Bighorn River Alliance
The Research Initiative
Plans and Priorities

Final Report
August 18, 2018

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1.0 Introduction

The Bighorn River Alliance (BHRA) Research Committee recognizes that the health of the Bighorn River fishery is dependent upon the ecological integrity of the entire river corridor.[1] To better understand how the Bighorn River ecosystem responds to natural and human factors, more needs to be known about the biology (aquatic and terrestrial plant and animal life), hydrology, water quality, and channel geomorphology of the river. The BHRA Research Committee initiated the development of the Research Initiative (RI) based upon the understanding that a quality interdisciplinary information base is critical to the BHRA in meeting its stewardship objectives in the areas of policy, projects and education. There are important questions about the ecosystem that have not been fully answered with respect to those objectives. To that end, the topics we intend to address include the following:

- Effect of flows including their frequency, duration and amplitude.
- Processes responsible for the frequency, extent, and duration of turbidity.
- Effects of irrigation diversions, irrigation returns, and tributaries.
- Influences on fish condition and recruitment.
- Trends in the economic importance of river-related activity to the regional economy.
- Identification of river uses and land use practices dependent upon the Bighorn River.
- Cultural significance of the Bighorn River to the Crow Nation.
- Forces responsible for channel migration and bank erosion.
- Trends in the warm water/cold water fishery interface.
- Effects of recreational pressure on the Bighorn River fishery and what can be done to improve the fishery.
- Identification, distribution and trends of aquatic grasses and algae.
- Effects of Yellowtail Dam operating procedures on river processes.
- Potential effects of climate change.
- Identification, distribution, and extent of aquatic and terrestrial invasive species in and along the Bighorn River.
- Bighorn Lake sedimentation.
- Coordination of Montana BOR and Wyoming BOR dam operations.
- Forces responsible for trends in water quality including temperature, dissolved oxygen, nitrogen, phosphorous, selenium, and others.

This list is not complete and perhaps other important topics are yet to be identified. The overall objective of this initiative is to outline a program of monitoring and analysis that will address both the issues on the table now and unanticipated issues that will arise in the future. Ultimately, our collective success in addressing these issues will depend on the quality of information used to better understand the system's operation and function.

The RI is organized around seven research categories: socioeconomic considerations, spatial information, hydrology, geomorphology, terrestrial and aquatic biology, water quality, and climate.

[1] This initiative is focused on Bighorn Lake and the portion of the Bighorn River from Yellowtail Dam to its confluence with the Yellowstone River. More accurately this is the lower Bighorn River as distinct from the upper Bighorn River above Bighorn Lake. For simplicity and with deference to local usage, in this report we will often refer to the lower Bighorn as simply the Bighorn River.

Within each category there are study component that include research questions, tasks, temporal and spatial extent, estimated costs, and deliverables. Each study is designated as either a baseline study or dependent study. Baseline studies do not require any prerequisite studies and should be completed early on. Dependent studies require information generated from one or more baseline studies and should be initiated after the pertinent baseline studies have been completed. Refer to Appendix A – Study Sequence Flow Chart. The recommended prioritization of baseline studies is listed in Appendix B.

The RI addresses 84 miles of the Bighorn River from Yellowtail Dam down to the its confluence with the Yellowstone River. Most studies are restricted to the active river channel or adjacent floodplain. The river was divided into reaches as certain studies will focus on specific sections of the river while others will include the entire 84 miles. The reaches are:

- Reach #1: Yellowtail Dam (River Mile 84) to the Little Bighorn River Confluence (River Mile 42)
    - Subreach 1.1: Yellowtail Dam to Three Mile FAS
    - Subreach 1.2: Three Mile FAS to Bighorn FAS
    - Subreach 1.3: Bighorn FAS to Mallard's Landing FAS
    - Subreach 1.4: Mallard's Landing FAS to Two Leggins FAS
    - Subreach 1.5: Two Leggins FAS to the Little Bighorn River Confluence
- Reach #2: Little Bighorn River Confluence (River Mile 42) to Yellowstone River (River Mile 0)

A preliminary bibliography of investigations and reports associated with Bighorn Lake, Bighorn River, and comparable regulated rivers in the western United States was compiled in May/June 2018 by a Rocky Mountain College student in Billings. The Mendeley web-based reference application is being used to manage the citations. The BHRA should designate a person to manage the reference application and be available to "invite" others to access and use the application.

Bighorn River

2.0 Technical Consultation

To effectively implement the RI, the BHRA Research Committee should consult with qualified river specialists to assist them in setting research priorities, reviewing study proposals, selecting contractors, and assuring study deliverables are credible and meet expectations. For the first year, a small ad hoc technical committee would be adequate to help the Research Committee get started. After the first year, the Research Committee should consider employing a science advisor to assist with the items listed above as well as with RFP development, contracts, scopes of work, project administration, and education/outreach. This staff person would be supervised by the BHRA Research Committee and work closely with the BHRA Executive Director.

The preliminary bibliography completed in June 2018 has been useful in developing the RI, but it needs additional work regarding content and application.

Cost Estimate: $6,000: Ad Hoc Technical Committee - Year 1.

$25,000/yr.: Science Advisor (part-time staff) – Year 2+.

$5,000: Expand bibliography - Mendeley reference application.

3.0 Socioeconomics

The following section contains proposed research strategies for evaluating dam operations and regional socioeconomic conditions.

3.1 Governmental Operating Criteria and Authorities

Research Question(s): What are the operating criteria for Yellowtail Dam operations, the Afterbay facility, and what effects do they have on the Bighorn River as of 2010.? How do the operating criteria prioritize use allocations: (1) reservoir levels relative to flood control; (2) irrigation withdrawals; (3) hydroelectric power generation; and (4) fisheries and associated recreation—marina use and boating, and fishing access sites? How do the operating criteria for Boysen Reservoir and Buffalo Bill Reservoir interrelate with Bighorn Lake criteria? Is sediment accumulation in and between the reservoirs actively managed and if so, how? How have the deliberations by Bureau of Reclamation and the Big Horn River System Issues Group since 2010 influenced operating criteria for Yellowtail Dam and Bighorn Lake as well as Boysen Dam and Buffalo Bill Dam and their reservoirs? What is the relationship between flood control operating criteria and seasonal operating criteria applied during normal, non-flood conditions? How are decisions made in applying operating criteria in the face of annual variation in release flows below flood level? How are decisions made about where in the reservoir water column outflows are released; and, are there physical constraints for where in the water column releases are made? What are the responsibilities of the Montana Department of Environmental Quality (MDEQ), the Environmental Protection Agency (EPA), and the Crow Tribe regarding water quality monitoring on the Bighorn River and tributaries?

Tasks:

1. Determine the historical and present allocation of water resources to the recognized major uses of water in the Bighorn River system: hydroelectric power generation, flood storage, agricultural irrigation, recreation (fishing, boating), and municipal/domestic use.

2. Given the circumstances of floods, normal flows, and drought flows, determine what process is used to set priorities among uses. For water shortages or too much water from flooding, determine if and how impacts to various uses are mitigated.
3. Determine how differences in jurisdiction (Federal - Bighorn National Recreation Area, COE and BOR, States of Montana and Wyoming, and the Crow Nation) affect water allocation for resource uses.
4. Use tabular/graphical analysis and narrative explanation to document changes through time.
5. Detail any sedimentation control measures among the three principal reservoirs (Boysen, Buffalo Bill, and Bighorn) and if utilized how they have been used and what the effects have been on reservoir sediment deposits.
6. Identify points of conflict in water use for different user groups and stakeholders.
7. Note water column release decisions that may affect water quality downstream (e.g. hydroelectric generation requires water withdrawal from a specific depth, possibly influencing oxygenation, PSAT, and temperatures downstream).
8. Outline jurisdictions, responsibilities and policies of the MDEQ, EPA and Crow Tribe regarding water quality on Bighorn Lake and the Bighorn River (including tributaries).

Supporting Data/Information: Bureau of Reclamation policies and records for Montana and Wyoming Area Offices, Great Plains Regional Office, and Denver Technical Service Center; Proceedings and records of the Bighorn River System Issues Group; Crow Nation treaties and water compact agreement; Montana Department of Fish, Wildlife and Parks records, Wyoming Fish and Game records.

Temporal Extent: Operational History Period for Yellowtail Dam and Bighorn Lake, Boysen Dam and Reservoir, and Buffalo Bill Dam and Reservoir, 1967 to Present.

Spatial Extent: Yellowtail Dam and Reservoir; Upstream units affecting flow into Bighorn Lake that include Boysen Dam on the Wind/Bighorn River and Buffalo Bill Dam on the Shoshone River; Downstream River reaches from Yellowtail Dam to confluence with the Yellowstone River (Reaches #1 & 2).

Sequencing: Baseline Study. This study would provide context for the hydrology, geomorphology, and biology studies.

Deliverables: Written report with graphics detailing the operating criteria for all facilities identified above. The report would explore operational effects on, or in response to, major uses (i.e. Crow Nation treaty rights, hydroelectric power generation, agricultural irrigation, flood storage, municipal/domestic water withdrawals, recreational fishing/boating, and the Crow Nation water compact).

Cost Estimate: ~$15-$20,000.

Demonstration/Restoration Project Opportunities: None.

3.2 Regional Sociopolitical and Economic Considerations

Research Question(s): How do the various uses of Bighorn Lake and the Bighorn River relate to the local communities, the region, and the state of Montana? These uses should be characterized by (1) the economic benefits they provide to stakeholders associated with the Bighorn River System, and to

governmental entities—namely local and regional cities, counties and the State of Montana; and (2) the social implications for the various users. At a minimum, the uses should include: flood protection, hydroelectric power generation, agricultural irrigation, recreation, Crow Nation activities, and municipal/domestic water.

Tasks:

The tasks outlined below may need to be divided into separate studies, depending on contractor expertise.

For each use/user group (listed above):

1. Determine economic contribution to communities, region and states (Montana and Wyoming).
    a. Income and employment.
    b. Business opportunities and investment.
    c. Direct economic contribution of river corridor uses, and the multiplier effect to local communities, the region and the state.
2. Determine user group activity and perspectives regarding social need or acceptance
    a. Recreational Use: Conduct user survey with a structure and methodology that will compare results from the MT FWP 1993 study (Reach #1).
    b. All Uses: Conduct representative user interviews to determine local and regional perspectives on the use and condition of the Bighorn River derived from 1) Yellowtail Dam and Bighorn Lake, 2) Bighorn Canyon National Recreation Area, and 3) treaty rights/obligatory agreements associated with the Crow Nation.
    c. Minimum analysis (from direct research and documentary sources) required:
        i. Estimate user numbers.
        ii. Analyze integration of use into community, region and state.
        iii. Analyze river use by discrete locations where use occurs. Consider whether additional public access points would help distribute use and possibly increase use.
        iv. Analyze recreation use by type and locations: Bighorn National Recreation Area, Bighorn Lake, and the Bighorn River below Yellowtail Dam.
        v. Crow Nation: identify social interaction needs between tribe and other user groups relating to Crow treaty rights, water rights, and water compact.
        vi. Crow Nation: Identify and explore potential interaction among user groups and tribal interests; and the potential mutual support for use of Crow Tribe Reservation lands that border the Bighorn River.
3. From the confluence of the Little Bighorn River to the Yellowstone River (Reach #2), analyze the extent to which operation of Yellowtail Dam and Bighorn Lake impacts the economics and social conditions for:
    a. Flood management effects.
    b. Irrigated agriculture.
    c. Recreational use of the river for fishing, boating and hunting.

Supporting Data/Information: FWP survey data from 1993; Census data.

Temporal Extent: 1967 (Beginning operation of Yellowtail Dam and Bighorn Lake) to present.

Spatial Extent: Primary focus on Bighorn Lake, Yellowtail Dam, and the Bighorn River down to the Little Bighorn River confluence (Reach #1). This study would also address the economic and social conditions downstream from Little Bighorn River confluence to the Yellowstone River main stem (Reach #2).

Sequencing: Dependent Study. The study should be initiated after baseline studies show the nature of river uses and their spatial extent.

Deliverables: Survey and interview data, generalized through written description and tabular and graphical data presentation. Written report detailing economic and social findings by river use as outlined above in Tasks Section.

Cost Estimate: Task #1: Economics ~ $30,000; Tasks #2 & 3: Social Considerations ~ $30,000-$50,000 depending on the design and extent of the social survey.

Demonstration/Restoration Project Opportunities: This study could be the basis of effective outreach demonstrating the economic and social benefits of various uses of the resources made available and predictable by the installation and operation of Yellowtail Dam. This study could also be the basis of creating a working partnership with Crow Nation to benefit both the Native American and larger Montana community.

4.0 Spatial Information and Data

The compilation of spatial information will provide a key foundation for most subsequent work. This includes compiling modern and historic air photos, mapping physical features, and using that information to map historic channel locations.

4.1 Spatial Imagery and Channel Feature Delineations

Research Question(s): What is the coverage extent and quality of historic and recent maps/imagery to help support other research study components? Where are physical features (bank armor, floodplain dikes, irrigation diversions, irrigation return discharges, bridges, etc.) located within the river corridor? How much channel migration has occurred over the last 75 years?

Tasks:

1. Compile existing Bureau of Reclamation air photos from 1939-2006 from Yellowtail Dam to Mallard's Landing FAS (22 miles).
2. Download and georeference General Land Office Survey (GLO) maps of area.
3. Purchase and/or download the following historic imagery (note that 1970s and earlier will need to be orthorectified):
    a. 1956 (USGS, Pre-Dam), or 1961 (USDA, Pre-dam, St Xavier to Yellowstone Confluence).
    b. 1970s.
    c. 1978 Flood Maps (Montana Dept of Transportation).
    d. 1990 DOQQs.
    e. 2003 – 2017 National Agricultural Imagery Program (NAIP).
4. Compile available LiDAR high resolution topographic mapping of the river corridor (NRCS will collect imagery in 2018 and have it available in early-mid 2019).

5. Compile other available datasets as appropriate:
    a. Geology.
    b. National Wetlands Inventory.
    c. Cadastral (ownership).
    d. Land Cover.
6. Inventory all physical features along the Bighorn River channel and adjacent floodplain. The physical features will be digitized and attributed on 2017 NAIP aerial imagery using ArcGIS software.
7. Digitize channel bank lines for a select set of imagery (1950s, 1970s, 1990s, 2000s, most current). This information will be used to determine channel migration rates, island evolution, and side channel changes (6.1 Channel Migration Zone Mapping).

Supporting Data/Information: Available GLO maps and historic photo imagery

Temporal Extent: Late 1800s (GLOs) to 2017

Spatial Extent: Reaches #1 and #2 (Yellowtail Dam to the Yellowstone River) – 84 miles.

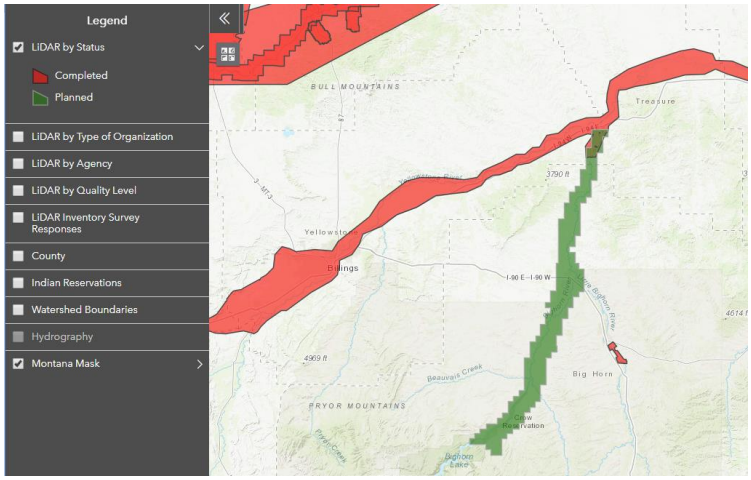
Sequencing: Baseline Study. Images/data compiled and features delineated are a prerequisite for several subsequent studies (i.e. Studies 5.2, 6.1, 7.1, and 7.3).

Deliverables:

1) Technical Report that describes compiled imagery, sources, and resolution. The report will also outline methods used for digitizing physical features and channel bank lines.
2) ArcGIS geodatabase with compiled imagery, mapped physical features, and digitized bank lines.

Cost Estimate: $25,000.

Demonstration/Restoration Project Opportunities: This baseline inventory will provide an initial evaluation of pre- and post- Yellowtail geomorphic and riparian conditions in the river corridor and adjacent floodplain.



LIDAR mapping (green shading) will be available in 2019.

5.0 Hydrology

The evaluation of system hydrology will assess how the dam is operated regarding the magnitudes and patterns of flow releases, and how that has changed through time. With the hydrology evaluated, the results will then be used to assess how those flows are manifested in the river corridor in terms of flooding extent and flow energy.

5.1 Hydrology – Flow Releases and Fluctuations

Research Question(s): How have the patterns and magnitudes of flow releases from Yellowtail Dam and the Afterbay changed through time?

Tasks:

1. Evaluate hydrologic patterns using the USGS St. Xavier gage station (USGS #06287000) records. This station has mean daily flow measurements since 1934. Compile mean daily flow data into the following time series:
    a. Pre-1966: Prior to dam closure.
    b. 1967 - 1992: Dam closure to drought cycle.
    c. 1993 - Oct 1, 2009: Pre-operating criteria, drought cycle, and the expansion of Buffalo Bill Dam.
    d. Oct 1, 2009 - current: New operating criteria.
2. Evaluate each time series using the Indicators of Hydrologic Alteration (IHA) software program developed by The Nature Conservancy. This program assesses 67 ecologically-relevant statistics that provides an analysis of hydrologic impacts affected by human activities. The program uses daily hydrologic data. Generate statistical output and summarize statistics for IHA Parameters using:
    a. Mean Flows: Monthly Magnitude (12 parameters).
    b. Extreme Flows: Annual Minima, Maxima, and Base Flow Index (12 parameters).
    c. Timing of Extreme Flows (2 parameters).
    d. Frequency and Duration of High and Low Pulses (4 parameters).
    e. Rate and Frequency of Water Condition Changes (3 parameters).
3. Explore statistical output and summarize statistics for Environmental Flow Components (EFCs) that supplement the IHA analysis to understand key flow-ecology relationships on the Bighorn River and the Yellowstone River (Bighorn River confluence to Miles City).
    a. Monthly Low Flows (12 parameters).
    b. Extreme Low Flows (4 parameters).
    c. High Flow Pulses (6 parameters).
    d. Small Floods (6 parameters).
    e. Large Floods (6 parameters).

Supporting Data/Information: USGS Gage Records, The Nature Conservancy's IHA model, Yellowstone River Cumulative Effects Analysis – Hydrology Appendix (2016).

Temporal Extent: 1930s to 2017.

Spatial Extent: USGS St Xavier and Bighorn (above Tullock Creek) Gage Stations.

Sequencing: Baseline Study. The study is a prerequisite for studies 5.2 and 7.1.

Deliverable:

1) Technical report with IHA model runs that describe methods, results, and spatial trends (historic and future projections) for each gage station.

Cost Estimate: $30,000.

Demonstration/Restoration Project Opportunities: This analysis will help identify operational patterns that may affect river health.

5.2 Flow Hydraulics and Inundation

Research Question(s): What are the floodplain inundation patterns for key flows (historic 100-year floodplain and BOR's 20,000 cfs maximum release from Yellowtail Dam)?

Tasks:

1. Construct and run a HEC-RAS model above St Xavier (Using 2-D and GEO-RAS if budget allows)
    1) Review available data (BOR, 2012):
        a. BOR one-dimensional HEC-RAS model.
        b. BOR depth averaged SRH-2D model.
        c. Bathymetry, LiDAR.
    2) Develop flow scenarios using results of hydrologic analysis and generate water surface elevation profiles for selected flows above St Xavier:
        a. 20,000 cfs as maximum Afterbay release.
        b. 8,000 cfs at point where "recreation becomes impaired".
        c. 1,500 cfs low flow threshold set by MFWP.
        d. Other flows identified by the BHRA.
    3) Use water surface elevations generated from model above St Xavier to roughly calibrate inundation model downstream using LiDAR.
    4) Recalibrate the model below the Little Bighorn River (Reach #2) using at-a-station hydraulic geometry to estimate stage/discharge.

Supporting Data/Information: BOR modeling, BOR digital elevation model, NRCS LiDAR data.

Temporal Extent: Recent.

Spatial Extent:

1. Yellowtail Dam to St Xavier Bridge (Existing BOR Model).
2. Below St Xavier Bridge to the Yellowstone River (Inundation Estimation).

Sequencing: Dependent Study. This study should be undertaken after the following baseline studies are completed: 4.1 Spatial Imagery and Channel Feature Delineation and 5.1 Hydrology: Flow Releases and Fluctuations.

Deliverable:

1) Technical report that describes methods and results with supporting floodplain inundation maps for Reaches #1 and #2.

Cost Estimate: $25,000.

Demonstration/Restoration Project Opportunities: This analysis will help describe the implications of operational patterns on geomorphic stability, disturbance potential, and riparian/aquatic habitats. The results can also be used to identify cost-effective sites for restoring hydrologic connectivity and disturbance processes that will rejuvenate habitat and promote riparian colonization.

6.0 Geomorphology

The physical dynamics of the project reach will be evaluated through an assessment of channel migration, which will determine how land use affects erosion rates, how lateral migration affects vegetation patterns, and how bank armoring has impacted those processes. The results of this evaluation will include Channel Migration Zone maps that can be used extensively in corridor planning and restoration opportunity identification.

6.1 Channel Migration Zone Mapping

Research Question(s): What are the rates of lateral movement along the Bighorn River and how are they influenced by flow management and/or land use? What is an optimal management footprint for river function?

Tasks:

1. Delineate the Historic Migration Zone (HMZ) based on digitized bank lines completed under *4.1 Spatial Imagery and Channel Feature Delineations*.
2. Map current land use/land cover in footprint defined by the 20,000 cfs inundation zone or 1,000 feet from the active river channel, whichever is greater.
3. Determine Channel Migration Rates:
    a. Measure channel migration rates through time.
    b. Statistically evaluate rates by reach and subreach.
    c. Compare to hydrologic trends.
    d. Compare to land use/land cover (compute migration rates through various cover types).
4. Generate Channel Migration Zone (CMZ) Maps that project channel migration over the next 100 years:
    a. Assign Erosion Hazard Area (EHA) based on Migration Rate Statistics.
    b. Map Avulsion Risk Zones (AHZ).
    c. Identify Restricted Migration Areas (RMA).
    d. Develop composite CMZ maps with all map units uniquely identified (Channel, HMZ, EHA, AHZ, and RMA).

Supporting Data/Information: Aerial imagery, LiDAR data, geologic maps, digitized bank lines, physical Features Inventory.

Temporal Extent: 1950s to 2017.

Spatial Extent: Reaches #1 and #2 (Yellowtail Dam to the Yellowstone River) – 84 miles.

Sequencing: Dependent Study. 4.1 Spatial Imagery and Channel Feature Delineation should be completed before this study begins. CMZ mapping can be completed in conjunction with *7.1 Aquatic and Riparian Assessment* to determine the role of channel dynamics on aquatic habitat formation and fish populations.

Deliverables:

1) Technical report that summarizes methods, and provides interpretations regarding the influences of land use, hydrologic history, and geologic controls on river migration.
2) CMZ maps—digital and hard copy.
3) ArcGIS geodatabase with all mapping information compiled (imagery, banklines, migration vectors, CMZ).

Cost Estimate: $25,000.

Demonstration/Restoration Project Opportunities: This mapping would provide an understanding of channel migration rates and how factors such as flow release patterns, land use, and vegetation may affect those rates. The mapping will help identify restoration opportunities such as side channel reactivation, riparian buffer development, wetland restoration, and potential CMZ easements.

7.0 Biology

The biological research category includes evaluations of aquatic habitat, riparian habitat, macroinvertebrate populations, invasive woody plants, bird populations, and fish populations. These results will be integrated with previous studies to consider cause-and-effect relationships as well as to identify restoration strategies that will benefit the Bighorn River ecosystem.

7.1 Aquatic and Riparian Habitat Assessment

Research Question(s): What are the spatial and temporal trends of aquatic and riparian habitats in Reaches #1 and #2? How do they relate to other study components and the fishery?

Tasks:

1. Field evaluate physical features that were remotely mapped under *4.1 Spatial Imagery and Channel Feature Delineations*. Structure condition, functionality, on-site and off-site impacts, and potential restoration project opportunities will be evaluated and added to an ArcGIS attribute table.
2. Assess existing aquatic habitat:
    a. Float river and map aquatic habitat (e.g. pools, riffles, large woody debris, side channels, etc.).
    b. Review BOR bathymetry data collected upstream of St Xavier to summarize bedform diversity (residual pool depth, frequency, habitat unit distribution).

c. Evaluate aquatic habitat characterization by reach/subreach and compare to fish populations.

3. Assess existing riparian habitat:
    a. Float river and map bank line riparian condition, species diversity, invasive plant infestations, use, etc.
    b. Correlate field mapping to land use/land cover mapping from CMZ scope.
    c. Summarize spatial trends by reach and subreach.
4. Summarize spatial and temporal trends in aquatic and riparian habitat:
    a. Evaluate channel feature trends and habitat complexity by reach/subreach.
    b. Evaluate riparian condition/sustainability by reach/subreach.
    c. Integrate results of CMZ evaluation, invasive plant mapping, etc. into interpretations.
    d. Revisit the 2010 and 2012 BOR Side Channel Investigations to determine if the frequent high flows have changed the findings of the reports that indicated the side channels hadn't degraded but were merely plugged.

Supporting Data/Information: Aerial imagery, LiDAR data, geologic maps, digitized bank lines, physical Features Inventory.

Temporal Extent: 1950s to 2017.

Spatial Extent: Reaches #1 and #2 (Yellowtail Dam to the Yellowstone River) – 84 miles.

Sequencing: Dependent Study. Studies 4.1, 5.1, 6.1, and 7.3 are baseline study prerequisites.

Deliverables:

1) Technical Report that summarizes methods and results
2) ArcGIS geodatabase with all mapping information compiled

Cost Estimate: $50,000. (Three field personnel, 12 field days, analysis, and reporting).

Demonstration/Restoration Project Opportunities: This study will be the main field study to identify aquatic and riparian habitat restoration projects.

7.2 Stream Health – Benthic Macroinvertebrate Monitoring

Research Question(s): As a bioindicator, what does the Bighorn River's benthic macroinvertebrate population (species composition and diversity) suggest about spatial and temporal trends in aquatic habitat health, as influenced by aquatic macrophyte beds, algae, aquatic invasive species, sedimentation, water quality, dissolved gases, and regulated flows?

Tasks:

1. Conduct an in-depth literature search of reports, studies, and data pertaining to benthic macroinvertebrates and periphytons in the Bighorn River and comparable regulated rivers. Benthic macroinvertebrates were collected as early as the mid-1980s to determine their response to elevated concentrations of dissolved gases below Yellowtail Dam. Compile and interpret existing data to define historic conditions and help guide the development of a sampling analysis plan.

2. Develop a long-term benthic macroinvertebrate quantitative sampling analysis plan (SAP) for the Bighorn River and selected tributaries to determine spatial, temporal, and seasonal variations. The SAP will provide guidelines on sample site locations, sample numbers/site, methods, metrics, and analysis. The SAP should consider the following:
    a. Establish a minimum of five sampling stations at or near locations where real-time flow is being recorded:
        - Afterbay – BOR HydroMet station.
        - Bighorn FAS (St. Xavier gage station).
        - Two Leggins USGS gage station.
        - Tullock Creek USGS gage station.
        - Little Bighorn River near Hardin - USGS gage station.

        The BHRA may want to add sample stations at the Three Mile FAS and/or the Mallard's Landing FAS. After 2-3 years of sampling, some sites may be dropped if they are not providing significant information to the effort.
    b. Sampling protocols should follow the Montana DEQ standard operating procedures to maintain consistency and credibility. A Hess or Surber sampler should be used at all sites.
    c. Samples should be collected annually in the early spring (March) and/or late fall (October). Sampling dates and sample numbers/site should be consistent from year to year to allow for statistical trend analysis. Periodic winter sampling may also be included in the SAP to characterize winter macroinvertebrate populations.
    d. An annual written report and presentation should be offered to the BHRA on spatial, temporal, and seasonal trends and the response of macroinvertebrate populations to key ecological factors identified by the 5.1 Hydrology IHA model.

Supporting Data/Information: Reports and data sets from Montana FWP, Montana Department of Environmental Quality (MDEQ), and possibly the Crow Tribe

Temporal Extent: Annual monitoring over the next 5+ years.

Spatial Extent: Reaches #1 and #2.

Sequencing: Baseline Study.

Deliverables:

1) Technical Report: A literature review of past sampling of benthic macroinvertebrate in the Bighorn River and tributaries. The report will include a compilation and analysis of data to determine data credibility and historic trends.
2) Sampling Analysis Plan (SAP): The SAP will outline benthic macroinvertebrate sampling objectives, methods, sampling locations, frequency, metrics, and analysis.
3) First Year Monitoring: Sampling and analysis of benthic macroinvertebrates will begin based upon SAP guidelines. A written report will summarize first year results

Cost Estimate: ~ $15,000. Tasks 1 and 2: Complete the literature review and develop the SAP. This level funding should also be adequate for first year monitoring and data analysis.

Annual monitoring costs are estimated to be approximately $10,000 annually. This includes field time, equipment, and lab analysis ($250/sample).

Demonstration/Restoration Project Opportunities: Once the monitoring program is in effect for 3 – 5 years, the monitoring results may be used with flow management decisions and suggest areas along the river where irrigation water efficiency, habitat enhancement, and stream corridor improvement projects would benefit aquatic health.

7.3 Riparian Sustainability – Invasive Woody Plants

Research Question(s): What are the impacts from invasive woody plants on native riparian/wetland plant community sustainability, livestock forage production, terrestrial wildlife habitat, and aquatic habitat (side channels in particular). How can these impacts be minimized?

Tasks:

1. Biological treatments may be the only practical approach to widespread control of invasive woody plants along the Bighorn River. Complete an in-depth review of past and current research on the biological control of Russian olive, salt cedar and common buckthorn in the western United States that would be applicable to the Bighorn River corridor.
2. Sponsor invasive woody plants biological research and demonstration projects on the Bighorn River in cooperation with the Weed and Invasive Plant Ecology and Management Group at Montana State University, the Montana Biocontrol Coordination Project, and/or the Sidney Agricultural Experiment Station.
3. Develop a strategy to aggressively remove invasive woody plants encroaching upon critical sites along the river (i.e. fishing access sites, side channels, etc.). The strategy will identify high priority sites and outline site-specific treatment alternatives. A monitoring component will be included in the strategy to evaluate project success and native riparian recovery.

Supporting Data/Information: 2018 Russian olive mapping on the Bighorn River - Yellowstone River Conservation District Council.

Temporal Extent: 5+ years.

Spatial Extent: Reaches #1 and #2.

Sequencing: Dependent Study. Task 1 and 2: The compilation of past and current biocontrol literature and research sponsorship could begin as early as 2019. Task 3: Developing the strategy to control invasive woody species on critical aquatic habitat should come after 4.1 Spatial Imagery and Channel Feature Delineation and 7.1 Aquatic and Riparian Habitat Assessment.

Deliverables:

1) Technical Report: A review of past and current research being conducted on biocontrol of invasive woody plants. The report should include a compilation of pertinent research and identify potential cooperative projects with biocontrol groups, experiment stations, and universities.
2) Invasive Woody Species Control Strategy – Critical Aquatic Habitat: The strategy will identify critical habitats, develop a prioritization scheme, and outline specific removal methods.

Cost Estimate: Task 1: $2,000. Compiling biocontrol research. Task #2: Sponsorship of research and demonstration projects would have a range of costs with an estimated average of $8,000 per project. Task 3: $3,000. Development of an Invasive Woody Plant Control Strategy for critical aquatic habitat sites along the Bighorn River.

Demonstration/Restoration Project Opportunities: This study would lead to research/demonstration projects that test widespread biological control of woody invasive species along the Bighorn River. For specific aquatic habitat areas affected by invasive woody species encroachment, the Invasive Woody Plant Control Strategy would identify high priority restoration sites with site-specific treatment alternatives and costs.

7.4 Terrestrial Wildlife Habitat – Avian Surveys

Research Question(s): What does the Bighorn River's avian population suggest about spatial and temporal trends in riparian vegetation condition, island/channel bar nesting and habitation, and terrestrial wildlife habitat integrity, as influenced by river bank modifications, riparian forest management, invasive woody species infestations, and land use conversions?

Tasks:

1. Conduct an in-depth literature search of reports, studies, and data pertaining to avian surveys along the Bighorn River, tributaries, comparable regulated rivers in the West, and the adjacent reaches of the unregulated Yellowstone River. Compile and interpret existing information to guide the development of a study design.
2. Develop an avian survey design that encompasses a range of habitat types and landscape settings to determine bird responses to the long-term effects of human influences. Habitat types will include various seral stages characterized by differing vegetation structure and species composition. The avian monitoring plan will provide specific guidelines on survey locations, timing, frequency, methods, metrics, analysis, etc. The design should consider the following:
    a. Use a standard fixed radius point count method at each location.
    b. Conduct systematic surveys at each location at least three times during the breeding season to attain a representative sample of the bird community.
    c. Statistical analysis to evaluate the effects of land use, management, invasive species, and river bank modifications on the distribution and abundance of bird species.
3. Avian Surveys: Survey will be conducted as outlined in the avian survey design (Task 2).

Supporting Data/Information: Reports and data sets from Yellowstone River Conservation District Council, Yellowstone Valley Audubon, the Montana Heritage Center, and perhaps the Crow Tribe.

Temporal Extent: Periodic monitoring to determine temporal trends.

Spatial Extent: Reaches #1 and #2.

Sequencing: Dependent Study. Study components 4.1 (Spatial Imagery and Channel Feature Delineations), 7.1 (Aquatic and Riparian Habitat Assessment), and 7.3 (Riparian Sustainability – Invasive Woody Plants) should be completed before avian survey sites are selected.

Deliverables:

1) Literature Review: A literature review of avian surveys in the Bighorn River and tributaries. The review will include a compilation and analysis of data that will be the basis for a detailed avian survey design.
2) Avian Survey Design: The design will provide details on avian survey objectives, methods, survey locations, seasonal timing, frequency, metrics, and analysis.
3) Avian Survey: Survey and analysis of avian populations. A written report and presentation to BHRA will follow each year a survey is completed that summarizes the survey results and overall temporal trends.
4) Bird Lists: For each survey location, a bird list will be provided to the landowner.

Cost Estimate: ~ $5,000. Tasks 1 and 2: Complete the literature review and develop the avian survey design.

Task 3: Avian surveys for a breeding season are estimated to be $15,000/year depending upon the number of survey locations.

Demonstration/Restoration Project Opportunities: Once the avian survey program has begun, survey results may suggest areas along the river where riparian improvement projects would benefit terrestrial wildlife habitat and improve river bank stability.

7.5 Fish Surveys

Research Question(s): What effects do anthropogenic stressors such as the altered hydrograph, water quality, aquatic plant growth, and in-channel structures have on fish health, recruitment and populations?

Tasks:

1. Collaborate with Montana Fish, Wildlife and Parks (MFWP) on the design and implementation of a sampling design that can determine relative abundance, age classes and spatial distribution of game and non-game fish populations on the Bighorn River. The two historic trout section surveys should be continued to collect population estimates. BHRA support may include logistical support, stakeholder outreach, fish tag returns, equipment, etc.

Supporting Data/Information: Montana Fish, Wildlife and Parks, Yellowstone River Conservation District Council.

Temporal Extent: Periodic fish surveys. Survey frequency will be outlined in the fish sampling design. Maintain spring and fall trout survey. Surveys on Reach #2 will be rotated on a 3 to 6 year rotation.

Spatial Extent: Reach #1: cold water fisheries; Reach #2: transition and warm water fisheries.

Sequencing: Baseline Study.

Deliverables:

1) Annual report and presentation to the Bighorn River Issues Group and/or the BHRA.

Cost Estimate: $0. direct cost to BHRA, dependent however on MFWP funding and staffing. The BHRA may incur expenses if they assist MFWP with activities that require time, equipment, materials, or possibly sponsoring fish surveys if MFWP is unable to do the work.

Demonstration/Restoration Project Opportunities: Fish surveys may target projects that include side channel habitat improvements, fish passage at irrigation diversions, and flow releases from Bighorn Lake.

8.0 Water Quality

Water quality is a key aspect of riverine health that links several research components such as dam operations and fisheries. The evaluation of water quality will require long-term monitoring to optimize the quality and usefulness of the data.

8.1 Water Quality – Long-Term Monitoring

Research Question(s): Why are there extended periods of high turbidity in the Bighorn River? What are the physical, chemical, and biological constituents in the water column that affect aquatic plant and algae growth? How does Bighorn Lake destratification and Yellowtail Dam flow releases influence the water quality in the Bighorn River? What are the implications of climate change for long-term trends in water quality?

Tasks:

1. Conduct an in-depth literature search of reports, studies, and data pertaining to water quality in the Bighorn River and the Bighorn Lake. Water quality sampling occurred as early as the late 1940s, prior to the construction of Yellowtail Dam. Compile and interpret existing data to define historic conditions and provide direction for future monitoring.
2. Develop a long-term sampling analysis plan (SAP) for the Bighorn Lake, Afterbay, and the Bighorn River to determine spatial, temporal, and seasonal differences. The SAP will be designed to examine water quality relationships between Bighorn Lake and the Bighorn River. The SAP will also provide guidelines on collecting data to better understand how river hydrology, irrigation return flows, and river corridor management affect water quality and aquatic habitat. Sampling site locations, parameters, methods, frequency, and analysis in the SAP should consider the following:
    a. Past Monitoring: Previous water quality monitoring efforts on the Bighorn Lake, the Bighorn River and the Little Bighorn River; and water quality monitoring programs developed on comparable river systems in the western United States (i.e. Beaverhead River, Missouri River, Henry's Fork River, etc.).
    b. HydroMet Station: Bureau of Reclamation's HydroMet station located below the Afterbay that provides real-time data (1-hour frequency). This station's parameters could be expanded to include turbidity.
    c. Automation: Augment select USGS streamflow monitoring stations on the Bighorn River and Little Bighorn River with real-time water quality sondes (15 min frequency). Parameters may include turbidity, dissolved oxygen (DO), PH, specific conductivity (SC), and water temperature. Sonde probes could be purchased and managed by the BHRA or; the BHRA could cost-share with USGS on the installation, maintenance,

QA/QC, and data analysis for each automated station. Sonde installation would need to address floating algae that is common in the summer months.

d. Field Sampling: Complement automated real-time water quality data collection with field sampling of nutrients (Total Nitrogen and Total Phosphorus), total suspended solids (organic and inorganic), selenium, and chlorophyll. Summer sampling should be weekly, shoulder season sampling biweekly, and winter sampling every 4-6 weeks.
e. Sample Locations: Field sampling locations should correspond with automated sampling sites. Additional field sampling may include key tributaries and irrigation return discharges. Water quality sample locations should also correlate with macroinvertebrate sampling sites (7.2 Benthic Macroinvertebrate Monitoring) to the extent possible.
f. Bighorn Lake: Establish 2-3 surface-to-bottom vertical profiles in the Bighorn Lake that measure water temperature, turbidity, DO, nutrients, and selenium; and collects chlorophyll, and plankton samples. Sampling bottom sediment constituents at the edge of the depositional plume in the reservoir should also be considered.
g. Database Software: Purchase database software to store and manage water quality data to determine spatial/temporal trends and relationships. Several water quality database software packages are available; however, customizing the Henry's Fork software may be worth considering. There will also need to be a qualified analyst to run the software and interpret the data.

Supporting Data/Information: Reports and data sets from Bureau of Reclamation (BOR), US Geologic Survey (USGS), Montana Department of Environmental Quality (MDEQ), the Bighorn River Alliance (BHRA), and possibly the Crow Tribe.

Temporal Extent: Historic records: 1940s to current day; long-term monitoring for the next 10 years.

Spatial Extent: Selected sites on Reaches #1 and #2 (Yellowtail Dam to the Yellowstone River). major tributaries (i.e. Soap Creek, Little Bighorn River) and the Bighorn Lake.

Sequencing: Baseline Study.

Deliverables:

1) Technical Report: An in-depth literature review of water quality sampling of the Bighorn Lake, Bighorn River, and major tributaries. The report will also include a compilation and analysis of existing data to help determine data credibility, historic trends, and the appropriate locations and parameters for future monitoring.
2) Sampling Analysis Plan (SAP): The SAP will include both automated real-time data collection opportunities and complementary field sampling options. The SAP would be finalized upon the review and agreement of the BHRA Research Committee.

Cost Estimate: $10,000. Tasks 1 & 2: Completing the literature review and developing the SAP.

Field Sampling: Estimated costs for field sampling and lab analysis would be ~ $10,000/year; however, actual costs would be dependent upon sampling frequency, water quality parameters, site numbers and whether there were any automated sites.

USGS Gage Automation Option: The costs for automating USGS gage stations to collect real-time data on water temperature, dissolved oxygen, and turbidity over an 8-month seasonal period would

have an initial set-up cost of 21.5K per site. Subsequent years would be 12.6K per site. These costs are in addition to a 40% cost-share match that would be provided by USGS.

BHRA Automation Sampling: For the BHRA to manage their own automated sampling sites, the initial set-up includes the purchase and installation of multiparameter sonde probes (with accessories) at a cost of approximately 17K per site. If the site was set-up for real-time sampling, the initial costs would be 23K. Data analysis software would be approximately 7K with a qualified staff or consultant managing and interpreting the data (5-10 hours per week) at 30K/year (Henry's Fork Foundation estimates).

Bighorn Lake Profiles: USGS costs for automating a real-time profiling of Bighorn Lake is ~ 120K per site. For manual sampling, a USGS two-person crew, sampling twice per month, would cost approximately $1,400/month.

Demonstration/Restoration Project Opportunities: This baseline effort will provide guidance towards the development of a long-term monitoring program. Once the monitoring program is on-going, the data may influence flow management and target areas along the river where irrigation water efficiency and stream corridor improvement projects would be most beneficial to water quality.

9.0 Climate

Climate change in the Bighorn River Basin is uncertain at this point. For the BHRA to advocate effective strategies regarding long-term river management, an understanding of modern climate science and projected future changes will be necessary.

9.1 Climate Change

Research Question(s): What is the state of research on how climate change will affect Montana waters and what data sources can be used to determine the effect of climate change on the Bighorn River Basin? From that research, what can be extrapolated about extremes in future spring runoff (high and low flows), and the timing of runoff? How can these extremes affect the operation of Yellowtail Dam? What flows might be expected in all seasons? What are the climate change implications for resiliency planning for major uses of the Bighorn River environment in Montana, namely (1) fishing and fisheries, (2) irrigation and agriculture, (3) hydroelectric power generation using reservoir waters, and (4) flooding between Yellowtail Dam and the confluence of the Bighorn and Yellowstone Rivers?

Task:

1. Using the Montana Climate Assessment as a starting point, conduct an in-depth literature search for all relevant research and documentation on potential changes to water quantity and hydrographs over the relevant period. Climate research work has extensively modeled various temperature, precipitation and water availability parameters for the upper Yellowstone River Basin above the Bighorn River confluence and the Powder River Basin. For the factors listed below, determine how similar the Bighorn River Basin is to the two watersheds mentioned above. Estimate resilience needs for the uses mentioned in the research questions and the risks attendant to flood and drought conditions.

a. Snowpack.
b. Snowmelt runoff and timing.
c. Annual stream flow.
d. Groundwater resources.
e. Drought.

Supporting Data/Information: Montana Climate Assessment and appendices (http://montanaclimate.org), National Climate Assessment, and other research associated with Wyoming.

Temporal Extent: Three data points: present, mid-21st century, end-21st century.

Spatial Extent: Reaches #1 and #2 (Yellowtail Dam to the Yellowstone River) – 84 miles.

Sequencing: Baseline Study. The climate modeling would complement conclusions derived from the 5.1 Hydrology: Flow and Fluctuations study.

Deliverables:

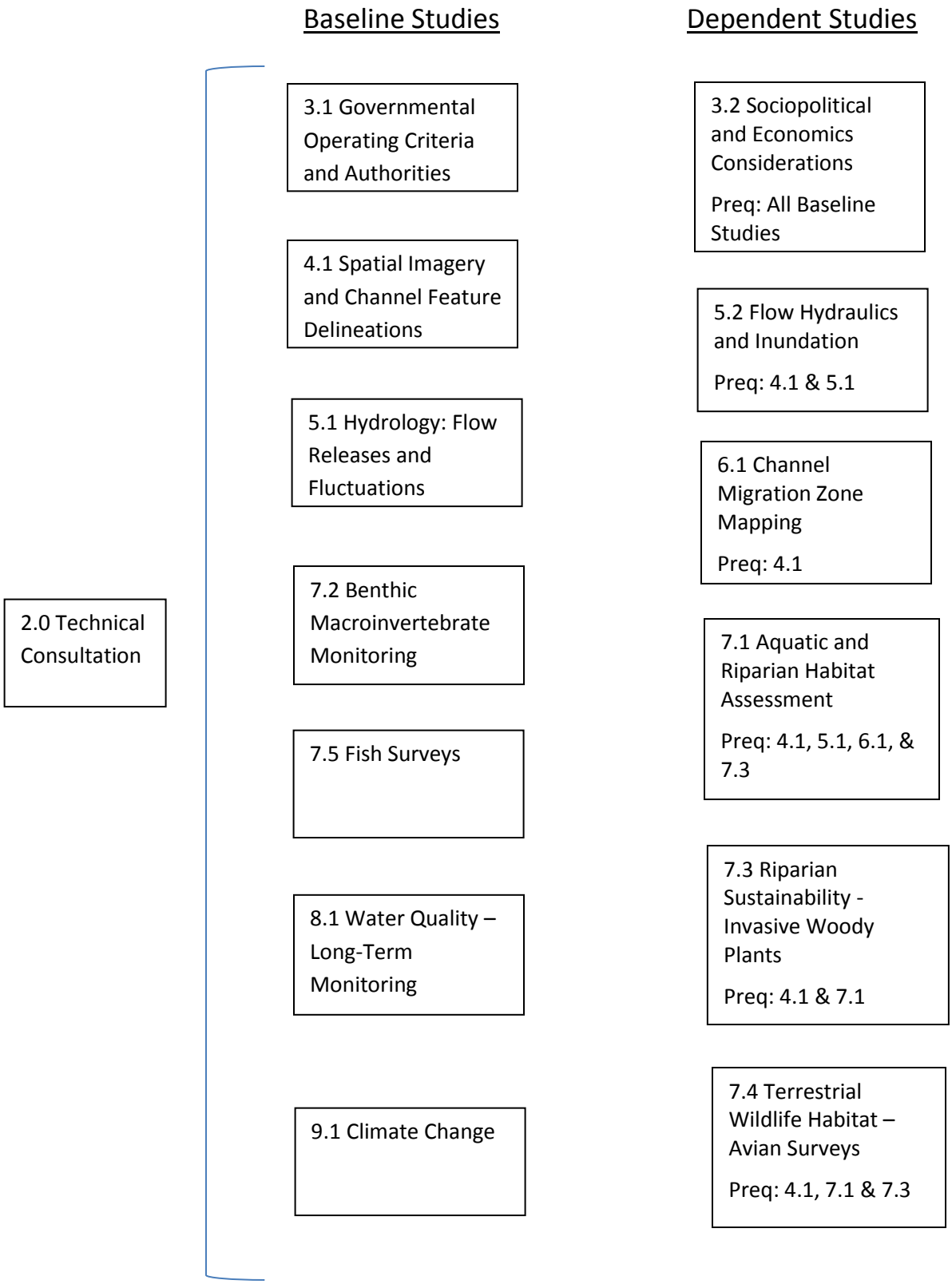
1) Technical Report that outlines methods, analysis, tables, conclusions (and degree of certainty).
2) Evaluation of the appropriateness of extrapolating Montana and Wyoming climate modeling to the Bighorn River and/or directly modeling the Bighorn River Basin.

The Bighorn River Basin has not been modeled in the Montana Climate Assessment, although the adjacent Yellowstone River Basin has been modeled. Wyoming has not completed a comparable climate assessment. Depending on future inquiries being made with the Montana Climate Assessment program, Deliverable 2 may need to be modified, along with the cost estimate.

Cost Estimate: ~ $ 15-$20,000.

Demonstration/Restoration Project Opportunities: The climate change analysis for the Bighorn River Basin could provide a planning tool for future water management.

Appendix A: Sequencing Flow Chart



Appendix B: Baseline Studies: Recommended Order of Prioritization

1. 2.0 Technical Consultation (1st year consultation and bibliography)
   - Est Cost: 11K. Duration: 6 – 7 months

2. 3.1 Governmental Operating Criteria and Authorities
   - Est Cost: 20K. Duration: 3 - 4 months

3. 4.1 Spatial Imagery and Channel Feature Delineations
   - Est Cost: 25K. Duration: 6 months

4. 7.5 Fish Surveys
   - Est Cost: $0. Lead Responsibility: MFWP

5. 5.1 Hydrology - Flow Releases & Fluctuations
   - Est Cost: 30K. Duration: 4 months

6. 8.1 Water Quality – Long-Term Monitoring (Tasks 1 and 2)
   - Est Cost: 10K. Duration: 3 - 4 months

7. 7.2 Stream Health - Benthic Macroinvertebrate Sampling (Tasks 1 and 2, 1st year monitoring)
   - Est Cost: 15K. Duration 5 months

8. 9.1 Climate Change
   - Est Cost: 20K. Duration 4-6 months