RiverRAT: SCIENCE BASE AND TOOLS FOR ANALYZING STREAM ENGINEERING, MANAGEMENT, AND RESTORATION PROPOSALS.

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BACKGROUND AND NEED

Management of stream corridors spans a wide range of intended outcomes, including reconstruction/renovation of structural assets, channel rehabilitation, stabilization of eroding streambanks, management or diversion of in-stream and flood flows, sediment management, river restoration and habitat enhancement to promote a species or biodiversity, or for mitigation. However, streams are complex and dynamic systems, and projects undertaken with the best of intentions may still cause unintended outcomes that could pose unacceptable risks to fisheries or habitat, either directly or by imposing additional constraints on natural processes. While implementation may result in short-term impacts, alteration of fluvial processes may result in longer-term, and thus more adverse, effects.

Guidelines and manuals do currently exist for the development of specific elements of stream management projects; however their focus is typically on the engineering or design aspects without provision for a watershed process or management context. No accepted standard of guidance exists for stream management projects; hence all guidelines are limited in scope with respect to the specific needs of the reviewing regulatory agencies.

NOAA’s National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) (Services[1]), given Endangered Species Act (ESA) and Essential Fish Habitat (EFH) consultation authorities, and review authority under the Fish and Wildlife Coordination Act FWCA), have a responsibility to evaluate river projects funded, authorized, permitted, conducted, or consulted on in any way by the Federal agencies—in essence, any project in a river environment that may have an impact on protected species or the stream processes, habitat, or ecosystem they depend upon. Other federal and state agencies bear similar responsibilities for evaluating proposed stream projects in a range of specific regulatory contexts. All organizations that fund stream projects have an inherent responsibility to evaluate projects and measure their success relative to stated goals and objectives. Our team has identified a specific need for Services staff to review river management projects in the context of both watershed setting and fluvial geomorphic processes. To this end, we have produced *RiverRAT* (River Restoration and Analysis Tool) and a suite of evaluation tools, supporting science, and training that create a solid

[1] “Services” herein refers primarily to NOAA’s National Marine Fisheries Service (NMFS) and USFWS as a primary audience, though not intended to be exclusive of state fish and wildlife agencies. Acknowledging that Services employees are largely trained in biological sciences, these resources emphasize understanding of physical processes that influence stream habitat and that are affected by management actions.

scientific foundation for a thorough and comprehensive review of river restoration projects, beginning with problem identification, developing goals and objectives, understanding physical and biological processes in relation to project effects, assessing risks to resources and risks of the project, post-project appraisal, and compliance and effectiveness monitoring.

OVERVIEW OF RiverRAT, APPROACH AND PRODUCTS

Our team produced three products: (1) a widely-vetted and peer-reviewed science document that emphasizes the physical processes related to the formation and maintenance of river system habitats, (2) integrated evaluation tools that provide for a transparent review process, including a project screening risk matrix, information checklist, and on-line project analysis tool, and (3) training in the use and application of the science document and tools.

These products are available to the public at: **www.restorationreview.com**.

The goals of this joint project were to enable project reviewers to:

- Understand the connections between physical processes and aquatic habitat.
- Understand the connection between common management actions, effects, and associated risks to protected species and habitat.
- Understand alternatives that can minimize project-related risks to protected species and habitat.
- Provide science and understanding that promote the design of sustainable projects, resilient to physical processes and changing environmental conditions.
- Document and streamline project review, and foster consistency among project reviewers.
- Promote effective post-project appraisals, leading to more effective future river management.

While an emphasis on salmonid recovery and ESA context in the Pacific Northwest and California is inherent in this NMFS-led effort, the resources and tools have broader utility and could easily be adapted to other agencies jurisdictions, other geographic regions, and specific ecological resources.

RiverRAT Science Document

The *RiverRAT Science Document* begins with a description of three new tools for project review: a project screening risk matrix to help determine the depth of review a project might require, a project information checklist to help assure that a proposal includes everything necessary for review, and web-based River Restoration and Analysis Tool itself. The bulk of the *Science Document* is then devoted to a synthesis of the integrated science of fluvial geomorphology as it relates to river habitat, starting with physical watershed controls, and progressing through stream processes and channel forms, thus providing a thorough scientific foundation for evaluating the potential impacts of stream projects. The document presents a logical process for the development of engineering or management actions in rivers, including those intended to improve habitat, such as restoration and stabilization projects. In addition, it provides tools for the evaluation of project proposals. Together, the document and tools provide a sound foundation in fluvial geomorphology and its relevance to river habitat so that proposed projects may be thoroughly evaluated in a timely manner with respect to their potential risks to species and habitat.

To facilitate deeper review of project design and analyses, the science document also includes:

Appendix 1: investigative analyses that form the basis for evaluating existing and proposed conditions.

Appendix 2: design approaches and the application of design criteria to development of specific design elements as well as for developing specific monitoring metrics.

Appendix 3: additional management alternatives.

Appendix 4: annotated bibliography of stream management and restoration design guidelines.

The *Science Document* highlights common approaches to stream management (including restoration) that may not account for temporal or spatial variability or may actually constrain natural channel processes. Projects proposed as restoration, stabilization, and/or remediation often include project elements that are site-specific (e.g. 10's to 100's of meters in stream length), in large part because many constraints to aquatic species are identified at this scale. Many projects are unsuccessful because they address local-scale symptoms without understanding the wider causes of habitat loss or degradation, which are often reach or watershed scale problems. Site-specific actions, such as meander reconstruction, the addition of weirs, installation of large wood structures, and biotechnical bank stabilization, have become the default solution to many habitat problems and constraints, yet they are often planned and implemented without consideration of physical processes that may influence their outcomes or the potentially negative impacts of some project elements.

Application of traditional engineering design standards, such as 'factors of safety' biased towards structural stability, affords certain benefits in terms of professional accountability and rigorous analysis, but also simultaneously tends to increase risk aversion. The inherent problem with risk aversion in 'stream restoration' schemes is that it commonly leads to over-design, and hence a greater reliance on engineered structures to ensure an acceptable 'factor of safety'. The resulting projects often impose unnecessary and undesirable constraints on natural channel adjustment and evolution - limiting long-term habitat value and potentially inhibiting habitat creation and maintenance.

To address these issues, the science document and tools facilitate identification and evaluation of the constraints, uncertainties, and risks associated with proposed projects. To this end, the document and tools discuss and encourage project development and review to include:

- Understanding how engineering and management actions affect the physical stream processes operating at varying scales (e.g., site, reach, and watershed).
- Accepting that uncertainty is inherent to all engineering and management actions in rivers with respect to predicting project outcomes and potential risks to physical processes and the habitats and species they sustain.

- Promoting solutions to identified problems that address the root causes at appropriate scales, rather than simply treating the symptoms of the problem at the site-scale.
- Acknowledging that human influences are fundamental components of all ecosystems, at all scales.

While an emphasis on salmonid recovery and ESA context in the Pacific Northwest and California is inherent in this NMFS-led effort, the resources and tools have broader utility and could easily be adapted to other agencies jurisdictions, other geographic regions, and specific ecological resources.

Tools For Project Review

The *Science Document* provides the scientific basis for the *Project Screening Risk Matrix*, the *Project Information Checklist*, and the *River Restoration Analysis Tool (RiverRAT)*. The *Risk Matrix* is intended to assist reviewers in making an initial analysis of the level of risk to resource associated with a proposed project, in order that reviewers may match the depth of review to the level of risk posed by the project should it be permitted; it is also intended to help reviewers decide whether the risk is sufficiently high to merit technical assistance from specialists in associated disciplines. The *Project Information Checklist* is used to determine whether the project proposal contains sufficient information to allow Services' staff to conduct a comprehensive review and highlights any missing information. The checklist reporting function makes clear to project proponents exactly what information will be needed for a review to proceed, so that the information can be provided efficiently, thus speeding up the review process. After receiving all pertinent information, reviewers can use *RiverRAT* to conduct a thorough, comprehensive, transparent, and documented project review.

RiverRAT Project Screening Risk Matrix

Effective and efficient review of stream projects begins with a determination of relative project risk. Assuming that project review workloads will always outpace review capacity, it is critical that reviewers allot their limited time to the projects that pose the greatest risk to resource. The need for staff to use their time efficiently means that effort cannot be expended over-scrutinizing proposals that pose very little risk. Clearly, a balance must be struck through which the possibility of missing a high risk proposal is properly set against the need to move proposals through the review system efficiently.

Experienced reviewers are generally able to achieve this balance, and hence allocate the appropriate level of effort to each proposal based on their professional judgment; however, the natural tendency for new reviewers is a precautionary approach, thus leading to long review times. Decision deadlines introduce an additional danger that a high risk proposal will be overlooked without proper analysis. To help reviewers develop and improve their capability to match the intensity and extent of review to the inherent project risk, a screening tool has been developed (Figure 1). While initially intended for new reviewers, we believe that even experienced reviewers may find it helpful to refer to the screening tool to refine their approach and increase consistency. The screening tool is **not** intended as an alternative to professional judgment. Rather, it is intended as a training aid that can be used in developing and refining that professional judgment, for which there is no viable alternative.

The *RiverRAT Project Screening Risk Matrix* is in the form of a 2-axis matrix in which the X-axis = Risk to Resource due to Stream Response Potential, and the Y-axis = Risk to Resource due to Project Impact Potential.

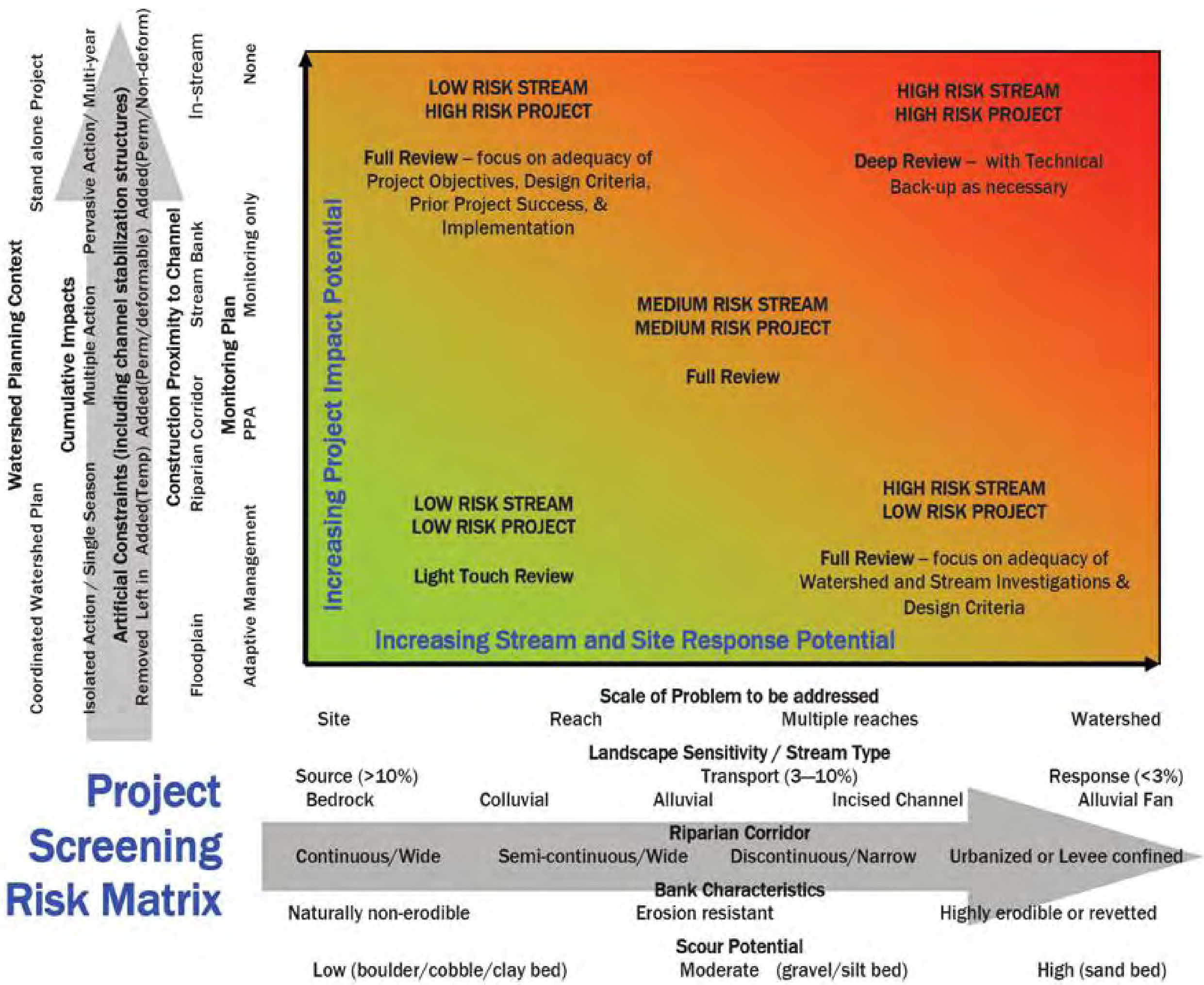

Figure 1. The Project Screening *Risk Matrix*.

The principle underlying the *Risk Matrix* is that actions and projects should do no lasting harm. Within this principle, reviewers will assess the risk of doing harm to ‘resource’ within the context of the relevant legislation. For example, in the case of NMFS this will usually center on Section 7 of the Endangered Species Act, and so ‘resource’ will refer to one or more listed species and their habitat. However, it should be noted that staff with the US Army Corps of Engineers (USACE), who are also operating under Section 404 of the Clean Water Act, would have an expanded definition of ‘resource’. The ‘resource’ in their case is, primarily, water quality in a ‘Water of the United States’, which is a strictly defined type of water body. USACE staff may also be working under Section 10 of the 1899 Rivers and Harbors Act (as amended), in which case ‘resource’ would be expanded to include navigability.

The *Risk Matrix* as presented here may be adapted for use by different reviewers/agencies and in different contexts according to their needs. However, the matrix presented here is intended primarily for use by staff with NMFS or the USFWS with emphasis on aquatic species and their habitats.

The ***x-axis*** represents the risk to resource associated with the sensitivity to natural or anthropogenic disturbance of the stream and its habitat. This axis uses stream attributes, such as gradient, bed and bank material, and localized geomorphic context, to assist reviewers in making an initial assessment of the overall risk to resource stemming from the landscape context, natural system resiliency, and imposed human modifications. Some stream types are naturally sensitive to disturbance, while others may have become sensitized due to land use history and past engineering/management in the river network. The inherent sensitivity of a stream to disturbance depends on numerous factors, but we have narrowed these down to the following five:

1. The spatial and temporal scale of the problem to be addressed (site, reach, or watershed scale);
2. Landscape setting and associated stream type, such as source, transport, and response reaches;
3. The resilience of the stream system to absorb and adjust to changes in flow and sediment, indicated by floodplain extent and condition of the riparian corridor;
4. The ability for the stream to adjust laterally to changes in flow and sediment as determined by the bank characteristics; and
5. The ability for the stream to adjust vertically to changes in flow and sediment as determined by the scour potential of the stream bed.

In terms of risk to resource, factors 1 and 2 combined control the probability that a given action will trigger changes in fluvial processes that are sufficiently effective, extensive and persistent to destabilize the channel. Factors 3, 4, and 5 determine the consequences of process changes and morphological responses in terms of the potential of loss of riverine habitat and direct or indirect threats to species.

The ***y-axis*** represents the risk to resource associated with the proposed action or project type. Some disturbance to the fluvial system is inevitable when performing actions in or near a stream or undertaking a restoration scheme. This axis, therefore, uses indicators of the project scale, context, cumulative impacts, introduced artificial constraints, and the ability to detect impacts to assist reviewers in making an initial risk assessment of the proposed action or project.

There are numerous risks that stem from project implementation and maintenance, which we have narrowed to five overarching factors:

1. The watershed planning context, including the quality and scope of planning for the action or project and, particularly, whether the catchment context has been properly established;
2. The potential for cumulative impacts, especially those impacts that may propagate upstream and/or downstream;
3. The degree of artificial lateral and vertical constraints and the capability of the stream to accommodate future changes in the flow and sediment regimes;
4. The degree of construction impacts that may adversely impact in-stream, riparian and/or floodplain habitats and the species that inhabit them; and
5. The level of post-project appraisal and adaptive management to address undesirable morphological responses to the action or project that may impact habitat and species.

While factor 1 addresses the project context and overall potential value to species and habitat, it is factors 2, 3, and 4 that dictate the probability that the proposed action or project will result in fluvial process adjustments that are sufficiently effective, extensive and persistent to destabilize the channel. Factor 5 represents the degree to which the proponents of the proposed action or project have recognized that not all risks to resource can be foreseen, and hence have developed mechanisms to reduce potential consequences of any adverse process changes or morphological adjustments for habitat and species.

The overall risk to resource is represented only by a spectrum that begins with green for low risk and ranges to red for high risk (Table 1). The axes of the risk matrix presented here purposefully have no scales; similarly, no examples are given of projects that might typify a particular level of impact potential or streams that possess representative levels of response potential. The lack of quantification and examples does not reflect a lack of knowledge or understanding of potential project impact and stream response. Rather, the matrix has not been quantified or populated because there is no cook-book way to assess the risks associated with a proposed action or project *a priori*. Our purpose here is not to tell end-users the answers to difficult questions, but to help them to understand risks and pose the right questions in the first place.

In screening out low risk projects on low risk streams and using the time saved to allow deeper scrutiny of higher risk projects and more sensitive streams, responsibility for balancing expediency against thoroughness rests with the individual making the decisions on a daily basis. In this spirit, the *Risk Matrix* is offered as a training aid with which Services staff who are new to reviewing proposals can quickly and effectively develop and refine their decision making skills. By populating the *Risk Matrix* with their own examples, new reviewers will learn both from more senior colleagues and through their own experience how to recognize project types that pose greater risk to resource, and which streams in their geographical area are more sensitive to disturbance.

Table 1. Selection of treatment based on risk sources and level of overall risk to resource.

Impact & Response Potential	**Risk to Resource**	**Indicated Treatment**
Low Risk Project Low Risk Stream	Low	As both sources of risk to resource associated with this action or project are low, overall risk is low and a light touch may be taken in evaluating it using *RiverRAT*.
High Risk Project Low Risk Stream	Medium	As the action or project carries a high risk to resource the proposal merits a full review, paying particular attention to the adequacy of: the Project Objectives, those Elements of the project that pose the greatest threats, the Design Criteria, evidence of prior success with similar projects, and the implementation plan. However, as the risks associated with the stream are low, it is likely that responses to the action or project will be limited to the project and adjacent reaches. Hence, a lighter touch may be taken in evaluating the wider watershed and stream system contexts and implications of the proposed work.
Medium Risk Project Medium Risk Stream	Medium	As risks arise equally from the project and the stream in which it is to be implemented, a full review, involving careful application of *RiverRAT*, should be performed.
High Risk Stream Low Risk Project	Medium	A low risk project may still pose serious risk to resource if implemented in a stream that is highly sensitive to destabilization. Hence, a full review is merited, emphasizing scrutiny of the adequacy of Watershed and Stream Investigations, Design Criteria related to preventing the impacts of the project from perturbing the fluvial system and plans for post-project monitoring and adaptive management to limit the effects of unforeseen impacts to within the project reach.
High Risk Project High Risk Stream	High	Proposals that have a high overall risk to resource merit a deep review that goes beyond that routinely applied. Proposals in this category are often complicated or ground breaking and it may also be the case that the engineering, geomorphological or other technical/social/economic aspects of the proposal are sufficiently complex or challenging as to require back-up from subject specialists, and reviewers should not hesitate to seek assistance where necessary.

RiverRAT Project Information Checklist

The *RiverRAT Project Information Checklist* (Figure 2) queries the user regarding information sufficiency and applicability. The user is encouraged to enter comments and print the results, which can be filed for documentation of the review, or shared with a project applicant if appropriate.

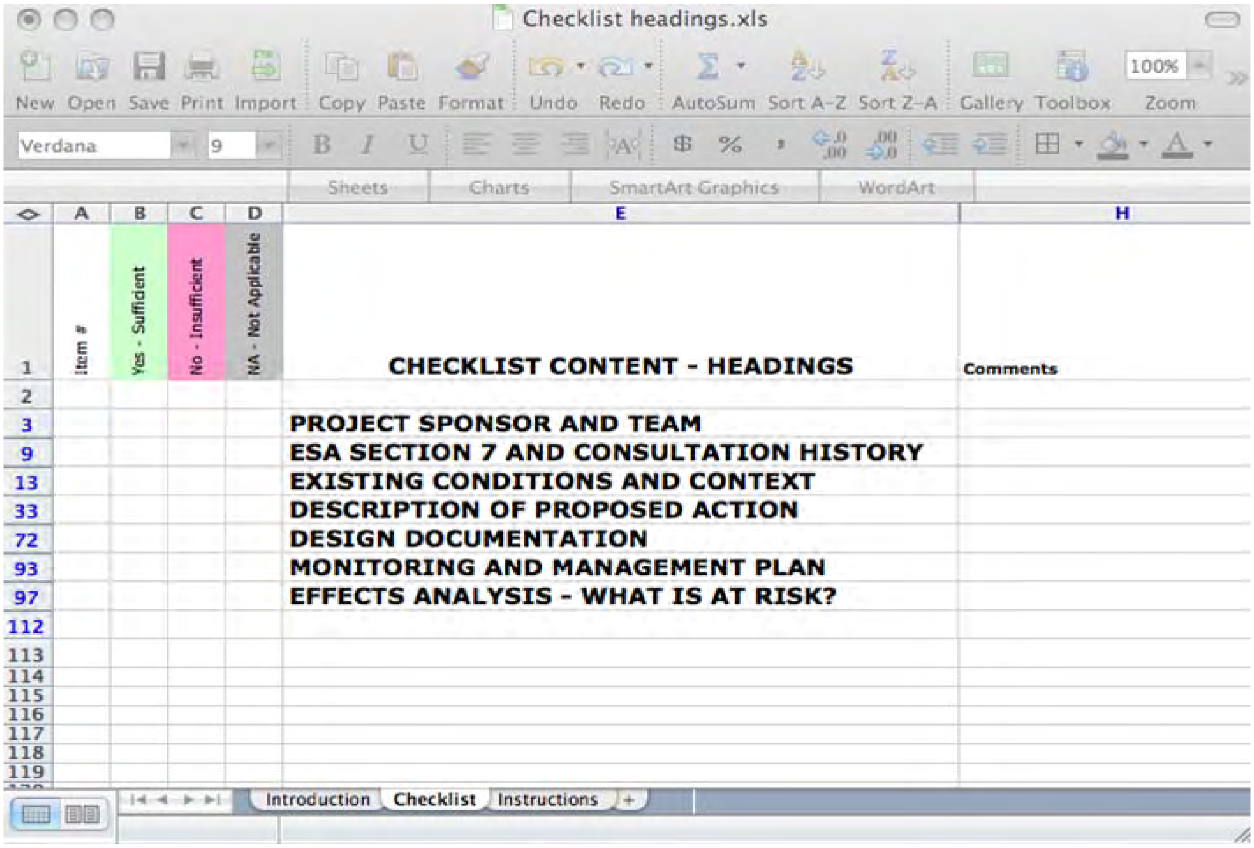

Figure 2. The major information categories in the *Project Information Checklist*.

The *Project Information Checklist* is a comprehensive list of all information that a project proposal could contain for a thorough review by Services' staff and has been developed for use as a template for a Biological Assessment (BA), thus providing a consistent model for the organization and content of a complete BA. The primary purpose of the *Checklist* is to determine if there is sufficient information provided to facilitate the use of *RiverRAT*. However, it may also be used to determine if there is sufficient information to conduct a pre-consultation or pre-application review, or it may be employed during or after evaluation to ensure that the review process has been properly completed.

An excerpt of the detailed questions is provided in Figure 3. By providing all information suggested in the checklist, a project team can avoid delays during the review process, and a reviewer can be reasonably assured that a project team has put in the effort required to develop a well-thought-out project that encompasses appropriate spatial and temporal scales, landscape context, risk, design approach, and adaptive management. Ideally, use of the checklist by both project developers and reviewers will promote time and resource efficiency and will make the review and consultation process more transparent to both parties.

DESIGN DOCUMENTATION

	Y	N	NA	*Design team*
57	☐	☐	☐	Name and titles of firms and individuals responsible for design.
58	☐	☐	☐	List of project elements that have been designed by a licensed Professional Engineer.
	Y	**N**	**NA**	***Hydrologic analysis***
59	☐	☐	☐	Description of historic, ongoing, or anticipated impacts to basin hydrologic regime.
60	☐	☐	☐	Summary of hydrologic analyses conducted, including data sources and period of record.
61	☐	☐	☐	List design discharge (Q) and return interval (RI) for each design element.
	Y	**N**	**NA**	***Sediment transport and dynamics analysis***
62	☐	☐	☐	Description of previous or anticipated impacts to basin or reach sediment supply.
63	☐	☐	☐	Summary of sediment supply and transport analyses conducted, including data sources.
64	☐	☐	☐	Describe sediment size gradation used in streambed design.
	Y	**N**	**NA**	***Hydraulic analysis***
65	☐	☐	☐	Summary of hydraulic modeling or analyses conducted and data source.
66	☐	☐	☐	Inundation map for design and flood flows before and after implementation.
	Y	**N**	**NA**	***Vegetation design***
67	☐	☐	☐	Species list, materials sources, and plant form.
68	☐	☐	☐	Planting plan map (distribution and density by species) and irrigation plan.
	Y	**N**	**NA**	***Soils and geotechnical analysis***
69	☐	☐	☐	Summary of geotechnical analyses including stratigraphy and grain size of materials.
70	☐	☐	☐	Groundwater elevation, flow direction and seasonality within floodplain and banks.

Figure 3. An example of details in the *Checklist*, under the design documentation section.

The Project Analysis Tool – *RiverRAT*

RiverRAT is an on-line framework for project evaluation that guides reviewers through a thorough review of a project proposal (Figure 4). The entire project development process is addressed, beginning with problem identification in the planning stages, progressing through the design phase, and culminating with project monitoring. While *RiverRAT* is geared toward answering the question of "what are the potential impacts and risks to resource", it also enables a review of project and design integrity with respect to species or ecosystem recovery. In an ESA context, *RiverRAT* can be used during pre-consultation, in preparation of a Biological Assessment, or in effects analysis for a Biological Opinion. In a FWCA context, *RiverRAT* can also be used for pre-application discussions or evaluation of potential project impacts to the Services trust resources. Access to *RiverRAT* by project sponsors, stakeholders, and specialists will give them insight regarding the review process and will guide them to developing project proposal documents that are both more informative and better tuned to the needs of the Services' staff who must review the proposal.

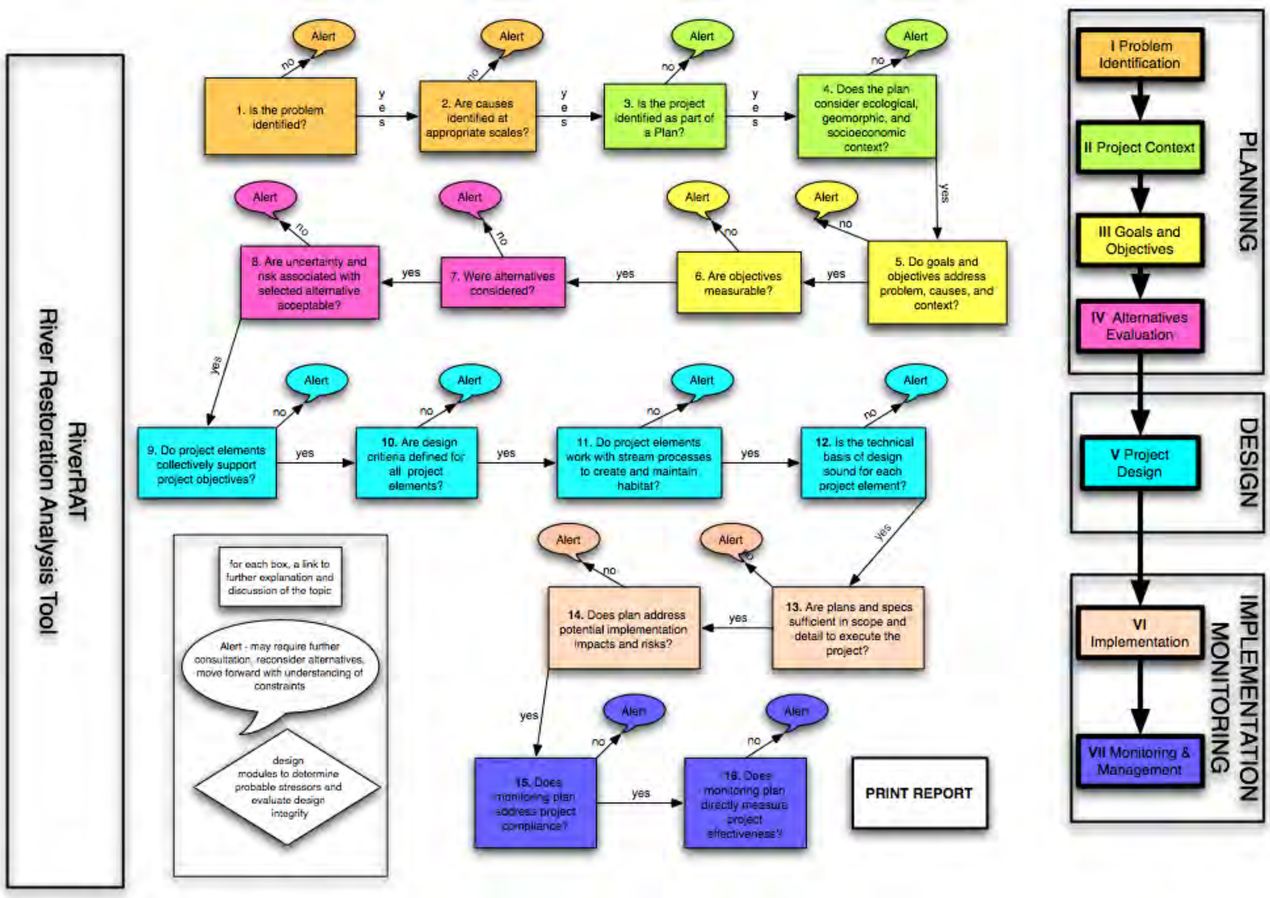

Figure 4. The *RiverRAT* framework.

RiverRAT provides a framework and links to additional technical resources and assistance that may be needed to support in-depth and detailed scientifically based and objective treatment that is justified for projects that carry a high risk to resource. The *RiverRAT* homepage (Figure 5) also provides access to the *Science Document*, its supporting *Appendices*, the *Risk Matrix*, and the *Project Information Checklist*, all anonymously. To gain access to *RiverRAT* through the webpage requires a login with a username and password that are obtained by request via email.

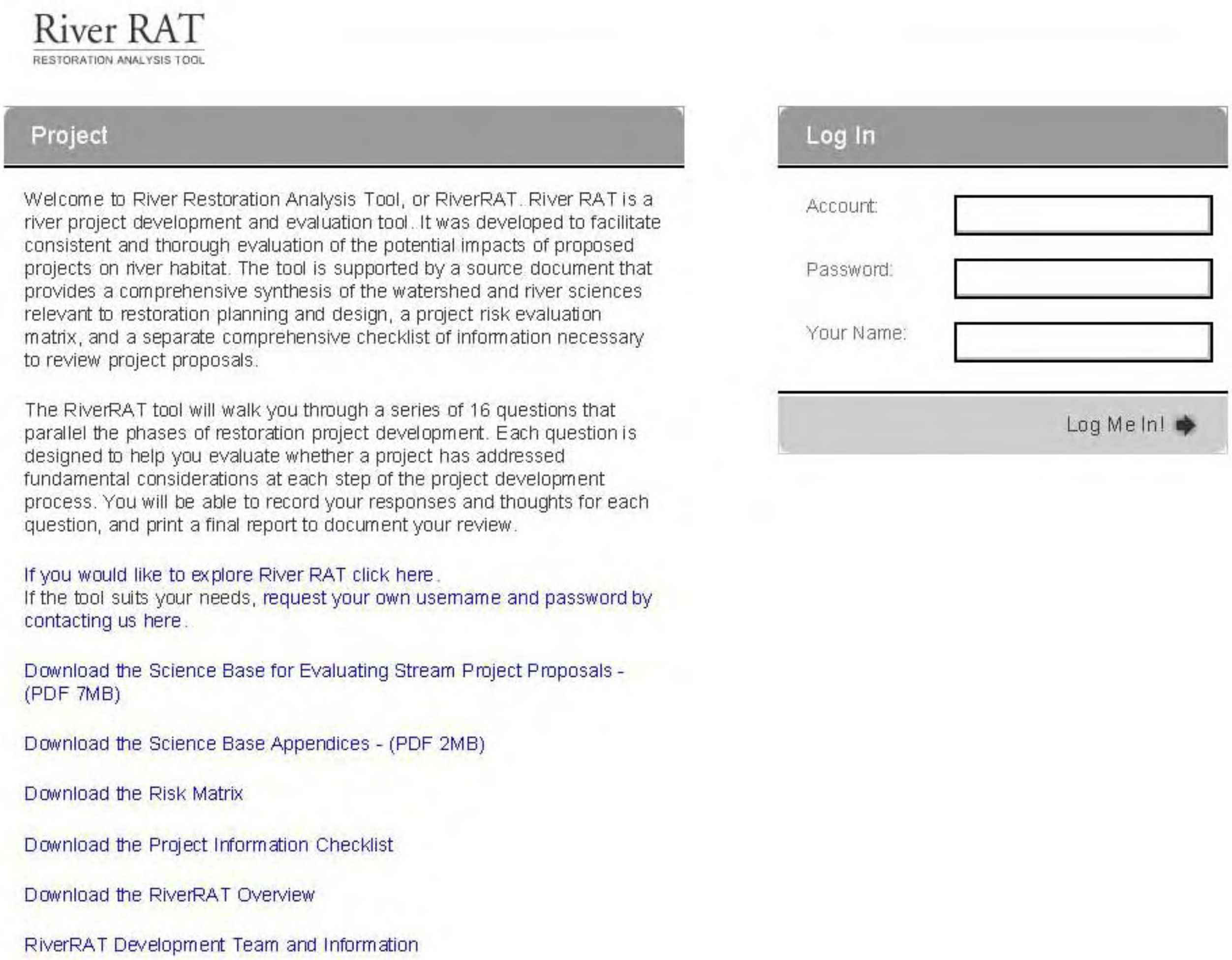

Figure 5. The *RiverRAT* homepage at restorationreview.com.

Once logged in, a user must enter a project name, which can be unique or shared with other users in collaboration. The review tool then steps the user through a series of questions in *yes/no* format. *RiverRAT* is multi-layered in its supporting information to help the user thoroughly evaluate each question in the proper context. Clicking '*need more information*' provides excerpts from the *Science Document* that support the need for the information as well as a reference to the actual supporting document where the topic is thoroughly discussed (Figure 6).

We have found from experience that users gain the most from this evaluation tool by using its reporting capability, which is accomplished by entering comprehensive notes to support answers to the questions. The review session may be saved and accessed later, while the notes are date stamped and user identified. A coordinated review can also be shared with collaborators for a panel of reviews. If used collaboratively, the notes of each user are identified so that each user can view their collaborators responses. Reporting the review and comments is in standard text format for use in any word processor.

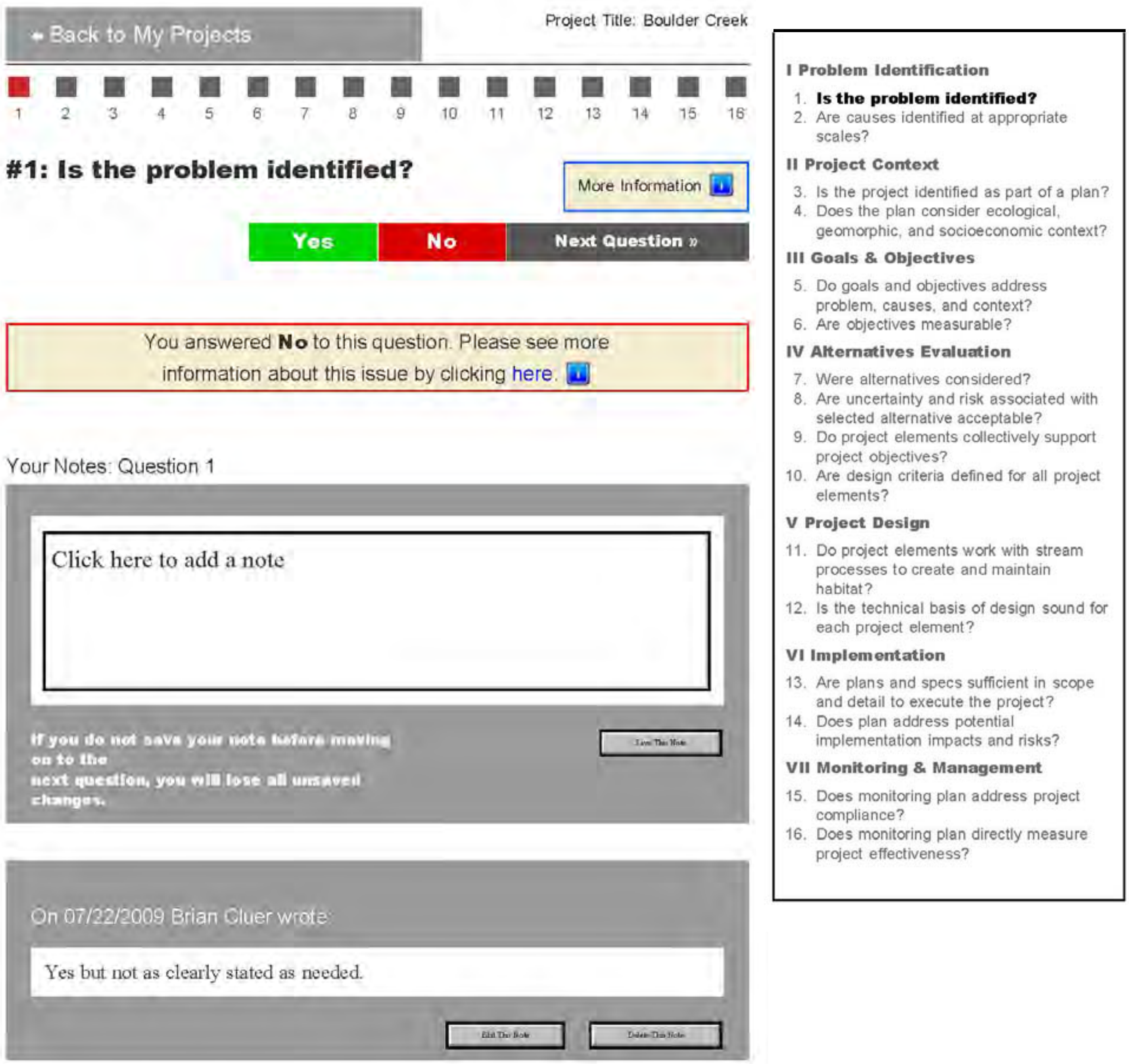

Figure 6. Example of *RiverRAT* structure and function. Each button links to additional information such as what supports a yes or no response, and more information to educate the user in the importance of the question being asked.

SUMMARY

Our Team produced a suite of tools, supported by scientific synthesis, for analyzing river management projects and proposals, including restoration works; collectively called *RiverRAT*. The River Restoration Analysis Tool—and suite of supporting tools and documents enable project reviewers to understand: (1) the connections between physical processes and aquatic habitat, (2) the connection between common management actions, effects, and associated risks to protected species and habitat, and (3) alternatives that can minimize project-related risks to protected species and habitat. Our aim was to provide science and understanding that promote the design of sustainable river management projects, resilient to physical processes and changing environmental conditions. Utilizing the products can aid documentation and streamline project review, foster consistency among project reviewers, and promote effective post-project appraisals, leading to more effective future river management.

RiverRAT and its supporting tools, the *Risk Matrix* and the *Project Information Checklist*, have a common set of information needs and are coordinated so that information is considered in the same sequence; the sequence proceeds in a logical order in which information is considered in general project development. The three tools help determine the depth of review required, assure that a project proposal is complete, and guide reviewers through a thorough and scientifically sound project review. The tools are coordinated with the *RiverRAT Science Document*—the scientific underpinning of the tools—which includes a synthesis of fluvial geomorphology from physical watershed controls to stream processes and channel forms, as well as a synthesis of the project design process from problem identification through project design and post-project appraisal. Utilizing these tools can improve review consistency and transparency, and we believe that there can be a feedback with project development to improve project designs, and most importantly, place problems and solutions in context with physical process drivers and geomorphic controls on aquatic habitat creation and maintenance.

ACKNOWLEDGMENTS

The products described in this paper were developed by a team of NMFS and USFWS staff, together with their contractors. In addition to the principal author team, a panel of experts was convened in December of 2007 for brainstorming the project and giving guidance; and who later reviewed drafts of the document. The expert review panel included William Dietrich, University of California Berkeley, Peter Downs, Stillwater Sciences, Matt Kondolf, University of California Berkeley, Greg Koonce, InterFluve, Inc., and Douglas Shields, USDA-ARS National Sedimentation Laboratory. Additionally, interviews with Services managers, and workshops with over 50 potential end users from a wide range state and federal resource agencies were conducted to solicit input, guidance, and feedback on draft products.

For more information and access to the *RiverRAT Science Document, Appendices*, and the associated *tools* discussed in this paper, please refer to **www.restorationreview.com**.