NHP
Four-Square-Mile Survey Data	Prairie Pothole Region waterfowl survey	U.S. FWS

With the exception of the Four-Square-Mile Survey Data, which was not available, all datasets in Table 9 were obtained and evaluated for the project and selection of the hydrology–ecology hypothesis (previously described in Section 4.1). Sample locations for each dataset were projected and mapped to the study area, and these locations were then intersected with the hydrologic data prepared at the HUC12 watershed scale. In addition to spatial coverage, datasets were also evaluated for sample size, temporal span, and variability; summary statistics (mean, median, minimum, maximum, first and third quartiles, and standard deviation) were calculated for the relevant biological response. Brief descriptions of these data are provided below. Additional information on the biological datasets is located in Appendix I.

Montana Fisheries Information System (M-FISH). The M-FISH database was developed by the Montana Fish and Wildlife Division (FWD) and contains information on fish species for selected streams and lakes in the Montana prairie wetlands region. Depending on the waterbody, the data may include species distributions, population surveys, habitat information, and dewatering pressures due to natural variation or human withdrawals (primarily irrigation during July–September). A variety of agencies contribute to the database, including Montana Fish, Wildlife and Parks (FWP), U.S. Forest Service (USFS), U.S. Fish and Wildlife Service (U.S. FWS), U.S. Bureau of Land Management (BLM) and tribal fisheries biologists. Sampling sites with consistent data tend to be located on larger perennial streams, which are relatively rare in the region, such as Cottonwood and

Whitewater Creeks. Many other survey sites in the prairie wetland region report dewatered conditions, which presented limitations to the use of these data for the project and case study analysis.

MDEQ Stream Observed/Expected (O/E) and Index of Biological Integrity (IBI). Post-2000 stream O/E and IBI values calculated from Montana Department of Environmental Quality (MDEQ) fish and macroinvertebrate data were obtained with the help of MTPWTT. O/E values compare observed (sampled) species data at a site to the biological assemblage that would be expected if that site were in an undisturbed or reference condition; the difference between the two species assemblages can be used to characterize the degree of habitat disturbance or impairment. IBI values are also calculated from species assemblage data, and can be used to quantify a range of characteristics of the biological sample, including tolerant/intolerant species and functional species groups (habitat preference, feeding preference). The sampling locations of these data cover a range of streams across the study area of the Montana prairie wetlands regions. However, sample locations were not associated with lentic habitats. Therefore, these data could not be used to characterize biological response in prairie wetlands.

U.S. EPA Regional Environmental Monitoring and Assessment Program (REMAP). Stream fish and macroinvertebrate metrics, as well as macroinvertebrate abundance, were obtained from sampling efforts completed under U.S. EPA's Office of Research and Development (ORD) REMAP. The dataset also includes chemical and habitat survey data for sampling locations. REMAP was instituted to assess the approach of the U.S. EPA's Environmental Monitoring and Assessment Program (EMAP). The overall goal of EMAP was to use monitoring data to characterize ecological resources at multiple spatial and temporal scales. REMAP sample dates range from 1999 to 2001. Sample locations are spread throughout the eastern two-thirds of the state, with 25 unique sample locations within the Montana project study area. The age of the sample dates, the relatively small sample size within the study area, and the lack of representation of wetland habitats resulted in these data being rejected for further consideration in the case study analysis.

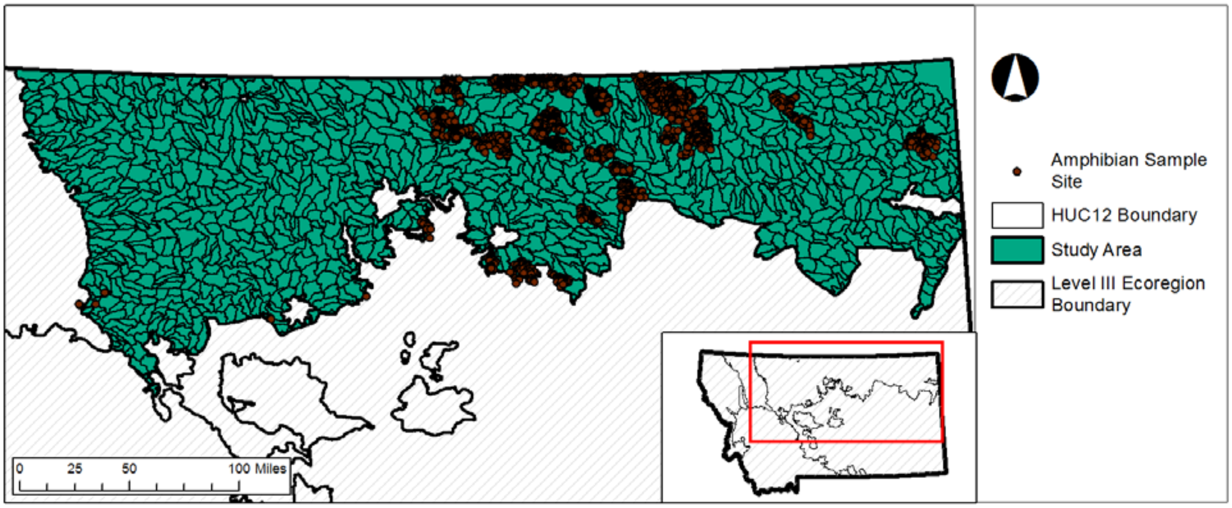
North American Breeding Bird Survey. The North American Breeding Bird Survey conducted by the USGS contains range information and transect sampling data for over 400 bird species in the United States, Canada, and Mexico. Breeding and nonbreeding bird presence/absence and species abundance by year are available at 12 transect points in the selected study area of the Montana prairie wetlands regions. Survey routes are along roads, and all species seen or heard within 0.25 miles during a specified interval are recorded. Although these data cover a substantial period, the relatively small number of sample sites (12) in the study area did not provide a large diversity of spatial locations. In addition, the location of survey sites along roads meant that these data could not be used to directly characterize wetland, especially undisturbed, habitats.

Montana NHP Maxell Amphibian Database. The Montana NHP Amphibian Database contains amphibian population survey data for upland sample sites across the state. The intended level of spatial resolution of these data is the HUC12 watershed, which integrates habitat patches, amphibian dispersal, local breeding populations, and natural and anthropogenic disturbance regimes (Maxell, 2009). Amphibians are identified to the species level. Counts include eggs, juvenile, and adult life stages. Twenty-six species at the juvenile and adult life stages are represented in the database; sixteen of these were sampled in the project study area. Sample dates range from 1998 to 2011, with most of the sampling falling within 2001 through 2008 (**Table 10**). In addition to population data, the database also contains information on sample site alterations (impoundments, grazing impacts, etc.), general water quality, and habitat condition. Sample sites are clustered within the north-central region of the Northwestern Glaciated Plains Ecoregion study area (**Figure 5**).

Table 10. Montana NHP Maxell Amphibian Database Survey Counts by Year (Number of Individual Surveys Completed)

Year	Individual Survey Count
1998	32
1999	17
2000	284
2001	902
2002	1,339
2003	1,265
2004	1,624
2005	1,374
2006	1,085
2007	1,153
2008	833
2009	275
2010	479
2011	392

Figure 5. Distribution of Unique Montana NHP Maxell Amphibian Database Sample Sites within the Montana Prairie Wetlands Study Area (Northwestern Glaciated Plains Level III Ecoregion)



Amphibians and the Montana NHP Maxell Amphibian Database were selected as the best taxa and dataset to represent biological response for the hydrology–ecology hypothesis and case study analysis in the Montana prairie wetland region. The main criteria or conditions that influenced this selection included:

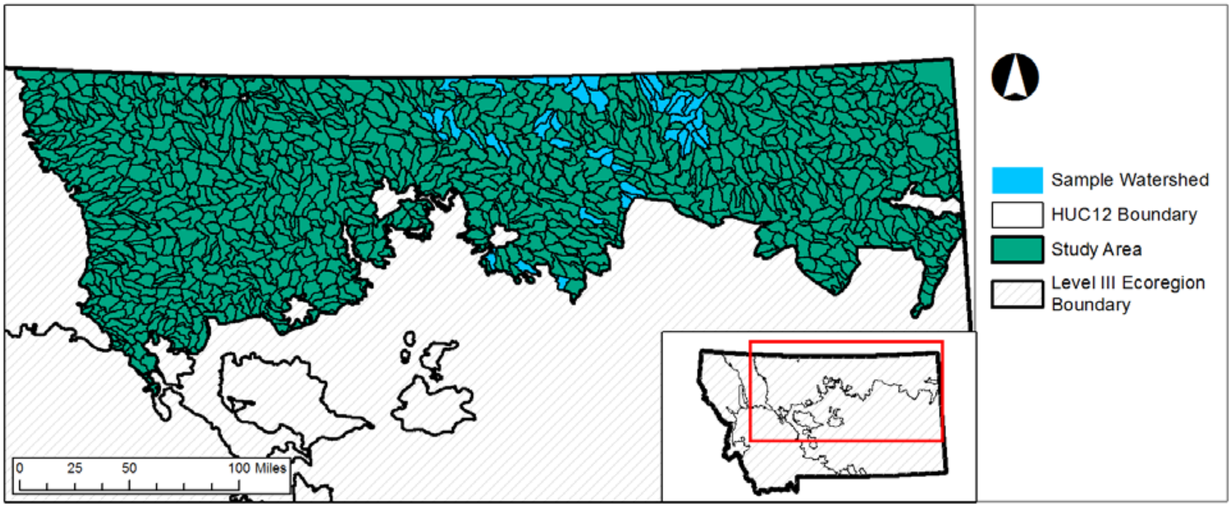
- Relative to the other available biological datasets, the amphibian Montana NHP Maxell Amphibian Database contains numerous sample sites in the study area of the Montana prairie wetland region (Figure 5).
- The database includes detailed habitat information that allows for additional filtering and characterization of the sample sites.
- Sample sites are focused on upland lentic habitats, in contrast to the largely lotic sample locations associated with fish and macroinvertebrate data. The amphibian database was therefore the biological dataset with the best representation of prairie wetland, as opposed to riparian, habitats.
- The sample sites of the Montana NHP Amphibian Database are well dispersed across the landscape and can be meaningfully summarized at the HUC12 watershed scale, the same spatial resolution as the hydrologic datasets and variables adopted for the case study analysis (see Section 4.2.1.1).
- There is literature support for the impacts of landscape and hydrologic alteration on amphibian diversity.

The Montana NHP Maxell Amphibian Database was filtered and formatted prior to use in the case study analysis (**Table 11**). To maximize sample size, all post-2000 data in the study area were retained. The data were then restricted to survey IDs (i.e., individual samples at a unique sample site) with at least one species count (i.e., surveys with zero recorded species were removed). The Database Survey Type criterion was also included in the data filter process; only sample sites categorized as 'worth future survey' were retained. To increase site diversity, counts for adult and juvenile life stages were summed for each unique sample site location. Following the application of the filters, the data from each sample were summed at the HUC12 watershed scale producing a total of 45 HUC12 watersheds with amphibian data for the case study analysis (**Figure 6**). Additional filtering criteria such as impoundment condition and grazing impact were also considered, and are described further in Section 4.2.2.1.

Table 11. Summary of Initial Formatting and Filtering Steps Applied to Montana NHP Maxell Amphibian Database Amphibian Data

Filter	Rationale
Survey ID with no specimens removed	Standard practice in the analysis of ecological community data
'Survey Type' field limited to sites characterized as 'lentic, worth future survey'	Focus on true upland depressional wetland sites rather than dry washes, ditches, etc.
Combine juvenile and species count data	Increase the variability of the biological response in order to improve modeling results
Keep individual sample site sums and also sum at HUC12 scale	Increase the variability of the biological response and target same spatial scale as landscape/hydrologic alteration variables
Subset sites by impoundment status (Y/N) and grazing impact	Potentially useful screening step to improve modeling results

Figure 6. Distribution of HUC12 Watersheds with Summed Montana NHP Maxell Amphibian Data within the Montana Prairie Wetlands Study Area (Northwestern Glaciated Plains Level III Ecoregion)



4.2.2 Technical Approach

This section describes the stepwise analyses that were conducted to evaluate hydrologic and amphibian data, determine relationships between hydrologic and biological conditions, and develop a model to characterize the relationship between hydrological alteration and biological response in the Montana prairie wetland study area. A variety of diversity indices were calculated from the amphibian community data in order to characterize community composition. These indices were then correlated to the hydrologic variables (Table 8) to identify potential relationships between amphibian response and landscape alteration, with the most promising relationships explored further through scatterplot analyses. Finally, a model was fitted to quantify statistically significant trends across the range of the biological response (i.e., diversity index value) to a measure of hydrologic alteration.

4.2.2.1 Exploratory Data Analysis

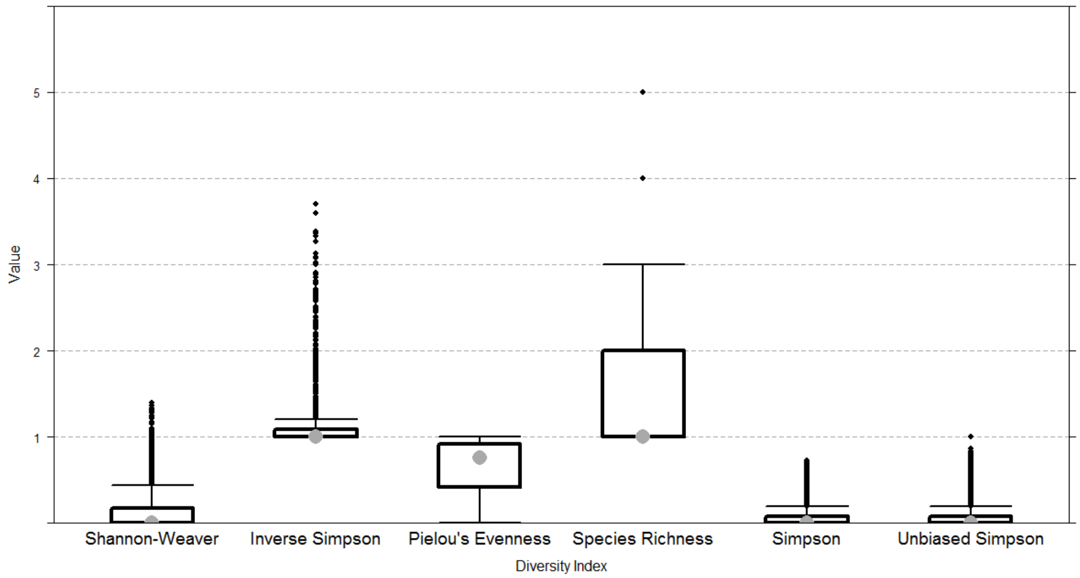
The exploratory data analysis phase of the case study analysis involved five main steps to evaluate the hydrology–ecology relationships and determine the variables to include in the hydrologic alteration and biological response model.

Step 1—Diversity Indices. To evaluate the relationships between landscape and hydrologic condition and the amphibian community in the Montana prairie wetland study area, a range of common species diversity indices were calculated from the formatted Montana NHP Maxell amphibian community data using the R package {vegan}, which contains compiled code for a number of useful ecological analyses (**Table 12**). Diversity indices provide more information on the composition of the biological community than species richness (i.e., the number of different species). Diversity indices typically account for species abundance (how many of each species are present) and evenness (relative abundance across different species). Several diversity indices were calculated from the amphibian community data: Shannon-Weaver Diversity, Simpson, Inverse Simpson, unbiased Simpson, Pielou's evenness, and species richness indices. When calculated at the individual survey site scale, the range of values within each index was found to exhibit little variability and were highly skewed (**Figure 7**). However, within-index variability for most diversity measures increased when the indices were calculated from amphibian community data summed at the HUC12 watershed level (**Figure 8**; **Table 13**). These results further supported the aggregation of the amphibian diversity data by HUC12 watershed. All subsequent exploratory and modelling analyses therefore focused on amphibian diversity index values calculated from community data summed at the HUC12 watershed scale.

Table 12. Diversity Indices Calculated from the Amphibian Community Data (Developed from the Montana NHP Maxell Amphibian Database)

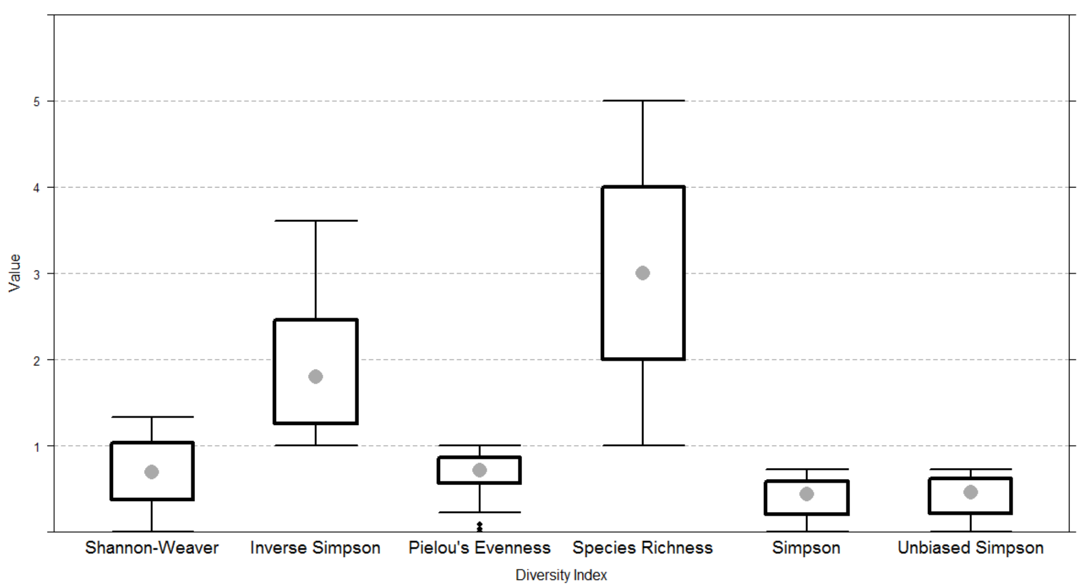
Index	Formula	Description
Shannon-Weaver	$H = -\sum_{i=1}^{R} p_i \ln p_i$	Proportion of individual species (evenness) relative to the total number of species (richness), multiplied by the natural log of this proportion; a measure of the difficulty of predicting the next species in a sample (higher richness and evenness equals more difficult prediction)
Inverse Simpson	${}^{1}/_{\lambda} = \frac{1}{\sum_{i=1}^{R} p_i^2}$	Inverse value of Simpson's Index of Diversity
Pielou's Evenness	$J = H/\log(S)$	A measure of how close the numbers of different species are to one another in a sample
Species Richness	$S = count\ of\ unique\ species$	The number of unique species in a sample
Simpson	$1\text{-}\lambda = \sum_{i=1}^{R} p_i^2$	Probability that two randomly selected individuals from a sample will belong to the same species
Unbiased Simpson	$D_2 = \sum_{i=1}^{R} \left(\frac{n_i}{n}\right)\left(\frac{n-n_i}{n-1}\right)$	Version of Simpson's Index of Diversity that minimizes bias due to differences in sample size

Figure 7. Amphibian Species Diversity Index Values Determined at the Individual Amphibian Survey Site Level.



Box Plot—gray dot = median value, upper box = 3rd quartile value, lower box = 1st quartile value, whiskers = 1.5 * inner-quartile range (IQR) (1st quartile to 3rd quartile), points = values beyond 1.5*IQR). Amphibian data are from the Montana NHP Maxell Amphibian database.

Figure 8. Amphibian Species Diversity Index Values Determined at the HUC12 Watershed Level (Sample Site Values Summed within Each HUC12 Watershed)



Box Plot—gray dot = median value, upper box = 3rd quartile value, lower box = 1st quartile value, whiskers = 1.5 * inner-quartile range (IQR) (1st quartile to 3rd quartile), points = values beyond 1.5*IQR). Amphibian data are from the Montana NHP Maxell Amphibian database.

Table 13. Summary Statistics for Amphibian Diversity Index Values at the Individual Survey Site and HUC12 Watershed Scale

	Statistic	Shannon-Weaver	Inverse Simpson	Pielou's Evenness	Species Richness	Simpson	Unbiased Simpson
Survey Site	Min. :	0	1	0.0004	1	0	0
	1st Qu.:	0	1	0.4138	1	0	0
	Median :	0	1	0.7636	1	0	0
	Mean :	0.1525	1.18	0.6582	1.382	0.09579	0.1254
	3rd Qu.:	0.1788	1.083	0.9183	2	0.0768	0.08
	Max. :	1.3948	3.705	1	5	0.7301	1
HUC12 watershed	Min. :	0	1	0.009219	1	0	0
	1st Qu.:	0.3807	1.262	0.56651	2	0.2075	0.2201
	Median :	0.6898	1.795	0.710769	3	0.4427	0.4618
	Mean :	0.6743	1.884	0.669779	3.109	0.3853	0.4063
	3rd Qu.:	1.0285	2.443	0.869075	4	0.5906	0.615
	Max. :	1.3362	3.604	1	5	0.7225	0.7308

Amphibian data are from the Montana NHP Maxell Amphibian database.

Step 2—Correlation Analyses. Step 2 of the exploratory analyses involved an evaluation of the relationships between the amphibian diversity index values and hydrologic variables. Pearson correlation coefficients were calculated for the amphibian diversity indices with the highest observed variability (Shannon-Weaver, Inverse Simpson, and Species Richness) and variables from the hydrologic datasets (Table 8). More specifically, the strength of potential influences of landscape-scale predictors, including HDI statistics, land cover, and wetland variables on the amphibian communities were evaluated (**Table 14**). Correlations between sample counts (i.e., number of samples within each HUC12 watershed) and diversity indices were also evaluated to determine the influence of sample count on the index values.

Correlations between the variables were found to be generally low (< 0.4), which indicates the lack of strong and/or consistent relationships between amphibian diversity and the hydrologic datasets prepared for this case study analysis. However, despite the relatively poor strength of the relationships, consistent trends between amphibian diversity and HDI, Human Land Use, MTWRF Area, and NWI and MTWRF wetland counts were apparent (correlations > 0.3). The Shannon-Weaver Diversity Index and species richness values exhibited stronger responses than inverse Simpson. Surprisingly, variables calculated to describe wetland change (i.e., change in wetland count, diversity, and area from NWI to MTWRF datalayers) did not show strong or consistent correlations. However, these results could be attributed to the aforementioned differences in the imaging and classification methodologies between the NWI and MTWRF datasets.

Table 14. Pearson Correlation Coefficients for Select Amphibian Diversity Indices, HDI, NHP Amphibian Database Sample Counts, Level 1 Montana Land Use/Land Cover Framework % Cover, and Wetland Count, Diversity, Area, and Change

Data Name	Shannon-Weaver	Inverse Simpson	Species Richness
Maximum HDI (Maximum value in HUC12 watershed)	−0.28	−0.20	−0.36
Mean HDI (Mean value in HUC12 watershed)	−0.38	−0.33	−0.41
NHP Amphibian Sample Count	0.00	0.00	0.31
MTLULCF Open Water / Wetland and Riparian Systems Land Cover	0.05	0.03	−0.08
MTLULCF Human Land Use	−0.33	−0.29	−0.39
MTLULCF Sparse and Barren Systems Land Cover	0.19	0.22	0.20
MTLULCF Forest and Woodland Systems Land Cover	−0.11	−0.10	0.12
MTLULCF Shrubland, Steppe and Savanna Systems Land Cover	0.07	0.03	−0.07
MTLULCF Grassland Systems Land Cover	0.07	0.09	0.15
MTLULCF Recently Disturbed or Modified Land Cover	−0.12	−0.18	−0.14
MTWRF Diversity	0.19	0.18	0.08
MTWRF Area	0.34	0.27	0.31
NWI Diversity	0.31	0.29	0.08
NWI Area	0.22	0.17	0.29
Change in Wetland Diversity	0.20	0.18	0.02
Change in Wetland Area	−0.08	−0.07	0.10
NWI Count	0.42	0.38	0.39
MTWRF Count	0.41	0.32	0.36
Change in Wetland Count	−0.09	−0.04	0.00

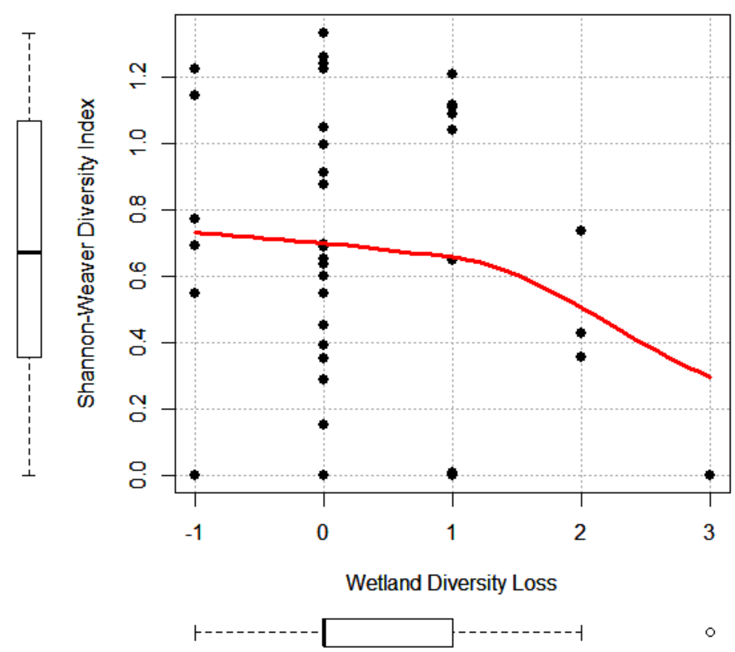
Correlation values > 0.3 are highlighted to the stronger relationships. MTLULCF refers to data from the Montana Land Use/Land Cover Framework dataset.

Also, of note were the higher correlations between species richness and sample count relative to the other diversity indices; species richness is generally highly correlated with sample size (i.e., the more times a site is sampled, the higher the species richness). The implications of these results are discussed further in Step 4.

Step 3—Scatterplot Comparisons. Following the correlation analyses and identification of the most responsive biological response variables, Shannon-Weaver Diversity and species richness indices were compared to individual hydrologic predictors in a series of scatterplots with added trend lines. The goal of these plots was to specifically evaluate potential response trends and identify predictor variables for the hydrologic alteration–biological response model. Although NWI and MTWRF wetland variables including wetland area, diversity, and count showed some of the strongest correlations with amphibian diversity, these predictors were not pursued in the scatterplot analyses, as these variables are not measures of change in hydrology. Only the relationships between the Shannon-Weaver Diversity and species richness indices versus HDI and changes in wetlands (e.g., Changes in Wetland Area, Diversity, and Count) were compared through scatterplots.

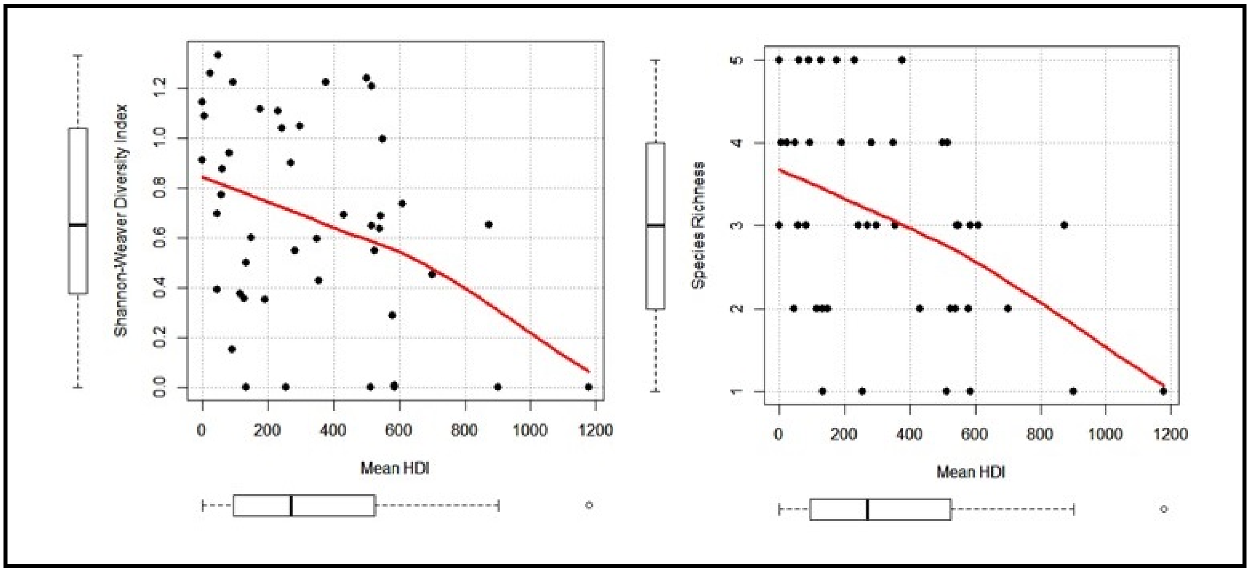
Results from the scatterplot analyses revealed that observed trends between the two diversity index values and measures of wetland change were not obvious. In many cases, only a partial trend was evident. For example, Shannon-Weaver Diversity Index at the HUC12 watershed level showed a general decline with increased wetland loss (**Figure 9**). The clearest trends were found between the diversity index values and the mean HDI scores (**Figure 10**), thereby suggesting that subsequent analyses should focus on mean HDI as the best predictor of amphibian diversity response.

Figure 9. Relationship between Shannon-Weaver Diversity Index and Wetland Diversity Loss at the HUC12 Watershed Scale



Positive wetland diversity loss values indicate the number of wetland types lost at the HUC12 scale from NWI wetlands (1980s) to current (post-2000) MTWRF wetland coverage; negative values indicate the inverse and an increase in the number of wetland types from the NWI to the MTWRF wetland covers. Marginal boxplots show the distribution of axes variables (Box Plot—black line = median value, upper box = 3rd quartile value, lower box = 1st quartile value, whiskers = 1.5 * inner-quartile range [IQR] [1st quartile to 3rd quartile], points = values beyond 1.5*IQR).

Figure 10. Relationships between Mean HDI and Shannon-Weaver Diversity Index (left) and Species Richness (right) at the HUC12 Watershed Scale



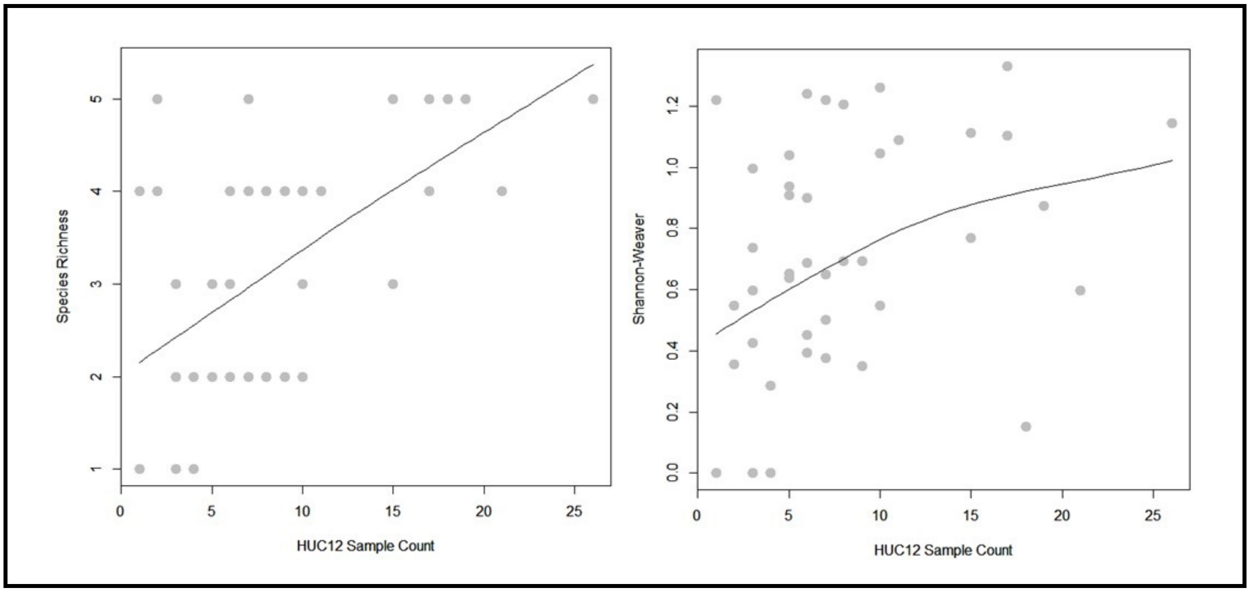
Marginal boxplots show the distribution of axes variables (Box Plot—black line = median value, upper box = 3rd quartile value, lower box = 1st quartile value, whiskers = 1.5 * inner-quartile range [IQR] [1st quartile to 3rd quartile], points = values beyond 1.5*IQR).

Step 4—Diversity Index Selection. Step 4 was conducted to select the diversity index to represent amphibian response to hydrologic alteration in the Montana prairie wetlands study area. Based on the results of the correlation and scatterplot analyses, both the Shannon-Weaver Diversity and species richness indices appeared to be suitable response metrics.

Sample count is known to have a large impact on species richness and, to a lesser extent, on other measures of biological diversity. In general, the more samples that are taken at a specific site (or the more sample sites per unit area), the greater the probability of finding a higher number of species; higher sample counts are therefore associated with higher diversity index values. Species richness is especially susceptible to this trend, since richness is the sum of the unique species found at a sample location. Indices which account for both abundance and evenness are less prone to this effect.

Comparisons of Shannon-Weaver Diversity Index and species richness values in response to sample size are presented in **Figure 11**. The same positive relationship between index value and sample counts is evident for both indices. However, the Shannon-Weaver Diversity Index values show evidence of plateauing as a function of sample count, while the trend for species richness exhibits a continued steep slope over the full response surface, thereby suggesting that the Shannon-Weaver Diversity Index is less influenced by sample counts than is species richness. This observation is further reinforced by the results of a Pearson correlation analysis between the two indices and HUC12 amphibian sample count (i.e., how many amphibian sample counts occurred in the HUC12). The correlation coefficient between species richness and sample count was 0.31, while the correlation coefficient between Shannon-Weaver diversity and sample count was 0.0 (Table 14).

Figure 11. Comparison of Species Richness (left) and Shannon-Weaver Diversity Index Values (right) Relative to Count of Montana NHP Maxell Amphibian Database Amphibian Sampling Sites within HUC12 Watersheds



Based on the trendlines depicted in Figure 11 and the results of the correlation analyses, the Shannon-Weaver Diversity Index was selected as the best metric to represent amphibian biological response in the Montana prairie wetland study area. The Shannon-Weaver Diversity Index values were less influenced by sample count than species richness. In addition, the Shannon-Weaver Diversity Index also demonstrated stronger correlations with human disturbance and wetland variables than the Inverse Simpson Index values (Table 14).

In addition to the empirical findings from the exploratory analysis, selection of the Shannon-Weaver Diversity Index to represent the amphibian community condition is reasonable because the index is well established in ecological studies and takes both species abundance and evenness into account (Table 13). There is also some evidence that the index performs better than other diversity indices across a range of sample sizes (Magnussen and Boyle, 1995), and may better characterize species diversity in complex environments (Morris et al., 2014).

Step 5—Amphibian Site Condition. As previously described in Section 4.2.1.2, the Montana NHP Maxell Amphibian Database contains information on habitat condition, including site conditions, general water quality, and anthropogenic disturbances, recorded at the sample site scale. During the review of the database with the MTPWTT, two variables related to anthropogenic disturbance were judged to potentially influence amphibian diversity: impoundment status and grazing impact. Impoundment status is a binary variable (i.e., yes/no) that describes whether water has been dammed or diverted at the sample location. Grazing impact describes alterations due to livestock presence with four possible values that range from 0 (no grazing noted) to 4 (water quality impact due to animal waste).

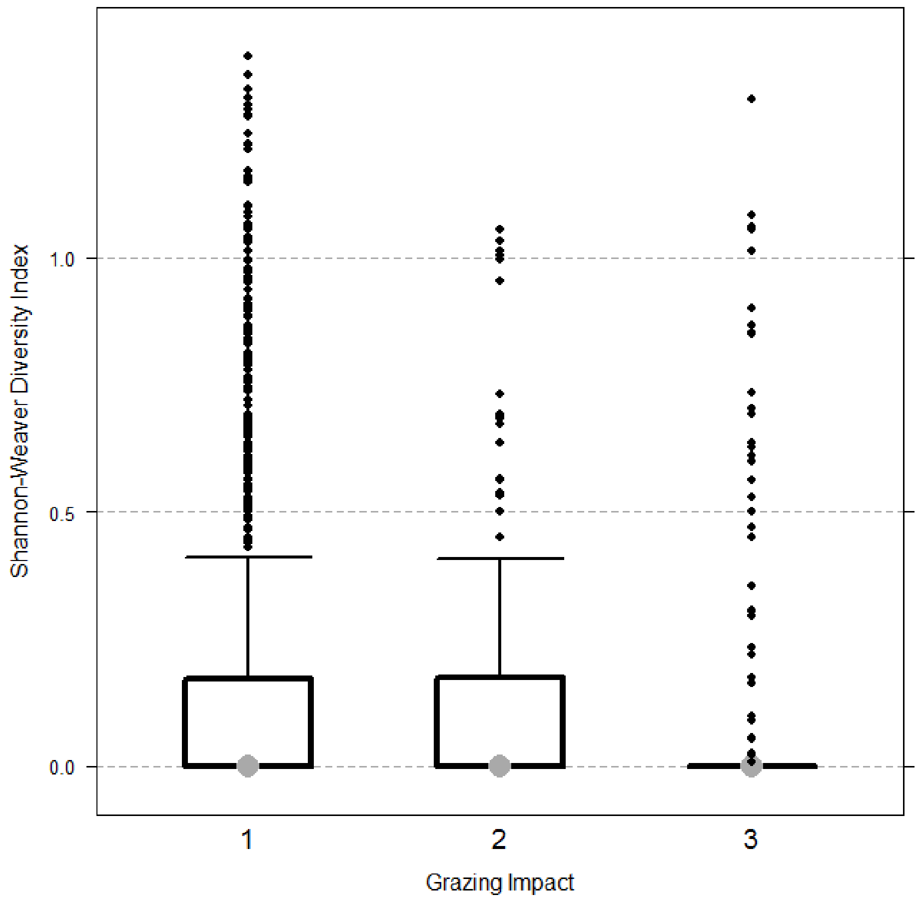
Prior to adopting the Shannon-Weaver Diversity Index calculated at the HUC12 watershed scale, it was necessary to evaluate the potential impacts of the condition variables on the diversity index values at the sample site scale. In other words, a HUC12 watershed could contain sample sites with different levels of hydrologic alteration and these different levels of alteration could influence the Shannon-Weaver Diversity Index value of the sites. If statistically significant relationships are found between the Shannon-Weaver Diversity Index and site condition values, site condition variables could be used to filter sites before summation at the HUC12 scale.

Figures 12 and **13** show the distribution of Shannon-Weaver Diversity Index values for unique sample sites as a function of site condition variables. For grazing impact, no and low grazing impact levels (1 and 2) were grouped together due to similar values, and grazing impact level 4 (water quality impact due to animal waste) was dropped due to low sample size relative to levels 1, 2, and 3.

To assess significant differences between the Shannon-Weaver Diversity Index values (grouped by hydrologic alteration), a nonparametric Kolmogorov–Smirnov (K-S) test, which compares empirical sampling distributions, was applied to diversity index values across all variable level comparisons. A K-S p-value below 0.05 provides evidence that the sample distributions (i.e., the distribution of Shannon-Weaver Diversity Index values) are not similar.

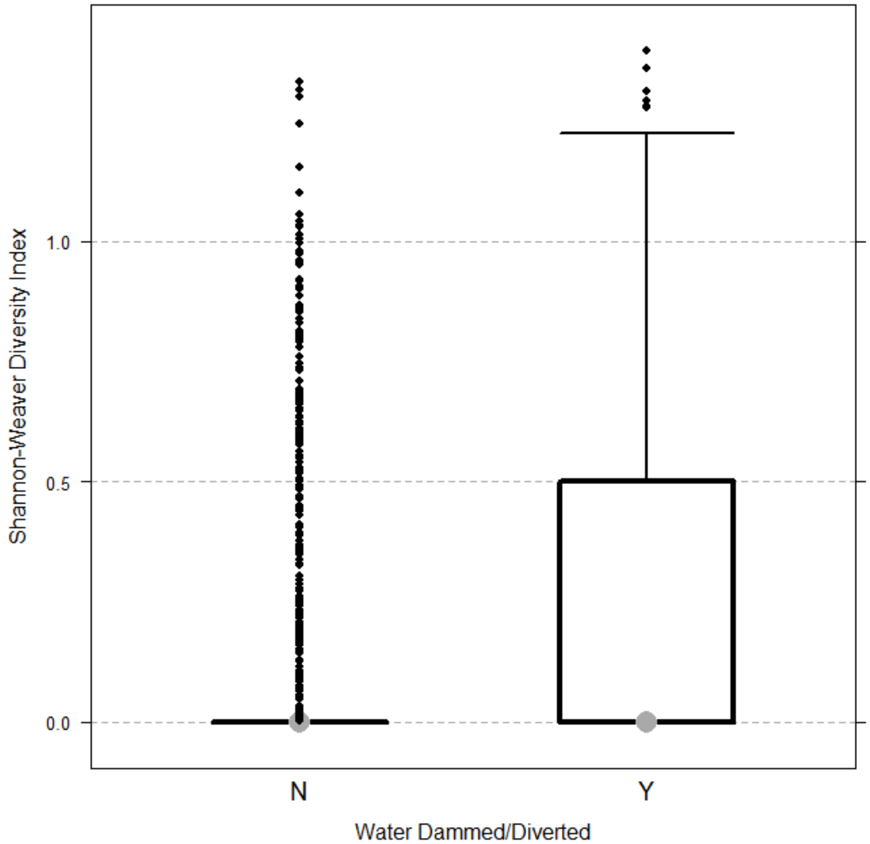
No statistically significant differences were found between the grazing levels (Figure 12). The p-values for comparisons between grazing impacts were 1 and 2 (p= 0.9478; 1 and 3 = 0.7998; and 2 and 3 = 0.5923). However, Shannon-Weaver Diversity Index values were significantly different across water dammed/diverted levels (Figure 13); the K-S p-value was 2.22e-16. This result suggests that sample sites with hydrologic alteration have higher overall Shannon-Weaver Diversity Index values. The reason behind this finding is unclear. It is possible that wetland sites with relatively more stable hydrologic regimes are more likely to be targeted for hydrologic alteration, and that these alterations increased habitat availability both spatially and temporally (larger wetted area, longer hydroperiod, etc.). In addition, several of the alterations mentioned in the field definition may be minimally invasive (pipe, trough, well, etc.). More information on the degree and nature of hydrologic alteration is therefore required. Regardless, the differences in Shannon-Weaver Diversity values for altered and unaltered sample sites were not large (**Table 15**), with differences confined to the third quartile. In addition, summation at the HUC12 scale averaged out the small variation due to hydrologic alteration. For these reasons, hydrologic alteration status was not used to filter sites for the calculation of Shannon-Weaver Diversity Index values at the HUC12 watershed scale.

Figure 12. Shannon-Weaver Diversity Index Values for Individual Montana NHP Maxell Amphibian Database Survey Sites Grouped by Grazing Impact Level



1 = no or limited impact grazing, 2 = heavy grazing impacts, 3 = 2 plus water quality impacts from animal waste (Box Plot—gray dot = median value, upper box = 3rd quartile value, lower box = 1st quartile value, whiskers = 1.5 * inner-quartile range (IQR) (1st quartile to 3rd quartile), points = values beyond 1.5*IQR).

Figure 13. Shannon-Weaver Diversity Index Values for Individual Montana NHP Maxell Amphibian Database Survey Sites by Water Alteration Status



X-axis—'Yes' = presence of "dam, well, water piped into water trough, excavated hole."; 'No' = no alteration. (Box Plot—gray dot = median value, upper box = 3rd quartile value, lower box = 1st quartile value, whiskers = 1.5 * inner-quartile range [IQR] [1st quartile to 3rd quartile], points = values beyond 1.5*IQR).

Table 15. Summary Statistics for Site Level Shannon-Weaver Diversity Index Values Across Hydrologic Alteration Status of the Sites in the Montana NHP Maxell Amphibian Database

Altered Status	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
No—water not dammed/diverted	0.00	0.00	0.00	0.12	0.00	1.33
Yes—water dammed/diverted	0.00	0.00	0.00	0.21	0.50	1.40

'No' indicates no water dammed or diverted at sample site; 'Yes' indicates water is dammed or diverted at sample site.

In summary, the exploratory analyses conducted correlation analyses to evaluate the relationship between hydrological variables and amphibian diversity indices, evaluated the most significant relationships between hydrologic alteration and biological response through scatterplot analyses, determined the most suitable biological response metric to characterize amphibian diversity, and tested and validated the calculation of the amphibian diversity at the HUC12 watershed. Based on the results of these analyses, mean HDI and the Shannon-Weaver Diversity Index calculated at the HUC12 watershed scale were selected to develop the model to characterize hydrologic alteration and biological response. The Shannon-Weaver Diversity Index values showed consistent correlations with human disturbance at the landscape scale and were less influenced by sample count than other diversity index values. The index is also well established in ecological studies and takes both species abundance and evenness into account. There is also some evidence that the index performs better than other diversity indices across a range of sample sizes (Magnussen and Boyle, 1995) and may better characterize species diversity in complex environments (Morris et al., 2014). The HDI was selected because it demonstrated stronger correlations to amphibian diversity than wetland change variables. Although HDI is not a direct measure of hydrologic alteration, the index is a proxy variable for hydrologic change because the activities associated with disturbed land uses (e.g., agriculture, development, resource extraction) are often correlated with indicators of wetland disturbance, including drainage, consolidation, and changes in hydrologic regime. In addition, the original purpose of the index was to screen landscape disturbance for the purpose of wetland restoration. The HDI also incorporates disturbance distance, thereby providing a higher spatial resolution than watershed-scale summaries of human land uses (i.e., area and percent area summaries). Mean HDI values can therefore be reasonably interpreted as a characterization of landscape change (i.e., departure from natural conditions) that is expected to negatively impact wetland health.

4.2.2.2 Development of Hydrologic Alteration–Biological Condition Model

The next step in the case study analysis was to develop the hydrologic alteration–biological condition model to characterize the relationship between amphibian diversity (Shannon-Weaver Diversity Index) and HDI. Because the data did not consist of repeated sampling following human disturbance, a 'space for time' analysis approach was necessary (i.e., characterizing responses to changes in hydrologic/landscape condition by evaluating ranges of hydrologic/landscape alteration and associated biological condition across the study area). This approach assumes that the full range of human disturbances and biological responses to those disturbances are represented in the study area.

A common technique for quantifying the relationship between two or more variables in a space for time analysis approach is statistical regression. Ordinary least squares regression attempts to estimate the mean response of this relationship (i.e., what is the impact of a predictor on the mean of the response variable distribution). However, ecological relationships often exhibit heterogeneous variance; the relationship between a predictor and response is not uniform across the response variable distribution (Cade and Noon, 2003). Thus, the rate of change or slope at the mean of the response variable distribution may be significantly different than the rate at the lower or upper end of the response distribution. In such cases, a researcher may want to examine the impact of a predictor across a range of response variable distribution subsets.

Quantile regression is a well-established method for undertaking this analysis. Quantile regression is a regression approach in which subsets, or quantiles, of the conditional response variable distribution are described by functions of one or more predictor variables (Koenker and Hallock, 2001). This approach is especially useful in ecological studies examining species responses to limiting factors (Cade and Noon, 2003). A limiting factor is a process that imposes an upper limit on a biological response. A given biological response may be subject to multiple limiting factors. In complex systems, not all limiting factors can be measured, and the impact of limiting factors which are measured often appear at the upper end of the response variable distribution. Quantile regression can be used to examine the impact of a measured limiting factor at this upper limit while not being influenced by the variance in biological response due to other unmeasured limiting factors (Cade and Noon, 2003). It is this component of quantile regression that often produces the 'wedge effect' of an upper quantile regression line delineating a limiting factor for a quantile of the conditional response variable distribution.

Results from quantile regressions are generally assessed in ways similar to classical linear regression. Statistical significance for a slope at a given quantile can be estimated using a bootstrap methodology described by Koenker (2006). Slope coefficients at different quantiles may exhibit different levels of statistical significance. A researcher may also want to know whether the slope estimates or coefficients of models at different quantiles are statistically different from one another; a modified analysis of variance (ANOVA) approach comparing the different models can be used to assess this question (Koenker, 2006).

Quantile regression analysis was adopted to model Shannon-Weaver amphibian diversity and mean HDI, both at the HUC12 watershed scale. Regressions were fit for quantiles at taus = 0.2, 0.4, 0.5 (median), 0.6, and 0.8. Each tau refers to a given percentile of the observed Shannon-Weaver amphibian diversity values; for instance, a tau of 0.4 corresponds to the 40^{th} percentile of diversity index values. Statistical significance for the slope associated with each quantile was estimated using the bootstrap methodology (Koenker, 2006). In addition, a standard ordinary least squares regression was fit for comparison purposes. All analyses were completed in R, with the quantile regression functions fitted using the R library {quantreg}.

4.3 Results

The results from the quantile regression evaluating the relationship between amphibian diversity and HDI are presented in **Table 16**. The modeling results show a consistent trend of negative slopes across the range of the response variable distribution (**Figure 14**). Amphibian diversity response to HDI is significant for several taus ($p<0.05$) and consistently declines across the range of HDI values; higher mean HDI scores are associated with lower amphibian diversity index scores.

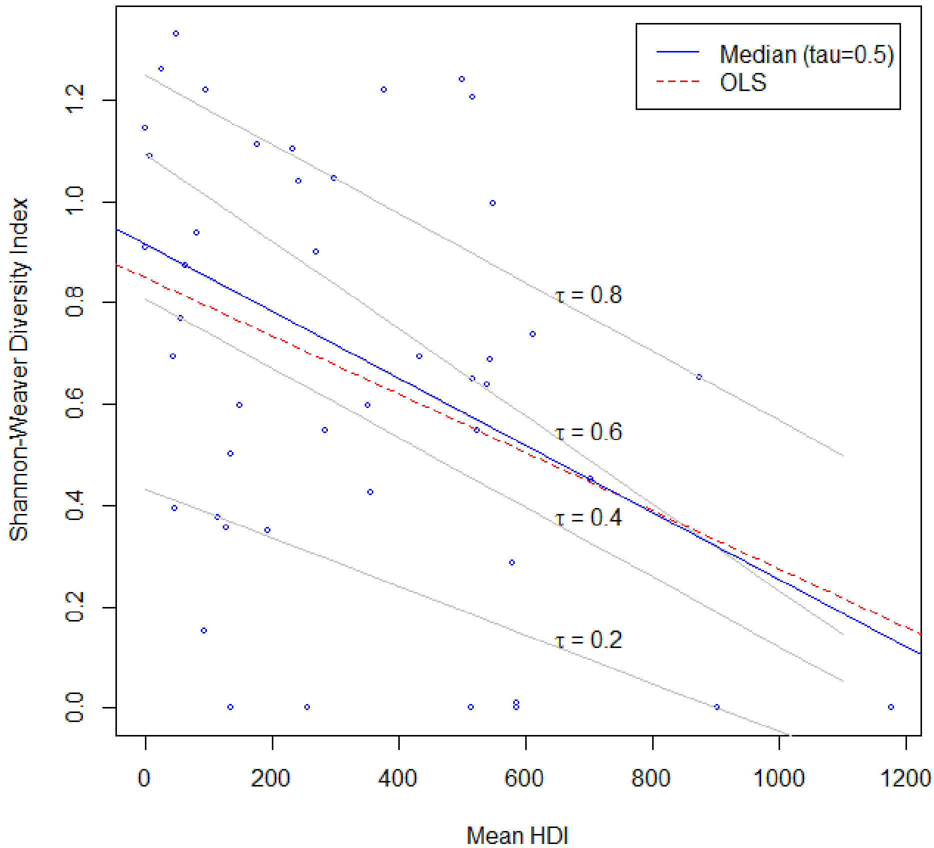
A comparison of the 0.2, 0.4, 0.6 and 0.8 quantile regression slopes through an ANOVA indicates that the individual response slopes do not differ from each other (p-value = 0.677). This suggests that the impact of mean HDI on amphibian diversity is similar across the range of biological response. In other words, the impact of HDI is not greater for higher diversity sites versus lower diversity sites. However, the regression slopes at the lower end of the response distribution (20^{th} percentile) are smaller (closer to zero) than at the 50^{th} to 80^{th} percentile range, suggesting that sites with midrange to high levels of amphibian diversity are more strongly impacted by human disturbance than those with lower levels of amphibian diversity. For instance, at the 0.2 quantile, each unit increase in mean HDI reduces the Shannon Diversity Index by −0.00048, whereas the same unit increase for the 0.6 quantile model reduces the index by 0.00086 (Table 16). This trend is assessed visually in **Figure 15**. In this figure, estimates of the mean HDI model coefficient are shown across a range of tau values, each of which represents a given percentile of the observed Shannon-Weaver amphibian diversity values. Although not statistically significant, a trend in mean HDI coefficient values is evident in the 'U' shaped curve; this suggests that mean HDI may be most consequential for diversity values in the 50^{th} to 80^{th} percentile range; sites with diversity values above the 85^{th} percentile or below the 15^{th} percentile appear to be less impacted by HDI values.

Table 16. Quantile Regression Estimates and Bootstrapped Significance Values for Mean HDI

tau	Variable	Value	Std. Error	Pr(>|t|)
0.2	Mean HDI	−0.00048	0.00031	0.12843
0.4	Mean HDI	−0.00069	0.00037	0.07345
0.5	Mean HDI	−0.00066	0.00029	0.02865
0.6	Mean HDI	−0.00086	0.00029	0.0053
0.8	Mean HDI	−0.00068	0.00031	0.03406
Mean (OLS)	Mean HDI	−0.00057	0.00021	0.00945

Response variable is the amphibian Shannon-Weaver Diversity Index (HUC12 watershed level). Model taus are 0.2, 0.4, 0.5 (median), 0.6, 0.8. Mean HDI coefficient for linear regression model is also shown (Mean OLS).

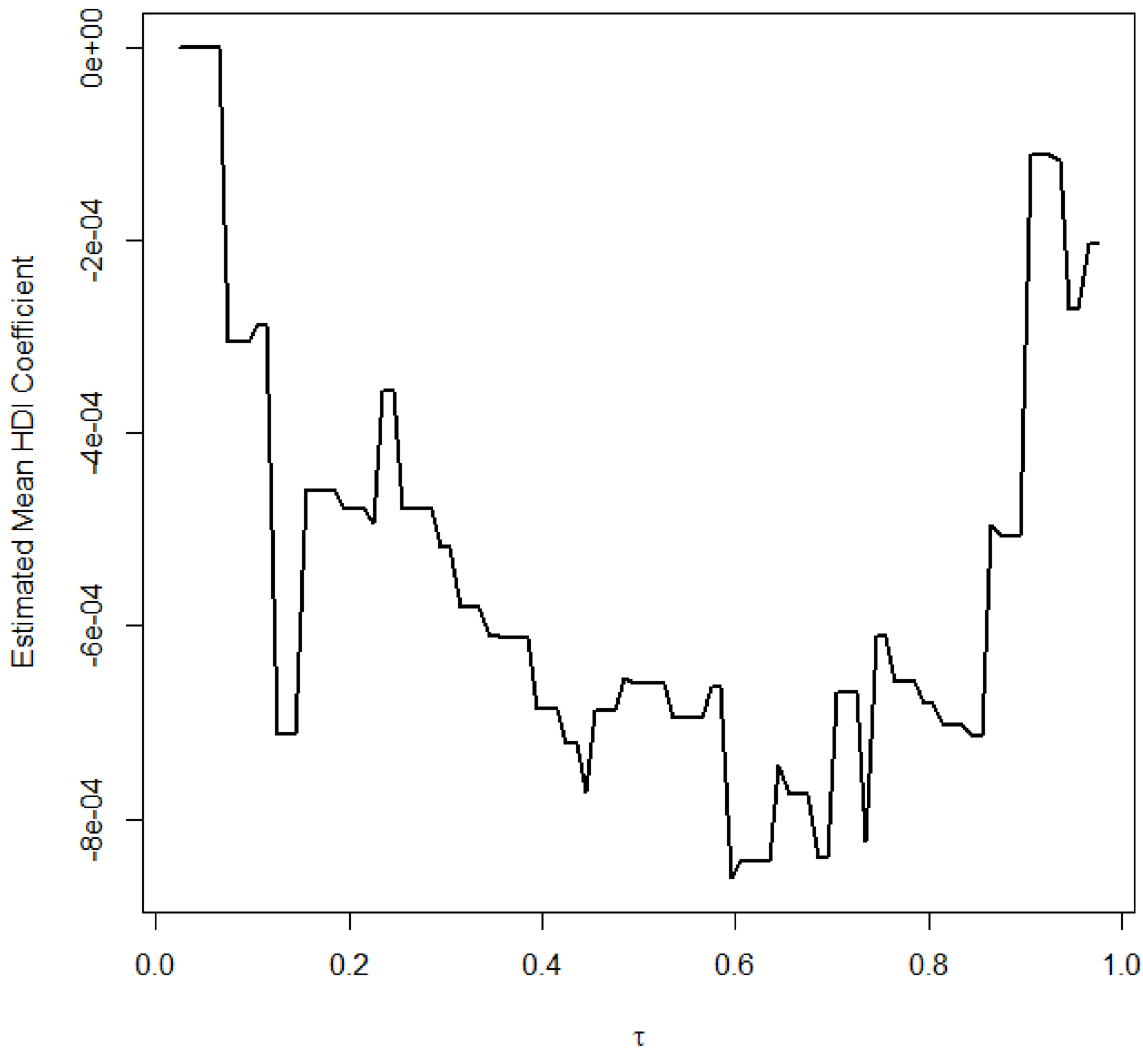
Figure 14. Quantile Regression Results (tau = 0.2, 0.4, 0.6, and 0.8) for the Relationship Between HDI and Shannon-Weaver Diversity Index for Amphibians in the Montana Prairie Wetlands Study Area



The pattern of reduced influences of human disturbance at the lower and upper end of amphibian diversity could suggest that low diversity sites have already been heavily impacted by human disturbance so that additional disturbance is not as consequential. Alternatively, the species associated with low diversity sites may be highly tolerant to anthropogenic disturbance regimes. Conversely, sites with higher amphibian diversity may be more isolated from human disturbance activities, either because of protected status or spatial location. Disturbance activities occurring elsewhere in the watershed may not be impact the wetlands or intermittent/ephemeral streams that are habitat to the amphibians. Due to the scale and resolution of the data, and in the absence of statistically different slope results from the ANOVA, it was not possible to determine the reasons behind the patterns of amphibian diversity response to HDI; the trends remain speculative.

Another finding unique to quantile regression is that the relationship between diversity values and mean HDI for sites below the 0.4 percentile of biological response are not statistically significant (Table 16). This suggests that human disturbance characterized by the HDI only acts as a significant limiting factor for the greater than 0.4 quantile region of the response variable distribution.

Figure 15. Model Coefficient for Quantile Regression Analysis of Mean HDI and Amphibian Shannon-Weaver Diversity Index (for tau values from 0.025 to 0.975, by intervals of 0.01) in the Montana Prairie Wetlands Study Area



4.4 Discussion

Wetlands and intermittent/ephemeral stream systems in the Montana prairie wetland region are subject to a range of disturbance pressures from land uses, including destruction, consolidation, fragmentation, and loss of diversity. These changes impose a complex set of interacting limiting factors on amphibian populations in the region (Joyal et al., 2001; Semlitsch, 1998). Given the region's complex hydrology, there are limited data on the ways in which these landscape disturbances and hydrology impact biology. As demonstrated in this case study analysis and modeling results describing the relationship between hydrologic alteration and biological condition, proxy variables related to hydrology such as wetland land cover and HDI values provide some insight into these processes and relationships. In the case of HDI, amphibian diversity characterized by the Shannon Weaver Index was found to be significantly and negatively impacted by human disturbance, with sites with higher amphibian diversity being more sensitive to the HDI than those with lower diversity. One interpretation of this finding may be that HUC12 watersheds with lower amphibian diversity may have already been impacted by other limiting factors; additional changes in HDI do not strongly influence amphibian diversity values in these locations.

The results of this case study analysis, therefore, suggest that is possible to develop hydrologic alteration–biological response relationships for the wetland and intermittent/ephemeral stream systems in the Montana prairie wetland region. In addition, these results indirectly support the hypothesis that, "*Altered hydrology of wetland and intermittent/ephemeral streams systems negatively impacts amphibian populations and communities.*" Amphibian diversity, as represented by the Shannon-Weaver Diversity Index, was found to be reduced by 0.00066–0.00086 units for every unit increase in human disturbance across the landscape. It may also be possible to use the results of this case study and the amphibian diversity–HDI model relationships to inform and potentially establish preliminary precautionary limits to hydrologic alteration. For example, management could focus efforts on HUC12 watersheds with Shannon-Weaver Diversity Index values above 0.5785 (i.e., the 40th percentile value where there is a significant relationship between amphibian diversity and HDI), and adopt land management strategies that limit human disturbances across the landscape management within an acceptable level of change in amphibian diversity (i.e., −0.00066 to −0.00086 units of change for every unit increase in HDI). Currently, 27 of the 45 HUC12 watersheds in the analysis have a Shannon-Weaver Diversity Index value above this proposed 0.5785 management threshold.

Despite the strength of the analyses, the results of this case study must be interpreted with caution. Limitations in the availability of relevant hydrologic data with adequate spatial coverage precluded the ability to develop and test direct relationships between hydrologic alteration and the condition of the amphibian community in the Montana prairie wetland region. The HDI was therefore proposed and used as a surrogate for hydrologic alteration for the Montana analyses. However, the relationship between HDI and hydrologic alteration was never tested and is yet to be confirmed.

5. Conclusions

This project addressed the hydrologic needs for healthy watersheds in Montana, and through a multistep process demonstrated that environmental flows and precautionary limits of hydrology alteration can be determined for the prairie wetlands of Montana. Through a collaboration with a technical team composed of expert scientists including federal and state resource managers, 20 hydrology–ecology hypotheses were identified for individual- and landscape-level wetlands and intermittent/ephemeral steams within the state. These hypotheses outlined hydrological alterations and the biological response to these alterations, and addressed potential impacts to macroinvertebrates, fish, amphibians, and birds.

One of the hypotheses was selected for a case study analysis to develop a proof-of-concept model relationship that describes hydrological alteration and ecological condition and supports the development of precautionary limits of hydrologic alteration. The hydrology–ecology hypothesis, *"altered hydrology of wetland and intermittent/ephemeral streams systems negative impacts amphibian populations and communities,"* was tested through a review of available data and the development of hydrologic alteration–biological response relationships.

The most significant relationship was found to be changes in amphibian diversity in response to human disturbances across the landscape; **as human disturbance increased, amphibian diversity decreased**. Although the relationship was linear and did not clearly indicate a threshold of response to set a precautionary limit of hydrologic alteration, watersheds with Shannon-Weaver Diversity Index values above 0.5785 can be significantly impacted by human disturbances across the landscape, and a one unit change in HDI can result in a 0.00066–0.00086 reduction in amphibian diversity. These landscape conditions and estimates of incremental response of the amphibian community to human disturbance could potentially inform precautionary limits of alteration and be used to set management goals to reduce impacts on amphibians in the prairie wetlands region of Montana. However, the human disturbance–amphibian diversity relationship does not directly relate hydrological alteration to the condition of amphibian communities within wetland and intermittent/ ephemeral stream conditions.

Recommended next steps in the determination of healthy watersheds and ecological flows for Montana prairie wetlands therefore include:

- Determine relationship between human disturbance and hydrologic alteration
- Update this study using grid-scale HDI values, which were not available at the time of the analysis
- Explore the relationship between HDI and other biological groups, including macroinvertebrates and fish (i.e., biological response to landscape disturbance in flowing systems)
- Incorporate additional hydrologic datasets expected to become available for the study area, such as USGS's Stream Stats
- Target biological sampling in regions where wetland change comparisons using NWI and Montana Wetland and Riparian Framework data may be justified; for instance, in the Cherry Moraine or Missouri Coteau ecoregions of the state

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Appendix I.
Publically Available Data
Considered in the Study Report

	Data Name	Source	Description	Availability
Hydrology Data	MT Land Use/ Land Cover Framework	MT Natural Heritage Program	Statewide coverage of natural and human land use and cover derived from imagery acquired from 2002 through 2005 and updated annually. 2013 version obtained for analysis.	http://mslapps.mt.gov/Geographic_Information/Data/DataList/datalist_Details.aspx?did={1C91607B-A788-4B23-B1BA-53EED2842D03}
	MT Wetland and Riparian Framework	MT Natural Heritage Program	The extent, type, and approximate location of wetlands, riparian areas, and deepwater habitats in Montana based on imagery acquired in 2005, 2006, 2009, 2011, and 2013. Coverage not statewide; new units released as processed.	http://mslapps.mt.gov/Geographic_Information/Data/DataList/datalist_Details.aspx?did={f57e92f5-a3fa-45b2-9de8-0ba46bbb2d46}
	National Wetlands Inventory (NWI) Mapping	U.S. Fish and Wildlife Service	The extent, approximate location and type of wetlands and deepwater habitats in Montana based on imagery acquired 1979–1989. Statewide coverage.	http://www.fws.gov/wetlands/Data/Mapper.html
	Human Disturbance Index (HDI)	MT Natural Heritage Program	Statewide representation of six disturbance categories—Development, Transportation, Agriculture, Resource Extraction/Energy Development, Introduced Vegetation, and Forestry Practices—based on 2014 MSDI Land Use/Land Cover Framework.	http://mslapps.mt.gov/Geographic_Information/Data/DataList/datalist_Details.aspx?did={639e7c86-8224-11e4-b116-123b93f75cba}
	Groundwater Information Center (GWIC)	Montana Bureau of Mines and Geology	Data on well number, depth, water level, and water quality for selected sites. Well locations not spatially referenced outside of quadrangle location.	http://mbmggwic.mtech.edu/
	NHD Plus v.2	U.S. Environmental Protection Agency	Suite of geospatial layers derived from National Hydrography Dataset (NHD) stream network (1:100,000-scale), Watershed Boundary Dataset (WBD) hydrologic units (12-digit), and National Elevation Dataset (NED) topography (30m). NHD Plus version 2 was released in 2012.	http://www.horizon-systems.com/NHDPlus/NHDPlusV2_home.php
	National Inventory of Dams (NID)	U.S. Army Corps of Engineers	Data on dams that meet the following criteria: 1) High hazard classification—loss of one human life is likely if the dam fails, 2) Significant hazard classification—possible loss of human life and likely significant property or environmental destruction, 3) Equal or exceed 25 feet in height and exceed 15 acre-feet in storage, 4) Equal or exceed 50 acre-feet storage and exceed 6 feet in height. Data in the 2013 database can be queried but not downloaded. GIS data available for 2006 data.	http://geo.usace.army.mil/pgis/f?p=397:1:0

	Data Name	Source	Description	Availability
Biology Data	Montana Fisheries Information System (M-FISH)	Fish and Wildlife Division of Montana Fish, Wildlife, and Parks (MT FWP)	Statewide coverage on stream and lake fish species distributions, population surveys and habitat information. Updated annually. Partners include MT FWP, U.S. Forest Service, U.S. Fish and Wildlife Service, Bureau of Land Management, and tribal fisheries biologists.	http://fwp.mt.gov/fishing/mFish/newSearch.html
	Maxell Amphibian Database	Montana Natural Heritage Program	Amphibian population data for sites across the state. Focus on lentic habitats. Counts include eggs, juvenile, and adult life stages. Also includes information on habitat and water quality conditions. Sample dates range from 1999 to 2011.	Contact information: http://mtnhp.org/
	Regional Environmental Monitoring and Assessment Program	U.S. Environmental Protection Agency	Stream fish and macroinvertebrate abundance and metrics, as well as chemical and habitat survey data for 87 sampling locations in eastern two-thirds of state. Sample dates range from 1999 to 2001.	Contact information: http://www.epa.gov/emap/remap/index.html
	North American Breeding Bird Survey	United States Geological Survey and Environment Canada	Breeding and nonbreeding bird range information and transect sampling data for 65 active transect routes in Montana. Sampling dates range from 1966 to 2014.	https://www.pwrc.usgs.gov/bbs/RawData/Choose-Method.cfm