Evaluating and Developing Multi-Purpose Riverine Projects: An Example from the Middle Rio Grande

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Abstract

Fluvial systems like the Middle Rio Grande (MRG) are inherently complex given its geology and characteristics as a semi-arid southwest river. Developing a cohesive framework for multi-disciplinary teams to integrate their expertise and analytical tools in a project development process is challenging due to the dynamic, uncertain, and complex nature of the riverine environment. The MRG has undergone both geologic, hydro-climate, and anthropogenic driven morphological changes resulting in the need to perform river maintenance to ensure effective water and sediment delivery, meeting socio-economic needs in the MRG valley. The observed morphological responses have also affected endangered species and their habitats. The U.S. Department of the Interior, Bureau of Reclamation (Reclamation) has evolved its project planning processes to balance sometimes conflicting needs of satisfying socio-economic and ecological needs in the semi-arid southwest. The methodology presented herein describes the framework for a robust decision making process by which project alternatives are formulated and analyzed comparatively, culminating in a preferred alternative for implementation. The procedure builds upon lessons learned in other fluvial systems and provides guidance based on MRG experiences through the alternative formulation, analysis, and selection process.

Developing goals, identifying constraints, formulating alternatives, defining specific project objectives, and systematically evaluating the alternatives involves two distinct steps. The first step is at a conceptual or appraisal level and is more qualitative than quantitative. This first step culminates in the formulation of potentially suitable alternatives. The second step includes the development and analysis of those potentially suitable alternatives in a systematic and holistic manner. This second step is typically more quantitative in nature, culminating in the development of a feasibility level or 30% project scope for the potentially suitable alternatives. This step also results in the selection of a preferred alternative. These two steps are preceded by an assessment(s) providing understanding of the underlying physical processes and environmental conditions occurring in the fluvial system.

Background

In the early to mid-1900s the MRG transported an estimated 30 to 40 million tons of sediment annually (Finch and Tainter 1995). This quantity of sediment created large geomorphic changes causing severe flooding, loss of water, damage to riverside facilities, and the loss of productive farmlands because of high water tables. This led to the Flood Control Acts (Acts) of 1948 (P.L. 80-858) and 1950 (P.L. 81-516) which established the MRG Project. Reclamation was authorized at this time to perform maintenance on the MRG. Essential maintenance performed by Reclamation is described in more detail in Reclamation's Plan and Guide (2007; 2012a), but generally includes ensuring channel capacity, protection of adjacent infrastructure, and effective transport of water and sediment between Velarde and Caballo Dam, New Mexico. An international treaty with the Republic of Mexico for delivery of water and the 1939 Rio Grande Compact, which regulates the distribution of Rio Grande water among the states of Colorado, New Mexico, and Texas also affects the MRG Project and associated essential maintenance activities. These maintenance actions provide a socio-economic service to the MRG valley, however, they also tend to limit the degrees of freedom the MRG has to adjust. Maintenance activities have evolved since the Flood Control Acts to include Federal responsibilities under the 1973 Endangered Species Act (ESA), including habitat requirements mandated by the 2016 Biological Opinion (USFWS 2016) for work on the MRG. Consequences of not performing these activities include substantial damage to riverside facilities, loss of water, and loss of endangered species habitat.

Habitat restoration work on the MRG also provides a socio-economic value by creating features that have aesthetic and recreational value along with the underlying ecosystem services function. There are circumstances where this type of work may conflict with maintenance needs that protect riverside facilities and ensure water and sediment can be conveyed downstream effectively. For instance, the creation of bank terraces and backwater embayments on the MRG restores a vital connection between the river and its floodplain. This helps dampen the flood peaks for some flows, encourages riparian vegetation that provides a level of bank stability that protect riverside facilities, and locally raises groundwater levels. These features also spread water out, make the effective transport of water and sediment less efficient, and potentially provide an avenue for fluvial adjustments of the channel to cause lateral migration of the banks towards riverside facilities. It is in considering both the socio-economic and ecological needs that a balance must be struck. Given that balancing these needs occurs within a complex and dynamic MRG, a multi-disciplinary team decision making process for formulating and evaluating alternatives has been developed and refined over the years on the MRG. This alternative analysis process that encompasses both the socio-economic and ecological needs along the MRG is further described in the following sections.

General Concepts and Preliminary Assessments

The river system and its processes, substrate, biota, and their dynamic inter-relationships provide challenges for multi-disciplinary teams in predicting channel conditions and responses to river projects. Key to the success and development of potentially suitable alternatives is to assess the underlying physical processes that are occurring within the fluvial system. Wohl et al. (2006) emphasizes understanding of the physical processes in the development of alternatives in order to provide a more self-sustainable river system, which helps with resiliency (Parsons and Thoms 2018). This understanding requires at least a basic understanding of the geology, fluvial geomorphology, sediment, hydrology, and hydraulics for the reach in which work is being pursued (Biedenharn et al. 1997; Watson et al. 1999; NRCS 2007a; Niezgoda et al. 2014). These assessments require the continuous or periodic collection of field data and an understanding of the history of channel conditions and trends to help assess changes that are occurring. On the MRG periodic data collection efforts are analyzed for current morphological trends on a project by project basis that considers the local fluvial area (Harris and AuBuchon 2016; Holste 2017). Larger geomorphic reaches are also evaluated on the MRG (Klein et al. 2018; Harris et al. 2018) to provide a system wide assessment. This process helps identify dominant processes occurring throughout a connected ecosystem (Wohl et al. 2015), allowing the potential for multiple projects to work with a river's self-sustaining processes. These studies coupled with collections of historical channel changes and anthropogenic influences on the MRG (Graf 1994; Scurlock 1998; MEI 2002; Massong et al. 2010; Makar and AuBuchon 2012; and Makar 2015) provide a framework for understanding potential fluvial system responses to proposed projects.

An understanding of the ecology within a fluvial system and the inter-dynamics, such as vegetation growth and biological activity (e.g. beaver and other animal burrows in the streambank), that influence the fluvial system (Cramer 2012) is also important. This also entails the consistent collection and analysis of field data. On the MRG, biological studies have focused on the needs of endangered species (e.g., Siegle et al. 2013; Tetra Tech 2014; Baird 2016; and Bachus and Gonzales 2017). There are a fewer broader and more holistic studies that have been pursued such as Crawford et al. (1993) and Mortensen et al. (2019) to help link observed biological changes with morphological, hydrologic, hydraulic, and sediment changes. Reclamation has also been working towards developing ecological function criteria (Reclamation, unpub. data, 2017) to help assess desirable morphological features for different life stages of endangered species. This helps to target better habitat improvement projects. Habitat suitability indexing, such as Harris (2017), have also been found to be useful on the MRG to identify potential Rio Grande silvery minnow habitat. Similar analysis would benefit an evaluation of habitat improvement potential during evaluation of alternatives. These types of evaluations, however, require an understanding of the ecological needs for a given biota (this may vary by life stage as well).

Finally, to successfully formulate alternatives, an understanding of available and appropriate river treatment methods are needed. These form a working "toolbox" from which to pull ideas during the brainstorming session that occurs as part of the alternative analysis process. There are a variety of resources and training courses available that help fill this toolbox. While not an extensive list, some useful references include NRCS (2007a), Baird and Makar (2011), Reclamation (2012a; 2012b; 2015), Baird et al. (2015), Baird (2016), Lagasse et al. (2016), Newbury (2016), Reclamation and USACE (2016), Sholtes et al. (2017), and Yochum (2018). These references provide guidance on a variety of river treatment methods.

Given the breadth of information required to conduct an alternative analysis, a multi-disciplinary team is needed along with a robust alternative analysis process. On the MRG there is a desire to ensure that both socio-economic and ecological considerations are developed and integrated together as alternatives are evaluated in terms of their effectiveness and costs. The alternative analysis allows the multi-disciplinary project team the flexibility and innovation required to integrate these diverse and sometimes conflicting needs. The goal being to make sound and defensible decisions, working towards a more self-sustaining and resilient system (Parsons and Thoms 2018).

Assuming data collection and reach assessments have been conducted, the alternative analysis process would then progress in two distinct steps. Both of these steps would involve a multi-disciplinary team. The first step, identified as alternative formulation, is a conceptual or appraisal assessment that develops and clearly articulates the goal(s), scope, and constraints of the project. A brainstorming session, based on the experience and knowledge obtained from previous projects and literature reviews, is then conducted to identify mutually exclusive, suitable alternatives. A suitable alternative implies that the team would formulate an alternative that meets a project's agreed upon goals/objectives, developed by the multi-disciplinary team, and that the alternative is realistic and achievable. The second step involves the analysis and rating of the suitable alternatives. During this step, the team develops an evaluation framework centered on engineering effectiveness, ecosystem function, and economic criteria. The second step is quantitative in nature, culminating in the development of a feasibility level (30% level of scope development) scope for the suitable alternatives. This step also typically results in the selection of a preferred alternative. Each of these steps is described in more detail in the sections below, including a listing of key work steps and a schematic diagram of the work process.

Step 1 – Formulation of Alternatives

The formulation of alternatives is the first step of a robust alternative analysis process. The formulation of potentially suitable alternatives begins after a general understanding of the underlying physical processes and environmental conditions is obtained, as previously described. The formulation of potentially suitable alternatives is more of an appraisal (i.e. conceptual or order of magnitude for cost) level assessment that begins by forming a multi-disciplinary team. This team works by consensus to develop and clearly articulate the goal(s), scope, and constraints of the project (Biedenharn et al. 1997; Watson et al. 1999; IPMP 2002; NRCS 2007a; Skidmore et al. 2011; Martin et al. 2016; Wohl et al. 2015; Sholtes et al. 2017). The goal(s) need to convey the value and intent of the desired work. This should be clearly and succinctly stated so others can readily grasp the project's vision and desired outcome. From this effort the project's scope is developed, which includes defining the purpose and need for the planned project. The team should also consider the potential consequences and impacts of not doing the project. Ideally the scope and effect of the project's benefits would be greater, or at least proportional, to the potential consequences and impacts of not doing the project. Potential project constraints are also identified to help refine the goal(s) and project scope. Constraints include verifying that there is legal (land use), statutory, and fiscal authority to pursue the project and identifying any limitations related to this authorization. These constraints may also be identified for other reasons, such as cultural, recreational, etc.

Ideally the multi-disciplinary team provides the expertise or understanding to make the background assessments described earlier or has the capability to collect and analyze additional data to provide this level of expertise in support of a project's alternative formulation. From this body of knowledge, alternatives can be proposed through a brainstorming exercise that would satisfy the stated goal(s), purpose and need of the project, and objectives. If an alternative is proposed that doesn't solve the problem (would not meet the goal(s) or objectives and is not within the identified constraints) then this alternative should be screened out from further evaluation.

The multi-disciplinary team may include primary stakeholders, such as landowners, as part of the team. One of the keys to working with a multi-disciplinary team is to keep a level of independence among the team for analyzing and rating alternatives. The desire in an alternative analysis is to have each team member provide feedback and ask challenging questions about the proposed alternatives, rather than relying on the opinions of one or two team members (Nemeth 2014). It is easy for teams, especially ones that work well together or with teams under significant time constraints, to rely on others in the team, instead of critically evaluating the proposed alternatives against the agreed upon goals, objectives, and constraints. As an example, one MRG project north of Albuquerque had to be redesigned at construction because not all concerns of the primary stakeholder were thoroughly expressed to the multi-disciplinary team during the alternative analysis process even though the team included members from the primary stakeholders. While not foolproof, developing clear and succinct goals, purposes, and needs during the alternative formulation process and having a team environment in which concerns can be brought forward and discussed is helpful to minimize potential problems experienced further down the planning road.

Involving the experience and expertise of construction personnel during this assessment may also be useful to understand which identified constraints can be overcome through utilization of an appropriate construction technique, such as minimizing damage to riparian vegetation by using amphibious excavators or employing specialized planting techniques, such as Longstem and Tallpots (NRCS 2007b; Dreesen et al. 2002), to increase viability of vegetation and aid in the bank stability in a more arid climate.

Alternatives should also be assessed if they will work with the dominant physical processes that are identified from the background assessments described previously. This in essence checks if the proffered alternative works with the identified physical processes. This can provide a further screening of alternatives, but would be dependent upon the originally stated goal(s) and objectives. For example, the reach of the MRG upstream of Elephant Butte Reservoir experiences loss of channel capacity concerns due to sediment deposition within the channel. This has created a main channel system perched above the adjacent floodplain. In this situation large sustained runoff events have caused the river's sediment load to entirely block the active channel, forcing all of the water into the floodplain, creating socio-economic concerns about loss of water for downstream users. Previous reach responses have focused on removing the sediment mechanically after an observed blockage. This alternative, while effective in the short term, works against the dominant physical processes that have created a perched channel condition and continue to cause sediment deposition. In an effort to provide a more sustainable approach, an alternative analysis (Holste 2014) identified an option to relocate the channel to a lower point in the floodplain further to the east. The relocation option provides an opportunity for the fluvial system to respond and self-adjust without continuous intervention. This alternative also provides more space between the infrastructure at risk when the river floods. The additional space allows the channel to self-adjust, facilitating the natural successional development of both morphological and vegetative features. Over the long term the continued deposition of sediment will result in perched conditions. The perched channel conditions will not, however, be as constrained due to the increase of available space for the river to adjust. Due to the goals associated with this alternative, monitoring of this project is geared to assess the increased resiliency and diversity that results from the channel relocation.

Screening alternatives at the appraisal level (e.g. proof of concept, meets purpose and need, works with the dominant physical processes, etc.) helps minimize the time required to perform the next phase of the alternative analysis process — the evaluation of alternatives. Identified alternatives for evaluation at a feasibility level (30% scope development) should be mutually exclusive so that their effects may be quantified and independently assessed. Based on experience in the MRG, having between 3-5 alternatives is sufficient to identify an initial array of alternatives and helps provide an efficient and timely alternative screening step. For example, some MRG projects (Lopez and AuBuchon 2012; Tetra Tech 2012) identified six or more alternatives. This extends the time needed to evaluate alternatives and results in a more laborious selection process to differentiate between similar alternatives. In hindsight, the number of alternatives should have been reduced by grouping together alternatives with the same function. For example, some of the MRG sites had different iterations of indirect bank protection like bendway weirs (low, flat structures perpendicular to the flow), rock vanes (sloped structures perpendicular to the flow), or a combination of bendway weirs and rock vanes. If these had been evaluated as a single transverse feature alternative, less time would have been spent during evaluation, facilitating a quicker transition into design.

When combining alternatives to form mutually exclusive options, it is important to remember that the purpose of the alternative analysis process is to assess the suitability of any given alternative to achieve the project goal(s). The design phase of the work, which is outside the scope of an alternative analysis, would delve into the details, such as the specific transverse feature type to provide an adequate design for the above example (Biedenharn et al. 1997; NRCS 2007a; Yochum 2018). Information developed during the alternative analysis phase, such as project goal(s), scope, objectives, constraints, etc. should also be carried into the design phase.

Key Work Steps: The following alternative formulation steps are provided as an outline for a project team conducting an alternative analysis for a specific site or reach. These steps are also illustrated graphically in Figure 1.

1. Form a project team
    a. Identify disciplines needed (engineering, biology, geomorphology, etc.)
    b. Start small, but add expertise as needed (such as addressing concerns related to lands or cultural resources).
2. Identify overarching goal(s)
    a. Why is this work being pursued?
    b. What is the intent/vision of the project?
    c. Develop the goal statement with cognizance of authority (see work step 4).
3. Identify the project's scope and intended outcome
    a. Includes the purpose and need statements.
    b. The scope and effect of the project's benefits would be greater, or at least proportional, to the potential consequences and impacts of not doing the project.
4. Identify constraints
    a. What is not allowed?
        i. Limits of disturbance, including site access
        ii. Limits of type of activities
        iii. Seasonal restrictions
        iv. Safety
        v. Anticipated site conditions
    b. Are there authority limitations (legal, statutory, and/or fiscal) to do the work?
    c. Are there are any other stakeholders that may have authority/jurisdiction to perform or to influence aspects of the work?
5. Brainstorm to obtain a list of mutually exclusive alternatives
    a. Based on reach understanding of fluvial geomorphology, including information on geology, sediment, hydrology, and hydraulics.
    b. Based on reach understanding of ecology and biota.
    c. Based on knowledge of river methods, suites of methods, track record for method application, and construction techniques that would help achieve the project goal(s).
    d. Useful to have around 3-5 mutually exclusive alternatives.
    e. Include the "no action" scenario (e.g. cost or effects of doing nothing).

Step 2 – Evaluation of Alternatives

The evaluation of each alternative formulated by the multi-disciplinary team is the second step. These alternatives are developed and analyzed to approximately the 30% design and planning level. This provides a means to rank each alternative, helping the multi-disciplinary team select a preferred alternative to implement.

The multi-disciplinary team generates an evaluation framework to objectively analyze the alternatives. The evaluation process relies on the multi-disciplinary team to determine the evaluation criteria. The evaluation criteria may be weighted by the team towards criteria that is considered more important to achieving the defined project goals and objectives. In general, there are three categories/factors of evaluation criteria used on the MRG: engineering effectiveness, ecosystem function, and economics (Biedenharn et al. 1997).

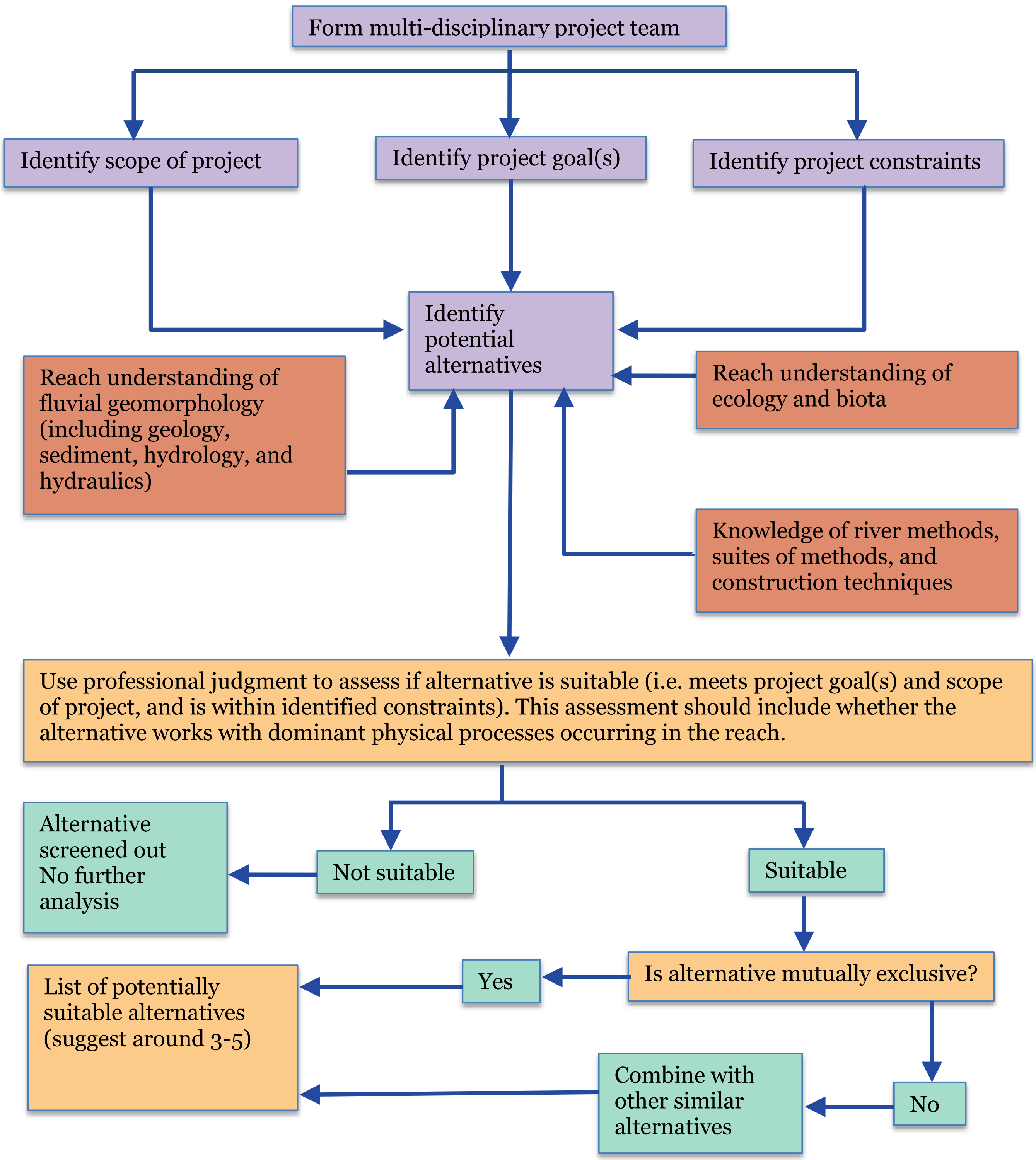

Figure 1. Flowchart of alternative analysis process – Formulation of Alternatives

1. *Engineering effectiveness* – This factor subset may include the following: function, public safety, constructability, reliability, adaptive management, design life, recurring maintenance, levee integrity, hydraulic capacity, sediment transport, and/or water delivery.
2. *Ecosystem function* – This factor subset may include the benefits and effects to the following: fish, bird, general wildlife, wetlands, riparian vegetation, and/or habitat diversity. General environmental considerations related to the Endangered Species Act (ESA), Clean Water Act (CWA), National Historical Preservation Act (NHPA), and National Environmental Policy Act (NEPA) may also be included.
3. *Economics* – This factor subset may include the following: implementation cost, maintenance cost, level of adaptive management, recreation and aesthetics, service life, and/or environmental compliance cost related to the laws listed in the ecosystem function evaluation criteria.

The intent of the three categories is to appropriately balance the needs of a project with sound engineering, environmental, and economic considerations consistent with satisfying socio-economic and ecological criteria. Implicit in the assessment of the first two evaluation criteria categories is an understanding of the geomorphic response. A geomorphic approach (working with the underlying physical processes) helps inform the team of how the fluvial system functions and responds to a given alternative. Both upstream and downstream effects of an example should be considered, given the current understanding of the current reach morphology. Generic morphological responses to changes in width, slope, sinuosity, sediment supply, etc as stated by Lane (1954) and Schumm (1969; 1977) are useful in assessing potential morphological changes. Changes from any particular action should be assessed both downstream and upstream when considering an alternative, as these responses may precipitate additional future remedial actions.

It should also be kept in mind that sometimes similar projects may have different morphological responses due to the complex and dynamic interplay of the riparian corridor processes. As an example, two side channel installations on the MRG, both north of Albuquerque (Bio-West 2005; Holste et al. 2012) resulted in different effects to the construction of inundated floodplains. One project (Bio-West 2005) created a side channel to realign a meander bend that threatened infrastructure. The intent of the side channel was to re-connect the river to the lower portion of the meander. The project accomplished this purpose, but the side channel also widened by eroding through an abandoned floodplain terrace. The widening brought additional sediment into a supply limited reach of the MRG and allowed for trees to fall naturally into the river. While the widening through the abandoned terrace had been foreseen, the random addition of trees created morphological variability, while the addition of sediment augmented the formation of an inset floodplain. The overall effect was the creation of additional habitat benefits (increased diversity) not foreseen in the alternative analysis evaluation.

A different side channel project (Holste et al. 2012) was conducted at another location on the MRG to also create floodplain habitat. A side channel was constructed through an existing floodplain terrace to facilitate water moving through the terrace at lower discharges. A small backwater embayment was constructed off this side channel to develop floodplain habitat. After construction, the side channel incised and abandoned the backwater embayment, resulting in lower inundation frequencies than originally expected based on the design. Beavers moved in a few years later and constructed a dam across the side channel, increasing the inundation frequency and facilitating a greater connection to the floodplain. These two MRG projects demonstrate the dynamic nature of the complex interplay between hydrologic, morphologic, and biologic interactions.

Evaluating the potential morphological adjustments and likely future maintenance actions helps in assessing both the long term cost implications and the ecological benefits. The geomorphic response is evaluated under one or more of the described factor subsets for engineering effectiveness or ecosystem function (side channel example). If the geomorphic response of a particular factor subset in engineering effectiveness or ecosystem is considered by the multi-disciplinary team to be critical to a project goal (e.g. improve sediment transport), that factor subset could be weighted more than other criteria within the corresponding engineering effectiveness or ecological function categories.

Objectives are then developed from the goal(s), scope, and constraints, through the use of the three evaluation criteria categories stated previously. Objectives need to be tied directly to the stated project goal(s) and are used after the project is constructed to monitor its success. Objectives need to be specific, measurable, achievable, relevant, and time-bound (i.e. SMART) (Skidmore et al. 2011; Kenney et al. 2012). Objectives may focus on an optimal condition (maximizing a desirable condition or minimizing an undesirable condition), be used to provide additional screening, or help to achieve the least damaging scenario (maximize the minima or minimize the maxima) (IPMP 2002).

Specific metrics are then developed for each objective. While objectives describe what is measured, the metrics tie to the objective and specifically describe how the measurement of an alternative will occur. They can be qualitative and/or quantitative. There may be a one to one or a one to many relationship between the objectives and their corresponding metrics. Metrics may involve professional judgment, modeling, or cost estimating. These metrics may be used later in the project when it is implemented as part of monitoring and adaptive management associated with the performance of the project.

It is the metric results that are used by the team to independently review and evaluate each alternative. Typically this is done within areas of expertise. For example, biologists on the team would evaluate the objectives associated with ecosystem function for each alternative, while engineers would evaluate the objectives associated with engineering effectiveness and economics.

Once independent discipline assessments are performed then the team reconvenes and collectively evaluates all alternatives, taking into account all of the objectives and their associated metrics until a consensus on a preferred alternative is reached. This method of using an expert panel to arrive at a consensus, after an independent assessment, is similar to the "Delphi method" (Prakash 2004), but without the stricter adherence to the assessors anonymity.

The independent and subsequent team evaluations of alternatives may use a linear scoring function approach (IPMP 2002), also known as valuation methods (Martin et al. 2016), to rank the overall preference of alternatives. The linear scoring function involves a process wherein each objective is assigned a weight and all objectives are assigned a numerical value indicating how well or poorly that objective was met. This is done for all of the alternatives. The individual product of the objective weight and the objective score are then summed to obtain a value for that alternative.

Alternatively, a more holistic or interactive approach (Martin et al. 2016), based on professional judgment and transitive ordering may be used. Transitive ordering refers to preferentially ordering alternatives based on the overall composite picture (or holistic view) of the metric results (IPMP 2002). This may be accomplished through expert elicitation from appropriate team members that relies on professional judgment or by iteratively comparing each alternative to each other to provide a relative ranking.

Both the holistic approach and the linear scoring function approach involve a level of uncertainty which requires the use of professional judgment that may or may not be explicitly defined. The final ranked alternatives are then evaluated by the multi-disciplinary team to choose a preferred alternative based on a group consensus. The preferred alternative may be a single or composite grouping of alternatives that are chosen. For example, a MRG project north of Albuquerque (Tetra Tech 2012) identified a combination of bank protection, floodplain lowering, and vegetation planting as the preferred alternative. All of these were originally considered as separate potential alternatives to meet the identified socio-economic and ecological needs.

Key Work Steps: The following alternative evaluation steps are provided as an outline for a project team conducting an alternative analysis at a specific site or reach. These steps for an alternative evaluation are also illustrated graphically in Figure 2.

1. Identify objectives
    a. Develop objective statements that tier off of the defined project goal(s).
    b. These are directly linked to the defined goals and scope of the project and must consider the identified constraints
    c. Need to follow SMART guidance: Specific, Measurable, Achievable, Relevant, and Time-bound (Skidmore et al. 2011).
    d. Should provide a means for monitoring post-project success.
    e. Should get at the implications of doing (or not doing) an action.
    f. Objectives may be tied with project success criteria.
2. Define evaluation metrics for each objective
    a. Describe how measurement will occur
    b. Qualitative or quantitative
    c. 1 to 1 or 1 to many relationship
    d. May involve professional judgment, modeling, and/or cost estimating
3. Develop an evaluation framework
    a. The evaluation framework includes the metrics assigned to each objective. Metrics may be developed on a one to one (one alternative to one metric) or one to many (one alternative to two or more metrics) correlation with an objective.
    b. Objectives should be based on three evaluation criteria
        i. Engineering Effectiveness
        ii. Ecosystem Function
        iii. Economics
    c. The framework may include assigning a weight for each objective and the conversion of the metric to a consistent numerical scale for evaluating each objective (linear scoring function approach).
    d. The framework may be defined more loosely and based on professional judgment (holistic approach).
4. Evaluate alternatives based on the evaluation framework
5. Develop identified alternatives to approximately the 30% design and planning level and no more
    a. Includes rough plan view sketch.
    b. Includes typical details.
    c. Includes at least a conceptual description of all perceived alternative elements.
    d. Approximate volumetric calculations.

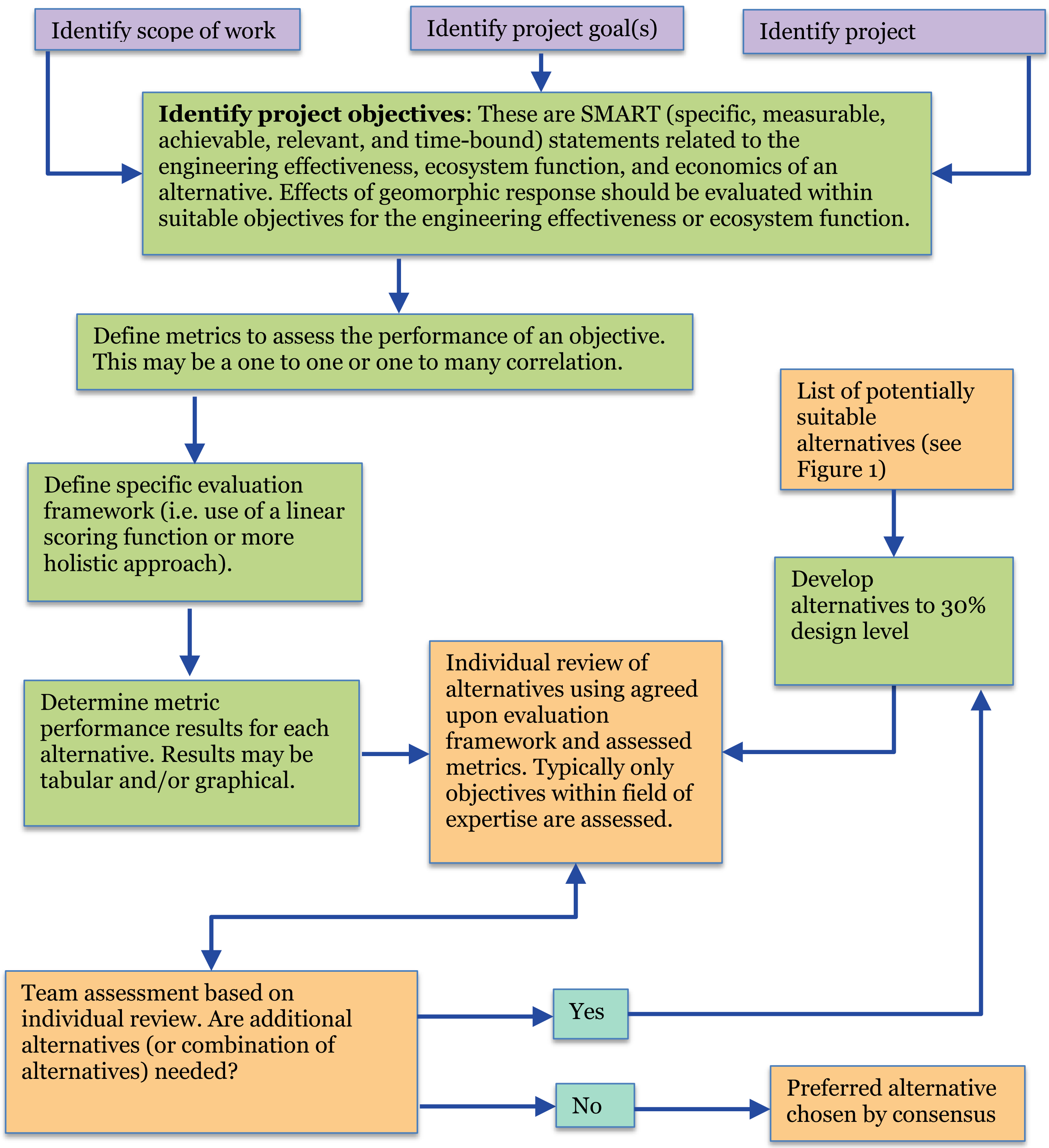

Figure 2. Flowchart of alternative analysis process – Evaluation of Alternatives

6. Project Team review
    a. Assess alternative evaluations
    b. Assess if there are benefits to grouping two or more of the alternatives (or aspects of those alternatives)
    c. Assess if additional alternatives are needed, but were overlooked previously.
    d. Repeat steps 4–6, if needed.
7. Choose a preferred alternative by consensus.

Conclusions

A framework for multi-disciplinary teams working on the MRG has been developed to assess and evaluate the socio-economic and ecological impacts of potential alternatives. The process has been refined over the years and is geared towards identifying alternatives that work with the river to re-establish or promote self-sustaining processes for increased resiliency to the extent possible. The methodology described the framework developed on the MRG, building on techniques developed on other fluvial systems and on lessons learned from MRG experience. The procedure provides guidance through the alternative formulation, analysis, and selection process. This alternative process is preceded by data collection and assessment(s) providing understanding of the underlying physical processes and environmental conditions occurring in the fluvial system. For work on the MRG, developing goals, identifying constraints, formulating alternatives, defining specific project objectives, and systematically evaluating the alternatives involves two distinct steps. The first step is at a conceptual or appraisal level and is more qualitative than quantitative. This first step culminates in the formulation of potentially suitable alternatives. The second step includes the development and analysis of those potentially suitable alternatives in a systematic and holistic manner for comparative analysis. This second step is typically more quantitative in nature, culminating in the development of a feasibility level or 30% project scope for the potentially suitable alternatives. This step also results in the selection of a preferred alternative by the multi-disciplinary team. In addition the team may undertake an additive approach where separate alternatives are combined or partially combined to get a preferred alternative that satisfies multiple goals and objectives.

Acknowledgement

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