BUREAU OF RECLAMATION

Technical Report No. ENV-2023-113

TSC Planning and Design Process Guidelines for River Projects

Manuals and Standards Program

U.S. Department of the Interior **September 2023**

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover Photo – Engineered log jam constructed on the Elwha River, Washington (Bureau of Reclamation/Nathan Holste).

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Bureau of Reclamation
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Acronyms and Abbreviations

1D	one-dimensional
2D	two-dimensional
AAO	Albuquerque Area Office
CMP	Comprehensive (type of program series)
D_{50}	median grain size
DEC	Design, Engineering, and Construction
EA	Environmental Assessment
EIS	Environmental Impact Statement
FDP	Final Design Process
FISRWG	Federal Interagency Stream Restoration Working Group
NEPA	National Environmental Protection Act
NMFS	National Marine Fisheries Service
NRCS	Natural Resources Conservation Service
O&M	operations and maintenance
PMP	Project Management Plan
QA/QC	quality assurance and quality control
Q_s	sediment discharge
Q_w	water discharge
Reclamation	Bureau of Reclamation
S	slope
SFO	Socorro Field Office
SOP	Standard Operating Procedure
SRH	Sedimentation and River Hydraulics
TSC	Technical Service Center
USACE	United States Army Corps of Engineers
VE	Value Engineering

Symbols

%	percent

Contents

Tables

Figures

Figure Page

Appendices

Appendix

I. Introduction

A. Overview and Purpose

Many of the Bureau of Reclamation's (Reclamation) design activities involve rivers, streams, or ephemeral channels. These river design projects often present unique challenges such as sedimentation, erosion, and a dynamic landscape that is shaped by how flowing water interacts with geologic features and vegetation. Project goals are varied and may include improving water delivery, protecting streamside infrastructure and lands, improving fish passage, supporting safe recreation and human access, establishing riparian or wetland areas, or incorporating habitat restoration features. To account for the complex fluvial environment and the diverse array of project types and goals, the Sedimentation and River Hydraulics (SRH) Group within the Technical Service Center (TSC) developed planning and design process guidelines for river projects. These guidelines supplement and do not replace existing Reclamation-wide methods for planning, design, and construction (see Directives and Standards and Final Design and Construction Guidelines). Additional information specific to river projects will assist designers by describing how to apply the existing requirements and guidelines.

Managing river systems should consider many factors before determining if it is necessary to construct engineered features. Where possible, a sustainable river management strategy is to allow space for rivers to move while restoring natural flow and sediment regimes. River design projects may be loosely described as alterations to the river corridor, which includes the active channel and floodplain, the zone of past or expected future channel migration, and the zone that would be inundated by floods. River corridor alterations for design projects may consist of excavation, fill, installing or removing structures, or adding natural material such as logs or boulders. River projects may also include non-mechanical alterations to affect geomorphic processes, such as managing the upstream flow and sediment, managing the downstream water level, or planting riparian vegetation. Example projects range from replacing a diversion dam with a rock ramp, realigning the main channel, setting back a levee, stabilizing an eroding bank, excavating a side channel, installing an engineered log jam, or changing floodplain connectivity. These projects are technically complex; however, the scope of this report focuses on the planning and design process and not the technical analysis or design of specific features.

Design and analysis for river projects is often led by hydraulic engineers and fluvial geomorphologists. However, the dynamic and complex nature of rivers typically requires interdisciplinary expertise from biologists, hydrologists, geologists, botanists, environmental compliance specialists, and other physical scientists and engineers. The scale of river projects ranges from smaller non-structural efforts to larger projects with structural features. An example of a smaller project is creating a floodplain bench along one meander bend, while a larger project could span across many acres of land and miles of river. River projects also may require consideration of external inputs that can affect project function, such as wildfires in upstream basins or altered hydrology and sediment loads due to upstream dams. Technical experts and project managers working on river projects may not have experience applying Reclamation's existing requirements and guidelines, which are focused on larger-scale civil works and infrastructure projects. Therefore, the guidelines described in this report are intended to facilitate communication between different groups when integrating river elements into a larger project or when developing a new stand-alone river design project.

The following text describes many aspects of planning and design for river projects. Also, note that Section IV provides a concise one-page summary that includes the general design and scoping considerations.

B. Existing Reclamation Planning and Design Process Guidelines

Reclamation's existing planning and design process guidelines begin with a 'Planning Stage', which consists of: (1) a preliminary study, (2) an appraisal study, and (3) a feasibility study. The completion of this planning stage initiates the 'Final Design Process' (Reclamation 2022), which is comprised of a 30 percent (%) design (also known as conceptual design), followed by 60%, 90%, and 100% final designs. Once the design is complete, acquisitions occurs if the project is a design-bid-build, followed by construction. The information below describes the relevant terminology contained within Reclamation's existing guidelines. As these elements are integrated throughout the river design process, it is important to first establish an understanding of Reclamation's current definitions.

A preliminary study consists of high-level planning that defines the problem and need through identifying the overarching issue and type of study that could be used to address it. Preliminary investigations use existing information and data to determine whether Reclamation has an interest and should be involved in the project. The preliminary level also defines primary and secondary objectives to guide data inventory and collection, alternatives forecasting, and a generalized evaluation of effects.

Appraisal studies (CMP 09-01) are an initial evaluation to determine the nature of water and water-related resource problems and needs in a particular location. Appraisal studies formulate and assess preliminary alternatives, determine Reclamation interest, and recommend subsequent actions. Appraisal studies are primarily based on available existing data. At study completion, a recommendation is made for Reclamation to either move the project forward through conducting a feasibility study, determine if there is interest in working with partners to pursue a solution, or conclude the evaluation.

Feasibility studies (CMP 09-02) are more detailed investigations to determine if congressional authorization should be sought to implement a project; they analyze the viability of a proposed plan or project and provide the basis for making recommendations to Congress about whether it should be authorized for construction. Cost estimates that support a feasibility study are typically used to request appropriated funds from Congress. Therefore, designs and cost estimates are detailed enough so that the overall project concept and associated costs will not change substantially when the project is advanced to final design. Feasibility studies require data collection and analyses to develop a full and reasonable range of alternatives and lead to the selection of a preferred alternative or a recommendation to take no action. Feasibility studies are used to assess how the recommended plan and alternatives will perform under present and projected future conditions.

The Final Design Process (FDP) provides Reclamation design teams with a workflow to prepare final designs and specifications efficiently and transparently for traditional design-bid-build project delivery. An important objective is to develop productive working relationships between program offices and service providers while providing the monitoring and review necessary to produce high-quality and cost-effective designs. The FDP starts after selecting a preferred alternative at the end of the feasibility study, thereby concluding the planning stage. The FDP consists of a continuous succession of interrelated activities with measurable milestones that include scheduling, determining design data requirements, design data collection and analysis, percent complete designs, final design, specifications preparation, bid solicitation, and construction. The FDP general flowchart detailing the steps involved with these milestones is shown in Appendix A.

While the stages of the design process outlined above work well when preparing plans for a water treatment plant, canal, or pipeline, they only partially incorporate considerations for river projects. The next section provides helpful background on riverine systems and fluvial geomorphology that drives the need for river project-specific planning and design guidance. Understanding river behavior and properly diagnosing the cause of channel instabilities or habitat deficiencies is important for all stages of the planning and design process.

C. River Dynamics and Fluvial Geomorphology

As previously mentioned, river corridors are dynamic and complex systems that present specific challenges not fully described in Reclamation’s existing guidelines. Riverine infrastructure and water delivery requirements significantly increase the complexity. The planning and design steps for a successful river project must consider fundamental geomorphic concepts and how a river evolves over time.

Natural river processes include surface water flow, groundwater exchange, sediment and nutrient movement (erosion, transport, or deposition), vegetation growth or senescence, and large wood interactions. These processes support aquatic, riparian, and terrestrial ecosystems. River corridors and their ecosystems are continuously changing in response to the upstream flow regime and sediment supply while being controlled by geology, vegetation, and large wood (Leopold et al. 1964; Castro and Thorne 2019). Alluvial rivers are a unique landscape feature because the channel bed and banks are comprised of material that can be eroded, transported, and deposited by the river. Therefore, rivers adjust their longitudinal slope, width, depth, cross-section shape, planform, and position within the floodplain so they can convey and transport their varying stream flows and sediment loads.

Channel adjustments can be relatively gradual and continuous, such as meander bends that migrate downstream and across the valley, or narrowing caused by vegetation encroachment during a drought. Geomorphic change may also be episodic and abrupt, caused by floods or landslides that rapidly widen or deepen a channel or create new flow paths. Some rivers completely change location during a single flood event through a process known as channel avulsion. Over a period of decades, rivers with geomorphic parameters (e.g., slope, sinuosity, width, depth) that fluctuate around a consistent average value are in dynamic equilibrium (Knighton 1998). Rivers in dynamic equilibrium have a relative balance between the driving and resisting forces. This relationship, first described and conceptualized by Lane (1955) as the water discharge (Q_w) and channel slope (S) compared to the sediment discharge (Q_s) and particle size (D_{50}), is known as Lane's balance (Figure 1). If the water discharge or sediment load changes, a river will typically respond by changing its bed elevation, width, or alignment.

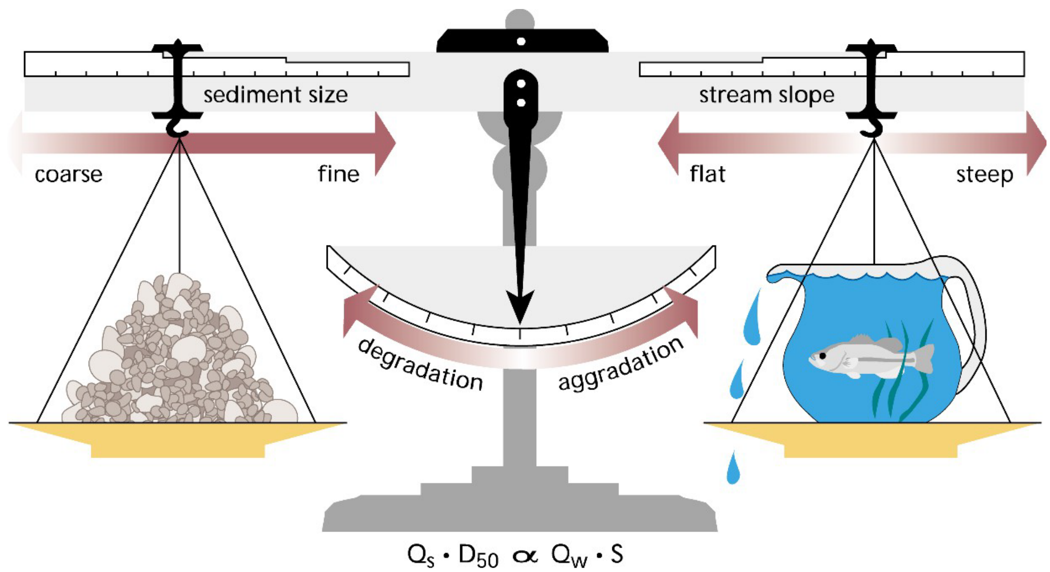

Figure 1.—Lane's channel stability balance describes how changes in sediment load, particle size, stream slope, and water discharge will cause the channel to erode (degradation) or deposit sediment (aggradation) (from FISRWG 1998).

Watershed disturbances, often caused by human impacts, disrupt the flow regime and sediment supply. Alterations to the river corridor such as installing infrastructure may also constrain the space available to the river (Biron et al. 2014). Figure 2 illustrates the hierarchy of drivers and controls from the landscape scale to the local reach scale. Changes to the watershed or valley that affect geomorphic processes will ultimately cause a change in the channel pattern, profile, or dimensions. These changes and corresponding river adjustments may indicate that a system is no longer in dynamic equilibrium. Depending on the magnitude, timing, and duration of impacts to the river, the channel may transition through a series of adjustment stages toward a new dynamic equilibrium. Channel adjustment stages often follow a predictable sequence known as the channel evolution model (Schumm et al. 1984; Simon and Hupp 1986) or the stream evolution model (Cluer and Thorne 2014). These channel evolution sequences are examples of conceptual models, which are important tools for understanding previous channel changes and the trajectory of possible future adjustments.

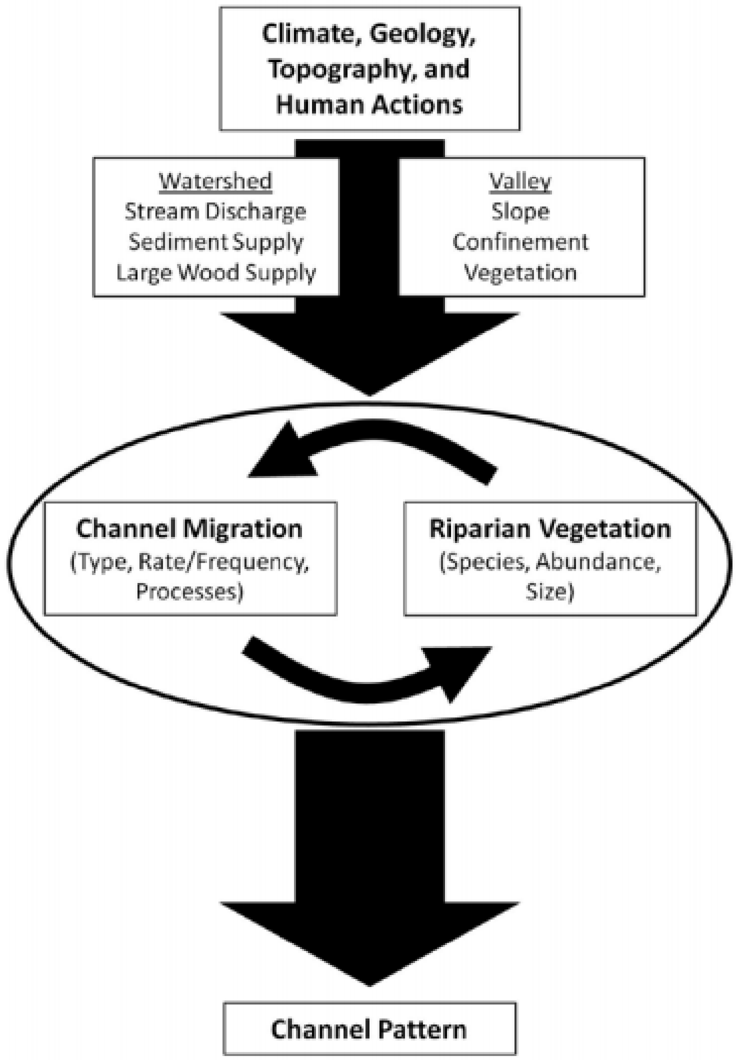

Figure 2.—Relationship between landscape controls, geomorphic processes, and channel pattern (from Legg and Olson 2014).

Common impacts to the river include land use changes (urbanization, grazing, wildfire), dams, and infrastructure within the river corridor. Urbanization typically increases runoff volume and peak flow magnitude because less rainfall infiltrates into the ground. Grazing may destabilize tributary channel banks and hillslopes, thereby increasing sediment loads delivered to the river. Wildfire may be natural or human caused and affects river corridors by increasing runoff and sediment yield from the watershed. Dams store water and sediment, which decreases downstream flood peaks and sediment supply. Riverine infrastructure (roads, pipelines, bank armoring, bridges, culverts, grade control structures, diversion structures, etc.) encroaches on the floodplain and the channel migration zone (Sholtes et al. 2017). This infrastructure limits how and where the channel can migrate to and may concentrate flow and decrease the inundated area, which increases flow depth and velocity. These changes can result in the erosion of finer river bed sediments, coarser bed material, less woody material, and less refuge habitat for aquatic species.

Ecosystem health, a common river project design goal, is closely integrated with the river dynamics and geomorphic processes. Overall biodiversity and the habitat for many species benefit from physical complexity. Rivers that provide a diverse range of erosional and depositional features, depth, velocity, and cover tend to support a variety of life stages for different species (Wohl et al. 2016). Three-dimensional connectivity (longitudinal, lateral, and vertical) is another important ecological process within the river corridor. Infrastructure features that disrupt water and sediment continuity are likely to limit the migration or passage of aquatic organisms. Infrastructure features that stabilize a river are likely to limit recruitment and germination of new vegetation, scour of decadent vegetation, and transport of large wood.

To summarize, rivers normally change and evolve. This evolution may be caused by natural environmental events or human impacts. River design projects need to account for how and why a channel is changing by considering principles of fluvial geomorphology. Resilient and sustainable projects rely on science-based approaches that first study a river system within a geomorphic context before developing design alternatives. Determining what, if any, natural river processes have been impacted by human activities is crucial for developing successful river project designs.

D. General River Design Considerations

Channel adjustments, watershed-level disturbances, human influence, and the complexity of ecosystems all factor into the planning and design process for river projects. As such, there are unique considerations when working in a fluvial environment. Engineering designs based on static analyses that don't consider the watershed scale or history are likely to be insufficient and can lead to failure. Understanding the various interacting physical dynamics early during the planning and design process will increase the likelihood of success. River projects are often intended to change, especially for habitat restoration projects. Conversely, bed or bank stability may be a goal for some projects. Each river project is different and following a planning and design framework is intended to provide a consistent project development process while accounting for the inherent variability in rivers.

Goals and objectives are essential for any project, but they are especially important to define for river projects because they will shape the planning and design process. Is the goal *form-based* such as maintaining river alignment near a bridge or installing a structure to divert flow? Or is the goal *process-based* such as promoting channel migration, overbanking flow, large wood recruitment, or vegetation growth? These questions inform if the design is intended to be static or dynamic. Note that static designs will still be affected by river changes upstream, downstream, and near the project. A geomorphologist or hydraulic engineer should be included on the project team early in the planning process for any structure within the river corridor or pipeline that crosses a river. After starting final design, it may be too late to change the location of these features to reduce failure risk from river processes.

A unique consideration for river projects, compared to projects in more static landscapes, is that the alignment and elevation of the river may change during planning and design. If it takes multiple years to progress from a feasibility study to construction, the river may have migrated laterally or changed its bed elevation. Depending on the type of project, this may require more than one survey to update the design before construction. Similarly, river design alignments and elevations may not need to specify a high level of precision. Elevations within 0.5 feet and alignments within 1 to 3 feet are often acceptable because the project geometry will change for an alluvial river as soon as flowing water is introduced. Rigid structures such as rock ramps to divert water while providing fish passage will likely require more precise design and construction to achieve the intended function.

In addition to changes within the river channel and floodplain, river projects should also consider potential changes to design input variables. Water discharge, either a specific target flow rate or a range of flows, is almost always a critical design parameter. Design flows can be developed from historical gage records, but this may not represent future conditions in the river. Like the dynamic equilibrium concept in fluvial geomorphology, the stationarity assumption in hydrology implies that precipitation and streamflow vary around a relatively constant average value. As the climate changes, non-stationarity will be common in the future. Non-stationarity implies that the magnitude, duration, and frequency of floods and droughts will be outside the range of previous observations. This would affect peak flows for hydraulic structure design, or the duration of low-flow periods where depth may be a limiting factor for fish passage. A hydrologist or climate change expert should be included on the interdisciplinary team for many projects to develop design flows and account for future changes.

1. Modeling and Analysis Overview

The role of hydraulic and sediment modeling (numerical or physical) is another unique and important consideration for river design projects. The FDP guidelines suggest that hydraulic modeling be completed by the 60% final design milestone, but the role of models is not discussed. The Sedimentation and River Hydraulics Group recommends incorporating modeling during the planning stage (appraisal or feasibility) and then updating the models as needed during 30% and 60% final design. Numerical and physical models are an effective tool to test and evaluate hypotheses about river processes while analyzing and comparing alternatives. Numerical and physical models typically provide simulations of flow depth and velocity for a range of river discharges and can sometimes simulate the erosion, transport, and deposition of sediment. The modeling level of effort should be scaled to the project complexity and risk. Simple spreadsheet models may be sufficient for some projects while other projects may require multi-dimensional models, developing new models, or integrating numerical and physical models.

Numerical or physical modeling is generally most effective after the preliminary site investigation, which is discussed in more detail in Section III.D.1. Understanding river impairments, the role of infrastructure and human impacts, and the cause of any channel instabilities is the most important step of the entire planning and design process. A geomorphic assessment and preliminary site investigation should identify relevant questions and hypotheses to inform the type of modeling and analysis needed to support the planning and design process. The model plan should also consider if the project is in a regulated floodway and if permitting will require specific modeling to assess flood risk. Successful modeling and analysis will include the following steps:

1. Define the question
    a. Identify specific questions to answer such as:
        i. What is the stable channel slope and bed material size?
        ii. What is the difference in future erosion or deposition volumes, for the project reach, between various alternatives?
        iii. What is the habitat suitability for specific fish species and life stages at a defined range of discharges?
    b. Avoid undefined questions or questions of inappropriate spatial or temporal scales, such as:
        i. What will happen in the future or what will the river look like? (Undefined if more specific information is not provided to refine the question.)
        ii. What is the fish habitat suitability at a one-foot scale when the channel survey data has a resolution of ten feet? (Resolution of model input data does not support such a specific result.)
        iii. What are the lateral differences in future sediment deposition magnitude over 50 years for 200 miles of river? (Lateral differences require a multi-dimensional model while the large spatial and temporal scale would likely require a one-dimensional model.)

2. Define the study scope
    a. Identify the spatial area of interest and relevant time scale
    b. Develop a conceptual model of the river system (may require multiple technical disciplines)
        i. Identify upstream and downstream controls on water discharge, water surface elevation, and sediment supply
        ii. Identify sediment sources and develop a qualitative sediment budget
        iii. Identify locations where the slope, bed material, width, or depth changes
        iv. Identify locations where the channel planform changes
        v. Identify geologic or infrastructure controls
        vi. Identify role of vegetation and large woody material
        vii. Identify how the channel location, channel planform, longitudinal slope, and cross-section dimensions have changed over time (i.e., how is the channel evolving?)
    c. Identify important physical processes

        i. Sediment erosion or deposition
        ii. Bed armoring
        iii. Hydraulic sorting of gravel and sand
        iv. Stream bank erosion
        v. Channel migration or avulsion
        vi. Vegetation growth or removal through scour
        vii. Unsteady effects such as differences between the rising and falling limb of a hydrograph
    d. Understand model or analysis limitations
        i. Physics-based models can accurately represent important processes, but they are simplifications of field conditions and are highly dependent on input data
        ii. Each type of model or analysis will have limitations
    e. Select appropriate model or analysis method
        i. Models are typically most effective when the scope is limited to a few specific study questions; the model or analysis method should be dictated by the spatial and temporal scale and the study question(s)
        ii. Consider if the study question(s) requires a numerical or physical model, a fixed-bed or mobile bed model, and a one-dimensional or multi-dimensional numerical model

3. Collect appropriate data
    a. Model and analysis calculations rely on input data, so the quality of results will depend on the quality of the input data
    b. Different models will require different data types, but a fundamental need is accurate topography for the floodplain and bathymetry for the stream channel

4. Involve experienced and knowledgeable experts
    a. A model or analysis method won't replace what the engineer or scientist doesn't already know
    b. The conceptual model should qualitatively predict how the stream channel will respond to certain alternatives. A numerical or physical model should quantify those predictions. If there are conflicting outcomes from the numerical or physical model and the conceptual model, then at least one of the model types is wrong and needs to be corrected.

The importance of understanding river processes, conducting geomorphic studies, and the role of modeling suggests that most of the overall work for river projects occurs before the FDP. A design is likely to be successful if it is based on the principles discussed above. The next section of the report (Section I.D.2) provides examples of different types of river projects and technical references to assist the designer. Later in the report, Section III describes the level of design and analysis at each stage from preliminary to 100% final design.

2. River Project Types and Technical References

To assist designers and project managers with identifying if their project is within a river corridor and therefore should follow the guidelines in this report, Table 1 summarizes the most common project types and methods. This list is comprehensive but does not include every possible river project. Reviewing the example projects provides a useful starting point when brainstorming alternatives and developing the plan for analysis and design. Many river projects will incorporate multiple types and methods, such as local channel stabilization that also includes restoration or fish passage components. Again, this emphasizes the need for an interdisciplinary project team.

Similarly, Table 2 provides a list of references with hyperlinks that describe planning and design guidelines for river projects. These references are only a small sample of relevant literature and focuses on Reclamation publications with a limited number of manuals from other agencies. The first two references in Table 2 (Yochum and Reynolds 2020; Sholtes et al. 2017) contain a more expansive list of publications related to river projects, including hyperlinks organized by topic areas. Readers should review these two references, among others, when planning and designing a river project.

Table 1.—Common types and methods for river projects

Project Type	Methods
Restoration (aquatic, terrestrial, wetlands)	• infrastructure removal • levee setback • conservation easement or vegetation buffer zone • floodplain connection • multi-threaded channels or wetland meadow • side channels • channel realignment • bank lowering • large wood or boulders • beaver dam analogs (mimics natural beaver dams) • vegetation planting • non-native vegetation removal • bankline alcoves or backwaters (variability in bank alignment to create low velocity areas) • floodplain bench (constructed surface next to existing tall banks that will inundate at lower flows) • gravel augmentation (adding gravel to river)
Fish passage	• dam removal • rock ramp or engineered riffle • nature-like fishway • large wood or boulders • resting areas
Channel stabilization (bank protection, scour protection)	• bioengineering (vegetation planting, often supported by geotextile fabric) • large wood or engineered log jams at toe of slope • stone toe (riprap placed at low elevation to resist hydraulic forces at toe of bank) • transverse features protruding from bank (e.g., rock vanes, barbs, bendway weirs, spur dikes) • riprap (e.g., revetment, windrow, trench) • grade control (e.g., cross vane, deformable riffle, sheet pile)
Infrastructure	• rock ramp • diversion dam • culvert • road or bridge
Sediment management	• increasing floodplain area available for sediment deposition • settling basin • sluicing • dredging

Table 2.—Selected references with planning and design guidance for river projects

Topic	Reference	Notes
General Guidance	Yochum and Reynolds (2020) Guidance for Stream Restoration	Organized as a series of short literature reviews with extensive hyperlinked references
General Guidance	Sholtes et al. (2017) Managing Infrastructure in the Stream Environment	Discusses riverine infrastructure and provides recommended steps for replacing, repairing, or building new infrastructure
General Guidance	Cramer (2012) Stream Habitat Restoration Guidelines	Provides detailed and comprehensive guidance for river project design with a focus on the Pacific Northwest
General Guidance	NRCS (2007) Stream Restoration Design	Provides detailed and comprehensive guidance for nearly all aspects of river project design, including specific technical supplements
Design Hydrology	Bledsoe et al. (2017) Guidance for Design Hydrology for Stream Restoration and Channel Stability	Provides guidance and tools to assess current conditions, perform hydrological and geomorphic analysis, and design the channel
Bank Stabilization	Baird et al. (2015) Bank Stabilization Design Guidelines	Provides guidance for selecting bank stabilization methods and includes detailed design procedures
Bank Stabilization	McCullah and Gray (2005) Environmentally Sensitive Channel- and Bank-Protection Measures	Provides design guidelines for stabilizing channels and banks using environmentally-sensitive techniques
Design Analysis	Reclamation (2006) Erosion and Sedimentation Manual	Provides comprehensive description of sediment transport, modeling, and analysis for rivers and reservoirs
Design Analysis	Pemberton and Lara (1984) Computing Degradation and Local Scour	Describes methods to calculate reach-wide channel incision and local bed scour
Large Wood Design	Reclamation and USACE (2016) National Large Wood Manual	Describes how to assess, design, and manage wood projects to restore rivers
Pipeline Crossings	Baird et al. (2019) Guidelines for Evaluating Pipeline Channel Crossing Hazards to Ensure Effective Burial	Describes best practices to determine the appropriate depth and lateral extent for pipeline burial to protect pipelines from stream-related hazards
Rock Ramps	Mooney et al. (2007) Rock Ramp Design Guidelines	Provides detailed guidelines for designing rock ramps
Rock Weirs	Gordon et al. (2016) Rock Weir Design Guidance	Provides detailed guidelines for designing rock weirs (channel-spanning loose rock structures)
Riprap Design	Lagasse et al. (2006) Riprap Design Criteria	Provides design guidelines and recommendations for riprap in river corridors

II. Scoping the Work

A. Client Goals and Communication

A river design project scope generally outlines: (1) project goals, (2) tasks, (3) deliverables, (4) milestone schedules, (5) budget, (6) roles and responsibilities, and (7) risks. When scoping a river design project, it is critical to work closely with the client to identify project goals. This initial step can require more time and iteration for river design projects than other engineering projects, simply due to the dynamic nature of river systems. For example, a potential client may approach the design team with a single problem identified, paired with a single goal. However, after listening to client concerns and taking some time to better understand the river system, the design team may uncover other important processes that also need to be addressed as part of the project goals, analysis, and design. Consequently, it is often beneficial to work with the client to setup a smaller project that focuses on a preliminary site investigation and literature review of available reports, papers, and data. This 'seed funding' for an initial assessment will ensure that the final scope addresses the underlying processes driving river behavior rather than only treating observed symptoms.

While working with a client to refine their goals for river design work, it is critical to prioritize communication with both the client as well as all stakeholders involved in the project. As previously mentioned, river design projects involve a collection of different entities and disciplines, including engineers, fish biologists, landowners, hydrologists, tribal members, and different government agencies. Holding an initial meeting with the client and stakeholders to discuss project goals is key. If floodplain reconnection has been identified as a primary goal of the project, what is the viewpoint of landowners or government agencies that manage the targeted areas of floodplain? If both fish passage and bank stabilization have been flagged as project goals, do fish biologists see any fundamental conflicts between habitat needs and engineering approaches? By having all voices present in a virtual or in-person meeting space, it is possible to obtain buy-in for the project and project goals before any design work begins. The scope should include enough time and budget for the design team to participate in meetings and ongoing communication with the client and stakeholders.

B. Accounting for River Processes

Even with information from an initial assessment in hand, it can be challenging to develop the scope for a river design project. The dynamic nature of rivers presents different variables to the project schedule, data collection logistics, and construction methods. All these elements need to be addressed in the Project Management Plan (PMP) submitted to the client. Sometimes, a client may have resources to fund a project in its entirety, including the initial assessment. Especially in this case, it will be important to consider risk when developing the project timeline. It will also be key to manage client expectations, as the outcome of an initial assessment may impact the original scope.

In a PMP for a river project, it is important to designate time and resources to be able to:

- Develop project objectives and goals in cooperation with the client and other stakeholders
- Perform a geomorphic assessment if one does not already exist (level of effort will vary based on project scale and identified concerns)
    - Accurately diagnose and fully identify the current geomorphic conditions, dominant fluvial processes, and the underlying causes of any undesirable conditions
    - Understand the role of human impacts and how the watershed has changed
    - Develop hypotheses and conceptual models to describe physical processes
- Complete quality assurance and quality control (QA/QC) on any data provided to the design team by the client or other project partners
- Participate in site visits with the client and stakeholders
- Collect field data required to inform project analysis (e.g., geomorphic mapping, topographic and bathymetric surveys, discharge and water surface elevation measurements, sediment samples, groundwater measurements, water temperature)
- Consider processes influenced by climate change that may impact river dynamics (e.g., wildfire burn scars that contribute additional sediment load to a watershed, changes in site hydrology driven by low snowpack levels)
- Develop and evaluate design alternatives
- Develop a modeling plan, if needed, for river assessment and design
    - Carefully consider the physical processes a model is expected to simulate and the questions the model is expected to answer
    - Build, run, and calibrate a numerical hydraulic model of the study reach
    - Consider construction of a physical laboratory-scale model to provide insight into processes difficult to model numerically
    - Receive and address feedback on model results from the client and stakeholders
- Work with the client and stakeholders to select a preferred alternative
- Refine the preferred alternative to develop the final design
- Produce construction drawings, specifications, and/or cost and material estimates
- Coordinate permits required for construction
- Document data collection, hydraulic modeling, alternatives analysis, and basis of design in written report(s)
    - Allow time for internal peer review and client review throughout the design

While the above list is by no means exhaustive, it includes important tasks that can factor into a river design project PMP. The design team should not proceed with developing alternatives until understanding river corridor impairments and their cause within the watershed, the role of human impacts, and whether the design scope and project footprint provide an opportunity to address the impairment. When considering appropriate tasks and deadlines to include in the project scope, consider the elements of risk introduced by dynamic riverine processes. Will unusually low or high flows prevent collection of field data at the planned date? Is there a risk that river conditions will change over the course of the design process and require additional surveys prior to construction? Are there important physical processes that will be difficult to represent in a numerical model, such as sediment transport through diversion dam gates? Is a physical model needed? By assigning realistic milestone schedules and clearly identifying risks in the PMP, it is possible to craft a scope that accommodates the dynamic nature of rivers.

III. Project Development Phases

Work can begin after developing a scope that considers river dynamics, fluvial geomorphology, information from models (conceptual, numerical, and physical), and the likely type of river project to be implemented. This section of the report describes each project phase from planning (preliminary, appraisal, feasibility) to final design (30% through 100%). Several activities occur throughout the process or can influence multiple stages of planning and design. These are discussed first and include ongoing coordination, parallel activities, and construction strategy.

Terminology in this report is specific to Reclamation's existing guidelines for consistency between river projects and other civil works projects. However, many river projects are at a much smaller scale and may have construction budgets that are only a fraction of Reclamation's traditional engineering projects. Many river projects are completed within the context of annual program budgets for regional and area offices and do not require separate Congressional authorization for each specific project. Therefore, many river projects do not require formal appraisal or feasibility studies because the work is already included within a previous authorization. Design and analysis tasks described below refer to the level of detail at the appraisal or feasibility stage, which does not imply that a formal appraisal or feasibility study is necessary for every river project. For these smaller projects, appraisal-level is the *alternatives development* stage and feasibility-level is the *alternatives analysis* stage. River projects may also be one component of a larger appraisal or feasibility study that includes other features.

Consultants and other entities often use terminology for river projects that is different from Reclamation's definitions. For example, others may say "conceptual-level design" or "15% design" to refer to projects at the early alternatives development stage, perhaps equivalent to Reclamation's appraisal-level design. Reclamation does not assign percentages during the planning stage; 0% final design represents the start of the FDP after the preferred alternative has been selected. Reclamation's 30% final design means that the overall project design will be more than 30% complete when accounting for the planning stage. For river projects, the time and level of effort for analysis (from the start of a project to the end of feasibility) is often more work than going from 0% final design to 100% final design. Performing assessments to understand river processes, developing geomorphically-compatible alternatives to meet project goals and objectives, and analyzing alternatives using numerical or physical models is a significant amount of work. Depending on the project, it may be relatively less work to refine the preferred alternative during the FDP than to perform analyses of river hydraulics, sediment transport, and geomorphology.

A. Ongoing Coordination

Coordination throughout the planning and design process is essential for a successful project. Section II.A above discusses how to incorporate communication while developing the scope, and Reclamation (2022) discusses coordination roles during the FDP. For river projects, it is important to identify all potential stakeholders early during the planning stage. This may include landowners, tribes, other federal agencies, state or local agencies, irrigation districts, environmental groups, other non-government organizations, landowners, and recreationists. The stakeholders may have a wide range of technical backgrounds and varying knowledge of fluvial geomorphology. The stakeholders also may have different values for water in the river and different opinions about incorporating static or dynamic features into the project. It is beneficial to work with stakeholders to develop a common level of understanding by having technical experts lead discussions about geomorphic concepts relevant to the project. These discussions often include site visits and workshops to observe and understand the river. Focusing on the physics of water conveyance, sediment transport, and river behavior, rather than on opinions subject to bias, is an effective way to resolve potentially controversial issues.

However, there may be fundamental differences about project goals and objectives related to the different missions of each agency or stakeholder. Even if these aren't completely resolved, ongoing coordination throughout planning and design will still lead to a smoother and more transparent process. The local Reclamation area office responsible for funding and implementing the project should lead the coordination and communication with project stakeholders with support from technical service providers as needed. Developing alternatives is typically an important time to involve stakeholders. Including a larger group usually leads to more creative and robust solutions to address the purpose and need of a project. Obtaining buy-in during alternatives development and analysis will reduce the potential for disagreements at later design stages.

Ongoing coordination with the design team and between the service provider and client is also critical to success. This communication should happen at least monthly, or more frequently if needed. Monthly status reports are an effective tool to document progress, budget, change management, and risks.

B. Parallel Activities

Reclamation (2022) discusses parallel activities that occur during the FDP. Many of these are also relevant to the Planning Stage. For large projects with expected construction costs over $10 million, a Value Planning Study should be conducted during the appraisal stage. Similarly, a Design, Engineering, and Construction (DEC) review is normally performed at the end of the feasibility study for large or politically sensitive projects. Parallel activities that occur during the final design to ensure a smooth transition into construction may include a Value Engineering (VE) Study, realty acquisition, compliance & permitting, various cultural considerations, and Standard Operating Procedures (SOP). There are unique considerations pertaining to river design projects, particularly because these projects are often intended to heavily leverage and promote natural river processes and ecosystem services. The parallel activities described by Reclamation (2022) are listed below, along with notes about any specific considerations for river projects:

1. Value Engineering Studies
    a. During the VE study, conceptual underpinnings of fundamental riverine or ecosystem processes may be tested due to the nature of non-static design considerations.

2. Realty (Real Estate/Right of Way)
    a. Projects that intend to promote habitat creation along riverine corridors may require large continuous parcels of real estate (purchase or easement) extending many channel widths on either side of the river. It is important to properly engage with stakeholders and include adequate time and resources to secure appropriate levels of access to these tracts of land through the final design process to maintain constructability on schedule and within budget.

3. Permits
    a. Projects that promote fish passage, transfer, or collection will likely be subject to additional permitting and compliance along with consultation and review from agencies like the U.S. Fish and Wildlife Service, National Marine Fisheries Service (NMFS), and state agencies. It is not uncommon to have review panel input during the design process with engagement from governmental agencies and non-governmental entities.

The National Environmental Policy Act (NEPA) contains laws, regulations, and policies that must be followed during the planning and design process (see Reclamation 2012). NEPA applies to many parallel activities including environmental, cultural, historical, and tribal trust responsibilities. The type of NEPA document could be a Categorical Exclusion, Finding of No Significant Impact, Environmental Assessment (EA), or Environmental Impact Statement (EIS). The NEPA process includes scoping, alternative development, environmental impact analysis, and public involvement.

4. Environmental
    a. Threatened and endangered species listed under the Endangered Species Act often play a large role in river projects. River projects may have a goal to improve habitat for listed species or may have a constraint of not negatively impacting habitat for listed species.

5. Cultural
    a. Please see FDP (Reclamation 2022) for more information.

6. Historical
    a. Please see FDP (Reclamation 2022) for more information.

7. Tribal Lands and Archaeology
    a. Cultural renewal may be a major driver for projects involving habitat restoration, as many Native American tribes throughout the western states define their heritage through rivers and the riverine ecosystem. Funding for projects may be directed through tribal councils, and tribal members, employees, or contractors may be involved to varying degrees in the planning, design, and construction.

8. Acquisitions Planning
    a. Please see FDP (Reclamation 2022) for more information.

9. Funding
    a. Please see FDP (Reclamation 2022) for more information.

10. Non-Contract Costs
    a. Please see FDP (Reclamation 2022) for more information.

11. Standard Operating Procedures
    a. River design projects may not require SOPs, as the built product is typically intended to operate autonomously over a range of natural or managed conditions. However, projects that intend to promote natural processes typically also allow for dynamic equilibrium of hydraulic, sediment, and riparian conditions, implying that an acceptable degree of continual change is expected from as-built conditions. Consequently, documentation of adaptive management techniques may be needed to provide some basis for acceptable evolution of project features and how these features may be maintained. Other projects may require routine management to promote the intended processes (e.g., gravel augmentation to build spawning habitat); guidelines will be needed regarding the timing and magnitude of such management actions.

C. Construction Strategy

The FDP Guidelines (Reclamation 2022) assume a traditional design-bid-build project delivery, which consists of Reclamation designing, soliciting bids, and managing construction with company performing the construction. This is an option for river projects but has disadvantages in a dynamic river corridor because field conditions at the time of construction may be different than assumed for the design and specifications package. Depending on the project, the design-bid-build method is more likely to require change orders or alterations to the construction plans.

River projects should consider using the design-build project delivery method or using Reclamation force account groups to perform the construction. The design-build method shifts more responsibility to the contractor and allows them to make changes in response to river channel adjustments or unexpected field conditions. Similarly, Reclamation force account construction employs the design-build method entirely with Reclamation personnel. The use of Reclamation forces to construct a project means they can be part of the design team and therefore specifications do not have to be as detailed. The Socorro Field Office (SFO), working for the Albuquerque Area Office (AAO) in the Upper Colorado Basin Region, constructs river projects within the Middle Rio Grande. These projects are designed by Reclamation personnel at AAO or TSC and then constructed by SFO. The Construction Services Group in Provo, Utah performs a similar role but works in all Reclamation regions rather than only the Middle Rio Grande. SFO and the Provo Construction Services Group have vast experience and specialized skills to construct successful river projects in challenging environments. SFO and Provo also participate and contribute throughout the planning and design process by helping designers with access, staging, and constructability considerations during the design process.

Constructing river projects is a difficult task that requires frequent communication and adjustments during construction. Under the design-build method, the final design taken into the field for construction is analogous to the 90% design because the last 10% of the project results from changes during construction. These construction changes are often needed to meet the design intent while accounting for changes to the river channel geometry or flow conditions, or the discovery of large boulders, bedrock, or debris.

The construction strategy will influence the acquisitions strategy and the type of specifications and construction drawings. Therefore, the construction strategy should be determined at the beginning of the FDP, or perhaps earlier during the planning stage.

D. Planning Stage

1. Preliminary

Reclamation’s existing guidelines contain limited information about preliminary studies, also known as preliminary investigations. However, this is a critical stage for river projects. The preliminary stage should focus on understanding river processes and dynamics before starting to develop alternatives. Outcomes of the preliminary investigation include an assessment of the river condition and developing hypotheses about the cause of any impairments. Then, the project team can decide whether to proceed with a project and what the general approach would be for more detailed studies, analyses, and alternatives. Local stakeholders may already have ideas about how a river is functioning. Sometimes these ideas are only applicable to certain river locations or specific time periods. Stakeholder perceptions about how a river is functioning are not always correct. Understanding the correct river processes (and how they may be impacted by human activities) is crucial for project success. Yochum and Reynolds (2020) suggest three main tasks and considerations that would apply to a preliminary investigation for a Reclamation river design project: (1) apply a watershed approach, (2) compile existing data, and (3) conduct an initial field assessment.

(1) Watershed approach, questions to consider (adapted from Yochum and Reynolds 2020)

- How has land use changed throughout the watershed (e.g., logging, mining, farming, road building) and what are the results of these disturbances?
- How are flow diversions or groundwater pumping impacting the river?
- Are flows added to the river from trans-basin diversions and what is the effect?
- Are there storage or flood control dams in the watershed and how have they affected the hydrology and sediment?
- Are there irrigation diversion structures or culverts that may affect flow or block fish passage?
- Are there significant populations of non-native species in the riparian zones?
- Are landslides or debris flows common and what is the effect?
- Is there active channel incision from headcutting or knickpoint migration and what is the cause?
- Are there historic or current mining activities and how have they affected water quality?
- Have changes to the watershed impacted flow and sediment regimes and disrupted the river’s dynamic equilibrium?
- Have recent or historical wildfires impacted sediment and wood loads or channel morphology?

(2) Data compilation (adapted from Yochum and Reynolds 2020)

- Relevant literature, case studies, and project reports
- Streamflow
- Sediment load and bed material grain size
- Surface water quality and temperature
- Groundwater elevation, temperature, and seasonal fluctuations
- Biologic inventories (e.g., species of vegetation, fish, and wildlife)
- Soils information
- Historical and current aerial imagery
- Elevation surveys (floodplain topography and channel bathymetry)
- Geologic, geomorphic, and vegetation mapping
- Climate, weather, and precipitation
    - Consider if ice jams are a factor that may periodically block flow
- Land use records and historical narrative accounts

(3) Initial field assessment and indicators to examine (adapted from Yochum and Reynolds 2020)

- Longitudinal slope
- Lateral confinement
- Channel entrenchment
- Riparian vegetation age class and diversity along with large wood deposits
- Overbank deposits to indicate floodplain connectivity

- Channel pattern (e.g., meandering, braided, anastomosing)
- Riverbank condition (e.g., eroding, stable, armored, vegetated)
- Sand and gravel bar presence
- Pool and riffle characteristics
- Bed material (e.g., clay, silt, sand, gravel, cobble, boulder, bedrock)
- Evidence of degradation
    - Headcuts and knickpoints
    - Narrow and deep channel
    - High terraces banks
    - Perched tributaries
    - Exposed pipe crossings or perched culvert outfalls
    - Undercut bridge piers, revetments, or exposed tree roots
- Evidence of aggradation
    - Channel bed and banks above floodplain elevation (perched channel)
    - Uncharacteristically low bank heights
    - Uncharacteristically high number of bars and islands
    - Reduced bridge clearance
    - Culverts, outfalls, or vegetation buried in sediment
- Evidence of stability
    - Vegetated bars and banks
    - Limited bank erosion and point bars
    - Bridges, culverts, or tributaries with at-grade bottom elevations
    - Armored channel bed (e.g., bedrock, large boulders)

Many of the above topics will be further analyzed during the appraisal or feasibility stage, but they should be considered initially during the preliminary stage. One result of the preliminary investigation should be identifying relevant physical processes and developing a conceptual model as described earlier in Section I.D.1. The conceptual model supports hypotheses about the dominant fluvial processes in the river system and what may be causing any problems. The preliminary stage may include brainstorming ideas about concepts to address problems or needs, but the focus should be on understanding the watershed and the river. Additionally, the preliminary stage should focus on defining the problem or need and how it would conceptually be addressed with a river project.

The preliminary stage and initial site assessment is also a good time to consider risks associated with a potential project; specifically, are there flooding impact concerns for people, property, or infrastructure? The project team should engage with stakeholders and landowners during the preliminary stage. They may provide important information for the initial assessment and their comments can be useful for developing project goals and objectives while identifying constraints.

Some projects may have already completed a geomorphic assessment as part of a previous background study. This would reduce the level of effort at the preliminary stage, but the designers and project team should still visit the site and review the previously compiled information. Conversely, for rivers without previous projects or compiled background information, the preliminary investigation will require significant time and effort. For these cases, the team should consider developing a scope and PMP for only the preliminary investigation. It will be easier and more effective to develop a targeted scope for the appraisal and feasibility stages after first understanding the river by completing the preliminary investigation.

2. Appraisal

The appraisal phase begins with reassessing and refining project goals and objectives. The goals and objectives will likely be slightly altered based on knowledge gained during the site assessment and development of the conceptual geomorphic model. Refining project goals and objectives is important at this stage to ensure that analysis and alternative development are targeted toward these goals. During the process of refining goals and objectives, the client should be consulted on these changes to ensure an ongoing collaboration where TSC ideas are in line with the client's project vision. Appraisal studies include the following (CMP 09-01):

1. Description of problems and needs
2. Opportunities
3. Potential benefits
4. Alternatives
    a. Analysis of Alternatives (assess if they can potentially resolve the problems or meet the needs)
    b. Alternative Viability (evidence that at least one alternative is likely to address the problems or meet the needs)

The main task in the appraisal phase is alternative development. Typically, this involves a broad initial effort to develop a range of reasonable design alternatives. These alternatives may include different types and combinations of project components or completely different strategies to achieve the project goals. At this point, project leads should identify whether other technical disciplines or design groups will be involved in the planning and design process. Other design groups may need to be involved if the potential designs include rigid or structural engineered features, or if design features and changes to the riverine condition will impact existing features. Hydrologists may need to analyze gage records or develop design flows in ungaged watersheds before hydraulic or structural analyses can proceed. Hydrology questions to consider for an appraisal study include:

- What level of flood protection is needed?
- Are there habitat elements or restoration goals that require a range of flows, or certain seasonal flow intervals that are critical to species life stages?
- Are there diversions or hydraulic structures that need to function at specific flows and water surface elevations?

In addition to refining goals and objectives, the appraisal stage should develop initial design criteria to consider when developing alternatives. Appraisal-level designs include written descriptions, maps, sketches, and general layouts of primary project features.

Appraisal studies primarily use existing data and information. Upon compilation and assessment of existing project site data, there may be a need to fill data gaps to be able to develop river design alternatives. Many sites will have previous lidar data that defines some of the topography or past surveys at the site. However, some sites may lack sufficient topographic data to understand the riverine system appropriately. In these situations, limited survey data may need to be collected during appraisal. Other types of data that may needed include streamflow history, sediment characteristics, geomorphic mapping, elevations of engineered features, or vegetation characteristics. The type of data compiled in this phase focuses on informing the hydraulic and sediment transport characteristics of the river.

Development of a conceptual model of river processes (hydraulics, sediment transport, and channel plan form) is important for formulating alternatives to address problems or meet needs. It is helpful to understand flow and sediment dynamics to know the extent of the problem at a site or what location along a reach might be best for design. Numerical or physical models can help quantify these processes. A coarse one-dimensional (1D) numerical model may be sufficient for some projects, or a more detailed two-dimensional (2D) numerical model or physical model may be necessary for other projects. The goals of the river design project as well as current infrastructure and river conditions will dictate which type of model is needed to answer study questions.

Updated project goals, analysis, and outcomes from the appraisal phase of design should be documented either in a stand-alone project appraisal report or within a broader project river design report that includes multiple phases. The model results or expanded site assessment can be used to further refine or determine limiting factors or habitat needs within the river design location. Approximately three of the design alternatives (sometimes more if in conjunction with an EIS) should be selected within the appraisal study to be further developed and analyzed in the feasibility stage. The appraisal documentation should also detail the expected performance metrics when alternatives are evaluated within the feasibility phase.

3. Feasibility

The feasibility stage begins with a subset of alternatives from the appraisal stage and adds detail so that the client, with stakeholder input, may choose a preferred alternative to seek Congressional approval. A Feasibility Design Report will evaluate the alternatives for selection of the preferred alternative. To ensure environmental regulations and laws are met, the EA or EIS are completed in the feasibility stage. With Congressional approval, the preferred alternative will continue to the FDP. Feasibility studies follow an iterative planning process and include the following steps (CMP 09-02):

1. Identify Problems, Needs, and Opportunities. These should have been identified during the appraisal process but can be refined or updated for the feasibility process.
    a. What exact problem or need will be addressed by the project or action?
    b. What is the study area? Who are the stakeholders and potential beneficiaries?
    c. What are the planning objectives and constraints?
2. Inventory Existing Resources and Forecast Future Conditions
    a. What are the historical conditions and expected future changes?
    b. What is the period of analysis?
    c. What are the likely future conditions without the project?
3. Formulate Alternative Plans
    a. What features or elements can be incorporated in each alternative to address the primary planning objectives?
    b. What are the design criteria or constraints that need to be considered?
    c. What features can be added to each alternative to avoid, reduce, or mitigate environmental consequences?
    d. What is the feedback from stakeholders and the larger public?
4. Evaluate Effects of Alternative Plans
    a. What is the forecast under existing (with-out plan) conditions?
    b. What is the forecast with-plan future conditions under each alternative?
    c. How do the plans address technical, environmental, economic, and financial criteria?
    d. Can an alternative be improved to better meet technical, environmental, economic, and financial criteria? If so, reformulate the alternative and re-evaluate future conditions.
5. Compare Alternative Plans
    a. How do the forecast without-plan and with-plan future conditions compare?
    b. How do the plans compare for acceptability, efficiency, effectiveness, and completeness?
    c. How well does each alternative meet the planning objectives?
6. Select the Recommended Plan
    a. What is the stakeholder input?
    b. What plan maximizes the net benefits?

Some of these planning steps were already conducted during preliminary or appraisal stages but are further refined during feasibility. To accomplish the level of detail necessary for both the Feasibility Design report and the EA/EIS, considerable data collection is necessary in the feasibility phase (as developed by Reclamation in the Design Data Collection Guidelines). For river design projects, this often includes additional data requirements such as:

- detailed topographic and geomorphic data (if not collected in the appraisal stage),
- hydrology analysis to generate input discharge statistics, flood peak frequency, and hydrographs
- hydraulic measurements (e.g., discharge, velocity, temperature, water surface measurements),
- sediment sampling (e.g., bed material, suspended sediment, bedload measurements).

The level detail of engineering design at this phase of the project will be determined by the project goals and requirements and must be sufficient to develop a project cost estimate and support EA or EIS documents. Typical feasibility design drawings are to provide facility layouts and cost estimates. For river design projects, elements of design development for feasibility may include CAD drawings and plan sets, GIS plan sets, or three-dimensional design surfaces. Typical river design features at the feasibility level may include design features and their specific locations within the river corridor (channel or floodplain grading, installing or removing boulders or woody structures, fish passage channels, etc.). Often, for the purpose of hydraulic modeling, these design features will need to be incorporated into topographic surfaces and will therefore require elevation information. For example, the channel or floodplain grading is often a cost driver, so estimating the quantities of cut and fill will be necessary for the project cost estimate. Design development will likely overlay or adjust the existing conditions topographic data for proper comparisons.

To evaluate the design alternatives, river design projects will likely require extensive hydraulic modeling or mobile bed sediment modeling. Hydraulic modeling may consist of 1D or 2D numerical modeling, or physical modeling, depending on the complexity and nature of the project requirements. For example, fish habitat analysis will likely depend on the lateral variability of hydraulic conditions for a given design, thus leading to 2D hydraulic modeling. The existing conditions hydraulic model should match the design alternative models to support comparison and evaluation. Due to the complex, dynamic properties of river environments, hydraulic modeling of the design alternatives may be iterative to achieve project goals and requirements. Iterations are especially common when interfacing with 'hard engineering' structures such as weirs, diversions, or bridges. Hydraulic considerations such as 100-year water surface elevations for freeboard and water velocity tolerances will influence design for these structures.

Some projects may require hydrologic modeling, such as how flows would be routed for different reservoir operations or how river flows may change for different climate scenarios. Hydrologic models inform river hydraulic and sediment models when forecasting future conditions and comparing alternatives.

For a design alternative to advance from the feasibility stage to final design, a preferred alternative must be selected. Often, feasibility designs are an iterative process because the evaluation of design alternatives will involve feedback from government agencies, other stakeholders, and the public.

E. Final Design Process

The Reclamation Final Design Process (Reclamation 2022) begins following completion of the feasibility level of planning. For larger projects, transition from planning to final design stages will coincide with Congressional authorization and appropriation of funds for the project. The final design process continues through the completion of construction closeout. The guidelines established within the FDP are intended to provide design teams with established protocols for preparing final designs and specifications efficiently and transparently for project delivery under the design-bid-build model. Herein, we discuss how river design projects fit within the defined stages of the FDP, pointing attention to some nuances and special consideration for these types of projects to improve planning and maintain efficiency. A central question regarding project scope will drive schedule and set milestones:

> *Is the overall project comprised solely of river design features or a combination of river design features and other co-dependent facilities?*

In other words, do the river design features define the entire scope of the project or a sub-set of a larger scope? If the latter, does the resulting hydraulic design data affect the details of other design facilities? For example, a full project scope may involve design of new channel and floodplain alignments to promote habitat enhancement as well as a diversion headworks to meet water delivery requirements to stakeholders. The details of the channel and floodplain features will influence the stage-discharge relationship that will inform design of the diversion structure. There may be the need for other features, such as fish screens, to be developed in concert.

Because design of 'hard engineered' facilities may be dependent on the hydraulic design elements, careful consideration must be given to the timing of river design project activities and how the hydraulic and sediment design data may be used by other disciplines in the design of new or modified facilities. To avoid a spiraling cascade of re-work, it is advisable to have designs of project elements determining hydraulic characteristics at a mature level of completion prior to advancing design of dependent facilities. This may require front loading hydraulic design efforts earlier in the process than is typically identified in the FDP. Also, consider the design data needs of the hydraulic design efforts and the timing required to meet the proposed schedule. In these types of projects, acquiring design data and performing the hydraulic analysis work may be the critical path. Otherwise, if the project is focused solely on river design aspects, then a different approach to scheduling milestones may be perfectly adequate. The key here is in identifying potential complicated design co-dependencies during the planning phase prior to beginning the final design process.

Additionally, iterations and review are a critical part of the FDP, especially when different design groups are involved. When hydraulic or sediment results and analyses are used as input data for structure or facility design, the design leader needs to include the hydraulic engineer or geomorphologist as a team member throughout the process. Check-ins at key milestones between the facility designer and the hydraulic engineer or geomorphologist will help ensure that the design is compatible with how the river is intended to function (e.g., depth, velocity, sediment load). Incorporating a feedback loop between the facility design and the river design will reduce the chance of riverine processes or data being misapplied. Similarly, if a hydraulic engineer or geomorphologist is designing a habitat restoration project, they should obtain feedback from biologists at key design milestones.

The PMP should establish a rational schedule for milestone deliverables that reflects a thorough planning phase. River design projects are commonly reliant on hydraulic and sediment transport modeling as part of the alternatives evaluation and continuing through to verification of design performance objectives; here, we highlight considerations at each standard FDP milestone.

1. 30%

Prior to initiation of the 30% stage, Reclamation generally recommends design alternative selection be complete or significantly refined. In many river design projects, alternative selection is informed by comprehensive hydraulic modeling. Consequently, hydraulic modeling studies (and the necessary data to support model development, calibration, and validation) will need to be conducted at or before the 30% design stage. For river design projects that do not feature complex co-dependencies with other design facilities, alternatives selection and refinement may continue through the 30% design stage and beyond.

Specific considerations:

- Hydraulic modeling will require a 30% design surface (as an iteration on surfaces developed during the planning stage), developed from topographic and bathymetric surveys. Design surfaces may be refined as needed based on results from feasibility analysis.
- Hydraulic modeling will require data for calibration and validation of the model, which at a minimum, typically consists of measured water surface elevations and discharge along the river reach.
- Hydraulic modeling will require flow input data developed from gage records, hydrologic modeling, or climate change modeling.
- Key features within the alternative(s) should be identified and tightly coupled to the Goals & Requirements and Basis of Design Document.
- The first set of design drawings for the preferred alternative will typically be developed. Cost estimates are typically developed as well. Consider that river design projects may require large earthwork quantities due to the spatial extent, particularly when floodplain connectivity and habitat are of importance.

2. 60%

River design projects may require the following during the 60% stage:

- Final hydraulic calculations (e.g., scour, riprap size)
- Final elevation of design surfaces
- Final hydraulic modeling that has all the details of the design surface

Consider that if significant changes are being made to the hydraulic analysis (such as through modification of the design surface) so that it will alter the local stage-discharge relationship, then the changes will also likely require modification to other hard engineered features and facilities being designed in concert. For some projects, if the computational mesh for a hydraulic model needs to be significantly adjusted at this stage of design, it may indicate that a resubmission of part or all of the 30% design level package is warranted.

3. 90%

During the 90% design phase, the design package, including drawings and report, should be nearly complete. Hydraulic analyses should be complete prior to start of the 90% design phase. For many river design projects, the 90% level is considered complete and ready for construction.

4. 100%

Many river design projects will not have designs to the 100% level. Drawings are commonly taken into construction from 90% in a design-build project; the final 10% of adjustments (90 to 100) reflect decisions made during construction based on field conditions at the time.

5. Acquisitions

As discussed earlier, acquisitions will depend greatly on the construction strategy. Reclamation (2022) describes the acquisitions steps for the design, bid, build under the FDP. For river projects, acquisitions may also consider the design, build process or constructing projects with Reclamation forces when field conditions may be uncertain. River projects may need to consider obtaining an as-built survey and post-construction monitoring data.

6. Construction

River projects typically require significant involvement from designers and inspectors during construction to ensure the design intent is met when field conditions differ from design assumptions. This may include periodic surveys during construction and technical assistance to solve issues that arise during construction. Changes in flow, water surface elevation, and channel geometry are common. The target construction period is usually limited to the low flow season when working in the river and can also be seasonally limited based on threatened and endangered species. It is critically important to complete an as-built survey to compare constructed features to the design drawings and to provide a baseline for post-construction monitoring.

F. Monitoring and Adaptive Management

After construction, traditional civil works projects are transferred to operations and maintenance (O&M) status. River projects are typically not facilities and therefore may not have O&M. The equivalent post-construction process for river projects is to perform monitoring and adaptive management. The goal for restoration projects may be to activate geomorphic processes such as channel migration, whereas the goal for infrastructure projects may be to maintain the constructed dimensions. In either case, post-construction monitoring is necessary to evaluate if the river project is achieving the intended goal. Monitoring includes items such as channel and floodplain surveys, sediment sampling, and aerial imagery. Monitoring should be repeated at consistent intervals or in response to sediment-mobilizing high flow events.

Monitoring informs the adaptive management process, which is addresses uncertainty and improves effectiveness of current and future projects. Adaptive management provides an opportunity to learn from the project response and make changes based on what's learned. Monitoring and adaptive management plans should be developed during the design process. The plans include predictions or hypotheses about the project and environmental conditions will respond to future conditions and structured data collection to evaluate the hypotheses. Monitoring and adaptive management plans can be an effective tool to address stakeholder concerns about a project. Monitoring will identify if the project is not performing well. If the project is not responding as predicted, determine why and develop adaptive management plans to better achieve project goals and objectives.

IV. Summary

These guidelines provide a framework for planning and designing a river project. Project goals, types, and methods vary widely, but an overall goal should be that the post-project river is more self-sustaining and resilient than pre-project conditions by incorporating natural fluvial and ecological processes. Rivers are dynamic and exhibit complex responses to changes in flow, sediment, infrastructure, and watershed disturbances. Therefore, river-specific guidelines provide supplemental information to Reclamation's existing planning and design process, which is focused on larger-scale civil works projects.

Table 3 summarizes general design and scoping considerations, Table 4 summarizes the planning stage (preliminary, appraisal, feasibility) and Table 5 summarizes the FDP (percent design, acquisitions, construction, monitoring plan). These tables provide a quick reference that describes the TSC planning and design process guidelines for river projects.

Table 3.—Summary of general design and scoping considerations for river projects

General River Design Considerations

• Remember that rivers are dynamic
  ○ Rivers adjust their pattern, profile, and dimensions in response to watershed disturbances, infrastructure, and changes to water and sediment discharge. Rivers are influenced by hydrologic, geologic, and biologic (e.g., vegetation) controls.
• Define goals and objectives
  ○ Consider if goals require limited channel movement or promote active channel migration; consider if hard points will be integrated in an evolving river channel
  ○ Establish design criteria and known constraints
• Develop a conceptual model and identify important physical processes
  ○ Identify geologic controls, sediment sources, and locations of slope or width change
  ○ Identify vegetation conditions, channel migration, and locations of sediment erosion or deposition
  ○ Identify channel evolution trends
• Identify any impairments affecting natural river processes
• Develop a plan for modeling and analysis throughout the planning and design process, with a focus on the planning stage
  ○ Define the study questions
  ○ Define the study scope
  ○ Determine the analyses and modeling necessary to answer study questions
  ○ Collect data to support analyses and modeling
  ○ Involve experienced and knowledgeable experts
• Consider the likely type of project to be implemented and review relevant case studies and literature
  ○ Examples include restoration, fish passage, channel stabilization, infrastructure, and sediment management
• Account for changes to river channel geometry that occur during the planning and design process
  ○ Specify an appropriate level of precision for constructed features depending on project type

General Scoping Considerations
• Work closely with the client to develop tasks, deliverables, and milestone schedules • Include time for ongoing coordination with client and stakeholders (this can be significant) • Consider starting with a smaller scope to conduct an initial assessment to understand the river processes and trends

Table 4.—Summary of planning stage tasks (preliminary, appraisal, feasibility) for river projects

Preliminary Stage

• Focus on understanding river processes and the cause of any impairments
• Conduct initial assessment to include:
  ○ Watershed approach
  ○ Compilation of existing data
  ○ Initial field assessment
• Develop hypotheses based on conceptual models and physical processes
• Define the problem or need and how it would conceptually be addressed with a river project

Appraisal Stage

• Identify a reasonable range of solutions that could address the problem or need
  ○ screen out alternatives that are not viable
• Designs are primarily based on existing data
• Designs include narratives, simple sketches, and general layouts of primary features
  ○ Level of design is sufficient to determine if an alternative is viable (i.e., can potentially resolve the problem)
• Analysis may include existing conditions modeling to better understand the problem or coarse alternatives modeling for initial assessment
• Consider if the proposed alternatives are sustainable with river processes or what maintenance would be needed

Feasibility Stage
• Formulate and evaluate alternative plans; typically evaluate about 3 alternatives • Designs are based on existing and new information; may require significant data collection • Designs include detailed narratives, typical cross sections and profiles, and specific layouts of project features   ○ Level of design is sufficient to estimate quantities for nearly all project features and to evaluate technical and environmental compliance factors • Analysis is likely to include detailed modeling to evaluate without-project conditions and design alternatives • With stakeholder input, the decision maker selects the preferred alternative and requests authorization for construction

Table 5.—Summary of FDP tasks (percent design, acquisitions, construction, monitoring plan) for river projects

30% Final Design
• Refine preferred alternative • Refine hydraulic modeling • Prepare draft hydraulic calculations • Prepare 30% final design drawings • Prepare draft Basis of Design (BOD) report
60% Final Design
• Update design details • Finalize design terrain surface • Finalize any numerical models (hydraulic or sediment simulations) • Finalize hydraulic analysis and calculations • Prepare 60% final design drawings • Update BOD report • Complete VE Study (if construction cost is greater than $1 million)
90% Final Design
• Finalize design features • Complete checking, technical approval, and peer review • Prepare 90% final design drawings (ready for regional or administrative review) • Finalize BOD report
100% Final Design
• Complete and sign 100% final design drawings
Acquisitions
• See FDP (Reclamation 2022) for design-bid-build projects • Consider acquisitions needs for as-built survey or post-construction monitoring
Construction
• Provide technical support and inspections to meet design intent while accounting for any changes to field conditions
Monitoring Plan
• Develop a monitoring and adaptive management plan • Include questions, hypotheses, and a plan for data collection • Consider how to adjust project if not performing as intended

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Appendix A

Reclamation Final Design Process: General Flowchart

Reclamation Final Design Process

Figure 1: General Flowchart

6/1/2022

Time Estimates	Pre-30%	30% to 100%	Acquisitions
Dams	6–21 months	10–24 months	5-10 months
Pumping Plants	3–21 months	10–15 months	5-10 months
Power Plants	3–21 months	10–15 months	5-10 months
Pipelines	3–21 months	12 months	5-10 months
Canals and Tunnels	3–21 months	10 months	5-10 months
Water Treatment Plants	5–21 months	18–24 months	5-10 months

Legend

BOD	Basis of Design	IGCE	Independent Government Cost Estimate
CE	Construction Engineer	PM	Project Manager
CO	Contracting Officer	PMP	Project Management Plan
DDR	Design Data Request	PMT	Project Management Team
DEC	Design, Estimating, and Constru ction	PREVAL	Pre-validation
DOC	Designers' Operating Criteria	RFI	Request for Information
DSO	Dam Safety Office	RFP	Request for Proposal
FBMS	Financial and Business ManagementSystem	RSN	Required Submittal Number
FBO	Federal Business Opportunities	TM	Technical Memorandum
FER	Field Exploration Request	VE	Value Engineering
IFB	Invitation for Bid		

PLANNING STUDIES

- Planning studies completed (Preliminary, Appraisal, Feasibility)
- Value Planning and DEC Review completed (if required)

DESIGN (13 39 Months)

PREWORK
1-3 Months

- PM assigned by originating office
- PMT may be established
- Project features identified and proposed project schedule developed
- Funding source for design work is identified
- PM identifies design service provider and requests services
- Design team leader assigned

START

PLAN
1-6 Months

- Design team formed
- Scheduling activities initiated
- PMP developed and approved
  - Goals and Requirements developed
- Design cost accounts are open to service provider charges
- Design Team
  - Prepare Design Data Request for major items that impact schedule or budget
  - Determine need for: geologic field exploration, material testing, hydraulic model, water treatment pilot plant
  - Identify special studies: seismotectonic, hydrologic, hydraulic, biological

DESIGN PMP

CONCEPT
2-18 Months

- Develop / refine initial concept
- Develop Design Data Request (DDR) and Field Exploration Request (FER)
  - Submit detailed DDR and FER
  - Receive and evaluate data for completeness
  - Receive Final Design Geologic Data Report
  - Submit supplemental FER, if needed
- Request material testing and hydraulic modeling
- Develop alternative concepts (if required)
- Prepare 30% Final design cost estimates (recommended)
- Identify preferred design concept cost, additional data requirements, and revised schedule / resources
- Identify acquisition type
- Prepare concept drawings
- Perform security reviews (if required)
- Identify TMs to be prepared
- Prepare draft Basis of Design (BOD) document
- Prepare preliminary calculations to verify technical feasibility and support cost estimate
- Hold milestone concurrence briefing and sign decision document

30% FINAL DESIGN — CONCEPTC

DESIGN
4-10 Months

- Supplemental design data is received and incorporated into designs
- Complete laboratory testing (hydraulic models included)
- Receive Supplemental Final Design Geologic Data Report (if required)
- Complete analysis of structures, foundations, and systems
- General arrangement drawings, typical sections, and single-line diagrams drawings are developed
- Identify and coordinate details across technical capabilities
- Complete VE study (>$1,000,000)
- Prepare draft VE accountability report
- Prepare draft construction schedule
- Perform constructability review
- Prepare draft specifications table of contents, bid schedule, division 1 paragraphs, and drawing list
- Prepare draft TMs and identify additional TMs to be prepared
- Update BOD document
- Coordinate with PM on required permits and environmental reviews
- Prepare 60% final design cost estimate (optional)
- Hold milestone concurrence briefing and sign decision document

60% FINAL DESIGN — DESIGNC

DRAFT SPEC
2-6 Months

- Check analysis of structures, foundations, and systems
- Submit draft specifications and technically approved drawings to specifications coordinator for TASPEC
- Complete and approve final TMs before SPECD
- Update BOD document before SPECD
- Complete TASPEC review of specifications package (if required)
- Prepare 90% final design cost estimate (optional)
- At 90% final design
  - Draft specifications package submitted to contracting office
  - Memorandum sent to all involved parties that draft spec and drawings were sent, info on REVIEWC meeting, and instructions on coordinating comments

TASPEC

DRAFT SPEC
1-1.5 Months

90% FINAL DESIGN — SPECD

REVIEW
1 Month

- Involved parties review draft spec package and documents comments
- Review meeting is held with involved parties and the design team (1-5 days)
- Prepare final review meeting notes that list areas of discussion, schedules, and individuals responsible for follow-up actions
- Hold REVIEWC closeout briefing and sign decision document

REVIEWC

FINAL SPEC
1-1.5 Months

- Changes discussed and agreed to at REVIEWC are made– additional info or data, if required, is provided to the design team
- Final drawings signed through peer review are sent to speccoordinator
- Specifications signature sheet signed through technical approval
- Final spec and drawings in .pdf format sent to acquisitions
- For RFP: Design team and CE develops evaluation criteria and delivers to CO
- Checked and peer reviewed quantities furnished to the estimator
- Prepare 100% final design cost estimate (optional)
- Start Prevalidation cost estimate (required)
- Complete Design Summary and Designers' Operating Criteria (DOC)

100% FINAL DESIGN — SPECB

ACQUISITIONS (5 10 Months)

100% FINAL DESIGN — SPECB

BOOKPRE
2 Months

- Finalize VE accountability report (>$1,000,000)
- Funding requirements (Prevalidation estimate) furnished to CO by estimator, 2 to 5 weeks after SPECB.
- Contracting office enters purchase request in FBMS
- CO submits socio-economic screening form
- CO submits draft solicitation for review
- Pre-solicitation notice issued by contracting office at least 15 days before issue
- CO posts solicitation on FBO website

ISSUE

BID
IFB: 2-3 Months
RFP: 5 Months

- IFB
  - Special inspection requirements resourced
  - Pre-Bid information meeting conducted by contracting office
  - Amendments prepared and sent to contracting office
  - IGCE prepared and transmitted to CO (required)
  - Bids opened by contracting office
- RFP
  - Special inspection requirements resourced
  - Pre-proposal conference conducted by contracting office
  - Amendments prepared and sent to contracting office
  - Amendments are issued by contracting office
  - IGCE prepared and transmitted to CO
  - Technical proposal evaluation committee (TPEC) evaluate proposals
  - TPEC sends evaluation of technical proposals memorandum to CO

BID

AWARD
IFB: 1 Month
RFP: 3 Months

- IFB
  - Address protests
  - Bids evaluated
  - CO determines contractor responsibility
  - Contract awarded
- RFP
  - CO prepares pre-negotiation memorandum
  - CO determines contractor responsibility
  - Contract awarded
  - Debrief offerors
  - Address protests (if required)

AWARD

CONSTRUCTION

CONSTR
varies

- CO Issues Notice to Proceed
- Contractor performs construction activities
- Design Team
  - Participates in readiness review, preconstruction, and concrete preplacement meetings
  - Prepares revisions and corresponding cost estimates to modify the contract (if required)
  - Reviews contractor's RSNs and RFIs
  - Inspects and approves foundations
  - Provides technical assistance
  - Provides technical analysis of claims
  - Prepares foundation acceptance summary memorandumss
- CE
  - Performs field and factory inspections
  - Assists in developing and implementing acceptance test procedures
  - Technical acceptance of field modifications
  - Monitors progress of work
  - Lists all outstanding project requirements which have not been completed
  - Accepts the work as substantially complete

SUBCOMP

CONSTR
varies

- Review all RSNs for completion
- Ensure as-builts are complete
- Assist in preparation of punch list for completion
- Assist in equipment checkout and startup
- Perform warranty inspections
- Assist with final inspection
- Acceptance of all work as complete

CONSTRC

COMP
1.5-3 Months

- Analysis of claims
- Provide expert testimony
- Assistance in startup and initial O&M
- CO accepts release of claims
- Prepare Final Report of Construction
- Complete contract closeout
- Finalize Design Summary and DOC
- Hold lessons learned meeting and document lessons learned

COMP