CLIMATE CHANGE & MANAGEMENT OF RIVER, RIPARIAN, AND WETLAND HABITATS IN WYOMING

Summary from Wyoming Game and Fish Department Climate Change Workshop - April 28-30, 2020

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Executive Summary

In April 2020, the Wyoming Game and Fish Department (WGFD) held a workshop where WGFD managers could learn about the latest science on recent and future climate changes, and discuss the consequences of those changes for aquatic and terrestrial habitat management in the State. Focused on river, riparian, and wetland ecosystems, the workshop was designed to help managers consider the ways in which those habitats might be impacted by a changing climate, which types of watersheds and Wildlife Management Areas might be most vulnerable to climate change, and what management actions would be important to helping fish, wildlife, and plants cope with those impacts. Ultimately, results from the workshop were intended to inform and be incorporated into the 2020 revision of the Wyoming Statewide Habitat Plan.

The **workshop goals** were to:

- Learn about the best-available climate change projections and research on impacts to river, riparian, and wetland habitats in Wyoming;
- Explore the consequences of climate change for the WGFD Statewide Habitat Plan actions and priorities;
- Identify climate-informed habitat protection and restoration actions that could be taken in specific Wildlife Habitat Management Areas or watersheds; and
- Develop a list of data, information, and analyses that would be useful for making climate-informed habitat management decisions in the near- and longer-term.

Although climate change presents challenges to meeting management goals across all habitat types in Wyoming, this workshop was focused on river, riparian, and associated wetland habitats. Narrowing the focus this way allowed for greater specificity in workshop discussions while ensuring relevance to both the aquatic and terrestrial habitat components of the Statewide Habitat Plan. Several workshop breakout sessions focused on one of four focal geographies across the state: the Bear River watershed in southwest WY, the Horse Creek watershed in southeast WY, the Spence and Moriarty Wildlife Management Area (WMA) in central WY, and the Yellowtail Wildlife Habitat Management Area (WHMA) in north-central WY. These watersheds and management areas were selected to represent a diversity of ecosystems and to intersect several common management issues.

The interactive portion of the workshop included breakout discussions on:

- Climate change impacts of concern facing river, riparian, and wetland habitats,
- Factors that influence the relative climate change vulnerability of watersheds and wildlife management areas (WHMAs/WMAs) across the state,
- What's different about "climate-informed" habitat management for river, riparian, and wetland ecosystems,
- Priority climate-informed strategies for inclusion in the 2020 revision of the Statewide Habitat Plan, and
- Climate-related research and information needs.

Climate Change Impacts of Concern

Climate projections vary somewhat across the four focal geographies, but all climate models that were examined for this workshop agree that Wyoming will be significantly hotter by 2040-2069 relative to the baseline period of 1971-2000. Warming is projected to occur across all seasons, with annual increases ranging from approximately +3^{0}F to +8^{0}F, depending on the climate model and assumptions about future greenhouse gas emissions. Associated with that warming will be an increase in the number of extremely hot days with heat index > 90^{0}F, a longer growing season, and more growing degree days. Precipitation projections are more complicated and therefore less certain. However, a majority of climate models project that annual, winter, and spring precipitation will increase. Some climate models project decreases in summertime precipitation, although model agreement is medium-to-low and varies across the four focal geographies. Future projections for snow water equivalent (SWE) on April 1st vary across the four geographies, with Yellowtail WHMA and Bear River watersheds likely to see declines, Spence Moriarty WMA likely to see increases, and greater uncertainty for the Horse Creek watershed. Evapotranspiration is likely to increase at all locations in the spring and summer, with the exception of the Horse Creek watershed which may see declines in evapotranspiration in summer. Soil moisture is notably difficult to predict using climate models, but the models considered tend to suggest that soil moisture will increase in the spring and decrease in summer and fall. Other climate changes of note include high confidence that there will be increases in the intensity of precipitation events, springtime flooding, and future droughts; and rise in the elevation of mountain snowlines.

After reviewing the future climate projections, workshop participants identified more than 70 climate change impacts of concern related to the following aspects of river, riparian, and wetland ecosystems:

- Surface and groundwater availability (including quantity, quality, temperature, and timing),

- Physical stream conditions (including sedimentation and erosion),
- Aquatic habitat and species (including invasive aquatic species),
- Upland habitat and species (including invasive terrestrial species),
- Wetlands,
- Human water use (including irrigation).

With respect to hydrology, a common thread across the breakout groups surrounded the management implications of having to deal with both higher high flows and lower low flows, or greater fluctuations in stream flows across seasons and years. These hydrological changes could then lead to increasing rates of channel adjustments and erosion, which may render historical reference conditions less relevant when designing stream restoration projects. Biological impacts of concern to aquatic and terrestrial habitats include declines in some key habitats (e.g., for cold water fish such as cutthroat trout), shifts in species distributions (e.g., warmer-water fish moving upstream, and vegetation communities shifting upslope), and increases in the presence and abundance of invasive species. There was also a recognition that in addition to worrying about the direct effects of climate change on fish and wildlife and their habitats, it is also important to consider the "wild card" of how humans are responding to climate change. For example, climate changes will likely alter the timing and amount of water needed for irrigation, which could further limit water availability for fish, wildlife and plants.

Climate Change Vulnerabilities of Watersheds and Management Areas

Climate change vulnerability is defined as a function of a species' or area's exposure to changes in climate conditions (EXPOSURE), the sensitivity to those changes (SENSITIVITY), and the ability to cope with or respond to those changes (ADAPTIVE CAPACITY). An assessment of the relative vulnerability of watersheds or wildlife habitat management areas to the impacts of a changing climate can help target habitat protection and restoration efforts. Workshop participants identified a wide range of factors that might make a watershed or wildlife habitat management area relatively more or less vulnerable to the impacts of a changing climate on river, riparian, and wetland ecosystems, including:

Factors	Examples
Rate and magnitude of projected changes in climate	amount of warming, changes in precipitation, changes in snow water equivalent (SWE), timing of water availability, frequency of drought, elevational shifts in the snowline.
Physical conditions	geology, elevation, aspect, soils, size and shape of watersheds, amount of watershed above or below future snowline, topographic and geological diversity, presence of microclimates, stream basin connectivity (longitudinal, vertical, lateral, and temporal), presence or absence of barriers to movement
Ecological conditions	divergence from healthy condition, presence of invasive species, amount of vegetation cover, presence or absence of beaver activity, genetic diversity, presence of refugia
Hydrological conditions	amount of reservoir shoreline that could be exposed to lake level fluctuations, presence of wetlands, level of floodplain connectivity, soil water holding capacity, % of streams that are perennial/intermittent/ephemeral, whether the watershed is glacier-, snow-, or rain-fed
Water management	ability to manage water resources (via irrigation, reservoir operations), availability of water rights for instream use
Changes in disturbances	changes in pest outbreaks or wildfire regimes
Distribution and abundance of sensitive species	specialist species, species at the edge of their range, high vs. low species diversity
Land ownership	private versus public lands and the ability to do larger scale restoration efforts
Support and resources	funding and public support

What's Different About Climate-Informed Management

Building off of discussions about climate change impacts and vulnerabilities, workshop participants tackled the question: ***"What, if anything, might we need to do differently about our work to be effective in light of expected climate changes and impacts?"***

Breakout groups discussed how several core management strategies that are common to WGFD's work -- riparian habitat protection and restoration, stream restoration, fish passage and stream connectivity, and water management -- might need to be modified in order to be effective in a changing climate, and identified strategies that may not necessarily need to be different, but which were flagged as being particularly important or urgent to address climate change impacts.

Climate-Informed Modifications to Current Practices:	Strategies and Actions With Increased Priority and/or Urgency:
• Design projects under the assumption of increasing likelihood of higher high flows, lower low flows, and more frequent extreme flood events, rather than historic or current hydrological conditions. • Use plant species or genetic stock that is more likely to thrive under future climate conditions in restoration projects. • Craft restoration and connectivity projects with future species' ranges and habitat conditions in mind. • Take climate change into account when prioritizing projects and articulating project goals. • Increase flexibility around water management and habitat restoration to address new problems that will need new solutions.	• Increased importance of retaining and conserving water. • Increased importance of securing and managing water rights. • Increased importance of riparian restoration and protection. • Greater urgency for landscape-scale conservation and management.

Priority Climate-Informed Actions for the Statewide Habitat Plan

Workshop participants identified over 75 habitat management actions that could help to address climate change impacts on river, riparian, and wetland habitats in Wyoming. There was a great deal of emphasis on actions relating to water availability and use. Nearly 20% of the identified actions related to water rights, water storage, water management, and irrigation. Strategies that the identified habitat management actions support include:

- Managing land and water use with an eye towards future conditions.
- Building watershed health and resilience to a changing climate.
- Maintaining species diversity and habitat needs in a changing climate.
- Making climate-informed decisions about angling, trapping, and setting goals for habitat management areas.
- Prioritizing habitat management efforts using a climate change lens.
- Establishing and implementing monitoring methods and protocols that can help to anticipate changes and set climate-informed priorities.

Information and Research Gaps

The final session of the workshop was dedicated to gathering participants' input on: ***What does the Agency need to know in order to make better climate-informed decisions in the next 5 years?***

In response, participants identified a large number of research questions, data products, and inventories that could help support climate-informed management decisions for river, riparian and wetland habitats. Workshop organizers combined similar topics from this discussion into a refined list of 44 information needs related to several themes, including: riparian and wetland ecosystems; aquatic habitat and fisheries; beaver and other process-based restoration approaches; assessments of climate change vulnerability, refugia, and prioritization/ planning; invasive species; fish passage and stream connectivity; hydrology and water balance; stream restoration; water management; and baseline data and monitoring.

Following the workshop, we asked WGFD staff how useful each of the identified information needs would be to their ability to consider climate change effects on their work on river, riparian, and wetland habitats. Eight (8) of the information needs identified during the workshop were rated as being "Useful" or "Very Useful" by over 60% of survey respondents. These include efforts to identify important places for habitat management actions, such as streams that may become more (or less) suitable for particular fish species under a changing climate, or areas of "climate refugia" for imperiled species. They also include research designed to support our understanding of the effects of particular climate-informed management actions, such as the influence of process-based restoration approaches on water availability for downstream users, or how upland habitat treatments affect watershed hydrology under more intense precipitation events, or what are the tradeoffs and benefits of different water management approaches in a changing climate (e.g., flood vs. pivot irrigation, or managing water for instream vs. out-of-stream habitats). Lastly, they include information needs related to invasive species, such as which invasive species might be expected to increase or arrive in Wyoming as the climate changes, and what are the best management strategies for disadvantaging invasive plant and fish species.

Next Steps

The April 2020 Climate Change Workshop represented a valuable step in advancing WGFD staff's consideration of climate change in their habitat management work. Next steps to apply and build on the discussions at the workshop include:

- Incorporating climate-informed habitat management strategies into the 2020 Statewide Habitat Plan revision.
- Sharing this report within WGFD via a dedicated webpage, and formal and informal presentations.
- Presenting a summary of workshop discussions and products to the Wyoming Game and Fish Commission.
- Considering organizing similar climate change discussions within WGFD focused on additional regions, ecosystem types, or WGFD programs.
- Exploring research partnerships to focus on some of the high priority information needs identified by WGFD staff.
- Sharing methods and results from this project with other natural resource managers interested in making climate-informed management decisions.




Introduction

In 2020, the Wyoming Game and Fish Department (WGFD) began revising its Statewide Habitat Plan (SHP). The SHP articulates priorities for protection and enhancement of aquatic and terrestrial habitats across the state, and influences how the WGFD allocates annual funds. Since the SHP was last revised in 2015, WGFD managers have become increasingly concerned with how recent and potential future changes in climate could influence their management goals and actions. In response, habitat management leadership within the Department decided to hold a workshop where WGFD managers could learn about the latest science on recent and future climate changes, and discuss the consequences of those changes for aquatic and terrestrial habitat management in the State. Initially focused on climate change impacts and management responses in river, riparian, and wetland ecosystems, the workshop was intended to provide WGFD staff with access to information and approaches for climate-informed planning that could also support management thinking in other habitat types. Workshop sessions were designed to help managers consider the ways in which river, riparian, and wetland habitats might be impacted by a changing climate, which types of watersheds and Wildlife Management Areas might be most vulnerable to climate change, and what management actions would be important to helping fish, wildlife, and plants cope with those impacts. Ultimately, results from the workshop were intended to inform and be incorporated into the 2020 SHP revision.

Workshop Details

Workshop Goals and Desired Outputs

The **workshop goals** were to:

- Learn about the best-available climate change projections and research on impacts to river, riparian, and wetland habitats in Wyoming;
- Explore the consequences of climate change for the WGFD Statewide Habitat Plan (SHP) actions and priorities;
- Identify climate-informed habitat protection and restoration actions that could be taken in specific Wildlife Habitat Management Areas or watersheds; and
- Develop a list of data, information, and analyses that would be useful for making climate-informed habitat management decisions in the near- and longer-term.

The **desired outputs** included:

- A report that summarizes workshop discussions (this report);
- A list of specific strategies and actions that could be incorporated into the draft revision of the Statewide Habitat Plan (see Summary Results section of this report);
- A list of information needs (e.g., research, analyses, products, inventories) that could be the focus of new research and partnerships involving WGFD and outside climate change experts (see Summary Results section of this report).

Focus on River, Riparian, and Wetland Habitats

Although climate change presents challenges to meeting management goals across all habitat types in Wyoming, we chose to focus this workshop on river, riparian, and associated wetland habitats. Narrowing the focus allowed for greater specificity in workshop discussions, while ensuring relevance to both the aquatic and terrestrial habitat components of the Statewide Habitat Plan. The focus also coincides with widespread concerns about the impacts of climate change on the management of freshwater, riparian, and wetland ecosystems among State fish and wildlife management agencies in the North Central region (Montana, Wyoming, Colorado, North Dakota, South Dakota, Nebraska, and Kansas) (Crausbay and Cross 2019). During workshop discussions, we considered future climate conditions that are projected for the time period 2040-2069. This time period was chosen because of the availability of future climate projections for those years, and because it was considered relevant to thinking about the implications of climate change on management actions being taken in the coming years, that are expected to have long-lasting effects on the provision of habitat for wildlife.

Workshop Format

The workshop was designed to follow common steps in proactive climate change adaptation planning (also referred to as "climate-smart conservation planning" or "climate-informed management planning"). A number of step-wise approaches to climate change planning exist (e.g., Cross et al. 2013, Stein et al. 2014, Swanston et al. 2016). These approaches share many similarities, including that they are:

- **Iterative** - by embracing an iterative plan-act-evaluate approach that allows for active learning and adjustments to account for new information or changing conditions.

- **Participatory** - by encouraging climate experts and natural resource managers to work together through the planning steps, so that the best-available information is considered and climate experts can learn about the types of information that are most useful to decision making.
- **Designed to generate specific adaptation options** - by bringing a level of specificity to discussions about climate change impacts and potential management responses that can be directly useful to managers.

The core steps in proactive climate change adaptation planning include assessing climate change impacts and vulnerabilities, reviewing and revising management goals in light of climate change impacts, and identifying adaptation options - or climate-informed management actions to help species and ecosystems adapt to a changing climate. Therefore, we designed the WGFD workshop to align with these steps and provide an opportunity for fish, wildlife and habitat managers to contemplate a series of questions about their work, including:

Will climate change alter the effectiveness of current actions?

Are new actions needed to achieve goals as climate changes?

Do management goals need to change?

Initially planned as an in-person workshop, organizers converted the workshop to a virtual format once it became clear that it would not be possible to meet in person during the COVID 19 pandemic. We chose Zoom as our video-conferencing program, due to its robust capabilities for all of the plenary and breakout sessions. We used shared, live-editable Google Docs to capture individual contributions and group discussions during breakout sessions. The workshop agenda (Appendix A) started on Day 1 with a ~2-hour panel of climate science presentations that served to summarize the best-available information on observed climate changes across Wyoming, modeled future climate changes in the state, and potential impacts on snowpacks, streamflows, fisheries, and wetlands (a recording of the Day 1 climate science webinar and all presentations from the workshop are available upon request from mcross@wcs.org; WGFD staff can access workshop materials on the internal WGFD website at: https://gfi.state.wy.us/ClimateChangeWS/index.asp). The interactive workshop portion started on Day 2 and continued into Day 3, with ~2-hour sessions in both the morning and afternoon. Each session included a brief plenary presentation on key concepts followed by interactive breakout discussions on topics such as:

- Climate change impacts on river, riparian, and wetland habitats & consequences for the Statewide Habitat Plan.
- Assessing relative climate change vulnerability of watersheds and Wildlife Habitat Management Areas (WHMAs) across the state.
- What's different about "climate-informed" habitat management for river, riparian, and wetland ecosystems.
- Priority climate-informed strategies for inclusion in the 2020 revision of the Statewide Habitat Plan.
- Climate-related research and information needs for the Statewide Habitat Plan revision and beyond.

For the breakout discussions on climate change impacts and priority climate-informed strategies for inclusion in the 2020 SHP revision, we chose to focus on four different geographies across the state: the Bear River watershed in southwest WY, the Horse Creek watershed in southeast WY, the Spence and Moriarty Wildlife Management Area in central WY, and the Yellowtail Wildlife Habitat Management Area in north-central WY (Figure 1). These watersheds and management areas were selected to span the state and intersect several common management issues. Identifying widely separated areas across the state was desired to effectively engage and generate interest with the habitat biologists that would be the primary audience for the workshop. Reasons for selecting these specific locations included:

- The Bear River watershed is one of the six watersheds identified in Wyoming's State Wildlife Action Plan, meaning that results from the workshop could be directly relevant to future iterations of that plan. Also, this watershed in southwest Wyoming is relatively small which allows for focused analysis. Finally, the Bear River basin has been a recent focal point and area of interest for a group of conservation partners led by the Intermountain West Joint Ventures Water 4 Initiative.
- The Horse Creek subwatershed in SE Wyoming was selected as a representative of a prairie stream ecosystem that harbors high fish diversity and species of greatest conservation need.
- The Spence Moriarty WMA was selected as a place under WGFD management that is relatively high elevation, harbors cutthroat trout, has extensive riparian habitat, and involves heavy irrigation practices. Climate change will likely have significant implications for influencing trade offs between hay production from irrigated meadows and fish production and survival in extensive stream environments.
- The Yellowtail WHMA was identified as a relatively low elevation management property that contains extensive wetlands, diversion and irrigation from a major river, farmed fields, and extensive riparian habitat. Issues of water management at this property would be relevant to other management properties held by the Wyoming Game and Fish Commission across the state.

Participants

Most workshop participants were WGFD staff, from across regions and divisions within the Department (Appendix A). Participants included regional terrestrial and aquatic habitat biologists, habitat and access biologists, fish management biologists, fish and wildlife managers, and a deputy director. Several external climate experts from the US Geological Survey, University of Wyoming, University of Colorado-Boulder, North Central Climate Adaptation Science Center, Wildlife Conservation Society, and The Nature Conservancy participated in portions of the workshop. The number of individuals participating in the workshop varied from approximately 35 to 65, depending on the session.

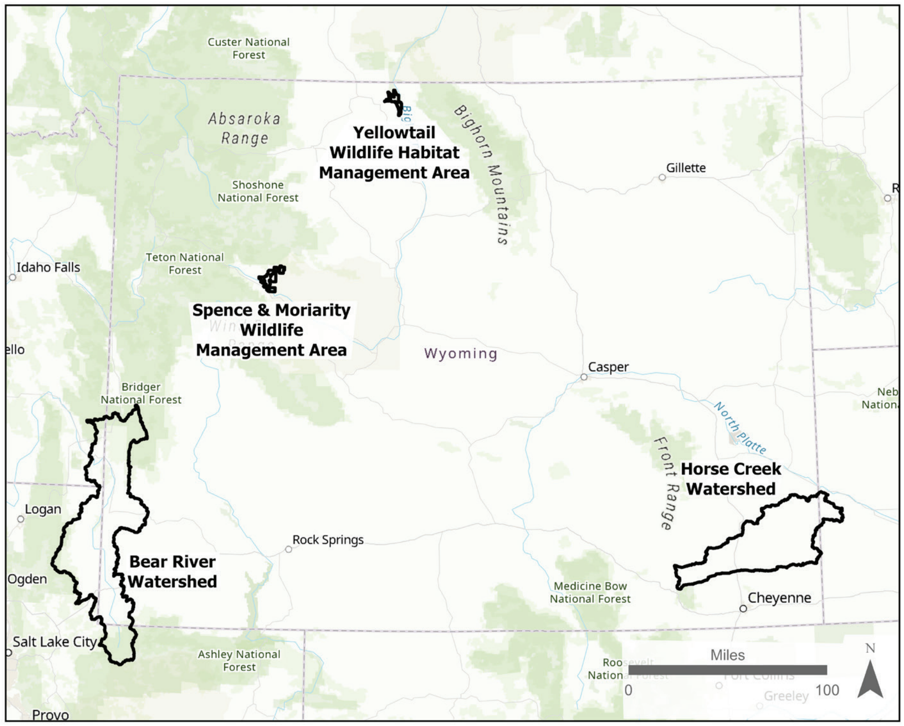

Figure 1. Map of Wyoming highlighting the four watersheds or management areas that were the focus of workshop discussions.

Applying the Workshop Approach to Additional Topics

As described in more detail in the following sections of this report, we developed a set of worksheets to guide workshop participants' discussions for each step in the climate change planning process. **This collection of worksheets can serve as a discussion guide for future workshops focused on other ecosystems, properties, species, or habitat types of relevance to WGFD or other agencies and decision makers.** Therefore, we have included blank versions of the worksheets (Appendix B) that could be used to help guide discussions during future workshops.

Summary of Results

Climate Change Impacts of Concern

Drawing on the climate change information shared during the Day 1 presentations and a worksheet that summarized future climate model projections (Table 1), workshop participants discussed the ecological consequences of those changes in climate for river, riparian, and wetland ecosystems. Future climate projections for the period 2040-2069 were summarized for each of the four focal geographies by Dr. Imtiaz Rangwala (University of Colorado-Boulder and the North Central Climate Adaptation Science Center), using climate model outputs downloaded from the ClimateToolbox (Table 1).

Climate projections vary slightly across the focal geographies, but all climate models that were examined for this workshop agree that Wyoming will be significantly hotter by 2040-2069 relative to the baseline period of 1971-2000 (Table 1). Warming is projected to occur across all seasons, with annual increases ranging from approximately +3^{0}F to +8^{0}F, depending on the climate model and assumptions about future greenhouse gas emissions. Associated with that warming will be an increase in the number of extremely hot days with heat index > 90^{0}F, a longer growing season, and more growing degree days. Precipitation projections are more complicated and therefore less certain. However, a majority of climate models project that annual, winter, and spring precipitation will increase. Some climate models project decreases in summertime precipitation, although model agreement is medium-to-low and varies across the four focal geographies. Future projections for snow water equivalent (SWE) on April 1st vary across the four geographies, with Yellowtail WHMA and Bear River watersheds likely to see declines, Spence Moriarty WMA likely to see increases, and greater uncertainty for the Horse Creek watershed. Evapotranspiration is likely to increase at all locations in the spring and summer, with the exception of the Horse Creek watershed which may see declines in evapotranspiration in summer. Soil moisture is notably difficult to predict using climate models, but the models considered tend to suggest that soil moisture will increase in the spring and decrease in summer and fall. Other climate changes of note include high confidence that there will be increases in the intensity of precipitation events, springtime flooding, and future droughts; in addition to a rise in the elevation of mountain snowlines.

Table 1. Summary of climate change projections for Yellowtail Wildlife Habitat Management Area[1] (climate change projections for other focal geographies can be found in Appendix C).

Climate/ Hydrological Variable	Future Projected Changes *2040-2069 relative to 1971-2000*			
	Range Across All Models & Emissions Scenarios	Mean for Moderate Emissions Scenario (RCP 4.5)	Mean for High Emissions Scenario (RCP 8.5)	Model Agreement[2]
Mean Temperature (°F)	Annual . . . . +3 to +8°F Winter. . . . . +3 to +8°F Spring. . . . . +3 to +8°F Summer . . . . . . +4 to +8°F Fall. . . . . +3 to +7°F	+4.6°F +4.5°F +4.5°F +4.9°F +4.3°F	+6.1°F +5.8°F +5.7°F +6.7°F +6.1°F	All models project increases
Days w/ Heat Index > 90°F *(2 days/year historically)*	Increase to a Total of 6 to 19 days/year	+9 days	+13 days	All models project increases
Precipitation (%)	Annual . . . . -2 to +15% Winter. . . . . 0 to +20% Spring. . . . . 0 to +25% Summer . . . . . -15 to +10% Fall. . . . . -5 to +20%	+6% +10% +13% -5% +8%	+9% +15% +16% -1% +9	High (+) High (+) High (+) Medium (-) Medium (+)
Growing season length (# days) *(historically 74 days)*	Longer growing seasons (+15 to +74 days longer)	+41 days	+52 days	All models project increases
Growing Degree Days (°F) *(historically 4200°F)*	Increase in growing degree days (Total of 4700°F to 6250°F)	5080°F	5780°F	All models project increases
April 1 Snow Water Equivalent (%)	Decreased SWE (-28% to -7%)	-14%	-19%	High (-)
Evapotranspiration (%)	Spring. . . . . . . +20 to +52% Summer . . . . . +2 to +10% Fall. . . . . +9 to +23%	+28% +5% +13%	+38% +6% +18%	High (+) High (+) High (+)
Soil Moisture (%)	Spring. . . . . +2 to +12% Summer . . . . . . -12 to -4% Fall. . . . . -11 to -5%	+6% -7% -7%	+8% -9% -8%	High (+) High (-) High (-)
Intensity of precipitation events	High confidence for increases in the intensity of precipitation events, particularly the hourly precipitation rate at 3-7% per 1°F warming.			
Flood frequency	High confidence for increases in springtime flooding (from increases in precipitation, increases in precipitation intensity, and rain on snow events).			
Drought	High confidence for increases in the intensity of future droughts; Propensity for increases in flash droughts (wet to dry in matter of weeks if there is a gap in precipitation).			
Mountain Snowline	High confidence it will move up. 250 ft upward shift for every 1oF warming.			

[1] Projected changes in climate and hydrological variables by 2040-2069 relative to 1971-2000 are obtained from the Climate Toolbox;
[2] Model agreement (an indicator of certainty level) = High (+) or High (-) (majority of models show increases or decreases); Medium (+) or Medium (-) (more than half the models show increases or decreases); Low (about equal number of models show increases or decreases).

After reviewing the future climate projections, workshop participants identified a range of climate change impacts of concern related to the following aspects of river, riparian, and wetland ecosystems (see Table 2 for details):

- Surface and groundwater availability (including quantity, quality, temperature, and timing),
- Physical stream conditions (including sedimentation and erosion),
- Aquatic habitat and species (including invasive aquatic species),
- Upland habitat and species (including invasive terrestrial species),
- Wetlands,
- Human water use (including irrigation)

With respect to hydrology, a common thread across the breakout groups surrounded the management implications of having to deal with both higher high flows and lower low flows, or greater fluctuations in stream flows across seasons and years. This also included challenges posed by larger and more frequent floods, and increasingly severe droughts. Biological impacts of concern to aquatic and terrestrial habitats include declines in some key habitats (e.g., for cold water fish such as cutthroat trout), shifts in species distributions (e.g., warmer water fish moving upstream, and vegetation communities shifting upland), increases in the presence and abundance of invasive species, and increases in toxic algal blooms.

Breakout groups identified increasing physical changes to stream channels as a concerning factor. Natural channel design approaches to stream restoration are based on understanding historic reference conditions created under a certain climatic regime. A changing climate, many participants pointed out, will result in increasing rates of channel adjustments and erosion, and may render historical reference conditions less relevant.

There was also a recognition that in addition to worrying about the direct effects of climate change on fish and wildlife and their habitats, it is also important to consider the "wild card" of how humans are responding to climate change. For example, climate changes will likely alter the timing and amount of water needed for irrigation, which could further limit water availability for fish, wildlife and plants. There was also a consistent recognition of the importance of coordinating with other stakeholders and decision makers in the landscape, since WGFD only has direct control over some aspects of these ecosystems, especially with respect to water management.

Table 2. Climate change impacts of concern to river, riparian, and wetland ecosystems in Wyoming (summary across all four geographic breakout groups)

Category	Climate Change Impacts
Surface- and ground-water (quantity, quality, temperature, timing)	• Precipitation is expected to increase, but timing and form of precipitation will affect timing and quantity of water availability and in-stream flows: - Higher high flows and lower low flows. - Changes in timing of floods. - Accelerated snowmelt and shifts in spring flooding result in earlier peak hydrograph and reduced amount of water during the summer. - Increase risk of streams going dry - Some reaches may go dry during base flow. - Increased precipitation could lead to higher base flows and lateral habitat connectivity. - More variability in flows, with impacts on seasonal habitat availability. • Increased evapotranspiration - Suggests the offsetting of any increases in precipitation and further stresses on reduced water supplies. • Change in flood recurrence interval will change bankfull discharge, with consequences for the design of stream restoration projects. • Increased water temperature may lead to eutrophic impacts or algal blooms in reservoirs. • Increased temperatures combined with potential increased nutrients from fine sediment, could lead to increases in harmful algal/cyanobacterial blooms on lakes. • Changes in groundwater recharge, especially for groundwater recharge that is influenced by evapotranspiration.

Physical stream conditions, sediment, erosion	• Physical changes to stream channel morphology: - Increased flooding could lead to more frequent channel migration. - More spring runoff leads to more scouring of streams and movement of banks/channels. - Channel adjustments and plant establishment out of sync could lead to instability. • Increased frequency of intense precipitation events could lead to: - Increase in overland erosion and fine sediment transport, scour, and deposition; leading to increased sedimentation in rivers, streams, deltas, reservoirs, and wetlands. - Stream bank erosion - places that are currently eroding will have even more pressure on the banks, riparian areas, etc. - Flooding • Loss of flood flows needed to transport sediment loads and promote stable channels. • Increased evaporation and possible increase in reservoir water level fluctuations could make soils increasingly saline.
Aquatic habitat and species (including invasive species)	• Changes in community composition and species distribution: - Warmer stream temperatures may allow other species to move in - including increased invasion by non-native fish (e.g., rainbow and brook trout), supplanting native fish or increasing hybridization risk (e.g., yellowstone cutthroat trout). - Lower base flows, warmer water temps, limiting Bonneville Cutthroat Trout habitat. - Yellowstone Cutthroat Trout may move upstream into currently fish-less streams. - Fish may need access to thermal refugia and connectivity for them to be able to access those refugia (e.g., cooler tributaries, streams with spring inputs, deeper pools, more shade). • Impacts on growth: - Longer growing seasons may allow for greater overall growth rate (especially for cold-limited species) and the ability to compensate for metabolically stressful periods (as long as warming isn't severe enough to result in mortality). - Reduced streamflows lead to increased density and lower growth of trout (drift feeders). - Lower base flows, particularly late summer/fall could lead to reduced fish abundance and biomass, and reduced recruitment. • Impacts on fish health and mortality: - Days with heat index >90 could be a potential trigger point for mortality, especially if combined with low flow and low oxygen levels. - Duration of temperature extremes are important - many fish species can handle stressors of warmer temps but not for long durations. - Increased susceptibility to disease (e.g. gill lice). • Loss of synchrony: - Biota are adapted to particular patterns of synchrony - With changes in timing and delivery of water, location of water availability, we expect a loss of synchrony -- but we don't know how to anticipate the real effects of this loss of synchrony. • Impacts on spawning: - Earlier spawning. - Increased sediment runoff, particularly in spring months, could negatively impact fish spawning and egg survival in riverine species above and below the dam. • Impacts from changes in water management (irrigation, diversions, reservoirs): - Increased potential for upstream irrigation dam and infrastructure failures that may degrade aquatic habitats. - Less flood irrigation could equate to less entrainment of fishes. - Reduced stream flows could lead to more instream manipulation for water withdrawal, and further reduced connectivity for fish and increased entrainment of fishes. - Source water temperature at diversions could be significantly increased due to irrigation return flows and warming/eutrophication, which could result in fish kills.

Upland habitat and species (including invasive species)	• Impacts to riparian vegetation: - Longer growing season could provide some benefits to plant growth, but less soil moisture, increased evaporation, and drought could decrease plant growth and degrade riparian areas. - Earlier snowmelt in the spring could affect reproduction of cottonwood and willows that are adapted to set seed and germinate later (Disrupted phenology). - Sediment transport could affect cottonwood recruitment. - Interaction of early season flooding and late season drought may negatively impact persistence of woody plants, leading to domination by herbaceous plants. • Impacts to upland habitats: - Upward elevation shifts in snowline could affect aspen recruitment and increase loss of aspen to conifers. - Drought and decreases in water in uplands will encourage congregations of wildlife (and possibly cattle), which could promote erosion. - Changes in the amount and quality of forage for ungulates. - Longer growing seasons and reduced upland vegetation production may lead to a greater reliance on irrigated meadows. • Increase in invasive species: - E.g., Cheatgrass and other undesirable annual grasses, tamarisk, Russian olive. - Earlier warm-up may allow for invasive annuals to get an even earlier start and foothold. - Warming will increase noxious weed treatments and require additional time to treat. - Greater uncertainty in water supply and potentially larger fluctuations in reservoir levels could result in opportunities for generalist riparian vegetation invasions. - Native junipers could outcompete riparian vegetation. - Consequences of increased invasive species include increased fire (especially with cheatgrass) and habitat loss. • Impacts to watershed function: - Increased flooding may blow out beaver dams. - Reduced summer soil moisture spells need for beefing up "sponges" via more intact wetlands, riparian plantings particularly in agricultural areas. • Changes in disturbances: - Longer and more intense fire season, higher fuel loads (due to increased vegetation growth from increased precipitation and longer growing season). - Increased grass density-combined with intensity of drought may lead to grass fires. - Changes in insects and diseases affecting plants (e.g., pine beetle). - Wet springs with hot dry summers may equate to increased grasshoppers. • Impacts to terrestrial wildlife: - Increase in very hot days could affect ungulates. - Upward shifts in snowline could lead to changes in use pattern for large carnivores (i.e., bears and moth sites) and ungulates (that are following spring green-up). - Increase in hot days and rapid rise and fall of ponds and reservoirs could lead to some wetland complexes drying out, placing stress on avian nesting and potential nest failures. - Increased growing season and growing degree days could shift the phenology of plants, leading to mismatched timing of pollination, insect abundance, and migrating wildlife (including birds).
Wetlands	• Loss of ability to flood irrigate could reduce wetlands. • Climate changes could lead to certain wetland complexes drying out. • Shallower wetlands and the loss of surface water in wetlands in late summer could lead to a lack of habitat or even sinks for waterfowl and amphibians. • Increases in fine sediment contributions could lead to wetland creation at reservoir margins.

Human water use (including irrigation)	• Increased water uses and changes in timing - Increased temperature, lower water availability, longer growing season, and increased aridity means greater demands for water, especially by agricultural water users but also for habitat management. - Need for irrigation earlier and later in season, and more often. - Changes in agricultural practices could lead to greater water demand - e.g., changes in crop type, longer growing season could increase potential for additional hay production or multiple crops in a season. • Impacts to water supply and changes in timing: - Reduced snow-water equivalent (SWE) could lead to reduced water availability for irrigation and wetland/pond complexes, having a negative impact on wildlife. - Decreased snow-water equivalent (SWE), declines in summer precipitation, and higher need for summer irrigation will lead to more frequent and longer duration of extreme low flows (e.g., flash droughts). - Loss of reliable streamflow may encourage more water storage developments (e.g., adding reservoirs, holding ponds), which could increase water temperatures or result in decreased in-stream flows. • Changes in agricultural practices: - Increased spring moisture could delay crops from being planted and increase flooding. - Unclear tradeoffs between flood irrigation (which has return flow benefits) vs. pivot irrigation (which is seen as more efficient but uses water in different ways). - Changing agricultural intensity or crop types will impact the availability (timing, quantity) of water for conservation • Human responses to climate change: - It is not just the direct effects of climate change, but the wild card of how humans are also responding to climate change (e.g., via different irrigation patterns, livestock patterns, human development patterns, etc). • Impacts to irrigation infrastructure: - Increased flooding could impact instream/inditch infrastructure. - Increased sedimentation could increase the need for maintenance of irrigation systems.

Climate Change Vulnerability of Watersheds and Wildlife Habitat Management Areas

Climate change vulnerability is often defined as a function of a species' or area's exposure to changes in climate conditions (EXPOSURE), the sensitivity to those changes (SENSITIVITY), and the ability to cope with or respond to those changes (ADAPTIVE CAPACITY). An assessment of the relative vulnerability of watersheds or wildlife habitat management areas to the impacts of a changing climate can help target habitat protection and restoration efforts. For example, areas of relatively high climate change vulnerability might be places where protection or restoration actions that reduce the exposure or sensitivity to climate change, or increase the adaptive capacity for coping with climate change impacts, may be necessary. Areas of relatively low climate change vulnerability might be places where proactive protection efforts could retain valued species or habitat characteristics that are currently found in those places, even as the climate changes.

Following an introductory presentation on core concepts of climate change vulnerability, workshop participants identified a wide range of factors that might make a watershed or wildlife habitat management area relatively more or less vulnerable to the impacts of a changing climate on river, riparian, and wetland ecosystems (see Appendix C for completed worksheets from each breakout session). Tables 3 and 4 summarize the potential measures of relative exposure, sensitivity, and adaptive capacity that were identified across all four breakout discussions. Table 3 captures vulnerability measures for watersheds; Table 4 captures vulnerability measures for wildlife habitat management areas (WHMAs).

Factors that could lead to relatively higher or lower **EXPOSURE** of watersheds or WHMAs to climate change included:

- **Rate and magnitude of projected changes in climate** - e.g., amount of warming, changes in precipitation (including the proportion of precipitation falling as rain vs. snow), changes in snow water equivalent (SWE), timing of water availability, frequency of drought, elevational shifts in the snowline.
- **Physical conditions** - e.g., geology, elevation, aspect, soils, watershed size.
- **Current ecological/hydrological conditions** - e.g., amount of reservoir shoreline that could be exposed to lake level fluctuations.
- **Current water management** - e.g., Areas where water management is already intense could have increased exposure to water limitations.
- **Changes in disturbances** - e.g., changes in pest outbreaks or wildfire regimes.

Factors that could lead to relatively higher or lower **SENSITIVITY** of watersheds or WHMAs to climate change included:

- **Distribution and abundance of sensitive species** - e.g., specialist species, species at the edge of their range, high vs. low diversity.
- **Physical conditions** - e.g., size and shape of watersheds, amount of watershed above or below future snowline.
- **Ecological conditions** - e.g., divergence from healthy condition, presence of invasive species, amount of vegetation cover.
- **Hydrological conditions** - e.g., presence of wetlands, level of floodplain connectivity, soil water holding capacity, % of streams that are perennial, intermittent, ephemeral, whether the watershed is glacier-, snow-, or rain-fed.

Factors that could lead to relatively higher or lower **ADAPTIVE CAPACITY** of watersheds or WHMAs to climate change included:

- **Ecological conditions** - e.g., presence or absence of beaver activity, presence of invasive species, genetic diversity, presence of refugia.
- **Physical conditions** - e.g., topographic and geological diversity, presence of microclimates, stream basin connectivity (longitudinal, vertical, lateral, and temporal), presence or absence of barriers to movement.
- **Water management** - e.g., ability to manage water resources (via irrigation, reservoir operations), availability of water rights for instream use.
- **Land ownership** - e.g., private versus public lands and the ability to do larger scale restoration efforts.
- **Support and resources** - e.g., funding and public support.

All of some of the exposure, sensitivity and adaptive capacity factors identified by workshop participants could be used to assess the relative climate change vulnerability of key properties or watersheds across the state. Ultimately, this information on climate change vulnerability could be included in habitat project designs when framing project goals and desired outcomes.

Table 3. Potential measures of exposure, sensitivity and adaptive capacity for WATERSHEDS across Wyoming

EXPOSURE	**SENSITIVITY**	**ADAPTIVE CAPACITY**
Exposure = The amount of change in climate experienced by a place or species. Higher Exposure = More Vulnerable	**Sensitivity** = The extent to which a species or place is affected by changes in climate. Higher Sensitivity = More Vulnerable	**Adaptive Capacity** = The ability of the landscape (or species) to cope with or respond to changes in climate. Lower Adaptive Capacity = More Vulnerable
Potential Measures of Exposure: • **Changes in temperature and precipitation:** - Watersheds that already receive more precipitation from rain rather than snow might be less exposed - Basins with a high percentage of area above future snowline will be less exposed to climate change. - Watersheds that are projected to experience a greater amount of warming are likely to be more vulnerable. • **Changes in timing of water inputs:** - Natural streamflow might be higher in fall/winter, lower in summer. Reaches receiving diverted water could be less vulnerable, pending changes in water use. • **Current water management:** - Areas where water management is already intense could have increased exposure of the area to water issues.	**Potential Measures of Sensitivity:** • **Distribution/abundance of sensitive species:** Watersheds that harbor sensitive species may be more sensitive/vulnerable: - Moose (b/c rely on riparian areas and are sensitive to warming) - Bluehead sucker (b/c they are currently constrained by barriers. - Migrating species with high fidelity to their routes (mule deer, cranes, etc.) - American Bittern (few options to move) - Foothill species (b/c they may be affected by lower elevation competitors/predators moving up, but they may not be able to migrate up into mountainous areas because physical conditions may not be suitable). - Areas with relatively more species - Areas with a high amount of the state's fish biodiversity will be relatively more vulnerable. - Fish species near the edge of their range may be pressured by temperature increases near their thermal tolerances. • **Physical conditions:** - Basins with lower elevation and smaller basins may be relatively more sensitive. - Long, narrow basins are more sensitive to flooding from high intensity rainfall events. - Basins with low percentage of watershed above current and future snowline are more sensitive to higher temperatures but less sensitive to reduced SWE (since they receive more inputs from rain than snow). • **Ecological/Hydrological conditions:** - Basins with fewer wetlands and lower soil water holding capacity are more sensitive to increased rainfall and droughts. - Basins with higher % of highly erodible soils and lower % of vegetative cover are more sensitive to high intensity rainfall. - Basins with fewer wetlands and less groundwater connection are more susceptible to extreme low flows due to reduced summer precipitation. - Amphibians may be more vulnerable to declines in areas with reduced floodplain connectivity and/or subsurface recharge. - Areas where water availability is relatively more secure and stable will be less sensitive/vulnerable.	**Potential Measures of Adaptive Capacity:** • **Ecological conditions:** - Watersheds that lack beaver or functioning riparian communities will have lower adaptive capacity and will lack water storage, aquifer recharge, temperature buffers and floodplain connectivity. - Amphibian habitat adaptive capacity may be reflected by historic trends in ephemeral aquatic habitats. - Current cheatgrass infestation in the area and surrounding areas = lower adaptive capacity, more vulnerable. • **Physical conditions:** - Streams/basins with more connectivity (longitudinal, vertical, lateral, and temporal) have greater adaptive capacity - Drainages with headwaters out of state or otherwise inaccessible=reduced ability to manage/meet interstate compact agreements - Local geology and its ties to the aquifer is a big driver in SE Wyoming - geological conditions could confer greater or lesser adaptive capacity. • **Water management:** - Areas with irrigation = higher adaptive capacity (b/c can manage water inputs to wetlands or other ecosystems). - Irrigation diversions reduce adaptive capacity. - Improved water irrigation practices could reduce return flows, resulting in less water in the creeks. - Proportion of flood versus pivot irrigation - Higher availability of water rights across sub basins = greater adaptive capacity - Areas with high urban water development via wells may have lower adaptive capacity. - Amount of multiple use across the area and potential limited management options. • **Human development:** - Level of human development - Lower development creates more opportunities for wildlife and ecosystems to adapt. • **Land ownership and management:** - Private versus public lands and the ability to do larger scale restoration efforts • **Support and resources:** - Public perception of management partners - Availability of funding

Table 4. Potential measures of exposure, sensitivity and adaptive capacity for WILDLIFE HABITAT MANAGEMENT AREAS (WHMAs) across Wyoming

EXPOSURE	SENSITIVITY	ADAPTIVE CAPACITY
Exposure = The amount of change in climate experienced by a place or species. Higher Exposure = More Vulnerable	**Sensitivity** = The extent to which a species or place is affected by changes in climate. Higher Sensitivity = More Vulnerable	**Adaptive Capacity** = The ability of the landscape (or species) to cope with or respond to changes in climate. Lower Adaptive Capacity = More Vulnerable
Potential Measures of Exposure: • **Physical conditions:** - General geology of area (e.g., that contribute to natural lakes (slope)) - Elevation of WHMA - Elevational gradient within the watershed - Aspect - Geo-hydrology and watershed area size for potential recharge - Soil texture - Is it a closed watershed or open? (ability to recharge; some only snowpack dependent) • **Future temperature/precipitation conditions:** - Magnitude of change in SWE - Magnitude of change in precipitation - Frequency of drought - Proportion of precipitation falling as rain versus snow • **Changes in disturbances:** - Expected changes in disturbances such as bark beetle outbreaks, wildfire - Increased frequency of high-concentration sedimentation events in the rivers and at confluence areas of the reservoir - Longer growing seasons, more fuel for wildfires/ increased fire intervals • **Ecological/Hydrological Conditions:** - Places with more open water may experience greater exposure to changes in river ice formation - Reservoir shoreline areas and backwater zones in rivers may be exposed to increased variability in wetting-drying along from lake level fluctuations.	**Potential Measures of Sensitivity:** • **Distribution/Abundance of Sensitive Species:** - Occurrence/abundance of generalist vs. specialist species - Number or conservation rank of species experiencing conditions exceeding physiological limits - Public sensitivity about numbers of species managed in the area (economic importance) • **Ecological Conditions:** - NDVI change (i.e., drought resilience of plant communities) - Vegetation communities - current place in state and transition models (Prioritize work based on how much effort would be necessary to maintain or reverse a community) - Presence/abundance of invasive species and non-natives - Divergence from proper functioning vegetative community - Native riparian vegetation species are more sensitive to big/sudden fluctuations in water levels relative to generalist/invasive species. - Presence or susceptibility to invasive annual grasses that will change susceptibility to fire • **Hydrological Conditions:** - % of streams that are perennial, intermittent, ephemeral - Hydroperiod for wetlands (% makeup) - Water source (e.g., glacier melt, snow melt, rain-fed) - Water budget - the amount of water held on the landscape - Degree of stream incision/ connectivity to floodplain	**Potential Measures of Adaptive Capacity:** • **Ecological Conditions:** - %, density, diversity of noxious weeds present - Canopy density/cover (& how that might influence infiltration) - Age class diversity - Presence of variable sites/niches for refuge from extreme events. - Genetic diversity / isolated populations • **Physical conditions:** - WHMAs with greater topographic variability can provide more microclimates - Presence of water features (rivers/wetlands) - Conservation potential for beaver & dam building limitations - Barriers to movement to reach suitable niches during extreme events - % of stream connectivity • **Water management:** - % total water tied up in water rights - WHMA's with more and senior water rights held by WGFC have greater adaptive capacity - Reservoir operations could be used to increase adaptive capacity by helping add water during droughts, and keeping water cooler during hot periods • **Land ownership and management:** - Land ownership (fragmentation) - WHMAs with high road densities have lower adaptive capacity (are more vulnerable) because there are barriers to species' ability to track optimal conditions as climate changes - Mineral rights ownership/exploitability of sub-surface minerals - WHMAs with, or adjacent to, irrigation districts and agricultural activities will likely be less able to adapt given the increase in mono-culture habitats

What's Different About "Climate-Informed" Management Strategies and Actions?

Building off of discussions about climate change impacts and vulnerabilities, workshop participants tackled the question: ***"What, if anything, might we need to do differently about our work to be effective in light of expected climate changes and impacts?"***

To support this discussion, participants were introduced to two core concepts related to planning climate-informed management goals and actions. First, Dr. Frank Rahel presented the Resist-Accept-Direct (RAD) framework (Thompson et al. 2020) for determining management goals in the context of a changing climate. The RAD Framework encourages managers to be intentional about how their goals relate to changes brought about by climate change. **Resisting** change involves taking actions to try and maintain ecosystems at a historical baseline. **Accepting** change acknowledges that some changes cannot be fully resisted and may even be acceptable to stakeholders; therefore, managers can accept or allow those changes to happen. **Directing** change is a more proactive approach to shaping ecosystem changes towards a new state, and may be appropriate or even necessary when changes are so dramatic that resisting is untenable and there is a feasible opportunity to steward changes towards a more desirable outcome.

Next, Dr. Molly Cross shared examples of how conservation practitioners are already starting to modify their conservation approaches to be more successful in a changing climate, by altering the design of their actions (WHAT), the locations where they are working (WHERE), the timing and urgency of their approaches (WHEN), and the goals for which they are striving (WHY). These "4 W's" offer useful prompts for a discussion about what, if anything, might need to be different about the agency's conservation and management work. Although not all conservation projects need to be modified in the What, Where, When and Why in order to be effective in a changing climate, it is important to take time to pause and ask these questions to ensure that the agency's work is as effective as possible.

Participants were divided into four breakout groups, each of which focused on one of the following management strategies that are common to WGFD's work:

- Riparian habitat protection and restoration
- Stream restoration
- Fish passage and stream connectivity
- Water management

Each breakout group discussed whether and how their assigned strategy -- and the actions undertaken to achieve that strategy -- might need to be modified in terms of the What, Where, When, and Why, in order to be effective in a changing climate (See Appendix C for completed worksheets from breakout discussions). Below, we summarize aspects of WGFD's habitat protection and enhancement work that might need to be modified to increase its effectiveness, and examples of strategies that may not necessarily need to be different, but which were flagged as being particularly important or urgent to address climate change impacts.

Climate-Informed Modifications to Current Practices:

- **Design projects under the assumption of increasing likelihood of higher high flows, lower low flows, and more frequent extreme flood events, rather than historic or current hydrological conditions.**

  As flows become more variable, it may not be adequate to use historic or current hydrological conditions as a benchmark for designing or retrofitting water-related infrastructure such as culverts, road crossings, irrigation diversions, and fish screens. These structures will be more effective if they proactively take into account future hydrological dynamics. The potential for more frequent, larger floods also could be incorporated into stream restoration designs, such as using larger woody materials that can withstand higher stream power. Increased flow variability, including more frequent extremely low flows, could be addressed using multi-level stream beds that provide a core channel that will have water even during very dry conditions.

- **Use plant species or genetic stock that is more likely to thrive under future climate conditions in restoration projects.**

  Changing climate conditions may make some areas no longer suitable for plant species that have thrived there in the past. Shifting the selection of plant species or genetic stocks towards those that are expected to be well-suited to future climate conditions is one strategy that could be used to improve the effectiveness of planting projects in riparian or wetland ecosystems. For example, managers could shift to sourcing willows for bank stabilization projects from warmer locations, or planting drought-tolerant native species when restoring riparian habitats.

- **Craft restoration and connectivity projects with future species' ranges and habitat conditions in mind.**

  As climate change causes some currently occupied areas to become unsuitable and improves the suitability of habitats in other areas, plants and animals will need to be able to move and shift their ranges in response. Habitat protection and enhancement efforts will therefore be more effective if they are designed to provide access to a variety of habitats that are likely to remain or become suitable in the future.

For example, this could include evaluating the effects of climate change on planned native fish restoration projects to identify stream reaches that may become available to those fish in the future (but which are not suitable today), and reaches where projects could fail due to changes that cannot be prevented. This information could also influence fish passage work, to focus on removing barriers in places where vulnerable fish populations will need to move in response to climate change, and installing barriers in places where climate change might facilitate the expansion of non-native aquatic species. Another example includes prioritizing riparian restoration projects in areas that are likely to retain perennial flows under future climate scenarios to ensure long-term vegetation growth.

Projects focused on amphibian habitat could be designed and planned with an eye toward climate change induced long-term and seasonal water shortages. These enhancements could address expected drought and evapotranspiration rates by creating deeper pools, for example, to maintain water through the breeding season. Wetland networks could also be emphasized to ensure connectivity as existing wetlands become increasingly dry.

- **Take climate change into account when prioritizing projects and articulating project goals.**

  Many factors go into decisions about which projects to prioritize to receive funding, capacity, and other resources. Climate change can be one of those considerations. For example, the agency could consider prioritizing areas for projects that are more likely to be resilient to climate changes and provide climate adaptation benefits to numerous species. Or the priority might be placed on river, riparian and wetland habitats where climate impacts are most immediate, or that house species of concern that are vulnerable to a changing climate.

  It may also be necessary to assess the feasibility of current project goals in light of climate change, and determine when to adopt goals related to Resisting, Accepting, or Directing climate-related changes. Although it may be possible to resist some climate changes and impacts in some places and times, it is likely that habitat management will also need to consider when and where to accept or even direct some climate-driven changes. For example, with the management of invasive species, it may be helpful to prioritize treatment areas based on whether climate models predict that those invasive species will increase or decrease in a changing climate. Invasive species control efforts could then be targeted at areas where there is a higher potential for success.

- **Increase flexibility around water management and habitat restoration to address new problems that will need new solutions.**

  As the climate changes, new and unanticipated problems and opportunities for fish and wildlife habitat management may unfold. Agencies such as WGFD would therefore benefit from increased flexibility to deal with those emerging challenges and opportunities. For example, legislative and policy issues around water management could be modified to provide more flexibility in how water resources are managed for the benefit of fish, wildlife and habitats as climate change alters water availability and timing. Increasing staff expertise and attention to water legislation and policy will allow the Department to be proactive.

Strategies and Actions With Increased Priority and/or Urgency:

- **Increased importance of retaining and conserving water.**

  Climate change is expected to have significant impacts on hydrology across the state, including increasing drought frequency, changing seasonal water availability in snowpack driven systems, increasing temperatures and evapotranspiration, and increased competition from other water users due to reduced supply. These changes add urgency and priority to strategies that the agency is already engaged in to increase natural water storage and improve the efficiency of water use for habitat enhancement and protection projects. This includes expanding water retention through natural and man-made practices that serve to raise the water table, encourage floodplain connectivity, and recharge shallow aquifers, such as translocating beaver or constructing beaver dam analogs, retention ponds, and other process-based restoration approaches. To address climate change concerns, these actions will need to be implemented at a larger scale and in new locations within watersheds, including upland meadows and within water irrigation systems to catch and save runoff. It could also include locating wetlands and flood irrigation in recharge areas (to increase aquifer recharge), and increasing irrigation-related water savings via more efficient techniques.

- **Increased importance of securing and managing water rights.**

  The WGF Commission holds 1076 water rights on its various properties for maintaining and enhancing fishery and wildlife populations. These include irrigation rights for producing wildlife forage; diversionary and storage rights to sustain wetlands and ponds; storage rights in reservoirs to sustain sport fisheries; and negotiated agreements to protect water storage and provide environmental flow releases. In addition, WGFD identifies important fisheries for instream flow water rights and identifies flow levels needed to maintain or improve those fisheries. Currently there are over 250 stream miles protected with instream flow water rights. With increased pressure on changing water supplies, it will become increasingly important to maintain the validity of existing water rights by surveillance of competing users and asserting WGFD rights through proper State Engineer's Office procedures. It will likewise be increasingly important to pursue additional water rights to protect and sustain fishery and wildlife resources. Climate-driven changes in agricultural intensity may create new opportunities for the state to secure additional water rights, which could be used to augment flows during dry periods or in areas where water availability decreases. The purchase of additional water rights could give the WGFD more certainty and control, and create opportunities for using water rights in new and creative ways to support wildlife conservation as the climate changes.

- **Increased importance of riparian restoration and protection.**

  Improving riparian habitat for wildlife connectivity via management of grazing, fencing, and riparian restoration is already a high priority for WGFD, but it becomes increasingly important as species need even greater opportunities for movement to track changing climate conditions. For example, ungulates may display greater riparian zone dependency if upland habitats dry out and become less desirable. Aquatic and terrestrial species may also need to move further upstream and upslope to track changing climate and habitat conditions.

- **Greater urgency for landscape-scale conservation and management.**

  Although not new to habitat management, thinking about and investing in conservation at a landscape scale is critical to addressing climate change impacts and helping species adapt. For example, keeping floodplains connected and functioning properly, especially with respect to aquifer recharge and sustaining later season return flows will be essential to addressing hydrological changes at a watershed scale. A focus on increasing connectivity at a larger watershed scale could create opportunities for large-scale climate-driven movements as habitat suitability changes. Maintaining or enhancing networks of wetlands will be important to providing connectivity for and maintaining populations of wetland-dependent species and hedge against local drying across seasons and years.

Priority Climate-Informed Actions for the Statewide Habitat Plan

Workshop participants were asked to identify climate-informed actions that could be included in the 2020 SHP revision, for each of the four focal geographies. Across all four breakout groups, over 75 habitat management actions were identified to help address climate change impacts on river, riparian, and wetland habitats in Wyoming. These actions ranged from managing land and water use with an eye towards future conditions; building watershed health and resilience to a changing climate; maintaining species diversity and habitat needs in a changing climate; making climate-informed decisions about angling, trapping, and setting goals for habitat management areas; prioritizing habitat management efforts using a climate change lens; and establishing and implementing monitoring methods and protocols that can help to anticipate changes and set climate-informed priorities (Table 5).

There was a great deal of emphasis on actions relating to water availability and use. Nearly 20% of the identified actions related to water rights, water storage, water management, and irrigation.

Table 5. Climate-informed actions to consider for the 2020 WGFD Statewide Habitat Plan.

Category	Sub-category	Example Actions
Land & Water Use	**Grazing**	Work with permittees and agencies on grazing management to build the resilience of vegetation.
		Develop grazing plans that can adapt to potential climate impacts.
		Explore vegetation management actions aimed at benefiting terrestrial species in a changing climate (with residual effects on aquatic species).
		Explore strategies (e.g., riparian fencing) to exclude trespass cattle from riparian areas to maximize riparian function and resilience.
		Develop strategies to market conservation practices to landowners - Potentially use wildlife species (turkey, whitetail deer, pheasant) instead of native non-game fish, to sell work.
		Monitor changes in vegetation species composition on winter ranges to ensure forage availability for wintering wildlife.
	Habitat Easements and Water Rights	Purchase unused or additional water rights.
		Long term "habitat easements" for riparian corridors, similar to a conservation easement, but just for a specific habitat that would protect and enhance a riparian area for long term. Farm Service Agency has the CCRP (Continuous Conservation Reserve Program) program that is similar, but the longest an easement can last is 15 years. Ideally, we would like to extend the length of this program.
		Incentivize habitat improvements with private landowners.
		Find private landowner champions to highlight projects.
		Lean on partners (Conservation Districts, USFWS, NRCS) to take an active role in habitat improvements.
		Sell unused water rights.
		Changing agricultural intensity may allow the state to buy more water rights, which could be used to augment flows during critical periods. By buying water rights we have more certainty and control. How can we use our water rights in new and creative ways to support wildlife conservation?
	Irrigation	Private landowner incentive programs for dry-land agriculture to reduce water use.
		USDA programs for stream course buffers in cropland areas (with WGFD Trust fund or other to cost share on practices).
		Assess irrigation technology (flood/pivot/sprinkler) for best use given climate change ramifications.
		Consider that flood irrigation can contribute to higher stream temperatures from return flows. Could switch to pivot irrigation lower in the watershed and store more water (by beaver, etc.) higher in the watershed to keep water temperature lower throughout the stream. Manage return water in efforts to reduce temperature increases and maximize total system function, i.e return to river/riparian/wetland as soon as applicable.
		If applicable, switching from flood irrigation to pivot or other more water-efficient methods (although see other points about need to better understand full water cycle implications of different irrigation technologies).
		WGFD system capacity is currently less than our water rights. Look forward to potential flow regime changes to ensure that our infrastructure can capture water rights.
	Partnerships	Partner with and support groups that encourage smart growth and the retention of agricultural open lands, and control the growth of subdivisions.
		Be aware of and use agency programs (NRCS/ Farm Bill) to incentivize and facilitate water and wetland and riparian improvements.
		Enhance capacity to track water management opportunities and engage with State Agencies and legislature to promote Department water use and rights.
	Water Management Plan	Work on water management plan to determine if WGFD can use Bump Sullivan water shares for instream flows, wetland maintenance, fish production, pheasant production, etc. Assess water use requirements / needs of landscape or drainage (crop, range, instream flow needs, wetlands, stock reservoirs, irrigation storage reservoirs). Identify senior water rights users & subdivisions & impacts for water management regimes.

Watershed Health & Resilience	**Water-Holding Capacity/Flood & Drought Resilience**	Develop wet meadows and beaver complexes to increase water holding capacity on the landscape (and hopefully increase water delivery).
		Riparian vegetation management actions aimed at benefiting terrestrial species (with residual effects on aquatic species).
		Keep water in headwaters longer using natural approaches like beaver, BDA's, small rock dams, and other Zeedyk structures.
		Riparian Restoration - maintain high water table and cottonwood gallery through beavers, beaver dam analogs, and wetlands.
		Create staged channels to better accommodate higher high flows and lower low flows.
	Floodplain Connectivity	Enhance and maintain floodplain connectivity on Shoshone and Big Horn Rivers - e.g., ice jams have removed dikes allowing oxbow connectivity.
		Emphasize floodplain reconnection with stream restoration to reduce future impacts of flooding.
		Improve stream channel function where necessary to increase floodplain connectivity.
	Sedimentation & Erosion	Protection and improvement of irrigation diversion and infrastructure.
		Yellowtail WHM- specific: Evaluate if upgrades to irrigation equipment/practices are required to reduce flooding, sedimentation.
		Consider diversion designs and management that would limit sediment from entering the systems due to changing flood regime.
		Remove unnecessary/unused 2-tracks.
		Implement overland erosion control measures.
		Beaver dam analog and willow-planting in erosion-prone areas; upland planting to hold soil together.
		Explore expanded use of drought-tolerant native plants.
		Identify management options/projects that would positively impact downstream systems (e.g., aspen restoration).
	Water Temperature	Enhance spring creeks as potential cool water refugia and reconnect these systems.
		Plant woody species for stream shading.
		Manage return water in efforts to reduce temperature increases and maximize total system function, i.e., return to river/riparian/wetland as soon as applicable (also noted above under irrigation strategies).
Maintain Species Diversity	**Genetic Assessment**	Range-wide genetic assessment of Yellowstone cutthroat trout to determine genetic variation/uniqueness of East Fork population.
		Research feasibility of genetic manipulation to help fish species adapt to predicted climate conditions, such as warming water.
	Manage Invasive Species	Inventory of invasive plant and animal species, and development of treatment plans. Consider downstream/upstream management for success in both aquatic and terrestrial invasion control.
		Rapid response to new invasive species.
	Assess Species-Specific Climate Vulnerability and Refugia	Species-specific climate-vulnerability assessments.
		Exploration of climate refugia, even outside of historic ranges (i.e., for imperiled species) that may serve as key source populations and allow for other limitations to be addressed.
	Manage Movement	Barriers - Construct barriers now that will prevent upstream movement of undesirable non-native species. Barrier(s) can prevent future interactions with species of conservation need (SGCN) that may be able to persist further upstream following climate change.
		Improve fish passage for SGCN by removing barriers and/or constructing fish ways at strategic locations that will allow movement currently and in the future to areas that may have suitable conditions (temperature and streamflow) following climate change.
		Connectivity-focused stream restoration for Great Basin fishes.
		Translocation - Future translocations of desired fishes to areas with suitable conditions.
		Active transition of community composition/sportfish to better adapted and preferred species.
		Identify strains of fish permitted to be stocked that are possibly more adapted to warming water temperatures

Game & Fish Management	**Angling**	Angling closures related to water temp and flow conditions.
	Trapping	Close areas to beaver trapping/change trapping regulations. Enact monitoring.
	WHMA management objectives	Conduct an exercise to see if management objectives of WHMAs would change based on climate projections.
Prioritizing Work/ Priority Designations	**Large-Scale Projects**	Emphasize watershed-scale work - prioritize more extensive work in fewer drainages.
	Climate Vulnerability, Resilience, and Risks	Develop an approach to identify vulnerabilities of landscapes, riverscapes, and species -- use to prioritize areas for protection & restoration.
		Develop a database of species-specific tolerances (aka climate vulnerability).
		Inventory of water temperatures by watershed and prioritize management based on species-specific tolerances.
		Identify places with higher risk of future flooding to prioritize floodplain reconnection with stream restoration to reduce impacts.
		Conduct widespread habitat assessments to determine riparian resiliency and appropriate diversity of habitats within the system (incorporate climate vulnerability into habitat assessments which are already conducted).
	Triage	Consider sacrifice areas where current conditions are very poor (e.g., Bear River wetlands near Cokeville).
	Stream Connectivity	Select sites that may be appropriate for construction of barriers now, that will prevent upstream movement of non-native species that are undesirable. This barrier(s) can prevent future interactions with SGCN that may be able to persist further upstream following climate change.
		Use predicted future instream habitat conditions to prioritize fish passage projects.
	Partnerships	Use remote sensing to prioritize areas and landowners to work with (& monitor changes).
	Beaver-Related Projects	Explore tributary drainages for suitable habitat to reintroduce beaver. Emphasis on identifying locations; include all headwaters.
		When transplanting beaver to areas for increased water storage, aquifer recharge and floodplain connectivity, consider the watershed's vulnerability to climate change.
		Facilitate the development of a working Beaver Restoration Assessment Tool (BRAT) model based on useful Landfire and NHD Plus data.
	Water Management	Use flow, temperature, and wetland resiliencies and importance to multiple species groups to help prioritize stream segments for instream flow water rights studies.
		Given predictions related to water shortages/drought, use monitoring data to identify need for and prioritize water management actions.
	Riparian and Stream Restoration	Use predicted future water temperature to identify stream courses and prioritize where to plant woody species for stream shading. Will also contribute to bank stability and prevent further downcutting.
Methods and Protocols	**Baseline conditions**	Find reference reaches (both terrestrial and riparian) to base future habitat improvements on.
	Aquatic monitoring	Streamflow & wetlands monitoring. Continue, increase. Include monitoring of inflows, evapotranspiration, water extents, etc. Use of remote sensing, in-situ equipment. Collect data to build on past flow monitoring to track significant changes in timing/amount/use. Determine, recommend minimum. Help understand local processes in light of predictions.
	Vegetation monitoring	Monitor changes in vegetation species composition on winter ranges to ensure forage availability for wintering wildlife.
	Large-scale monitoring	Develop novel ways of conducting large scale monitoring efforts efficiently (remote sensing, drones, loggers). Consider less monitoring in some cases.
	Design and Construction	New parameters for design criteria (e.g., design fish passage/culverts, irrigation infrastructure, stream restoration, etc. for floods that will be larger than typical).

Information and Research Gaps

The final session of the workshop was dedicated to gathering participants' input on: ***What does the Agency need to know in order to make better climate-informed decisions in the next 5 years?*** In response, participants identified a large number of research questions, data products, and inventories that could help support climate-informed management decisions for river, riparian and wetland habitats. Workshop organizers combined similar topics from this discussion into a refined list of 44 information needs related to several themes, including: riparian and wetland ecosystems; aquatic habitat and fisheries; beaver and other process-based restoration approaches; assessments of climate change vulnerability, refugia, and prioritization/planning; invasive species; fish passage and stream connectivity; hydrology and water balance; stream restoration; water management; and baseline data and monitoring (Appendix D).

After the workshop, we solicited input on which of the identified information needs are considered most useful by WGFD staff. We gathered this input via an online survey that was sent to all WGFD staff. The survey asked respondents to indicate how useful each of the 44 identified information needs would be to their ability to consider climate change effects in their work on river, riparian, and wetland habitats (using a scale of "Not At All Useful" to "Very Useful"). We also asked for additional details about those information needs that were flagged as "Very Useful", and an indication of how that information would be used in management decisions. Overall, 28 WGFD staff completed the information needs survey, representing a range of disciplines and departments within the agency (Figure 2). Most of the survey responses came from workshop participants (57%), although some WGFD staff that did not attend the workshop also chose to complete the survey (43%).

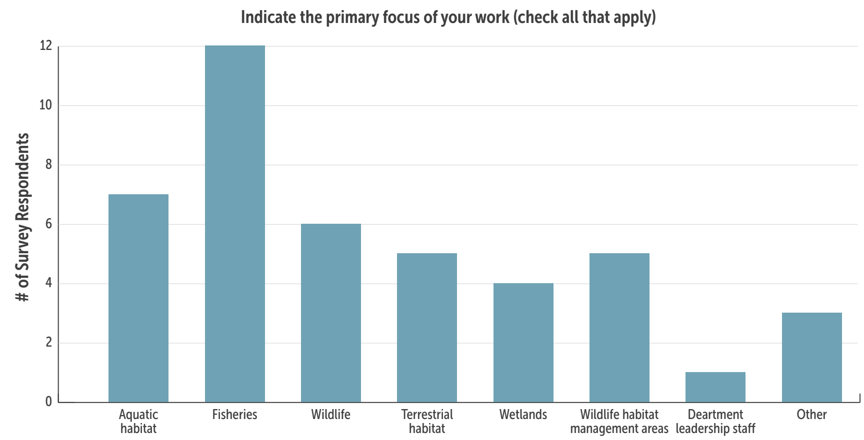

Figure 2. Primary focus of respondents to the Information Needs survey (total of 28 respondents).

Each of the 44 information needs had at least one survey respondent indicate that it would be "Very Useful" to their work; however, there were some information needs that were more consistently identified as being useful to WGFD staff (Figure 3). Eight (8) information needs were especially highly rated as being useful to climate-informed habitat management efforts, with over 60% of survey respondents indicating that they were "Useful" or "Very Useful" (Table 6, Tier I information needs). These include efforts to identify important places for habitat management actions, such as streams that may become more (or less) suitable for particular fish species under a changing climate, or areas of "climate refugia" for imperiled species. They also include research designed to support our understanding of the effects of particular climate-informed management actions, such as the influence of process-based restoration approaches on water availability for downstream users, or how upland habitat treatments affect watershed hydrology under more intense precipitation events, or what are the tradeoffs and benefits of different water management approaches (e.g., flood vs. pivot irrigation, or managing water for instream vs. out-of-stream habitats) in a changing climate. Lastly, they include information needs related to invasive species, such as which invasive species might be expected to increase or arrive in Wyoming as the climate changes, and what are the best management strategies for disadvantaging invasive plant and fish species.

An additional twelve (12) information needs were considered to be "Useful" or "Very Useful" to between 50-60% of survey respondents (see Table 6, Tier II information needs). All of the information needs identified during the April 2020 workshop are included in Figure 3 and spelled out in greater detail in Appendix D. Appendix D also includes survey responses on how respondents anticipate using the information in their work, and five additional information needs that were not discussed at the workshop, but which were identified by respondents as being "Very Useful" to their work.

One overarching recommendation provided by a survey respondent was that WGFD should consider building the human capacity needed to coordinate climate-related research, analysis, and data management. Even if research is conducted in partnership with other entities, WGFD would likely benefit from a coordinator with quantitative expertise to be able to see the big picture, direct all these efforts into usable information, and manage climate-related datasets.

All of these results on information needs will be shared with climate researchers in the region, including those affiliated with the North Central Climate Adaptation Science Center (NC-CASC). One of the goals of the NC-CASC is to foster applied climate research in support of natural resource management and decision-making. The decision-relevant information needs identified through this workshop will therefore be useful inputs to the NC-CASC's evolving Strategic Science Plan.

Figure 3. Usefulness of each information need identified at the 2020 WGFD Climate Change Workshop. Most information needs received a total of 28 responses, except for information needs #9-14, #22, #28-31, which each received 27 responses. More detailed descriptions of the information needs and ranking results can be found in Appendix D. A double asterix (**) indicates information needs that were deemed "Useful" or "Very Useful" by ≥60% of respondents; a single asterix (*) indicates information needs that were deemed "Useful" or "Very Useful" by 50-60% of respondents.

Table 6. Information needs perceived as most useful to considering climate change effects on Wyoming Game and Fish Department work on river, riparian, and wetland habitats

Tier I: Information Needs with ≥60% "Useful" or "Very Useful" Responses	Tier II: Information Needs with 50-60% "Useful" or "Very Useful" Responses
Beaver and other process-based restoration approaches: • Determine how process-based restoration approaches (e.g., beaver dam analogs, beaver, Zeedyk structures, etc.) affect the timing and quantity of water delivered to downstream water rights holders. **Aquatic habitat and fisheries:** • Develop fish habitat models that incorporate climate variables into stream suitability/vulnerability analyses for species and assemblages; Identify streams that could become suitable under future climate scenarios. **Climate refugia, prioritization, and planning:** • Identify climate refugia (within and outside of historic range) for imperiled species that may serve as key source populations and allow habitat limitations to be addressed. **Invasive species:** • Determine which invasive species we might expect to see that are not yet in Wyoming. • Identify management or habitat actions that disadvantage invasive fish and plant species. **Hydrology and water balance:** • Understand how upland habitat treatments (juniper removal, sagebrush mowing, etc.) link to water release into the watershed and system impacts with more intense precipitation events. **Water management:** • Develop a better understanding and examples of tradeoffs for water use and wildlife benefits for flood versus pivot irrigation. • Analyze tradeoffs between managing water use for instream vs. out-of-stream habitats (e.g., wetlands) (i.e., determine habitat and ecosystem function gains and losses per cfs).	**Riparian & wetland ecosystems:** • Investigate how different amounts of change in climate would lead to changes in a resource of interest (e.g., wetland area fluctuations in response to changes in precipitation). **Beaver and other process-based restoration approaches:** • Determine how process-based restoration approaches (e.g., beaver dam analogs, beaver, Zeedyk structures, etc.) affect shallow alluvial aquifers and riparian areas. • Assess beaver translocation success or failure to determine what drives survival and establishment of colonies, and understand spatial variability. **Aquatic habitat & fisheries:** • Develop an inventory of water temperatures by watershed and prioritize management based on species-specific tolerances. **Climate refugia, prioritization, and planning:** • Identify potential translocation sites for species of conservation concern that consider future climate conditions not just current climate conditions. • Develop a standardized, systematic protocol for evaluating and prioritizing watersheds for protection and restoration as related to climate change, that considers both aquatic and terrestrial needs. • Analyze management objectives of Wildlife Habitat Management Areas (WHMAs) relative to climate change predictions. **Climate change vulnerability assessments:** • Develop a database of species-specific tolerances of changes in climate. **Invasive species:** • Analyze the existing and potential future location of barriers in key watersheds relative to keeping native and non-native fish species apart. **Fish passage and stream connectivity:** • Develop or adjust design criteria for fish passage structures and culverts to account for larger floods and lower base flows. **Stream restoration:** • Identify places with higher future risk of flooding to prioritize floodplain reconnection with stream restoration to reduce impacts. • Predict future bankfull discharge and sediment transport resulting from increased peak flows and precipitation intensity, for use in stream restoration design.

Post-Workshop Evaluation

We asked participants to complete a post-workshop evaluation survey indicating how the workshop affected their knowledge, familiarity, and comfort with considering climate change impacts in their work. The survey illustrated several ways that the workshop was successful in advancing WGFD staff's ability to consider climate change in their work. Of the 35 WGFD staff that completed the survey, over 85% indicated that as a result of the workshop they:

- Gained new knowledge about climate change projections and impacts.
- Felt more comfortable integrating climate change information into their work.
- Felt more familiar with approaches and tools for climate-informed conservation planning, and climate change adaptation strategies and actions relevant to their work.
- Learned about new materials, tools, and resources that they can use to improve their understanding of climate change and impacts.

Approximately half of respondents said that they "met" new individuals with whom they will likely develop or share information about climate science in the future.

Nest Steps

The April 2020 Climate Change Workshop represented a valuable step in advancing WGFD staff's consideration of climate change in their habitat management work. Next steps to apply and build on the discussions at the workshop include:

- Incorporate climate-informed habitat management strategies into the 2020 Statewide Habitat Plan revision.
- Share this report within WGFD via a dedicated webpage, and formal and informal presentations.
- Present a summary of workshop discussions and products to the Wyoming Game and Fish Commission.
- Consider organizing similar climate change discussions within WGFD focused on additional regions, ecosystem types, or WGFD programs (if appropriate, using worksheets from this workshop to guide discussions - see Appendix C).
- Share the identified information needs with climate researchers in the region, and explore targeted research partnerships to address some of the high priority information needs identified by WGFD staff.
- Share methods and results from this project with other natural resource managers interested in making climate-informed management decisions.

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Appendix A - Workshop Agenda & Participant List

Appendix B - Blank Climate Change Planning Worksheets

Appendix C - Completed Worksheets

Appendix D - Detailed Information Needs