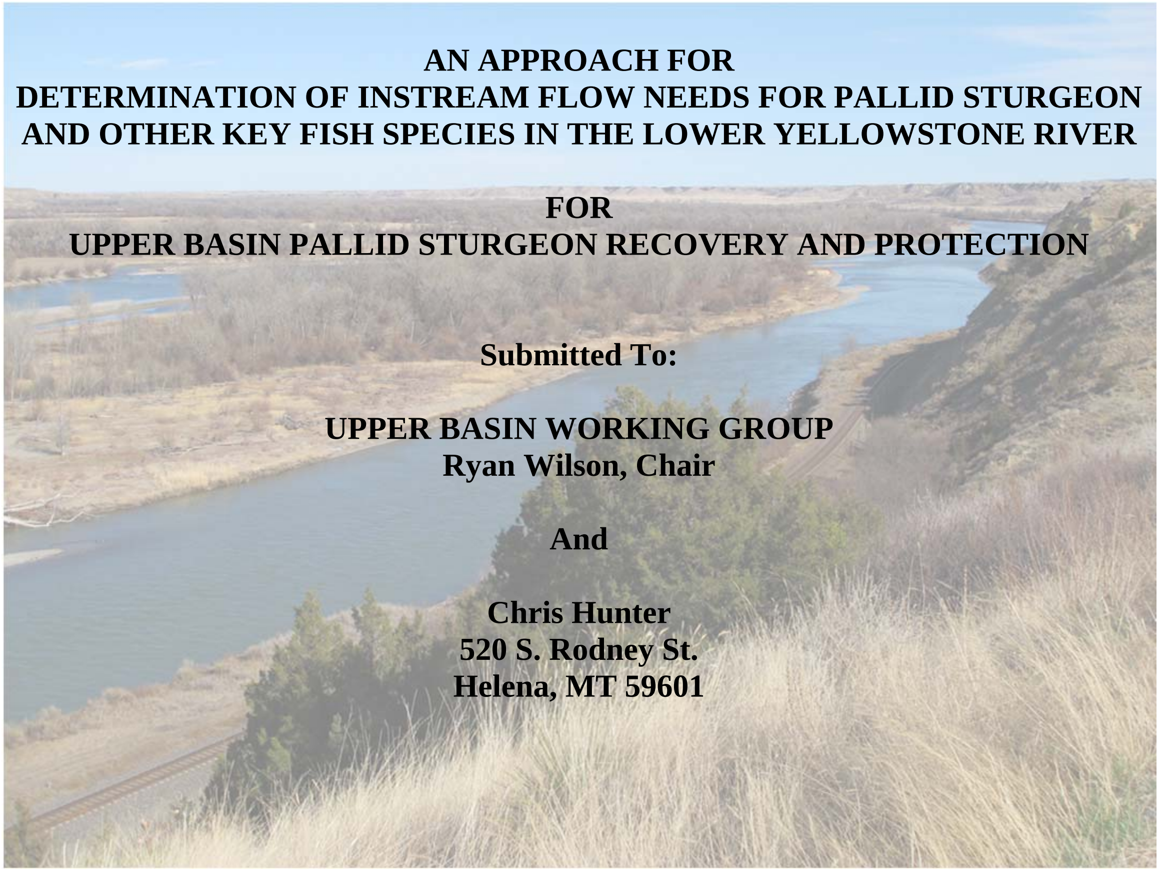
Final Report



AN APPROACH FOR DETERMINATION OF INSTREAM FLOW NEEDS FOR PALLID STURGEON AND OTHER KEY FISH SPECIES IN THE LOWER YELLOWSTONE RIVER

FOR
UPPER BASIN PALLID STURGEON RECOVERY AND PROTECTION

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Executive Summary

The Missouri River natural resources Council requested the development of an approach to determining Instream Flow Needs (IFN) for pallid sturgeon (*Scaphirhynchus albus*) and other native fish in a lower Yellowstone River from its confluence with the Bighorn River to its mouth at the Missouri River. This report provides the basis and background information for a recommended approach to determining instream flow needs. The approach presented here relies on existing data and other information that can be used to develop an instream flow recommendation for the lower Yellowstone River. Further it outlines additional data needed to go beyond use of the current data and provides recommendations for additional methodologies that could be employed with additional data gathering.

There were three objectives to development of the flow recommendation approach.

1) Review and analyze existing biological, hydrological, geomorphological data, as well as, the habitat requirements of the native fish assemblage and other relevant reports and studies to evaluate their adequacy for developing an instream flow regime for the lower Yellowstone River from its confluence with the Bighorn River to its mouth.
2) Identify additional data collection and analysis needed, if any, to develop an instream flow regime for the lower Yellowstone River from its confluence with the Bighorn River to its mouth. The purpose of this objective is to identify information gaps in existing data in a way that allows the Upper Basin Pallid Sturgeon Working Group (UBWG) to determine if collecting additional information will substantially improve our understanding of pallid sturgeon instream flow requirements and is cost and time effective.
3) Provide detailed recommendations on developing an instream flow regime for the lower Yellowstone River from its confluence with the Bighorn River to its mouth based on existing data, reports, and studies reviewed and analyzed in Objective 1 as well as additional data and analysis needs if any identified in Objective 2. The purpose of this objective is to create a comprehensive plan for the UBWG to follow in developing instream flow requirements for pallid sturgeon in the Yellowstone River.

We used an electronic data search and meetings with key agencies and individuals to locate the existing data. There are online data available on websites from agencies such as MFWP, USFWS, USGS, and Yellowstone River Conservation District Council. We supplemented the online search with personal contacts at these agencies. After the data was located and acquired, we cataloged the data according to subject with keywords and search terms. When practical, we used searchable electronic file formats to assist in the development of a strategy for developing instream flow need for pallid sturgeon and associated ecosystem in the Yellowstone River. We used the results of the data review to identify specific data gaps or limitations in the existing data sets. Any data gaps also included a list of approximate time and cost to acquire the data and what benefit that data

may bring to developing and instream flow regime. Detailed recommendations are included in this report, which documents the existing data (with a list of the documents in the references section and full reports, when available on a separate CD), a review of the existing data and its applicability to developing an instream flow regime, a discussion of data gaps and the cost and benefit of obtaining the missing data to develop an instream flow recommendation.

The potential approaches for developing instream flow recommendations range from river wide techniques based on generalized metrics to site specific approaches based on the needs of a specific species or group of species. The broad based approach is more appropriate where knowledge about flow-habitat needs of specific life stages or species are limited and generalized flow-ecology relationships can be derived. Site specific approaches are more appropriate where data or studies about individual species or groups of species have been collected. Several key ecosystem components are needed for defining instream flow needs and making instream flow recommendations. A comprehensive flow regime includes components of hydrology, geomorphology, biology, water quality and connectivity (Annear et al. 2004). There are approaches to instream flow determinations that include some but not all of these components.

The data requirements for each method or hydraulic model are similar but vary in the level of detail required. For each hydrologic approach, the data include hydrologic data, either gaged or synthesized for each stream or stream reach. Hydraulic model data include a channel description, stage–discharge relationships, hydrologic data, and, for the habitat suitability models, habitat suitability of use criteria for each species of interest. The hydrologic approaches require hydrology data for each stream or stream reach of interest. These data include, average annual discharge and if available, monthly or daily flow statistics to determine hydrograph shape. Hydrologic data sets for the lower Yellowstone River and Missouri River are available from USGS gage records. Habitat suitability of use criteria is required for any approach that couples hydraulic simulations and habitat use. For each approach, either one-dimensional or two-dimensional, hydrologic data are required, which are used to develop the relationship of flow with time.

Fish species have certain habitat requirements that can differ by life stage and by season. Data for habitat studies on pallid sturgeon and other key fish were reviewed to determine data for habitat use. Since the historical range of the species was throughout the Missouri River basin, studies from other sections of the river were included in the analysis to broaden the data sets for the habitat analysis. Numerous studies on pallid sturgeon life history, biology, reproduction, and migration have been conducted on the lower Yellowstone River and Missouri River since the 1970s. Additional biological studies were conducted in the 1980s and 1990s and continue to present. These data are applicable to the development of instream flow recommendations for pallid sturgeon.

The existing data from biological and physical habitat studies have sufficient information for use in making preliminary determinations of the instream flow needs for pallid sturgeon and other fish species in some reaches of the lower Yellowstone River. The evaluation of IFN for the Missouri River was not included in the original scope of work, however, after the data analysis and review it is apparent that adequate data exists to include the Missouri River from Fort Peck Dam downstream to the Yellowstone River in an Instream Flow Recommendation for Pallid Sturgeon. Many of the same data that would be utilized for the lower Yellowstone River are applicable to the Missouri River downstream of Fort Peck Dam. Further, the telemetry studies for pallid sturgeon document the use of both rivers by individual pallid sturgeon over multiple years. This biological link demonstrates the importance of developing concurrent instream flow recommendations on both rivers.

The instream flow determinations should include seasonal periodicity for the main species of interest and other species upon which they depend. Examples of this periodicity include spawning migrations, larval drift, and juvenile and adult feeding and resting behaviors. The instream flow determinations should specify which species and lifestage is the priority for each month or time period. The determinations should also include the rationale for how the determinations benefit other species present during those specific time periods.

The data analysis process for the instream flow determination downstream of Intake Dam would require the use of existing River2D data sets combined with the existing habitat use data. The habitat suitability criteria would need to be calculated from the existing habitat use data sets. This analysis would likely require one to two weeks time after all data sets are acquired. The data from the Gerrity studies has been acquired and is in digital form. The data from studies by Bramblett, Fuller and Bratten would need to be acquired. The data from the recent migration studies and larval drift studies would need to be obtained from the researchers.

The USGS collected River2D data sets that were evaluated as part of this project. River 2D simulation data files for the Intake, Elk Island, and Fairview sites are in digital form for a range of flows. New flows for those sites could be readily simulated if needed. Simulations for new flow would require approximately 1 day per flow. River2D data files from the Missouri River sites were acquired with the lower Yellowstone River River2D files. The Missouri River River2D files would need to have further evaluation but a preliminary analysis shows that the data sets could be used.

Habitat output for analysis could either be directly taken from River2D, if habitat suitability were generated for the model, or could be analyzed in a GIS framework. The habitat-flow relationships generated by River2D can be combined with hydrology data for a time series analysis.

A site-specific instream flow study is recommended upstream of Intake Dam on the lower Yellowstone River. A new instream flow study for site specific data is needed to develop instream flow needs for the lower Yellowstone River from Intake Dam upstream to the Bighorn River. While there are several potential instream flow techniques that could be applied, a two dimensional hydraulic model is recommended. The preferred model for the study is River2D from the University of Alberta to be consistent with other instream flow studies conducted on other sections of the lower Yellowstone River. River2D was used for instream flow studies downstream of Intake Dam and on the Missouri River between the Yellowstone River and Fort Peck Dam.

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Introduction

The Missouri River natural resources Council requested the development of an approach to determining Instream Flow Needs (IFN) for pallid sturgeon (*Scaphirhynchus albus*) and other native fish in a lower Yellowstone River from its confluence with the Bighorn River to its mouth at the Missouri River. This report provides the basis and background information for a recommended approach to determining instream flow needs. The approach presented here relies on existing data and other information that can be used to develop an instream flow recommendation for the lower Yellowstone River. Further it outlines additional data needed to go beyond use of the current data and provides recommendations for additional methodologies that could be employed with additional data gathering. There were three objectives to development of the flow recommendation approach.

Objectives

The objectives include:

4) Review and analyze existing biological, hydrological, geomorphological data, as well as, the habitat requirements of the native fish assemblage and other relevant reports and studies to evaluate their adequacy for developing an instream flow regime for the lower Yellowstone River from its confluence with the Bighorn River to its mouth.
5) Identify additional data collection and analysis needed, if any, to develop an instream flow regime for the lower Yellowstone River from its confluence with the Bighorn River to its mouth. The purpose of this objective is to identify information gaps in existing data in a way that allows the Upper Basin Pallid Sturgeon Working Group (UBWG) to determine if collecting additional information will substantially improve our understanding of pallid sturgeon instream flow requirements and is cost and time effective.

6) Provide detailed recommendations on developing an instream flow regime for the lower Yellowstone River from its confluence with the Bighorn River to its mouth based on existing data, reports, and studies reviewed and analyzed in Objective 1 as well as additional data and analysis needs if any identified in Objective 2. The purpose of this objective is to create a comprehensive plan for the UBWG to follow in developing instream flow requirements for pallid sturgeon in the Yellowstone River.

Methods

There are numerous studies and reports on the lower Yellowstone River Ecosystem that date to the 1970s. There are several tasks required to accomplish the overall objectives. These include:

1) Review and analyze the existing data.

This portion of the project included review and analysis of existing biological, hydrological, geomorphological data, as well as, the habitat requirements of the native fish assemblage and other relevant reports and studies to evaluate their adequacy for developing an instream flow regime for the lower Yellowstone River from its confluence with the Bighorn River to its mouth. We used an electronic data search and meetings with key agencies and individuals to locate the existing data. There are online data available on websites from agencies such as MFWP, USFWS, USGS, and Yellowstone River Conservation District Council. We supplemented the online search with personal contacts at these agencies.

After the data was located and acquired, we cataloged the data according to subject with keywords and search terms. When practical, we used searchable electronic file formats to assist in the development of a strategy for developing instream flow need for pallid sturgeon and associated ecosystem in the Yellowstone River.

After the data was located and compiled, we reviewed the information for applicability to developing the IFN. Key components included in the analysis were: a) instream flow data from previous studies, both 1D and 2D; b) hydrology data for flow regimes; c) biological data including habitat use, life history requirements, food habits, reproductive strategies, migration and movement; d) information on connectivity of river reaches, geomorpholgy and fish passage, and e) data on water quality for the lower Yellowstone. These key study components were used to catalog the studies into relevant categories. The primary selection factor for use in the approach was whether the data or study contains qualitative or quantitative data. Quantitative data is preferred over qualitative data, however, qualitative data may provide insights into behavioral needs that can be incorporated into the process for developing an IFN. The review included comments on each study or data set for future use or reanalysis. One example is the existing instream flow data from 2D habitat studies. There are existing 2D studies conducted by the USGS Fort Collins Science Center that might be used for additional analysis. Data sets such as these were reviewed and specific recommendations made regarding applicability of the data to the IFN, whether a reanalysis is needed or possible, and how to best use the data with the other data for the IFN.

2) Identify additional data collection and analysis needed, if any to develop an instream flow regime for the lower Yellowstone River.

This task followed Task 1 and used the results of the data review to identify specific data gaps or limitations in the existing data sets. Any data gaps also included a list of approximate time and cost to acquire the data and what benefit that data may bring to developing and instream flow regime.

3) Provide detailed recommendations on developing an instream flow regime for the lower Yellowstone River.

The detailed recommendations are included in this report, which documents the existing data (with a list of the documents in the references section and full reports, when available on a separate CD), a review of the existing data and its applicability to developing an instream flow regime, a discussion of data gaps and the cost and benefit of obtaining the missing data to develop an instream flow recommendation.

Results and Discussion

Overview of Instream Flow Techniques

The potential approaches for developing instream flow recommendations range from river wide techniques based on generalized metrics to site specific approaches based on the needs of a specific species or group of species. The broad based approach is more appropriate where knowledge about flow-habitat needs of specific life stages or species are limited and generalized flow-ecology relationships can be derived. Site specific approaches are more appropriate where data or studies about individual species or groups of species have been collected.

Several key ecosystem components are needed for defining instream flow needs and making instream flow recommendations. A comprehensive flow regime includes components of hydrology, geomorphology, biology, water quality and connectivity (Annear et al. 2004). There are approaches to instream flow determinations that include some but not all of these components.

Hydrology based approaches have been and are still used to specify flow regimes. Older methods such as the Tennant (1976) used a threshold type approach to specify a particular flow amount. Newer methods incorporate ecosystem function as well as hydrology components. These methods include the Ecological Limits of Hydrologic Alteration (ELOHA) (Poff et al. 2010) and Indicators of Hydrologic Alteration (Richter et al. 1996). These latter approaches have been applied in the lower Missouri River for specifying flow regimes for river function (Galat and Lipkin 2000; Jacobson and Galat 2008). The main assumption with the hydrology base models is that providing flows that follow the natural pattern will result in an ecological response. In river systems with a relatively large hydrologic alteration from natural conditions, the response may be more evident than in river systems with small hydrologic alterations.

Hydrologic and Biological Processes

Recently, research has focused on comprehensive ecologically-based hydrology regimes for management of riverine systems to provide function for both instream aquatic biota as well as near-stream riparian areas (Bunn and Arthington 2002, Chapin et al. 2002,Lytle and Merritt 2004, Lytle and Poff 2004, Richter et al. 2003). Natural flow regimes, with both floods and droughts, occurred for many years prior to any river regulation. The native biota in these ecosystems are adapted to changes in the physical environment as well as the biological adaptation to withstand floods or prolonged droughts in those systems (Lytle and Poff, 2004). Lytle and Merritt (2004) in their study of riparian forests concluded that a natural flow regime was the best prescription for maintaining near-stream cottonwood riparian areas.

In addition to instream flows, research has focused on river conservation and restoration (Trush et al. 2000). The study of river ecosystems includes all of the riverine components listed by the Instream Flow Council in the context of a functioning system that provides the components necessary for restoring and maintaining a diverse ecosystem similar to natural conditions (Annear et al. 2004).

The dynamic character of river systems has been stated as one of the important features in maintaining ecological integrity (Poff et al. 1997). The natural variability within riverine systems needs to be considered as part of restoration and flow manipulation efforts. Any specified instream flow management should include a strategy for incorporating this natural variability and also the potential uncertainty involved with that in restoration of river systems (Wissmar and Bisson, 2003).

Clipperton et al. (2003) incorporated four ecosystem components into a Instream Flow Needs Determination for the South Saskatchewan River Basin. The four components were: 1) fish habitat; 2) water quality; 3) riparian vegetation; and 4) channel maintenance. The objective of their determination was to provide a high level of protection for the riverine ecosystem that could be achieved by instream flows alone. Further, they wanted to provide for protection of aquatic habitats in the short term while protecting processes that maintained aquatic habitat in the long term.

Physical components of riverine systems that affect the biota both in the riparian and instream areas include hydrology, geomorphology, and water quality. Hydrology within riverine systems, especially in systems with snowmelt-driven hydrographs, usually have spring or early summer peak flows with base flows occurring in fall through winter. The magnitude and duration of the peak flows are variable and dependent on annual snowpack and also rainfall events that occur after snowpack has subsided. These flows affect the stream morphology. Specific flow magnitude and duration are required to move sediment, initiate channel migration, create and maintain habitat, and incorporate organic material in the form of woody and other organic debris into the system.

Research has shown that the geomorphic changes occur with peak flows of various return intervals. Hill et al. (1991) discussed the need for large flow events for channel migration and valley form influences. These events are generally large events that occur approximately 1 in 25 years or greater. More frequent flooding occurs on nearly an annual basis. These flows occur at a bankfull or slightly higher than bankfull level and are shown to rework channel features without a lot of channel migration. In general, these flows occur every 1.5 to 2 years in most stream systems. Research has shown that flows that occur during the annual peaks do most of the in-channel reworking of bars and instream habitat to create habitat for the base flow period of the year.

By considering various physical processes that occur in river systems, particularly in alluvial systems with cobble and gravel bedforms such as the the lower Yellowstone River, flow regimes can be specified that will modify channel morphology. These modifications can move from a present day condition which may be a detached floodplain and incised channel to a more connected floodplain with a less incised channel which provides function for both instream and near-channel riparian habitat (Trush et al. 2000). Riparian corridors also include terrestrial species of plants and animals that depend on instream flows. High flows during runoff inundate riparian areas which promotes new vegetation growth, maintains existing vegetation, and carries organic material into the stream channel.

The ecological flows should have a recurrence interval for overbank flooding that is approximately 1.5 to 2 years between flow events, to maintain connectivity with the riparian areas and maintain longevity of riparian forests. In addition the specified bankfull flows, to maintain instream channel habitat and create new habitats, should occur at a frequency that is generally found in the natural system and is suitable for present channel conditions. Habitat flow relationships for baseflow conditions and other seasons of the year can be determined from stream cross-sectional data for riffles. The riffle area is an indicator of benthic invertebrates' productivity.

Site Specific Instream Flow Methods

There are a variety of methodologies available for habitat evaluations in aquatic systems. Over the last 30 years, a wide variety of techniques have evolved, ranging from simple office procedures to very complex field and computer simulation techniques. The best approach for any analysis requires an evaluation of the problem and a determination of the level of detail needed to support the decisions (Stalnaker et al. 1995). The options evaluated here range from standard setting methods to two-dimensional (2-D) hydrodynamic models. Additional discussion of other instream flow methods is presented in Annear et al. (2004).

Standard Setting Methods

Standard setting methods are generally used in planning level instream flow assessments (Stalnaker et al. 1995). The projects employing these methods generally are not controversial, require a quick decision, and are based mainly on historical water supply data. These standard setting methodologies are not as well suited to negotiation as the incremental techniques.

One example of this type of method was developed by Tennant (1976). The Tennant method is an office type of procedure that judges the health of habitat based on a percentage of the historical annual hydrograph (Table 1). Health is determined by the flow as a percent of the mean annual flow for the winter period, October through March, and the summer, April through September. For example, minimum instream flows that meet 30 percent of the mean annual flow during October through March, and 50 percent of the mean annual flow from April through September, are judged to be excellent for the aquatic system (Tennant 1976). This simplistic approach is not appropriate for a complex system requiring sophisticated analyses (Stalnaker et al 1995). Annear et al. (2004) recommended that different flows should be recommended for different times of the year to follow the natural hydrograph to the extent allowed.

Table 1. Tennant Method instream flow regimes.

	Recommended Baseflow Regime	
Condition	**April-September**	**October-March**
Optimum Range	60% - 100% of the average flows	
Outstanding	60%	40%
Excellent	50%	30%
Good	40%	20%
Fair or degrading	30%	10%
Poor or minimum	10%	10%
Severe degradation	10% of average to zero flow	

Another type of standard setting method that is used for instream flow analysis is the evaluation of the change in wetted perimeter under varying flow conditions. This technique is used in several western states, including the state of Montana. An extensive review of this method including a description of appropriate applications is provided by Leathe and Nelson (1989).

The wetted perimeter technique requires obtaining cross-section measurements at strategic locations in the stream, usually riffles, and a hydraulic analysis of changes in wetted perimeter with flow. The measurement of the wetted perimeter is plotted versus streamflow, showing that as streamflow is reduced, the productive area of the stream becomes dewatered. At the point where the slope of the wetted perimeter line has a sharp downward shape, due to reduced flows, the productivity in the stream decreases rapidly. In some instances, there are upper and lower inflection points. These points note the initial change (upper inflection point) and point of rapid change (lower inflection point) in wetted perimeter. The discharge associated with an individual inflection point or somewhere between the upper and lower inflection point is used to set the minimum flow level for the stream.

In general, the standard setting methods are used to set minimum flows, not to judge change in habitat over a range of conditions. Standard setting methods have already been applied to the lower Yellowstone River in the 1970s and are not the recommended approach for a new determination of instream flow needs.

Other models have been developed to better address changes in habitat conditions relative to changes in flow, including both one dimensional and two-dimensional habitat models. These methods are generally described as incremental flow methods.

Incremental Flow Methods

One-Dimensional Habitat Models

In the late 1970s, several new methods were developed for instream flow evaluations that incorporated a habitat index component (Stalnaker et al. 1995). The foremost of these methods is the instream flow incremental methodology (IFIM). The main components of IFIM are the hydraulic and habitat simulation models generally referred to as the physical habitat simulation system (PHABSIM). This methodology, described in the detail by Bovee (1982) and Bovee et al. (1998), is used for a wide variety of stream systems and aquatic species. It requires field data collected from the stream or river under investigation. These data include hydraulic cross-section data to represent the physical habitat and habitat suitability of use indices for the target fish species (Figure 1).

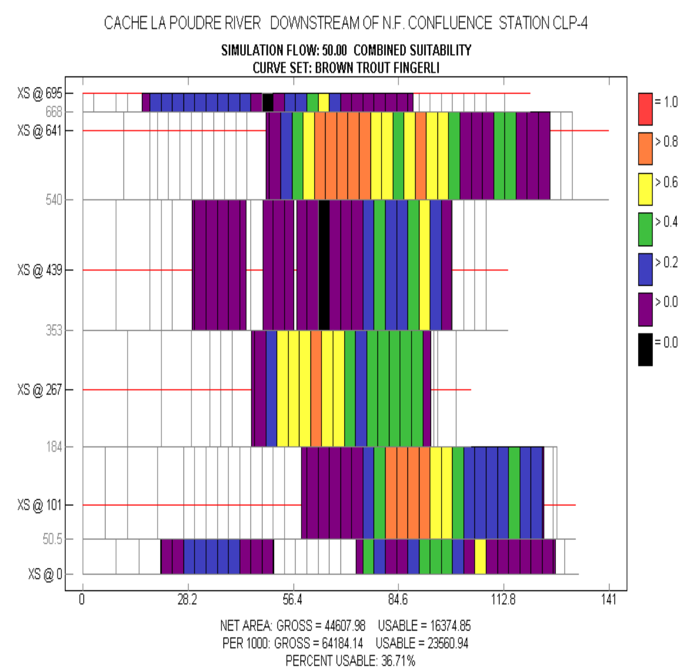

Figure 1. One-dimensional model representation of river channel (units for X and Y axis are in feet, legend on right side y axis is decimal weighting factor.)

This methodology can employ either a representative reach approach or a habitat mapping approach. The representative reach approach requires the investigator to select a section or sections of the river that are representative of the habitat components found in that river. A study site is then located within each representative section. Cross sections are placed within the study site to collect data used to define the hydraulic and habitat characteristics of that representative section. The hydraulic simulations use one-dimensional models to represent flow characteristics for depth and velocity at selected points along the cross section. It is assumed that these points are representative of the hydraulic conditions upstream and downstream from the cross section. The river is schematically represented as a series of rectangles across the stream at each cross section (Figure 1).

The habitat mapping approach requires hydraulic data collected at several cross-sectional locations representing the available habitat in the river including riffles, pools, and runs. The one dimensional models do not include the capability to evaluate complex habitats such as eddies or backwaters. The hydraulic portion uses standard hydraulic simulation techniques that rely on either energy gradients through the stream or step backwater techniques to simulate streamflow over a range of discharges. The model assumes a fixed bed with no change in bed elevations (scour or fill) over the range of flows simulated. This assumption is true for all one-dimensional and most two-dimensional hydraulic models.

Both the representative approach and habitat mapping approach require development of habitat suitability of use criteria. These criteria are developed by collecting data on depth and velocity at point locations where the species of interest occur in the stream. These data are not segregated by habitat type, only by the intervals within the measured variables. This allows for a continuum of depth and velocity suitability criteria for the full range of conditions expected in the river under study. No distinction is made within the model between different types of habitats, in terms of suitability values. Habitat specific criteria could be developed for each habitat type, but generally are not, due to the large number of collections required to develop the criteria.

The habitat suitability indices are developed from point measurements in micro-habitats, which are generally limited to depth and velocity at the locations where the species of interest is observed. This methodology does not simulate habitat or stream hydraulics over the river surface area. All simulations are made at specific points in the stream and extrapolated to represent a pseudo-surface area based on the wetted channel width (Figure 1). The point measurements and simulations along cross sections are extrapolated upstream and downstream from the cross section. This forms rectangles that represent the hydraulic conditions. The hydraulic conditions for each rectangle are compared with the habitat suitability criteria to determine a weighting factor. The weighting factor is calculated as follows:

$$\text{Weighting factor} = (SI_{di}) * (SI_{vi}) * (SI_{chi})$$

Where :

SI_{di} = suitability index for depth at location i

SI_{vi} = suitability index for velocity at location i

SI_{chi} = suitability index for channel index (substrate or cover) at location i

The surface area is multiplied by the weighting factor to calculate the Weighted Usable Area (WUA) for each rectangle. The WUA for all rectangles is summed to calculate the WUA for each simulated discharge.

While this method provides a means of more sophisticated analysis for the aquatic system of interest, its main assumption is that the hydraulics and habitat simulated at points in the stream are representative of a wider area surrounding that measurement or simulation point. The result is a function of weighted usable area vs. streamflow (Figure 2), which is the theoretical change in habitat as streamflow changes. This methodology requires a hydrology time series to evaluate the change in habitat with time. The result of the time series analysis is the decision point for this methodology.

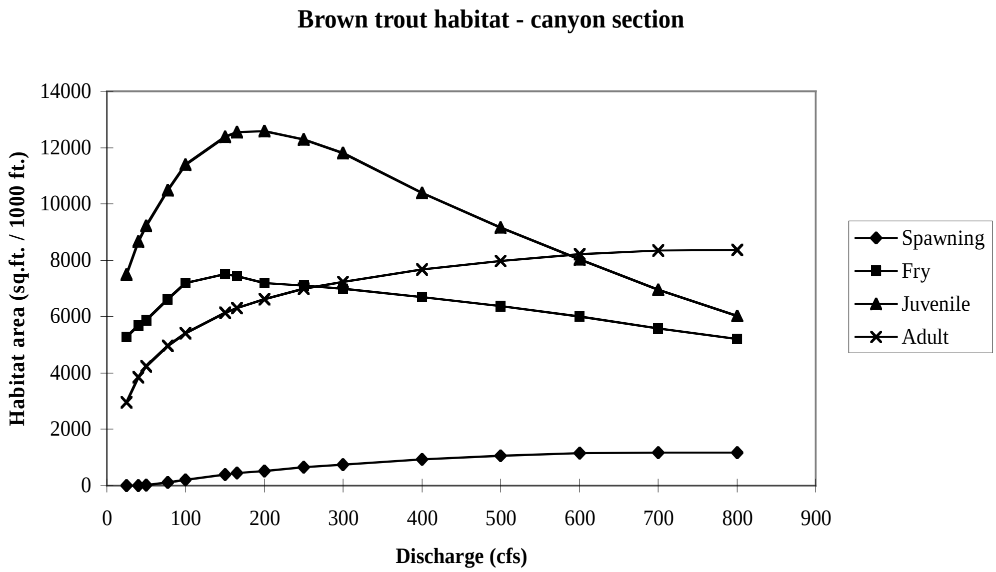

Figure 2. Example of the relationship between weighted usable area (WUA) and discharge for different life stages of brown trout.

The IFIM methodology has been applied to many streams in the western United States to develop instream flow recommendations for water management alternatives. The PHABSIM portion of IFIM is well suited to complex water management evaluations but is limited in its hydraulic simulation capabilities. The field data set is much more extensive than the standard setting techniques and requires multiple field data collection efforts for each study site.

The main limitation of 1-D PHABSIM is its inability to model complex velocity areas such as eddies and backwaters. This limitation can be overcome by using a two dimensional model. Stream size can also be a factor in model accuracy. Very small streams (first order) are hard to model with either approach. Larger streams (second order and larger) can be modeled with either model, however, the more complex the hydraulics become, the less accurately a one dimensional model will simulate the stream. PHABSIM could be used for determination of instream flow needs in the lower Yellowstone River.

Two-Dimensional Hydraulic Models

Two dimensional (2-D) hydrodynamic models have been used mainly for the determination of river hydraulic characteristics to determine the impacts of channel modifications (e.g., bridge abutments, channelization, diversion structures) on the stability of upstream and downstream channel areas. Only recently has 2-D modeling been incorporated into habitat evaluations (Leclerc et al 1995, Miller et al. 2004). 2-D modeling is the approach recommended by the USGS.

The 2-D models can simulate river areas with complex flow characteristics such as backwaters, eddies, and braided channels. The 2-D model requires river topography and velocity data just as the one-dimensional models discussed earlier do. The 2-D model data are usually more complex to better represent the water surface area at the study site. The 2-D models use a mesh to represent the streambed and analysis framework (Figure 3).

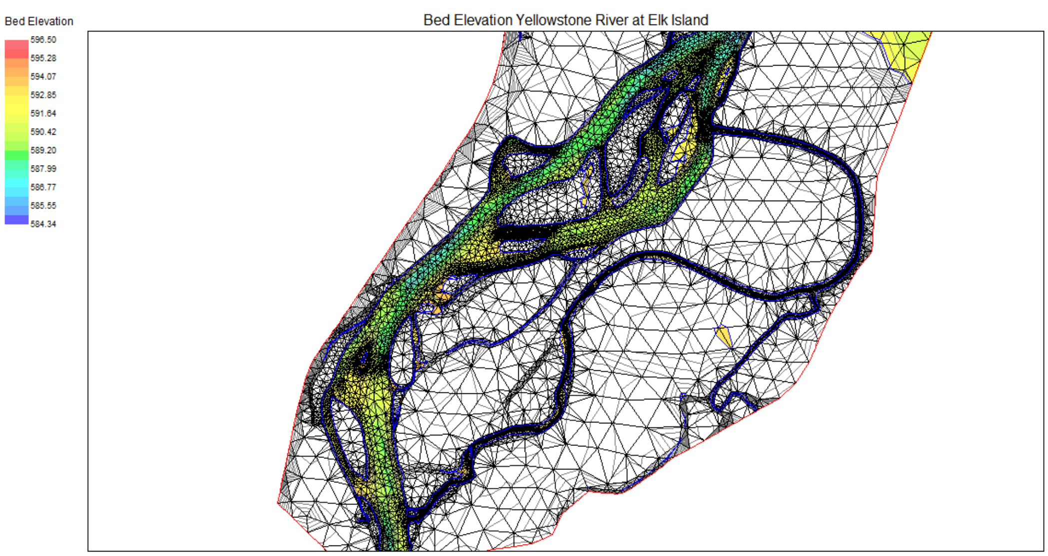

Figure 3. 2-D Representation of river study site.

The resulting 2-D hydraulic simulation can predict velocity by direction rather than only in the downstream direction, as in the one-dimensional model. These complex velocity patterns more accurately represent areas with complex velocity patterns such as eddies. Rivers with islands and channel braiding are better represented with 2-D models.

The selection of study sites for the 2-D model is similar to the selection for IFIM study sites. The field technique with 2-D does not require the investigator to estimate how far each cross section represents a certain stream area since the 2-D mesh can be adjusted to match river conditions. The 2-D model requires habitat suitability criteria to be determined if habitat analysis is part of the study. There are geographic information system (GIS) software packages that can be adapted for the habitat analyses, as long as the field data for the hydraulic model are geo-referenced. GIS based modeling can be used to incorporate non-standard habitat suitability criteria into the analysis.

The combination of 2-D hydraulic models with habitat suitability criteria requires that habitat suitability data are collected for specific habitats. Each data set can then be used to generate habitat suitability criteria for a specific habitat type. The physical description, in terms of range of depths and velocities for each habitat type, can be analyzed using the GIS software to delineate suitable habitat areas. The 2-D model develops contours for velocity at each flow level (Figure 4). The hydraulic model can produce a similar data set for water depth (Figure 5). The GIS model can merge the two data sets to calculate habitat as a function of river flow.

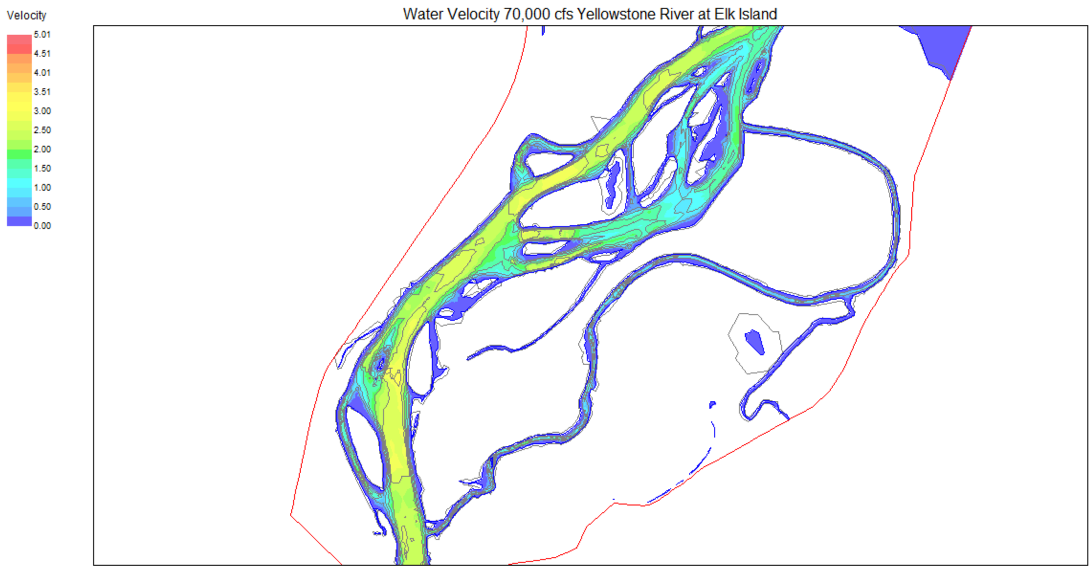

Figure 4. Example of 2-D velocity simulation.

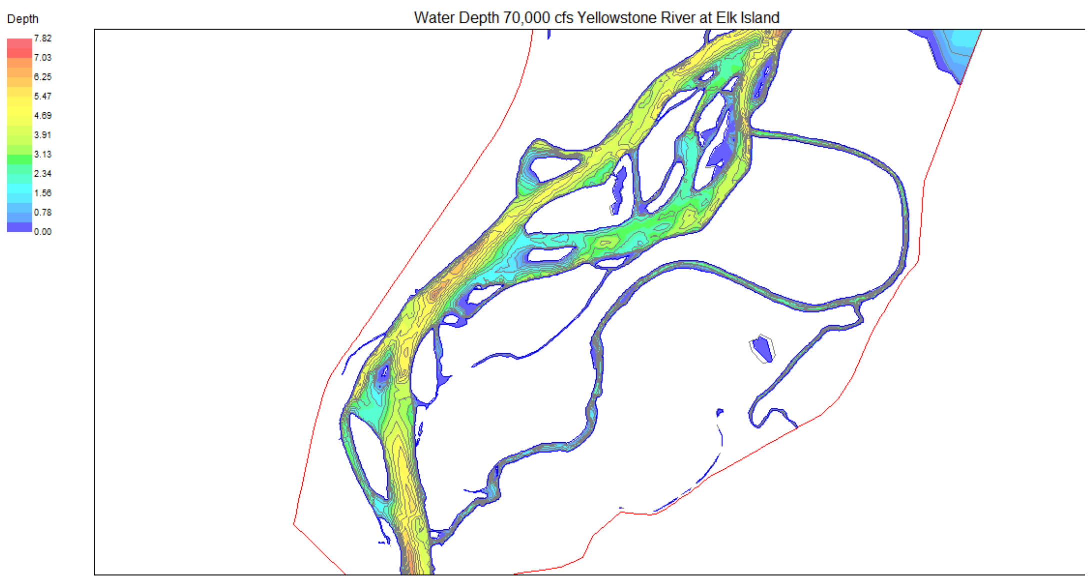

Figure 5. Example of 2-D model depth contours.

Other Habitat Methods

There are several other habitat modeling methods available for instream flow determinations. These methods range from site specific to basin wide applications. Three examples are provided below.

MesoHABSIM

MesoHABSIM is an instream flow model that was developed as an alternative approach to the Instream Flow Incremental Methodology to look at large scale habitats and river systems (Parasiewicz 2001). The objective of this methodology is to promote development and application of habitat assessment procedures capable of being incorporated into large frameworks for river restoration. This method used a large-scale quantification of major habitat units for meso-habitat types such as riffles, rapids, glides, pools and other such habitat types and overlays those using a GIS type approach onto riverine aerial photographs. These morphological units are mapped over a range of flows to provide habitat quantification as a function of flow. This mesoHABSIM type approach has been applied on the lower Platte River by the University of Nebraska. As with other PHABSIM-type approaches, the technique requires information about biological criteria for the species of interest. Biological criteria use fish presence within meso habitat units to determine the suitability of each of those habitat types for individual fish species. This procedure effectively classifies habitat units by fish abundance and takes into account the diurnal movement of fish within habitat reaches.

Application of this technique would require multiple sets of aerial photographs for habitat mapping at different flow rates. In addition, the analysis would require a collection of new biological data to determine habitat use of various meso habitats by the species of interest. Some of this data is available, however, some new data must be collected. Further, the technique may not be applicable to side channel areas whose features are obscured by dense vegetation.

Indicators of Hydrologic Alteration (IHA)

IHA is a technique that looks at hydrologic change to assess river ecosystem needs and changes to the biota within a river system was developed in the late 1990s by Richter et al. (1996). This technique uses hydrologic parameters. A group of 32 different parameters are interpreted by subgroups to look at changes from non-impacted flows to current flow regimes. The subgroups include magnitude of monthly water conditions, magnitude and duration of annual and extreme water conditions, timing of annual extreme water conditions, frequency and duration of high and low pulses and rate and frequency of water condition changes. Each of these subgroups is intended to address a specific group of ecosystem influences. The objective of the technique is to provide an analysis through an entire flow regime rather than an identification of a setting of a minimum flow.

Ecological Limits of Hydrologic Alteration (ELOHA)

Ecological Limits of Hydrologic Alteration (ELOHA) was developed recently as a method that could be used to evaluate multiple river reaches in a relatively short period of time as compared to the more time intensive site specific methods (Poff et al. 2010). This method includes both scientific and social processes. The scientific process includes evaluation of hydrologic characteristics, similar to the IHA, classifying of river segments, and developing the flow alteration-ecological response relationships. A key component of the scientific process is the development of the flow-ecology response relationships. These relationships require either data or expert knowledge on how particular ecological components (structure and function) react or respond to changes in flow. A limitation to using the method can be a lack of data to develop these relationships.

The social process is used to incorporate societal values into flow management. The first step of this process is to determine acceptable ecological conditions based on these values. The goal is not necessarily to restore pristine conditions but to understand the tradeoffs between human uses of the water and ecological degradation.

Summary

The data requirements for each method or hydraulic model, one-dimensional or two-dimensional, are similar but vary in the level of detail required. For each hydrologic approach, the data include hydrologic data, either gaged or synthesized for each stream or stream reach. For each hydraulic model discussed above, the data required include a channel description, stage–discharge relationships, hydrologic data, and, for the habitat suitability models, habitat suitability of use criteria for each species of interest.

The hydrologic approaches require hydrology data for each stream or stream reach of interest. These data include, average annual discharge and if available, monthly or daily flow statistics to determine hydrograph shape. These hydrology data can be used on either the Tennant method or IHA method. These data can also be used in the habitat time series analysis for the PHABSIM type models.

The channel description is obtained from field survey data, collected by surveying cross sections (1-D) or topography (2-D) at representative study sites. Survey data includes stream bed elevations, water surface elevations, and substrate descriptors. Stream discharge measurements are required for model calibration and to obtain velocity profiles for the river.

The channel description data provide the basis for the physical framework for the hydraulic simulation, and therefore the channel description data should include all major habitat types present in the river. Obtaining these data may require several study sites to accurately describe all of the necessary habitat conditions. Two-dimensional models usually require a higher level of resolution (i.e., more data points) for the simulations, and as such provide a finer level of detail for the analysis.

Habitat suitability of use criteria is required for any approach that couples hydraulic simulations and habitat use. Suitability criteria require rather extensive data sets to calculate suitability indices. The recommended number of observations for statistical rigor is generally over 100 data points (Bovee 1986).

For each approach, either one-dimensional or two-dimensional, hydrologic data are required, which are used to develop the relationship of flow with time. Without these data, the results of the hydraulic simulations are only theoretical values based on channel geometry. Actual habitat values are determined as a result of the stream discharges at the study site over time. The required hydrologic data sets are usually available from USGS gage records.

The following table shows a range of benefits and constraints for the various methods. Historically, the least intensive methods have been used in low priority or less controversial instream flow assessments. The methods used in less controversial projects (i.e. Tennant, Wetted Perimeter, R2Cross) can be used as part of an IFIM-type approach as additional support of the conclusions. For example, PHABSIM and River2D produce habitat area versus flow relationships, usually for fish, and the wetted perimeter analysis can be used to evaluate how the proposed flow regime impacts wetted area for benthic invertebrates. The Tennant approach could be used to develop initial target flow levels by month and then evaluate those flows with PHABSIM or River2D to determine the associated habitat value.

Table 2. Comparison of instream flow method, data requirements, constraints and benefits.

Method	Data requirements, constraints, benefits
Tennant	• USGS or other data (average annual, average monthly • Normal application results in single value for minimum flow • Modified application can result in monthly values • Inexpensive and quickly applied • Assumes biological protection to desired flows • Flows determined are "minimum" not "optimum" • Can be used in conjunction with other methods to determine year round instream flows Total analysis time ranges from 1-2 days per site
Wetted perimeter	• Requires site specific data for at least one discharge in a critical riffle (i.e. hydraulic control) • Multiple discharges allow calibration of hydraulic model • Normal application results in a single minimum flow. • Protection assumed from keeping majority of channel wet at flows equal to or higher than minimum. • Requires one or more site visits • Relatively inexpensive Total analysis time ranges from 2 to 5 days per site
R2Cross	• Requires site specific data for at least one discharge in one or more critical riffles (i.e. hydraulic control) • Multiple discharges allow calibration of hydraulic model • Normal application results in a single minimum flow for winter and another for winter. • Protection assumed from keeping majority of channel wet, depth protection for some fish passage, and adequate velocity for benthic productivity in riffles at flows equal to or higher than minimum. • Requires one or more site visits • Relatively inexpensive Total analysis time ranges from 2 to 5 days per site

PHABSIM	• Requires site specific data for channel geometry, depth and velocity at a minimum of one discharge and preferably three discharges for calibration. • Requires habitat use data for the species of interest • Normal application is for analysis of change in habitat with a series of proposed flow regimes. • Can be coupled with other analysis for use in incremental methods (IFIM) • Data intensive • Relatively expensive • Requires multiple site visits • Relatively detailed computer analysis and simulation required Usually requires 6 to 12 months for completion
River2D	• Requires detailed geo-referenced site specific data for channel geometry, depth and velocity at a minimum of one discharge and preferably three discharges for calibration. • Requires habitat use data for the species of interest • Normal application is for analysis of change in habitat with a series of proposed flow regimes. • Can be coupled with other analysis for use in incremental methods (IFIM) • Data intensive • Relatively expensive • Requires multiple site visits • Relatively detailed computer analysis and simulation required Usually requires 6 to 12 months for completion
MesoHabsim	• Visual observation technique combined with spatial mapping to determine habitat at each flow of interest • Requires high level of field effort to evaluation multiple flows • Requires moderate level of analysis effort • Moderately inexpensive Could require several months per site to obtain observations at multiple flows

ELOHA	• Requires detailed hydrologic data for analysis • Requires development of flow ecology relationship for each metric • Can be applied on a regional scale if flow-ecology relationships apply. • Includes both a scientific and social process • Can be applied to multiple watersheds in a short amount of time if flow ecology relationships do not vary Could require several months to a year to complete if data for flow ecology relationships are available.

Review of Data and Literature

The review of data and literature was separated into the five basic components described in Annear et al. (2004). These components are hydrology, geomorphology, water quality, habitat, and connectivity.

Hydrology Data

Hydrology data from current conditions and historical flows are important to understand the inter- and intra- annual variation in flows. Pallid sturgeon and the other key fish species have adapted to the historical flow regime. As flow regimes shift away from the natural variation, fish species may be impacted by the shift. The degree of hydrologic impacts the species depends on the habitat needs of the species. Hydrology affects the hydraulic habitat of the river. High flows during runoff create and maintain habitats. Alterations in these flows can alter the relationship between flow and habitat.

Hydrology data is available for several USGS gauges in the lower Yellowstone River. In addition, there are gauges on the major tributary streams in the lower Yellowstone basin. The period of record varies for each gage. One of the longest period of records is for the Yellowstone River at Miles city. The Miles City gage has data that extends from 1923 to present. The data for this gage includes years prior to the construction of the reservoirs on the Bighorn River and Tongue River that occurred in the 1950s and 1960s. Boysen

Dam on the Wind River, a Bighorn River tributary, was completed in 1952. Boysen Reservoir has a capacity of 802,000 acre feet. Yellowtail Dam on the Bighorn River was constructed between 1963 and 1966 and the reservoir has a capacity of approximately 1.4 million acre feet. Tongue River Dam was constructed in 1939 and has a normal capacity of approximately 70,000 acre feet.

The impact of these tributary dams on the mainstem peak flows is apparent from the USGS peak flow data. After the mid 1960s, the peak flows for the USGS gage on the Yellowstone at Miles City shows fewer peak flows greater than 60,000 cfs than prior to the mid 1960s (Figure 7). In addition, the majority of the peak flows are less than 45,000 cfs after the mid 1960s. The majority of the peak flows prior to the mid 1960s were greater than 45,000 cfs. It would appear that the storage on the Bighorn River may be the cause of the decline. The reduced peak flows may affect lateral connectivity to floodplains during runoff or may inhibit migration cues.

Other hydrologic parameters that can be used in the flow recommendations are the daily exceedence flows. Exceedence values of 90 percent (wet year), 50 percent (average year), and 10 percent (dry year) can be used to determine the range inter annual variability for a specific location. The daily values for these exceedence levels can be used to determine how often a particular flow is present. For example, August flows in the Yellowstone River in a dry year (10 percent value) are near 3,000 cfs at Miles City, Montana (Figure 8). These data can be used to determine the range of historical flows in the river and therefore, the desired flows based on the natural flow regime. The effect of the dams on the Bighorn River also are evident in the flows for the Yellowstone River at Sidney, Montana. Since the mid 1960s there has been a slight increase in base flows and a noticeable decrease in the peak flows (Figure 9) based on the long term gage at Sidney, Montana. An interesting change in the flow regime is the near elimination of the early initial peak discharge. Prior to the 1960s the Yellowstone River had a distinct double peak in most years. The first peak usually was nearly 50,000 cfs and occurred in late March or early April. The double peak in the hydrographs still exists but the magnitude is less than 40,000 cfs for most of the initial peak (Figure 6). The second peak was generally greater than 70,000 cfs and occurred in late May or June (Figure 10). If the pallid sturgeon spawning migrations are triggered by a flow of approximately 40,000 cfs, as hypothesized, the migration timing under a natural flow regime may have been triggered by the initial peak flows in late March or early April rather than the peak flows that now usually occur in May or June.

Zelt et al. (1999) provide a good discussion of hydrologic changes associated with changes in land use practices. In addition to basic hydrologic data, Zelt et al. (1999) provided background information on a range of hydrologic and other related river characteristics. The main impact of flow regulation from irrigation and storage has resulted in more consistent and somewhat higher base flows as well as lower peak flows (Zelt et al. 1999).

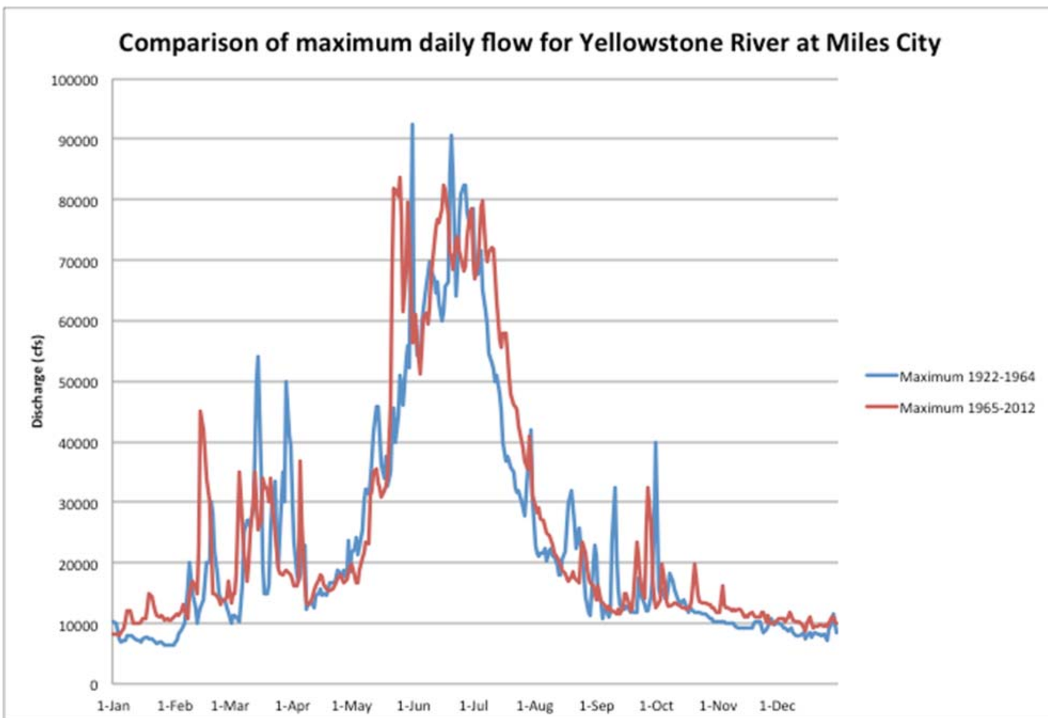

Figure 6. Comparison of daily maximum discharge for the Yellowstone River at Miles City.

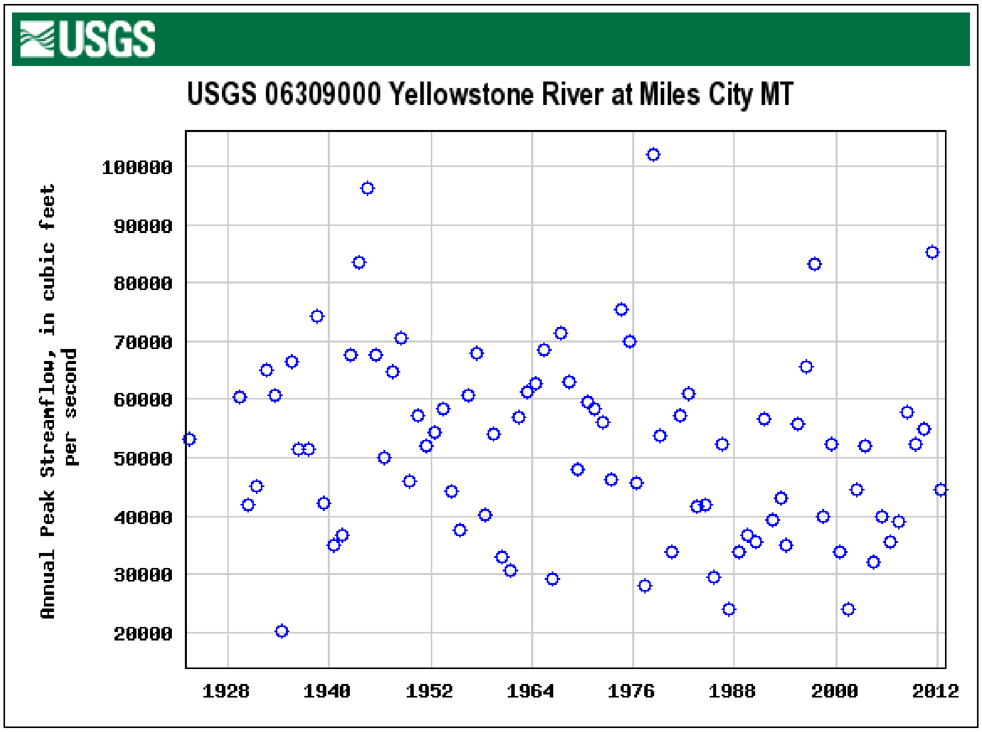

Figure 7. Peak flows for the period of record 1923 – 2012 for USGS gage 06309000 Yellowstone River at Miles City, MT.

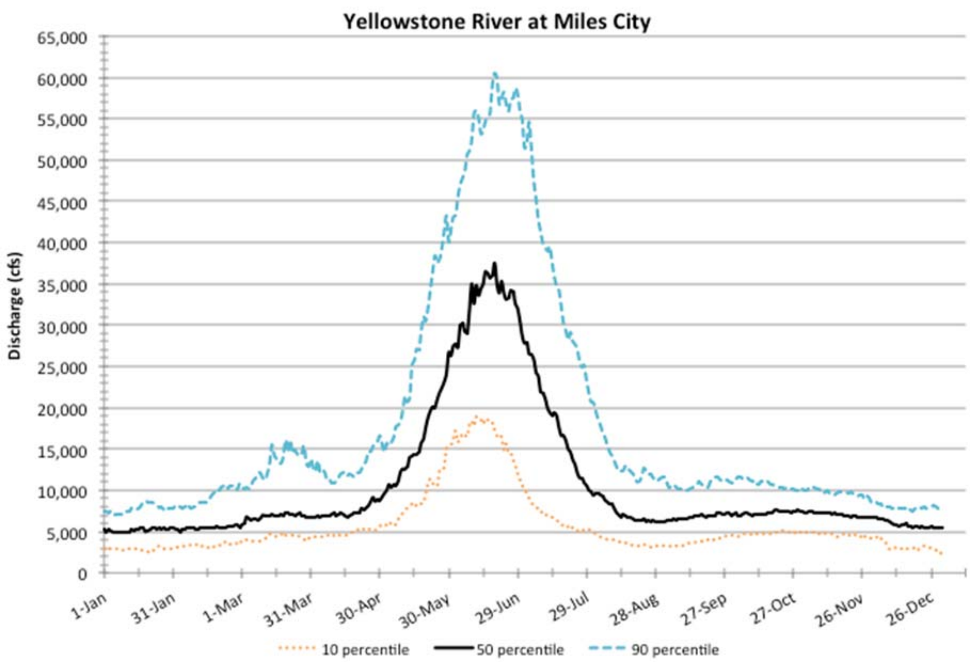

Figure 8. USGS 06309000 Yellowstone River at Miles City MT, flow exceedence percentiles for the period of record 1923 – 2012.

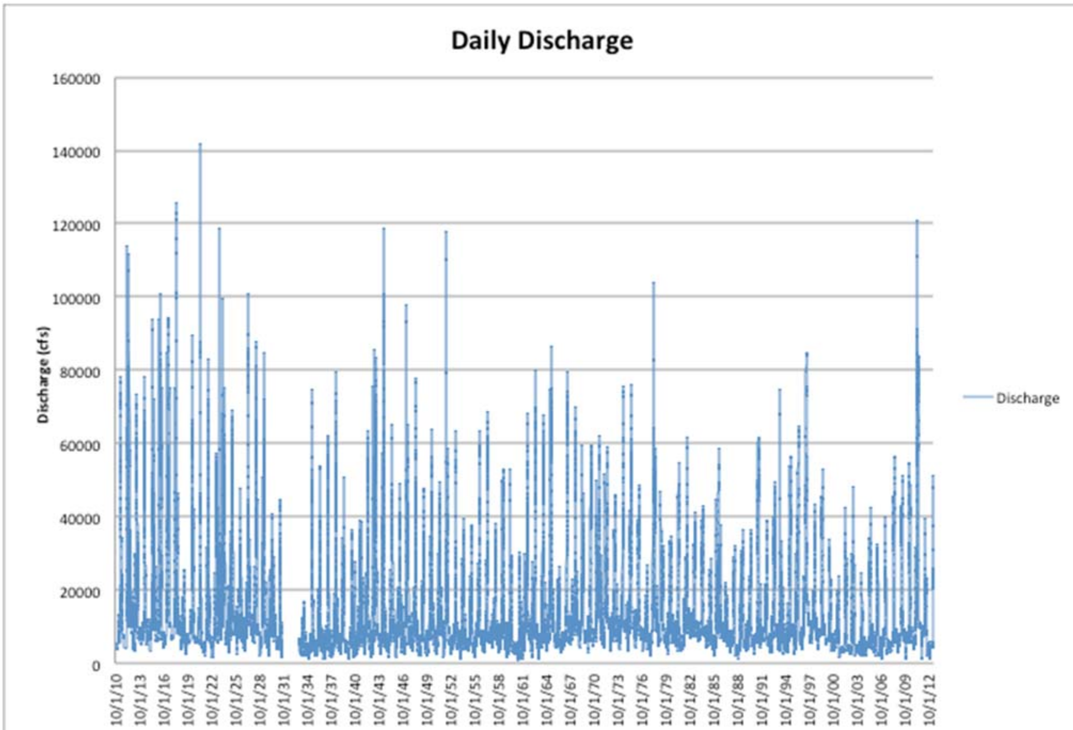

Figure 9. Average daily discharge for the Yellowstone River at Sidney, MT., 1911-2012.

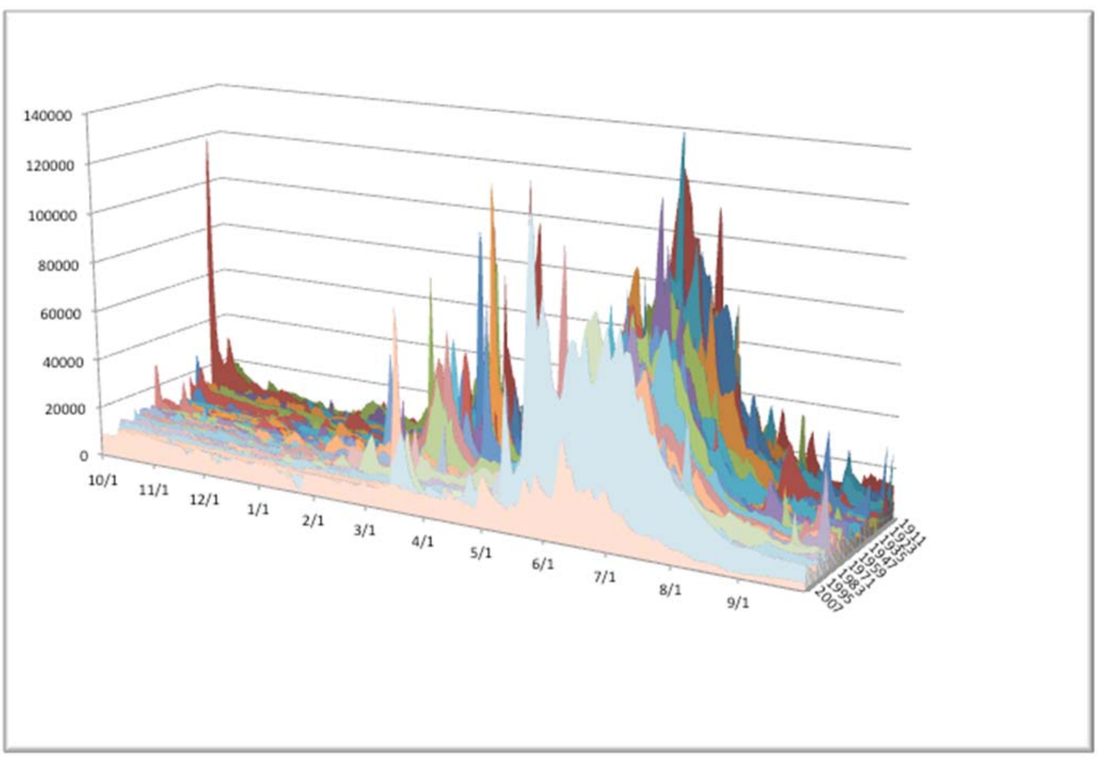

Figure 10. Annual discharge by water year for the Yellowstone River at Sidney, MT, 1911-2012.

Geomorphology

Data on geomorphology and sediment transport can be used to evaluate the amount of change associated with the change in hydrograph. The geologic and physiographic setting of the basin influences channel form and processes. The physiographic setting is described in detail by Zelt et al. (1999). A more recent study on Yellowstone River geomorphology is presented in a report to the Custer County Conservation District (Applied Geomorphology, Inc. and DTM Consulting Inc. 2004). The recent study includes descriptions of river geomorphology by river reach in the middle and lower Yellowstone River. The report also includes a description of natural grade controls in the lower Yellowstone River. The descriptions of the natural grade control structure could be used to determine physical characteristics of nature-like fish passage structures, if needed, for construction of fish passes at low head diversion dams.

There is a large amount of data available from on-line sources. One of the main sources is the Yellowstone River Corridor Resource Clearinghouse (http://nris.mt.gov/yellowstone/). This data clearinghouse includes aerial photography, inventory of physical features and land use maps. The historical aerial photography is useful in evaluating channel change over time. Channel change, or lack thereof, is an indication of channel stability, dynamics, and habitat creation and loss.

River geomorphology is also a function of sediment transport and supply. The geomorphic reconnaissance study (Applied Geomorphology, Inc. and DTM Consulting Inc. 2004) states that the sediment supply to the lower Yellowstone River from the Bighorn River has decreased by over 80% since the construction of Boysen Reservoir and Bighorn Lake on the Bighorn River. The sediment supply prior to dam construction was estimated at 7.2 million tons annually and at 1.5 million tons per year after closure of the dams. The documented changes to the Bighorn River include channel simplification and loss of gravel bars.

The reduction in sediment load and release of clean water can change the sediment dynamics in the lower Yellowstone River as well. Without the sediment source from the Bighorn River there would be less sediment transported to the lower Yellowstone River during high flows. The higher discharge during runoff would still have the power to transport sediment, which may result in more transport of local bed sediments or erosion of stream banks. The overall effect may be a more incised channel with less lateral connectivity than prior to dam construction on the Bighorn River.

Water Quality

Chemical characteristics such as dissolved oxygen (DO), alkalinity, nitrogen and pH are a function of the local geography, land use and sources of organic matter (Annear et al. 2004). Primary water quality constituents of water temperature and fine sediment data are the usual focus for instream flow prescriptions.

There is a limited amount of water quality data available for the lower Yellowstone River from USGS gages. The USGS gage for the Yellowstone River at Sidney, Montana collects data on suspended sediment and discharge. No USGS gages in the lower Yellowstone River collect daily water temperature data. Water temperature data is available from several of the ongoing studies on the lower Yellowstone River and Missouri River. The water temperature data from these studies is not a continuous record but does provide data that could be used for general water temperature evaluations.

The importance of maintaining adequate water temperature in the lower Yellowstone River was noted in the mid 1970s (MTDNR 1976). These studies include: Bramblett (1996), Bramblett and White (2001), Fuller et al. (2008) as examples of the type of data available. Other recent studies have collected water temperature data as part of their projects.

The water temperature data, while discontinuous, is available for a variety of hydrologic and meteorological conditions and should be applicable for developing instream flow recommendations. Blevins (2011) reported water quality requirements for pallid sturgeon, which could be used in conjunction with the water quality data to determine parameters that may be limiting.

Biology/Habitat

Fish species have certain habitat requirements that can differ by life stage and by season. Data for habitat studies on pallid sturgeon and other key fish were reviewed to determine data for habitat use. Since the historical range of the species was throughout the Missouri River basin, studies from other sections of the river were included in the analysis to broaden the data sets for the habitat analysis.

Numerous studies on pallid sturgeon life history, biology, reproduction, and migration have been conducted on the lower Yellowstone River and Missouri River since the 1970s. Some of the earliest comprehensive studies that we found were associated with the instream flow filing in 1980 (MTDNR 1977) and the impact study on future water withdrawals (Anderson et al. 1977) . Additional biological studies were conducted in the 1980s and 1990s and continue to present. Tews (1994) found pallid sturgeon in the lower Yellowstone River and Missouri River. The pallid sturgeon were documented to use the Missouri and Yellowstone rivers at different seasons. Tews (1994) reported pallid sturgeon in the Missouri River from August through April. The same fish were reported as using the lower Yellowstone River from April through August. Pallid sturgeon migrated into the Yellowstone River in April and May. Recent telemetry studies have shown that adult pallid sturgeon continue to migrate into the lower Yellowstone in April and May (Fuller et al. 2008).

Benthic species, including pallid sturgeon, were studied in the lower Yellowstone and Missouri rivers (Young et al. 1997). The series of benthic studies provide data on habitat use as well as species occurrence. The habitat use data should provide information for instream flow recommendations for the benthic species in the river. The data provided in Young et al. (1997) was supplemented by Berry et al. (2004) in the form of a final report for the benthic fish study. The data contained in Berry et al. (2004) is useful for developing comprehensive flow recommendations for a range of species in the lower Yellowstone.

Flow recommendations should include other species in addition to pallid sturgeon. Gerrity et al. (2006) reported on piscivory in juvenile pallid sturgeon. The main food items were native cyprinids including sturgeon chub (*Macrohybopsis gelida*) and sicklefin chub (*M. meeki*). Flow recommendations should incorporate the habitat needs of these species where data is available to develop the recommendations. There is some data on habitat use for these fishes in the benthic fishes studies.

Fuller et al. (2008) reported pallid sturgeon apparently spawning in the lower Yellowstone River shortly after river discharge peaked in 2007 with water temperatures of 20 C. Lower Yellowstone peak discharge during runoff was approximately 60,000 cfs in June, 2007. Goodman et al. (2012) reported shovelnose sturgeon spawning in response to elevated discharge in the Maria River. They concluded that certain discharge thresholds were more important than water temperature in cueing spawning. There may be a similar response by pallid sturgeon based on the data from Fuller et al. (2008). Bramblett (1996) hypothesized that the river regulation imposed by Fort Peck dam on the Missouri River flow patterns may be one reason for pallid sturgeon use of the lower Yellowstone River in spring and summer. In addition to migration triggers, discharge volumes can affect migration pathways. McElroy et al. (2012) showed that migration routes used by pallid sturgeon required less energy for migration when compared to other potential migration routes. They recommended including reservoir release manipulations to increase potential reproductive success.

Several studies have investigated larval drift and dispersal in the habitats in the Missouri River. The results of the studies by Braaten et al. (2008, 2012) can be used to develop flow recommendations for early life stage dispersal. The seasonal needs for larval dispersal in combination with other flow requirements for migration should be a component of a comprehensive flow recommendation.

Bramblett and White (2001) studied habitat use and movement of pallid sturgeon and shovelnose sturgeon in the lower Yellowstone and Missouri Rivers. They report that sturgeon moved during all seasons and times of day, however, movements were lowest in fall and winter. Bramblett and White (2001) reported pallid sturgeon using the lower portion of the Yellowstone River in spring and summer, which concurs with Tews (1994) findings.

One important aspect needed for instream flow recommendations when using standard site specific techniques are habitat suitability criteria. Gerrity et al. (2006) studied juvenile pallid sturgeon habitat use in the Missouri River upstream of Fort Peck Reservoir. Those data include information for micro habitat including depth, velocity, and substrate data. The information from that study should be transferable for use on the lower Yellowstone River, however, some validation should occur before using those criteria in the Yellowstone River. The validation can be based on physical data for each river since the species of interest is rare and collection of new data would require and extended period of time.

In addition, recent migration studies in a lower Yellowstone by Bratten, Fuller (2007) and others also collected information on depth and velocity for migrating pallid sturgeon. These migration study data could also be used to determine habitat use criteria for site-specific instream flow recommendations. McElroy et al. (2012) propose an approach for reservoir management, which could apply to the Yellowstone/Missouri system, to benefit migration and increase spawning success. Studies on habitat use and movement by Bramblett (1996) and Bramblett and White (2001) also provide habitat data for use in determining instream flow needs. In addition to the habitat studies specific to the Yellowstone River, there are habitat studies from the Missouri River that should be considered for use in developing instream flow needs on the Yellowstone. These include Hurley et al. (2004) and Jordan et al. (2006).

Data on other aquatic species in the lower Yellowstone River is less available and less abundant than the data for pallid sturgeon. There is information on habitat use of other native fish species collected in other sections of the Missouri River that may be applicable to the lower Yellowstone River. Spindler et al. (2012) studied habitat use and prey availability for juvenile pallid sturgeon. Young et al. (1997) studied habitat use and population structure of benthic fishes in the lower Yellowstone and Missouri Rivers. The final report for the benthic studies is provided in several volumes published in 2001. Not all of the volumes were available on-line but the descriptions suggest that these reports would contain data that would be useful for determining instream flow needs for benthic fishes.

Habitat data is available from several studies in the lower Yellowstone River. These data include direct measurements and computer simulations. Hydrodynamic modeling has been used to determine potential habitat by Jacobson et al. (2009) in the Missouri River. Bowen et al. (2001) used two dimensional models to identify shallow water habitats in the lower Yellowstone River and Missouri River. The studies in lower Yellowstone and Missouri rivers are directly applicable to the development of flow recommendations for those rivers. Kadlec (2010) used a GIS approach to develop a habitat suitability model from several physical habitat data sets.

Connectivity

Connectivity in rivers is the interaction between hydrology, geomorphology, biology and water quality to determine the flow and distribution of energy and other materials in the river ecosystem (Annear et al. 2004). River connectivity includes longitudinal, lateral, vertical and time components.

Longitudinal connectivity is important for species with migratory or drifting life history phases. Data on natural and man-made structures were reviewed to better understand habitat fragmentation and impact to migration and movement of the species. The impact to the species depends on the habitat requirements of the species.

The lower Yellowstone River has several low head diversion dams that may impede or disrupt longitudinal connectivity. The lowermost of these diversions is the Intake Diversion structure. This structure has been in place since 1910 and diverts irrigation water during the late spring, summer and early fall. There is a proposal to retrofit this structure to allow better function of the new head works on the Intake Canal. In addition, a fish passage channel is proposed to remove the current passage impediment.

Another consideration for connectivity is the inter-relationship between the lower Yellowstone River and the Missouri River. Several studies have shown that pallid sturgeon migrate from the Missouri River into the Yellowstone River during some seasons, in particular, during spring runoff. The importance of this connection between the two rivers should be a component considered in the flow recommendations for the lower Yellowstone River.

Lateral connectivity is important for energy flow from flood plain riparian zones into the river (Annear et al. 2004). Lateral connectivity allows access from riverine species to the flooded area during periods of high flow. These lateral connections can be important as areas for larval development. Factors that can limit lateral connectivity include man-made structures for bank protection and flood prevention. The Yellowstone River from the Bighorn River downstream to the Powder River has a relatively high amount of bank protection and levees, up to 30% of the banks in some areas (Applied Geomorphology, Inc. and DTM Consulting Inc. 2004).

Barriers to migration in the lower Yellowstone River include Intake and Cartersville diversion dams. White and Mefford (2002) provide background information on the passage impediment at Intake Dam. White and Mefford tested several fishway types using shovelnose sturgeon. They concluded that adult shovelnose sturgeon could negotiate channels with high velocities but the sturgeon could not hold or maintain position for extended periods of time. In addition, they found that eddies could delay or reduce passage success. Larger eddies caused a reduction in passage success.

Helfrich et al. (1999) studied low-head diversion dams and the relationship to fish passage, compositons and abundance. They concluded that while individual dams could be passable at certain flows the multiple dams in the Yellowstone may restrict fish distribution. They recommended modifications to the dams for better fish passage.

Data gaps and data needs for determining instream flows

Intake Dam downstream to the Missouri River

In previous projects we first develop a conceptual model of the components needed for the instream flow regime. Wildhaber et al. (2007) have developed a conceptual model for pallid sturgeon that can be applied to the instream flow approach.

Data for determining instream flows should include both physical and biological information for all river reaches of interest. There have been several instream flow studies in the lower Yellowstone River including multiple two dimensional hydraulic studies for habitat. Based on the work conducted by USGS (Bowen et al. 2003), there are data for the lower Yellowstone River from Intake Dam downstream to the confluence with the Missouri River to make instream flow determinations for some life stages of pallid sturgeon with only limited new data collection.

The study completed by Bowen et al. (2003) has multiple 2-D study sites that are representative of the lower Yellowstone from Intake downstream to the Missouri River. They did not model fish habitat suitability, only the occurrence of shallow water habitat. Further, they did not collect substrate data for the study sites. The substrate data would need to be collected and incorporated into the existing 2-D models for complete evaluation. The 2-D models would need to be run again with habitat suitability data for pallid sturgeon and other species. The data collected in previous studies by Gerrity, Bramblett, Fuller and Bratten in the upper Missouri River and Yellowstone River could be used for the pallid sturgeon in lieu of collecting new habitat suitability indices for the lower Yellowstone River. In addition, the recent habitat data collected during the pallid sturgeon migration study in the lower Yellowstone has the basic data to calculate habitat suitability indices for migrating adults. There are several studies where habitat data for other species were collected, however, the habitat suitability indices would need to be calculated. River2D uses a geo-referenced analysis framework, which allows the incorporation of non-standard habitat use data in any analysis through GIS. Since most habitat use data is in the form of habitat type (i.e. pool, riffle, run, etc) these habitat types can be analyzed using the River2D simulation output and GIS.

Bighorn River downstream to Intake Dam

The main reach of lower Yellowstone River with the most data gaps, for both physical and biological information, is upstream of Intake Dam to the mouth of the Bighorn River. The only instream flow data for that reach is in the form of the wetted perimeter modeling conducted in the 1970s. This reach would need additional data collection if a more up to date technique were to be applied to specific reaches upstream of Intake Dam. The habitat suitability data from other reaches of the lower Yellowstone River and upper Missouri River is likely transferable to the Yellowstone River upstream of Intake Dam and could be used in an instream flow determination.

The Science Review Report (PBS&J 2009) concluded that there was spawning habitat upstream of Intake Dam, which would suggest that there is sufficient habitat for use by migrating pallid sturgeon. The radio telemetry data has shown that pallid sturgeon do move up the lower Yellowstone River to Intake Dam, which indicates that if passage is provided they will move upstream of the dam.

There is very little information on habitat use by larval life stages. There are several studies on larval drift but the data is not in the standard form used for calculating habitat suitability indices. An alternative approach would be to use the results of those studies in combination with the 2-D hydraulic studies to determine the flow levels the provide access to the side channels and overbank areas where the larvae were observed.

The following graphs show the capability of River2D to provide data for water surface and velocity over a wide range of flows. These data were generated using the USGS data sets for the Elk Island site. We simulated a wide range of flows to determine the capability of the existing data sets for use in the instream flow determination. Other flows could be simulated if there are particular flows of interest based on recent studies. The change in water surface is shown in Figure 10 through Figure 13. The range of velocity changes with flow are depicted in Figure 14 through Figure 17 . There are a variety of other data that can be extracted from the River2D simulation files for additional analysis.

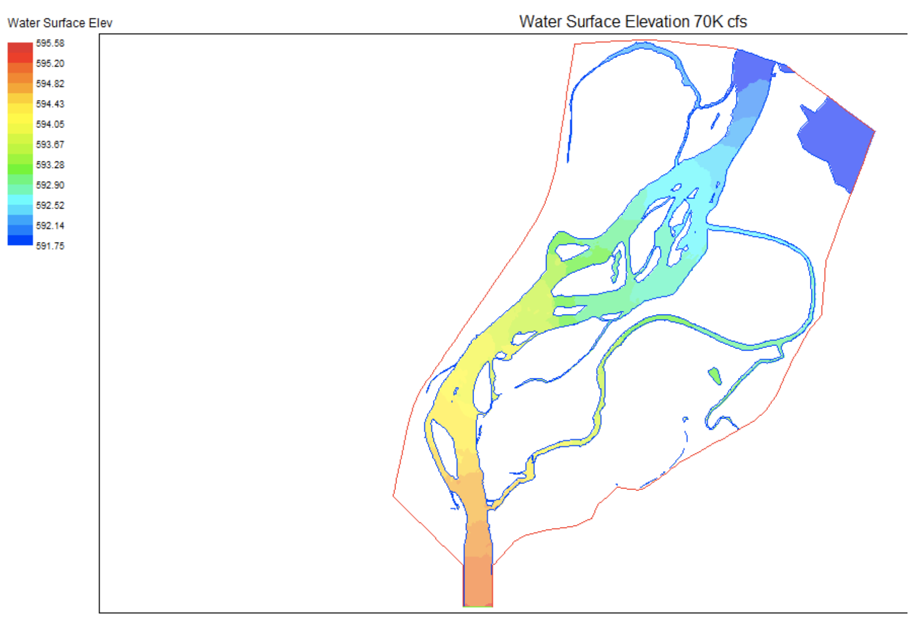

Figure 11. Elk Island study site at 70,000 cfs showing water surface elevations.

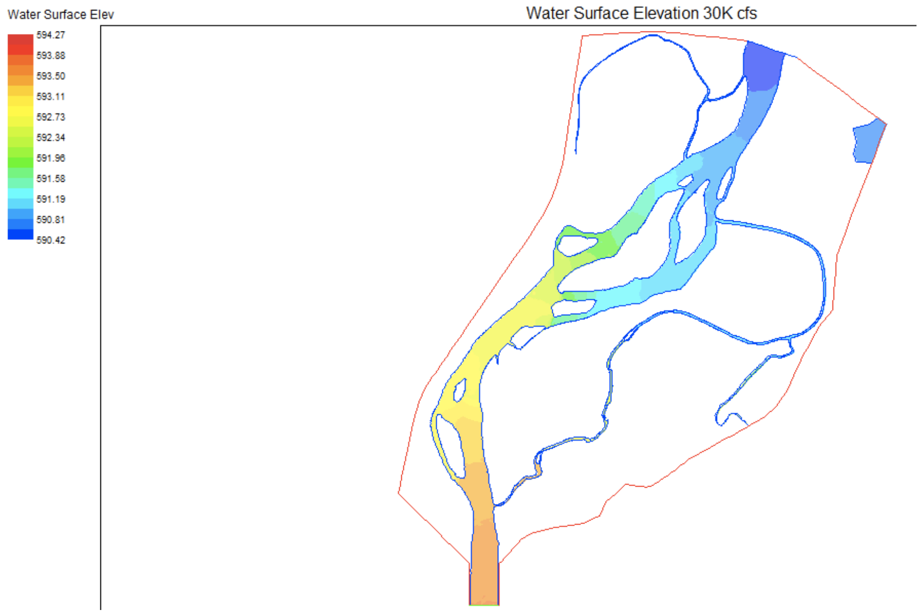

Figure 12. Elk Island study site at 30,000 cfs showing water surface elevations.

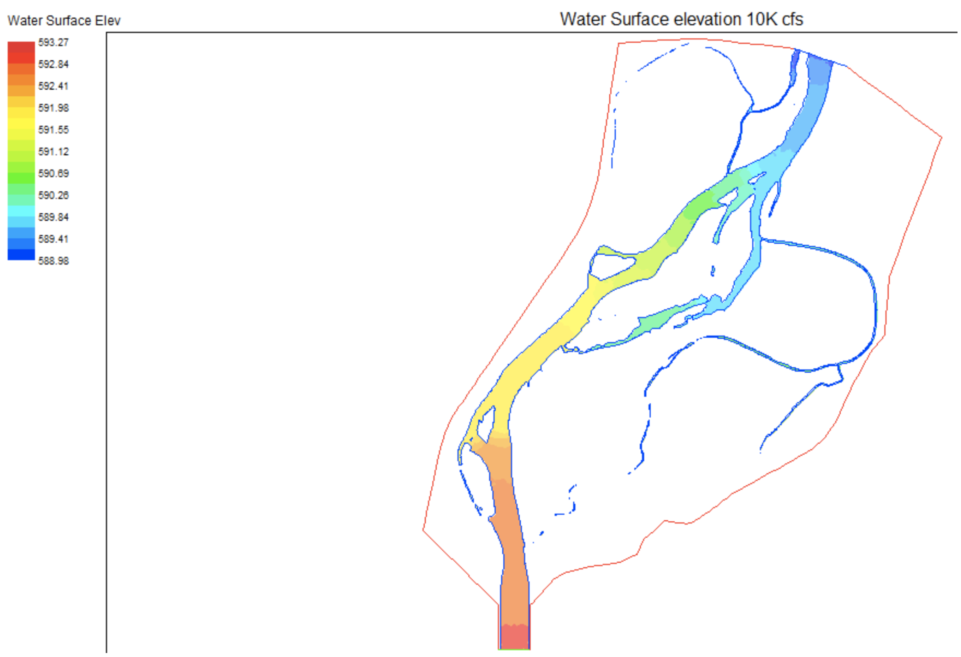

Figure 13. Elk Island study site at 10,000 cfs showing water surface elevations.

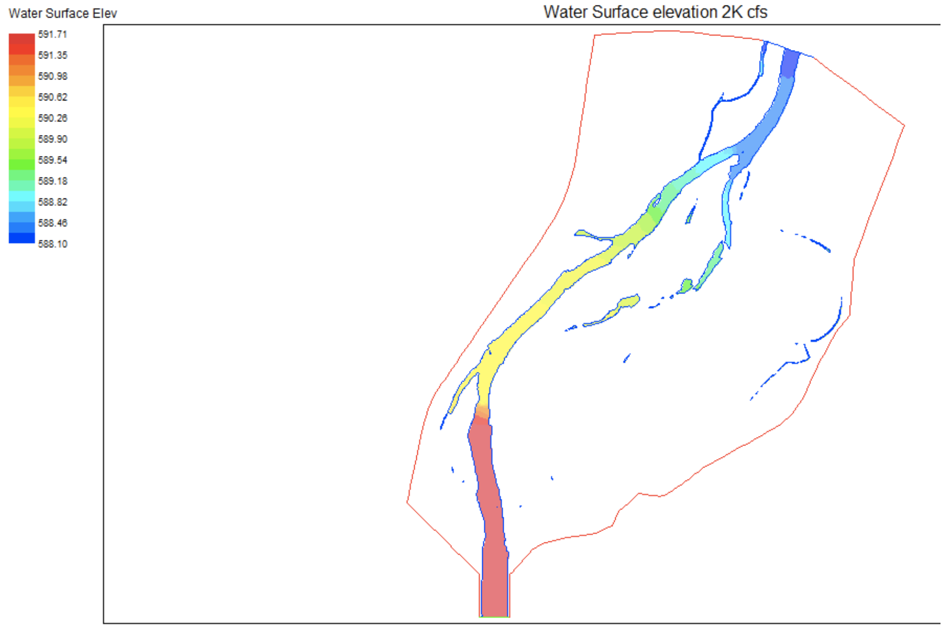

Figure 14. Elk Island study site at 2,000 cfs showing water surface elevations.

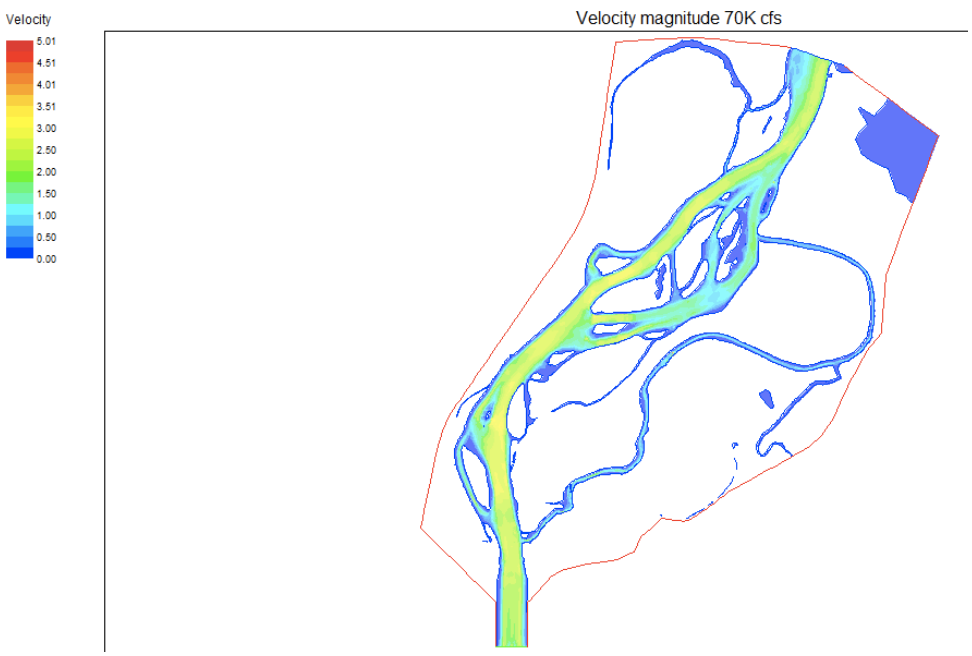

Figure 15. Elk Island study site at 70,000 cfs showing velocity contours.

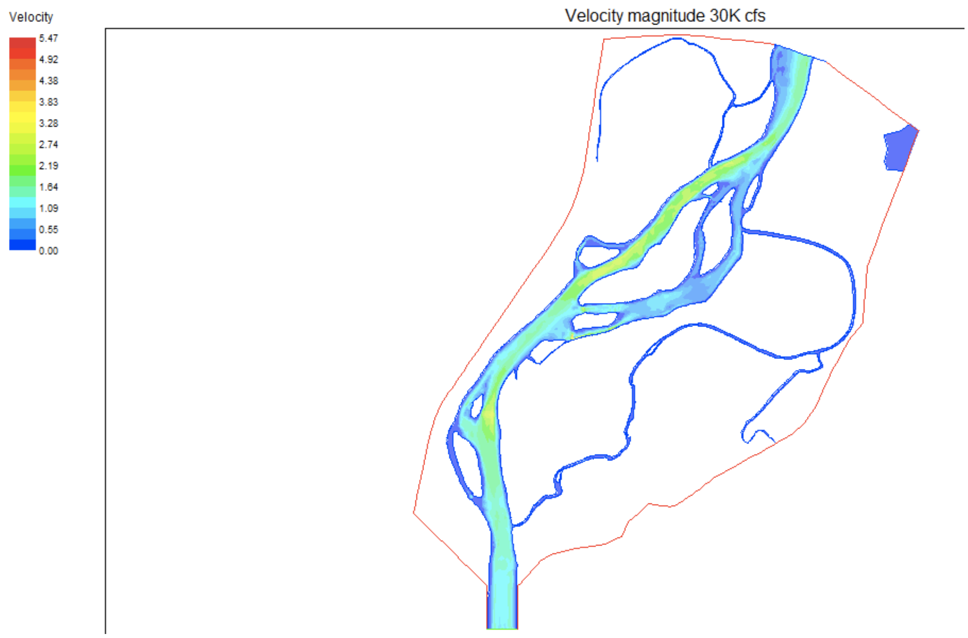

Figure 16. Elk Island study site at 30,000 cfs showing velocity contours.

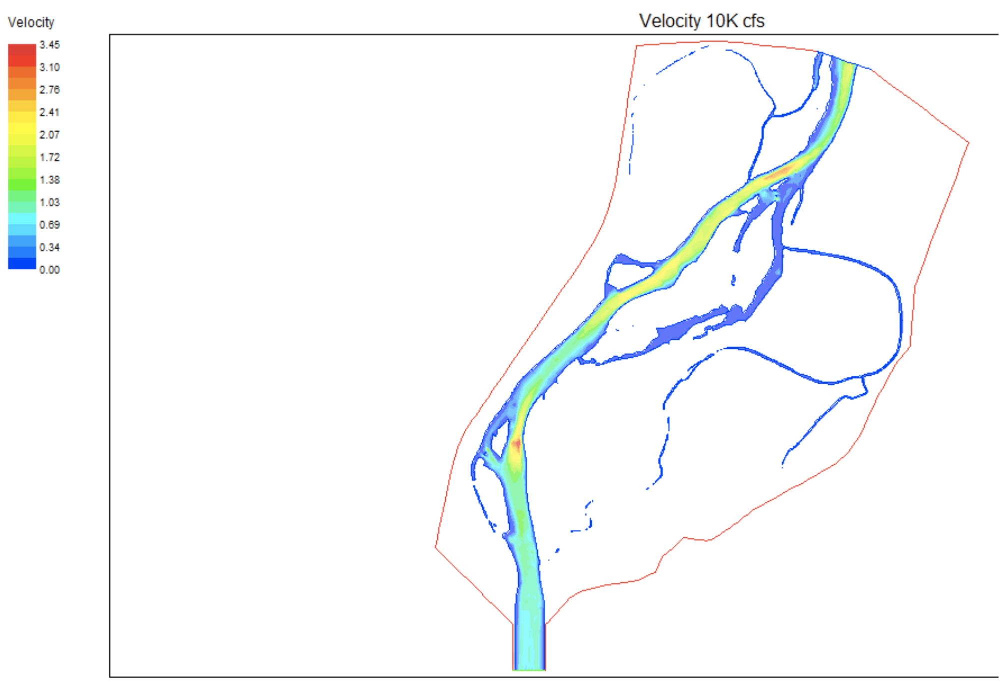

Figure 17. Elk Island study site at 10,000 cfs showing velocity contours.

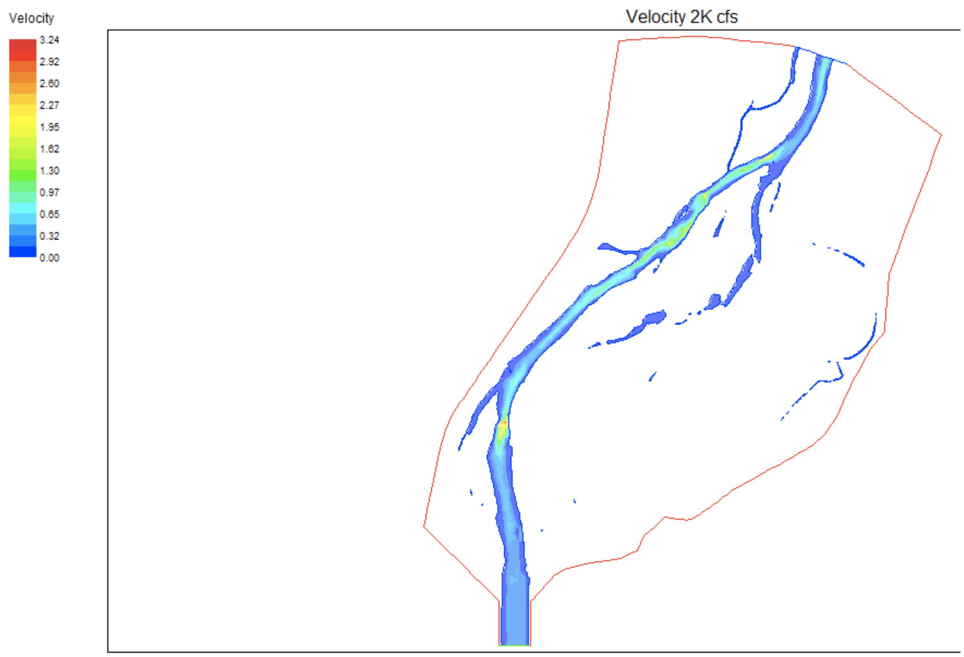

Figure 18. Elk Island study site at 2,000 cfs showing velocity contours.

Missouri River – Fort Peck Dam downstream to the Yellowstone River

The evaluation of IFN for the Missouri River was not included in the original scope of work, however, after the data analysis and review it is apparent that adequate data exists to include the Missouri River in an Instream Flow Recommendation for Pallid Sturgeon. Many of the same data that would be utilized for the lower Yellowstone River are applicable to the Missouri River downstream of Fort Peck Dam. Further, the telemetry studies for pallid sturgeon document the use of both rivers by individual pallid sturgeon over multiple years. This biological link demonstrates the importance of developing concurrent instream flow recommendations on both rivers.

Hydrology data is available from USGS gaging station at Culbertson, Montana and likely available from release records at Fort Peck dam. These data could be used for an analysis of hydrologic year types as described for the Yellowstone River. The USGS study conducted by Bowen et al. (2001) included two River2D study sites on the lower Missouri River. They concluded that these two sites were representative of the Missouri River from Fort Peck dam downstream to the Missouri River. Habitat suitability data that would be used on the lower Yellowstone River would be applicable to the Missouri River downstream of Fort Peck dam. These data include observations from the Missouri River. The benthic fishes studies included observations on the Missouri River as well as the lower Yellowstone. Many other biological reports for pallid sturgeon relied on for the lower Yellowstone River also include data from the Missouri River downstream of Fort Peck dam.

Recommended Approach

Yellowstone River from Intake Dam downstream to the Missouri River and Missouri River from Fort Peck Dam downstream to the Yellowstone River.

The existing data from biological and physical habitat studies have sufficient information for use in making preliminary determinations on the instream flow needs for pallid sturgeon and other fish species in some reaches of the lower Yellowstone River. It is recommended that the Upper Basin Working Group or a subset of the group be directly involved with the development of the recommendations. An example of this approach would be to contract the majority of the technical analysis (e.g. River2D simulations, calculation of habitat suitability, hydrologic analysis) to an experienced instream flow individual or firm and involve the Upper Basin Working Group at review and decision points in the overall process.

Some new data may need to be collected at the existing 2D study site locations to include substrate in the analysis. The data sets could be run for depth and velocity without new data collection if substrate were not critical for a particular life stage. The combined data set of physical and biological data includes information that can be used for recommendations of instream flow needs for the majority of the year. There are certain life stages and seasons where data is lacking but there are approaches that could be used for these life stages and seasons.

The instream flow determinations should include seasonal periodicity for the main species of interest and other species they depend on. Examples of this periodicity include spawning migrations, larval drift, and juvenile and adult feeding and resting behaviors. The instream flow determinations should specify which species and lifestage is the priority for each month or time period. The determinations should also include the rationale for how the determinations benefit other species present during those specific time periods.

The data analysis process for the instream flow determination downstream of Intake Dam would require the use of existing River2D data sets combined with the existing habitat use data (Figure 18). The habitat suitability criteria would need to be calculated from the existing habitat use data sets. This analysis would likely require one to two weeks time after all data sets are acquired. The data from the Gerrity studies has been acquired and is in digital form. The data from studies by Bramblett, Fuller and Bratten would need to be acquired. The data from the recent migration studies and larval drift studies would need to be obtained from the researchers.

The USGS collected River2D data sets that were evaluated as part of this project. River 2D simulation data files for the Intake, Elk Island, and Fairview sites are in digital form for a range of flows. New flows for those sites could be readily simulated if needed. Simulations for new flow would require approximately 1 day per flow. River2D data files from the Missouri River sites were acquired with the lower Yellowstone River River2D files. The Missouri River River2D files would need to have further evaluation but a preliminary analysis shows that the data sets could be used.

Habitat output for analysis could either be directly taken from River2D, if habitat suitability were generated for the model, or could be analyzed in a GIS framework. The habitat-flow relationships generated by River2D can be combined with hydrology data for a time series analysis. It is recommended that hydrology for average, wet and dry years be evaluated to determine the range of habitat conditions present based on water year type. This analysis could then be used to specific flow needs by water year type or by month in a particular year. For example, if the current flows in August in the lower Yellowstone River are approximately 5,000 cfs and future water development would drop flows to 2,000 cfs, the model could be used to determine the amount of change to habitat, benthic productivity (through loss of wetted area) and impediments to passage that may occur. This type of analysis should be conducted for all months of the year with emphasis on months with critical life stages present. The result would be a comprehensive flow recommendation for the lower Yellowstone River and Missouri River.

The time required to complete the instream flow recommendations for the lower Yellowstone River and Missouri River is estimated to range from 9 to 12 months. The total time would depend on the ability to acquire the remainder of the habitat use data and any new substrate data in a timely manner. The development of the flow recommendations also would involve multiple meetings with the Upper Basin Working Group and a contractor, which may increase the overall time required due to schedule conflicts and other duties by Upper Basin Working Group members. The overall cost of the analysis would depend on whether a contractor or the Upper Basin Working Group conducts the majority of the technical analysis. In general, it is estimated that the use of the existing River2D data sets would reduce the overall cost by approximately 50 - 60% of the cost of collecting new instream flow data.

Yellowstone River from Bighorn River downstream to Intake Dam

In addition, there are sections of the lower Yellowstone River that do not have adequate data either physical or biological for determination of instream flow needs. In particular, the section of the lower Yellowstone River from Intake Dam upstream to the Big Horn River. This river section has no recent physical data on river hydraulic habitat. The most recent data in that section of the river was collected in the 1970s and is limited to single cross sections. It is recommended that new studies be conducted upstream of Intake Dam to document the physical habitat and hydraulic habitat within the reach of river.

The hydraulic habitat simulation program recommended for the Yellowstone River upstream of Intake Dam is River2D. This same hydraulic simulation program was used downstream of Intake Dam for representative sites from Intake Dam to the Missouri River.

Biological data is sparse for pallid sturgeon observations upstream of Intake Dam likely due to the passage impediment caused by the dam. Data from other portions of the Yellowstone or Missouri rivers could be applied to the reach upstream of Intake Dam initially and later updated as data becomes available.

Preliminary instream flow determinations can be made using alternate techniques upstream of intake dam while hydraulic habitat data is collected and analyzed, if determinations are needed immediately. These techniques include hydrologic analysis based on flow exceedence levels specified for seasonal flow regimes, or techniques such as ecological limits of hydrologic alteration, which rely on broader metrics for descriptive instream flow recommendations.

A new instream flow study is recommended for the lower Yellowstone River from the Bighorn River downstream to Intake Dam. The existing data in that reach of river is limited to the data collected in the 1970s and 1980s and should be updated to be consistent with and as rigorous as the data downstream from Intake Dam. A new study would require a substantial effort and cost to complete, however, it would provide data that could be used for future analyses as new habitat use data are collected. The existing hydraulic data is not capable of incorporating the complexity that can be modeled with the newer 2D methods.

The total cost for a new instream flow study is difficult to estimate without knowing how many study sites would be required. The current cost for a full 2D study from field data collection through final report is approximately $70,000 to $120,000 per study site depending on complexity of the site. It is likely that more than one site would be needed for the reach from the Bighorn downstream to Intake Dam. Based on the number of sites in other reaches, an estimate of three sites for the reach is reasonable for planning purposes.

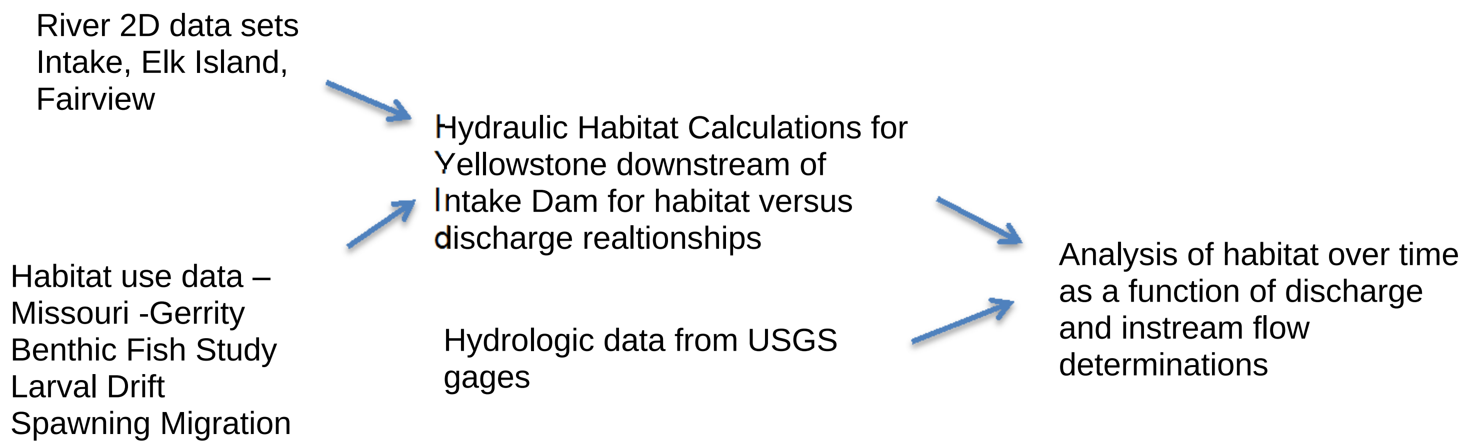

Figure 19. Flow chart of general process required for instream flow determination in the lower Yellowstone River, Intake Dam downstream to the Missouri River.

Data Collection needed in the lower Yellowstone River for developing instream flow recommendations.

Downstream of Intake Dam

- Substrate and cover data should be collected at existing 2D study sites at Intake, Elk Island and Fairview.

  The substrate data can be collected from field visits and mapping the substrate types on aerial photographs. These data sets are then transferred to River2D in the channel index file.

Upstream of Intake Dam

A site specific instream flow study is recommended upstream of Intake Dam. An new instream flow study for site specific data is needed to develop instream flow needs for the lower Yellowstone River from Intake Dam upstream to the Bighorn River. While there are several potential instream flow techniques that could be applied, a two dimensional hydraulic model is recommended. The preferred model for the study is River2D from the University of Alberta to be consistent with other instream flow studies conducted on other sections of the lower Yellowstone River. River2D was used for instream flow studies downstream of Intake Dam and on the Missouri River between the Yellowstone River and Fort Peck Dam. Data collection needed for the Yellowstone River from the Bighorn River downstream to Intake Dam would include:

Habitat inventory/site selection

The initial step for a new instream flow study would be to determine the number and location of study sites. This process would include a general characterization of habitat types from aerial photographs, determination of river slope, location of major tributaries, and the number of study sites required for the river from Intake Dam upstream to the Big Horn River. For each study site the following data would be collected.

Field data for two dimensional hydraulic model

River2D requires the collection of geo-referenced field data for stream bed topography, water depth, water surface elevations, current velocity and substrate. Measurement of these parameters is conducted for at least three different stream flows, high, mid and low flow. Field data can be collected over the course of a single year with appropriate planning. The data collect requires at least three field trips.

It is estimated that a crew of at least three would be required for safe and efficient data collection. The data collection would require approximately 2-4 days per site depending on the complexity of the study site. The total field time would depend on the number of sites. For example, if three study sites are required to represent the river, the total field time

The field data is converted to computer files for analysis and simulations. The computer software is available without charge from the University of Alberta. The software can run on most Windows based computers. The time required for the computer modeling depends on proficiency of the modeler and the speed of the computer processor.

Habitat suitability validation

Habitat suitability data from other reaches of the lower Yellowstone and upper Missouri rivers should be validated for this reach of the Yellowstone River. This validation can use either the river physical characteristics of width, depth, substrate and habitat types (pools, riffles, etc) or collect new habitat use data in the study reach to compare with the areas where the suitability data were collected. For endangered species it may not be possible to collect a sufficient number of habitat use data to validate the criteria. It is recommended that professional judgement be used in combination with the physical habitat characteristics to determine applicability of the habitat suitability criteria.

The recommended approach would be to apply the existing criteria from other portions of the upper Missouri River and collect new data over time for updating the criteria in the future.

Data Analysis required for developing the Instream Flow Determination

Data analysis includes transforming the surveyed field data to computer and into the River2D software for calibration and simulation. The data analysis portion of the 2D simulations can take from 2-4 weeks per site for a trained modeler. Computer simulation computational time (computer run time) can range from several hours to several days for completion. An estimated 20-25 computer runs are generally needed for complete calibration of each site. In addition, 10 – 20 simulation runs are required to generate the hydraulic simulations for each site.

Total time required for the new study would likely be 12 months if the study can begin in early spring with site selection. A start later in the year may require an additional two to three months to complete. The optimal schedule for a new study would be :

- Site selection – completed by late March
- Initial field survey of bank topography – April
- Survey of high flow water surface and velocity – June
- Survey of mid flow bed topography, water surface and velocity – July
- Survey of low flow water surface and velocity – August and September

- Data reduction/computer file construction – April through October
- Model calibration – November – December
- Model simulations – January
- Draft report – March
- Final report – April/May

The above schedule assumes that access to all sites is granted prior to initiation of field work. Any complex sites, complex logistics, or equipment failures during field work may add time to the schedule.

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