RRAT Phase II Report

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Introduction

Background

Managers of natural resource areas are increasingly faced with difficult decisions concerning restoration of disturbed habitats. Financial and workforce resources often limit these restoration efforts, and rarely can an agency afford to address all concerns within the region of interest. With limited resources, managers and scientists have to decide which areas will be targeted for restoration, and the restoration treatments to use in these areas. As an example, a large park with multiple degraded sites and different issues to consider at each of these sites can pose a real challenge to managers.

A broad range of approaches are used to make decisions like these, from well-researched expert opinions to gut feeling, with variable degrees of input from site visits, monitoring, data collection, and data analysis used to support the decision. A standardized approach including an analytical assessment of site characteristics, with a written or electronic record of all the steps taken along the way, would help make these decisions easier, scientifically defensible, and based on the best information available.

With these ideals in mind, the National Park Service (NPS) initiated the Restoration Rapid Assessment Tool (RRAT) project. The long-term goal of the NPS is to have a tool that will assist them with prioritizing and treating restoration areas in National Parks across the nation. This project is divided into three phases:

I. Develop a set of indicators that allow for rapidly quantifying the level of disturbance at a site, and for discrimination between sites.

II. Construct an analytical tool for prioritizing restoration projects based on the indicators developed in Phase I, and for recommending restoration methods or treatments.

III. Field test the tool and automate it for field use and delivery through on-line means.

The primary focus of this report is on Phase II, but elements of both Phases I and III will be covered as well.

Phase I of the RRAT consisted of the construction of a list of indicators, indicator rank descriptions, site values, and stressors (Appendices E, F, G & H), statistical tests to see if the RRAT indicators can distinguish between sites, and determination of whether or not the indicators and traditional methods of data collection correlate in site discrimination. Initial lists of indicators, site values and stressors used in the tool were written by Ron Hiebert, Pam Benjamin, Amy Richey and others at Northern Arizona University. Following this, an expert workshop was held in Las Vegas, Nevada in 2004 to focus on the indicators and rank descriptions. This workshop was critical in the RRAT development. Many of the indicators now used in the RRAT originated in this meeting, and the workshop members also changed existing indicators to make them more specific, and they clarified interpretations of the different ranking levels for each indicator. Statistical analyses were completed by Amy Richey (2005) for her Masters thesis at Northern Arizona University (NAU). The results of her research show that the indicators and traditional methods correlate well with each other regarding plant and animal communities, but hydrology and soils factors have proven to be more complex. Phase II (the project described in this report) uses these indicators, stressors and site values to rank sites and make general restoration recommendations. Phase III focuses on the end users of the RRAT, including how the tool works in the field with users, the most effective means of data collection (paper vs. field tablets, etc.), and the automation of tool input, analysis, and output delivery and distribution of the RRAT expert system. This phase is being conducted by Talise Dow (a Masters student at NAU), who is field testing the data collection aspect of the tool with NPS personnel, and by Kathryn Thomas (U.S. Geological Survey), who is leading the automation aspects of the project.

The goal of having a tool that can be used within any National Park is best reached by developing a modular tool, as not all specific habitat types (such as rivers, lakes, prairies, etc.) have similar physical properties, controlling processes, and ecosystem functions, and they do not all respond identically to disturbances and restoration treatments. The RRAT was designed from the ground up to be applicable to many habitat types and ecosystems, but the structure of the expert system (the analytical model described in this report) was designed modularly, which makes it easy to modify and upgrade. Fields of data that are entered by the user, specifically the site descriptors, visual indicators, site values, and stressors (referred to as Variables within the RRAT), will generally be the same between habitat types and ecosystems. The logic used to make decisions within each habitat type, however, is contained within its own module, referred to as Logic Blocks or Command Blocks, and these modules can easily be added to or subtracted from the model. For more information on Variables, Logic Blocks, and Command Blocks, see the section in the Methods called “Programming with Corvid”.

The RRAT team decided to focus on riparian areas for developing the first module of the RRAT. Riparian systems were chosen due to their particular susceptibility to exotic plant invasions (Stohlgren et al. 1998), one of the primary disturbances that restoration ecologists have to contend with, and because they are among the most impacted by humans and in need of restoration (Nilsson and Svedmark 2002). This module of the RRAT was designed for the user to include the actual aquatic habitat (the river or stream itself, as well as wetlands that are part of riparian areas) and all of the terrestrial habitat associated with the riparian area (see the section titled, "Riparian, stream, and river restoration" below) in the field data collection and the analysis that is done by the computer application. It was also developed to be applicable to all stream or river sizes. This module should not, however, be used for lakes or ponds—only lotic habitats (ones containing *flowing* water) were considered in its development.

Objectives

The primary objective of Phase II was to construct an analytical tool that will help the National Park Service prioritize riparian restoration projects/sites and provide information on potential treatments for those areas. In order to meet this objective, the following steps were taken:

1. Conduct restoration literature search and review
2. Determine appropriate restoration experts
3. Conduct expert interviews (knowledge elicitation)
4. Determine software (i.e., expert system tool) to be used
5. Construct knowledge base
6. Program knowledge base into expert system tool
7. Conduct rapid prototyping and sensitivity analyses
8. Evaluate final prototype using expert validation

Some of these steps were done in the order listed. For example, the knowledge base could not be constructed without first reviewing literature and/or interviewing at least one expert. Other steps occurred throughout the project, including literature reviews and expert interviews, and rapid prototyping and sensitivity analyses typically occur together.

Restoration theory and practice

Restoration ecology is a relatively young science. As opposed to well-established science disciplines that have had full integration of theory with practical application for many years, ecological principles have not always been applied to restoration projects, and research ecologists have infrequently used restoration ecology for advancing theory (Palmer et al. 1997). Over the last 16 years, however, there has been rapid growth in the number of papers focusing on restoration ecology in peer-reviewed journals (Young et al. 2005), and the field is also now brimming with journals, books, reports, and web sites on theoretical and practical aspects of restoration (as an example, see the list of references and resources pertaining solely to river and riparian restoration in Appendix A). As an indication of the maturing state of restoration ecology, there is an encouraging number of ecological concepts that are understood and used by restoration practitioners, including ones that are newly being incorporated into restoration practice: competition, niches, succession, recruitment limitation, facilitation, mutualisms, herbivory/predation, disturbance, island biogeography, ecosystem function, ecotypes, and genetic diversity (Young, et al. 2005). Despite the improving links between theory and practice, there is still room for improvement, as some restoration decisions are still made using gut instinct and controlled solely by political and budgetary constraints without regard to ecological factors. Plus, restoration ecologists have been prone to fall into two pitfalls: 1) assuming that there is a single reference condition that should guide restoration, and 2) viewing restoration as a single, discrete event (Pickett and Parker 1994).

There are some excellent resources available for restoration ecologists and practitioners, including the SER International Primer on Ecological Restoration (Society for Ecological Restoration 2004), which gives an outline of what attributes a restored ecosystem should have. Developing and following effective guidelines for planning and implementing restorations is another way to improve restoration effectiveness. Hobbs and Norton (1996) identified seven elements that are “essential for the successful integration of restoration into land management:

(1) Identify processes leading to degradation or decline.
(2) Develop methods to reverse or ameliorate the degradation or decline.
(3) Determine realistic goals for reestablishing species and functional ecosystems, recognizing both the ecological limitations on restoration and the socioeconomic and cultural barriers to its implementation.
(4) Develop easily observable measures of success.
(5) Develop practical techniques for implementing these restoration goals at a scale commensurate with the problem.
(6) Document and communicate these techniques for broader inclusion in land use planning and management strategies.
(7) Monitor key system variables, assess progress of restoration relative to the agreed-upon goals, and adjust procedures if necessary.”

Hobbs and Norton (1996) then suggested that “restoration activities frequently occur with little or no consideration of these processes.” Regardless of whether or not this has improved in the last 10 years, suggestions like these have at least been more thoroughly developed. As an example, the Society for Ecological Restoration (2004) published a list of 51 guidelines in their “Guidelines for Developing and Managing Ecological Restoration Projects”, from initial site selection in the beginning, to publicizing and writing about the restoration in the final stages. These principles are undoubtedly helpful with planning and implementing restorations, especially when restorationists pay close attention to ecological theory, and when they set appropriate, realistic goals.

One concept that is frequently used to establish restoration goals, determine the restoration potential of areas, and measure the success of restoration efforts, is the reference condition (White and Walker 1997). The reference condition relates to a historical or pre-disturbance state, typically before humans had a significant impact on the area (Galatowitsch 1990). Determining the true historical condition is fraught with problems, most notably the lack of good data on condition of the biotic and abiotic elements. The reference condition is also based upon nearby areas that have desirable characteristics, typically areas that are considered pristine or undisturbed. It may not truly represent historical conditions, but it can represent conditions that may be achievable. Three kinds of reference information are usually used to infer changes in the ecology of an area: current conditions, historic records, and legacy/latency. The last item deals with things that are detectable on the landscape that give some information as to past conditions on the site, including fire scars and geomorphological features (such as river meanders) (White and Walker 1997).

Another commonly used, but usually poorly defined, concept is that of restoration potential. Essentially it deals with the likelihood of restoration or revegetation being successful, whether through natural or human-directed means. Researchers mention such aspects as the hydrologic ability of the soils to support native plants (Harris and Olson 1997), the ability of plants to reestablish, grow, and reproduce rapidly (Pywell et al. 2003, Richardson et al. 2005, Orr and Stanley 2006), the ability of plants to deal with stress and disturbance (de Gruchy et al. 2001), and the appropriateness of the habitat for a specific vegetation type (Bolliger et al. 2004).

Restoration goals and objectives are not only based on science and ecological theory, they are also a value-based activity (Davis and Slobodkin 2004, Winterhalder et al. 2004). Values must be considered in the restoration equation, especially in the National Parks, where there can be an intimate connection with civilization, such as in the urban parks in the Washington D.C. area and the northeast, and where there are unique natural features and communities of plants and animals. In a broader sense, it can be very helpful to think of problems in terms of values, as opposed to alternatives. According to Keeney (1992), "Value-focused thinking involves starting at the best and working to make it a reality. Alternative-focused thinking is starting with what is readily available and taking the best of the lot." A restoration project may turn into an alternative-focused decision if only site-specific options are evaluated, but when broader, science-based concepts and human values are both considered, the solution can take a path that goes beyond the obvious alternatives.

These three concepts have been central to the development of the RRAT. First, for the indicators to be properly scored, the reference condition or desired future condition must be known or agreed upon. Second, the restoration potential is used to know the likelihood of restoration efforts being successful. And third, it is essential during the establishment of restoration goals to keep in mind the wide range of values that are inherent in restoration, from human-centric to nature-centric values.

Riparian, stream, and river restoration

Early in the RRAT planning, it was decided to focus on riparian areas for initial development of the tool. (Naiman et al. 2005) define riparian areas as "transitional semiterrestrial areas regularly influenced by fresh water, usually extending from the edges of water bodies to the edges of upland communities." Thus, riparian areas are not referred to in terms of specific distances from the riverbank, or in specific corridor widths, but they are usually defined by the habitat that is directly influenced by the surface water and groundwater along a river. In many areas this can be visually delineated by the extent of vegetation that relies on either saturated soils or higher water availability than that which is available to surrounding upland vegetation—the riparian vegetation would likely not exist in that spot if it were not for the presence of the river, its floodwaters, or its associated groundwater. When considering factors that influence a riparian community, one must step back and get a landscape perspective. Just as a river cannot be removed in theory or practice from its watershed (Hynes 1975), the riparian area cannot be separated from its river and the surrounding landscape. In fact, many factors influence riparian areas, including those at the site (erosion, physical disturbance, etc.), upstream from the site (sediment, pollutants, seeds floating in the water, etc.), downstream from the site (headcutting, non-native fauna traveling upstream, etc.), and in the surrounding landscape (nutrient and pollutants leaching from surrounding terrestrial areas, etc.). Therefore, for developing the RRAT, I focused on both riparian and channel restorations of rivers and streams. For simplification, within this document I will refer to rivers, even though both streams (usually defined as "small rivers" in dictionaries) and rivers are referred to in nearly equal proportions in restoration literature.

Major changes have occurred to the focus of river restorations in the past decade (Susan Galatowitsch, pers. comm.). Historically, river restorations were either focused on improving fish habitat (usually by modification of flow through the installation of in-stream structures), or they attempted to return the river to its "original" state. While the two historical approaches are still used, they are usually part of more comprehensive restoration plans or goals. Now most river restoration projects attempt to establish conditions that are both self-regulating and integrated within the surrounding landscape by focusing on one or more of the following: channel shape and meander modification, bank stabilization, native plantings and/or seedings, exotic plant removal, water quality improvement, dam removal, and reintroduction or encouragement of riparian or aquatic animals, especially fish.

Thanks to the popularity of riparian and river restoration work, there is a considerable amount of information available on these subjects (Appendix A). Three references that have been used by experts I talked with, and that were particularly useful during development of the RRAT, include *Stream Corridor Restoration : Principles, Processes, and Practices* (Federal Interagency Stream Restoration Working Group (U.S.) 1998), *Stream Hydrology : An Introduction for Ecologists* (Gordon et al. 2004), and *Stream Restoration Design Handbook (Draft 2)* (USDA NRCS 2005).

River health, rapid assessments, indicators and river classification

The analogy of health is frequently used to describe the condition of rivers, as it helps give some people an anthropomorphic framework that they can understand, but it is not always clear precisely what is meant by "health" or how it is measured (Norris and Thoms 1999). It is clear, however, that people have the desire to "fix" rivers that are not healthy, and that there needs to be some way to determine how to know when a river is unhealthy and how to heal it. This is frequently a difficult task. While it can be very obvious visually that a river or riparian area needs rehabilitation (e.g., presence of a streambank failure or an invasion of non-native plants), it is not as easy to visually determine problems with water chemistry and quality or populations of aquatic organisms. Even if these parameters are quantified, it can still be very difficult to know what needs to be done to rectify them.

Many river restorations are conducted with the help of river classification systems. These are attempts to put river reaches into different categories that capture key characteristics of the river. This often includes such things as the meander pattern, degree of channel braiding, streambed shape, rate of flow, parent material, and riparian plant community, to name just a few. Classifications are supposed to inform people of the “correct” properties that the river should conform to in the given reach, which can help with goal-setting in river restoration projects. Thus, some classification systems have been applied widely in river restoration projects. An excellent and well-used classification system was created by Cowardin et al. (1979), which is frequently used as a guideline for riparian vegetation assessments, especially within the U.S. Fish and Wildlife Service. This report covers all systems in the United States that are governed chiefly by water bodies, including marine, estuarine, riverine, lacustrine, and palustrine areas, and uses a hierarchical method to subdivide each into subsystems and classes for describing specific zones, substrates, and plant communities in these systems. While it was written for conducting habitat inventories and not specifically for informing restoration projects, this report is very useful for using common terminology in describing habitats and vegetation communities in riparian areas. One of the most popular river classification systems in the United States is the Rosgen Classification method (Rosgen 1996), but it is also one of the most highly criticized methods as well. It is considered a good tool for standardizing descriptions of river reaches, but there have been spectacular failures of restoration projects that used the Rosgen Classification (Malakoff 2004), and it does not pay as much attention to hydrogeological processes as some would prefer (Miller and Ritter 1996, Goodwin 1999, Juracek and Fitzpatrick 2003, Simon et al. 2005). According to Goodwin et al. (1997), it is more useful for restoration purposes to identify future processes than to describe current forms, which is what the Rosgen method focuses on. A number of assessment methods do focus on processes (Montgomery and Buffington 1997, Hauer and Smith 1998, Newson et al. 1998, Hurley and Jensen 2001, Kondolf et al. 2003, Brierley and Fryirs 2005, Snelder et al. 2005, Hey 2006), so there are plenty of alternatives available.

In addition to classification systems, environmental assessment techniques are commonly employed to get some measure of river condition or health, which can help in goal setting and the restoration actions to achieve those goals. These techniques are known under a number of names, such as habitat assessment, rapid assessment, bioassessment, ecological risk assessment, and environmental stress assessment, to name a few (Gordon, et al. 2004). Regardless of the name, most have a common element: the use of the indicator. Indicators are used to reflect the condition of ecological functions, structures, and/or processes more quickly and more easily than traditional parameters (such as recording information on many plant and animal species), and they can accurately reflect the stress or health of the ecosystem. As an example, aquatic invertebrates are often used as indicators of water quality, as they are very sensitive to changes in water chemistry (Norris and Thoms 1999), and the invertebrate community can be much easier and faster to sample than a suite of water chemistry parameters, which do not directly tell you what influence they have on the river system.

Indicators are not always the best answer, though. It can take a lot of work to find appropriate indicators, and to validate direct links between the indicators and the stressors (Boulton 1999). Researchers are putting considerable effort into proving links between stressors and indicators of ecosystem health, especially for aquatic systems (National Health and Environmental Effects Research Laboratory (U.S.) 2002, Nelson and Roline 2003, Niemi et al. 2004, Serveiss et al. 2004, de Zwart et al. 2006, Franzle 2006). Additionally, there can be a lot of personal bias in the indicators that are used, the response time of the indicator on both spatial and temporal scales can be problematic, and the reliability of indicators is not always good (Boulton 1999).

Unfortunately, there are nearly as many assessment and classification methods as there are rivers, and anyone unfamiliar with the field would quickly be overwhelmed by the abundance of options. However, there are some resources that can help one select appropriate methods for different situations. As an example, there are published reviews of assessment and classification methods (Boulton 1999, Innis et al. 2000, Verdonschot 2000, National Research Council (U.S.) 2002, Gordon, et al. 2004, Richey 2005). Gordon et al. (2004) also provide an excellent introduction to different river assessment approaches that are in use worldwide, the specific settings and habitats that they are designed to be used in, and their advantages and disadvantages. Many resource agencies also have specific methods or procedures for river assessment or classification, as well as specific restoration guidelines and prescriptions, that are well established and widely used in the agency and/or tailored to their specific region (see the "US Government" and "State organizations" sections of Appendix A for a brief listing of links to guidelines followed by various agencies).

The primary goal of the RRAT is to provide a very rapid method of assessing sites for the explicit purpose of prioritization of restoration projects. The RRAT is not intended to circumvent or replace other assessment methods, especially bioassessments that require rigorous data collection, or river classification systems that are currently being used to design restoration projects. This is especially true with regard to critical habitat for species that are listed as sensitive, threatened or endangered by the US government or any state—federal and state agencies often have strict guidelines regarding these areas, and these guidelines should always take precedence over RRAT assessments and recommendations. Nor is the RRAT designed to validate indicators, or to calculate the likelihood of stressor-effect relationships. It is, however, designed so that results from bioassessments, as well as links between stressors and indicators that have been determined from other research, can easily be added to the model.

Expert systems and their use in natural resource management

Computer programming has been used with great success for analyzing complex problems, especially ones with many variables. The goal to create computers that can simulate aspects of human thought processes, often referred to as artificial intelligence, led to the development of expert systems in the 1980's. Expert systems use special programming, called an inference engine, which allows computers to give responses similar to what an expert might give when faced with a problem. One simple example of this technology is automated phone systems that direct your call to the proper person at a large company. The automated system asks you questions, you touch the button that seems appropriate to your goal, and usually, after a few questions, you are directed to the right person. More sophisticated expert systems are used for such applications as online product selection guides, controlling machinery in factories, and for diagnosing diseases from the symptoms displayed by a patient (Jackson 1999).

Expert systems are constructed by gathering information from experts on the logic they use to make their decisions, and programming a computer with that logic. The process of gathering this kind of information from experts is called knowledge elicitation (a.k.a., knowledge acquisition, knowledge engineering, and decision analysis) and the person who takes on this role is called the knowledge engineer. The structured information that an expert uses to make decisions within a particular subject is called a knowledge base. This normally includes the variables that are considered in the decision process, the logic that is used to make decisions, the decisions themselves, and explanations for the variables (why those variables are important). The knowledge base is coded into a computer program called an expert system (a.k.a., expert system shell). Modern expert systems are frequently incorporated into decision support systems, which are used extensively by businesses and corporations to make wise management and economic decisions.

Using expert systems for natural resource management, ecological assessments, and ecological modeling is not a new concept (Noble 1987, Starfield et al. 1989, Johnston et al. 1990, Shields and Aziz 1992, Johnston et al. 1993, Sojda et al. 1994, Breen et al. 1995, Prach et al. 1999, Reynolds 1999, Sojda et al. 2002, Saunders et al. 2005). As an example, the Ecosystem Management Decision Support (EMDS) system, a decision support system designed by the US Forest Service for the integration of landscape evaluation and planning, has been successfully applied to watershed assessments and management in the northwestern US (Jensen et al. 2000, Reynolds et al. 2000, Reynolds and Hessburg 2005). It is an excellent example of integrating geographic information systems (GIS) and ecological/monitoring data with decision analysis techniques, and should be referred to during future development of the RRAT.

Decision analysis has been used to prioritize prairie restorations in Ohio (Cipollini et al. 2005), and decision support systems have been used for planning stream restorations in the Netherlands (Verdonschot 2000, Verdonschot and Nijboer 2002). The authors focused on assemblages of macrofauna within streams as an indicator of water quality and quantity change, habitat loss, and human interference. The ranking of these indicators, in combination with stream management and human impact in the area, are used in a decision tree to make general restoration recommendations (Verdonschot and Nijboer 2002).

Equally useful in some resource management decisions are risk analysis and assessments, especially in cases where there is potential for damage to resources, property, or life, and where there are legal ramifications of the decisions (Johnson and Huggins 1999, Burgman 2005, Forrest et al. 2006). I did not incorporate elements of risk analysis into the RRAT, as the information used to make risk assessments tends to be highly quantitative, and the decisions based upon extensive collection of field data and statistical analyses of these data.

Methods and Materials

Literature search and review

To compile information on how decisions are made in riparian and river restorations, I first turned to primary and secondary literature. I conducted literature searches using combinations of the following terms in title, keyword, and abstract searches: riparian, river, stream, buffer, restore, restoration, rehabilitate, rehabilitation, reconstruct, recover, repair, regenerate, regeneration, revegetate, revegetation, intervention, management, potential, priority, prioritize, prioritization. The search included journal articles, books, reports (published by governmental organizations, research institutions, non-profit groups, and private restoration consulting businesses), and web sites. I conducted searches on expert system, knowledge engineer, knowledge elicitation, decision support, decision analysis, risk analysis, and risk assessment to learn about expert systems development and decision support systems, especially those that are used in natural resource management. I also conducted searches for literature on environmental, biological, and ecological assessment techniques, river and stream classification, geomorphic classification, ecosystem stress and ecosystem health to learn about past and current methods used in assessing natural habitats and determining their condition.

I reviewed these sources and pulled out methodologies and concepts that are used to guide decisions in restoration projects, especially those dealing with restoration potential, restoration/site/habitat prioritization, river classification, and stressors. Some of these concepts were used to structure and guide, at least initially, the expert interviews that I conducted. I also determined appropriate methods for knowledge elicitation from the expert systems literature.

Expert selection & interviews

Two of the first steps in the knowledge acquisition process are to determine who the experts are and how to most effectively understand the experts' reasoning process. To create a contact list of potential experts to interview, I used both a literature survey and word-of-mouth. For the literature survey, I compiled author names from the bibliography I created (described above) and ranked them by number of publications for which they were an author. I selected individuals whose names appeared in at least 3 publications and whose work or research seemed applicable to the RRAT project (especially work relating to prioritization, restoration potential, and application of assessment and stream classification techniques to restoration). I also searched for highly cited authors in riparian, stream, and river restoration. I finally used word-of-mouth references from restoration experts that I interviewed to find additional contacts. A table of the experts I interviewed can be found in Appendix B.

One of the challenges in creating expert systems is the availability of the experts (Greenwell 1988, Scott et al. 1991, Hart 1992), which is the same reason that expert systems are often created in the first place: a well-designed expert system can, in some cases, take the place of experts who have limited time or availability. While it was time consuming and difficult to find experts who had time to meet with me, I was fortunate to be able to meet with eight experts, and I met with several of them more than once.

The most commonly used method of knowledge acquisition involves interviews with experts (Greenwell 1988). I used a structured interview process with specific lines of inquiry, partly based upon my literature review of restoration concepts, but also upon suggestions in expert systems literature regarding types of questions that are useful for determining the logic used to make decisions (Appendix C). Another recommendation that I followed from the expert systems literature was to make audio recordings of my interviews. While I took notes during my interviews, having a recording allowed me to go back and listen to parts that I missed, or parts that were unclear from the notes. Digital audio archives of the interviews will be kept with RRAT project leaders.

Software selection

The RRAT automation team conducted a review of 45 currently available expert systems in 2005. The team developed a set of criteria that was used for final expert system application selection. These criteria included:

1. Rule Based Architecture – The expert system should be designed to use "If-Then-Else" rules and logic. Some expert systems are designed to use Case-Based Reasoning, where information supplied by the user is compared with pre-set conditions, and decisions are made based upon the most similar case to that supplied by the user. This was deemed inappropriate for the RRAT.
2. Open Architecture with Microsoft and ESRI – The expert system should be able to have integration with Microsoft programs (especially Excel or Access) and ESRI software. These would help integrate the RRAT with databases and GIS applications.
3. Capable of tabular input/output – The expert system should be able to read from and write to tab-delimited text files and spreadsheet files if possible.
4. Licensing cost – The expert system should be inexpensive or free to distribute among many users nationally, at least in a format that the user can use to run the model and receive output.

In addition to these main criteria, other aspects of the available programs and their companies were considered:

- Rule-based and frame-based abilities:
    - Rule-based expert systems use IF-THEN rules to make decisions. This is a common characteristic of most expert systems.

    - Frame-based expert systems use data structures with typical knowledge about a particular object. For example, an object called *Person* might have the characteristics *name*, *weight*, *height*, and *age*. The expert system programmer uses these objects as a basis for analysis, design and implementation, and the object is usually a concept, abstraction, or thing with distinct purpose for the particular problem. The expert system itself then makes decisions based upon these objects, typically selecting the object that is the best fit or solution to the problem. This is also known as a case-based expert system.
- Ability to do both forward and backward chaining:
    - Forward-chaining is a data-driven process where a program is run in the order in which the lines of code are assembled in the program, and the same data are always collected regardless if they are needed to obtain an answer. In an expert system using forward chaining, the same questions are always asked, and they are asked in the same order.
    - Backward-chaining is an answer-driven process, where the expert system looks for the quickest way to get an answer, and only asks those questions that are necessary to get a quick answer. In an expert system using backward chaining, it does not necessarily always ask the same questions, and they are not asked in the same order.
- Reasoning – some form of fuzzy logic capability would be good
- Personal Digital Assistant (PDA) compatibility
- Easy to modify and expand
- Ability to integrate with web at later date

- Product and company stability

After careful consideration of all the products available, the decision was made to purchase the program Corvid, by Exsys (Albuquerque, NM). This application appeared to satisfy all elements we were looking for, and the program has been in development for over 20 years, indicating excellent product stability.

Programming with Corvid

The design of Corvid makes it very easy to modify different sections without needing to change the structure or programming of the entire model. This modularity is a critical characteristic of any model or program that needs to be changed or updated regularly. It also fits very well with one of the heuristics of model development: to build a suite of models instead of one all-purpose model (Nicolson et al. 2002). While this expert system runs as one model in practice, it is actually a suite of models that easily fit into one package.

There are three main tools with which one builds an expert system in Corvid: Variables, Logic Blocks, and Command Blocks. Variables are either values that are asked of the user at run time, or that are calculated internally when the model is run. Logic Blocks control how the variables are used, and how decisions in the system are made based upon the user input and the logic of the system. This is primarily where the knowledge base (containing the logic that experts use to make decisions) is constructed. Command Blocks control how the Logic Blocks are used in the system, the order in which different blocks or variables are used, and where and when the system starts and stops. Command Blocks can control other Command Blocks, and even Logic Blocks can be set to control Command Blocks if desired. This degree of flexibility makes Corvid very powerful analytically and structurally.

Model development

Site Descriptors, Indicators, Values, and Stressors

The development of the RRAT analytical model described in this report was guided by an evaluation of potential model input parameters that was conducted by another team prior to the development of the analytic model. The inputs and the techniques used to develop them will be presented in the following paragraphs.

The first set of input parameters collected for the RRAT are environmental site descriptors. These include the identifying information such as date of evaluation and site name,, information on the site's size, accessibility, topography, soils, and hydrology, and the extent and type of obvious disturbances (Appendix D). The last two types of information are important in determining the restoration feasibility of a site.

The second set of input parameters forms the core of the RRAT. The format used for these was based upon *Interpreting Indicators of Rangeland Health* (Pellant et al. 2005), which is currently in widespread use on grazing lands of the western US. This system uses a set of visual indicators that can be rapidly scored in the field to determine the relative condition or "health" of the site. The indicators are ranked based upon the departure from expected natural condition or management goal, on the following scale:

- None to Slight
- Slight to Moderate
- Moderate
- Moderate to Extreme
- Extreme to Total

We modified these categories slightly for simplification purposes to read as: none, low, moderate, high, and severe.

In the initial stages of development, spearheaded by Pamela Benjamin (2004), there were 65 indicators in the tool. This list was modified at an expert workshop in the winter of 2004, and at another workshop in April 2006. Modifications were also made based upon soil, hydrology, and restoration expert consultations, and upon peer-reviewed literature and other publications. The current list of 48 indicators (Appendix E) should be viewed as a working list that can be modified when necessary for different parks or ecoregions. Essential to the consistent, accurate scoring of indicators is a description for each ranking (Appendix F). This was developed in concert with the indicators (Richey 2005), and should also be viewed as suggestions that can be modified to suit each region or park. In its current version, the indicators used in the computer application cannot be modified by the user, but future versions may allow the user to enter their own indicators into the application. One of the indicators under the Invasive Non-native Plant heading, titled "Type of impact of invasive nonnative plants", references a separate list of impact types (Appendix G). The user can select one or more of these impact types and give a general rank for the severity of these impacts as with the other indicators. I assembled this list from a paper by Levine et al. (Levine et al. 2003) that discusses the reasons for impacts from invasive plants and breaks down the impact types in a logical manner.

The third and fourth sets of input parameters are site values (Appendix H) and site stressors (Appendix I), respectively. These were also developed during the expert workshops. The site value list includes eight items that capture broad themes faced by NPS managers and was based upon the concepts presented in the Restoration Theory and Practice section of this report. Site stressors, factors that can negatively impact a site, are selected by the user as likely reasons for departure in the indicators. The selection of a stressor, however, is not proof of causation between the stressor and an indicator. A more detailed list of specific stressors that relate to the general anthropogenic sources, called the Source-Stressor matrix, is in Appendix J. This is a working list of anthropogenic sources, specific stressors, explanations for the stressors, and a matrix showing potential direct relationships between the sources and the stressors, derived partly from Table 3.3 (pages 3-27 and 3-28) and Table 8.8 (pages 8-85 and 8-86) in the Stream Corridor Restoration manual (Federal Interagency Stream Restoration Working Group (U.S.) 1998). This framework was created to help people think about sources and stressors, and is not meant as proof or necessary indication of links between them. This matrix has been incorporated into the computer application so that the user can identify a more specific source of stress, rather than simply stating that "Agriculture" is the source of stress, which may not be useful in deciding what should be done to remove the stressor.

One approach that appears to be unique to the RRAT (in comparison to other assessment methods) is the inclusion of future *potentials* of the sites. This is assessed in relation to each indicator by including a data field called "Desired Future Rating", for which the user ranks the degree of departure for the indicator based upon the management goal (Appendix E). Similarly, Site Stressors are each ranked considering both current impacts and projected future impacts (Appendix I). In the Site Values module of the tool, the user not only ranks the current condition of the site, but also the potential future condition (Appendix H).

Building the knowledge base

I followed recommendations and guidelines from modeling literature to construct the knowledge base for the expert system (Plant and Stone 1991, Starfield and Bleloch 1991, Starfield et al. 1994, D'Erchia et al. 2001, Nicolson, et al. 2002). I first made an outline of the major concepts used to make restoration decisions from the expert interviews and the literature, and used this outline to construct decision trees, which are series of questions, potential answers to those questions, and the decisions that the answers lead to. The answers and decisions follow a "If, Then, Else" logical format, which is easily coded into logical statements in an expert system.

Restoration indices and weights

I developed a set of indices to summarize the model results, as opposed to ranking the sites on an arbitrary, linear scale from high to low restoration priority. These indices generally reflected concepts from restoration literature and concepts found useful by restoration practitioners, and the indices were determined to be useful in the expert workshops. I also employed weights in calculating values for the indices. Weights are commonly applied in decision analysis systems to give various levels of importance to variables or rules in specific settings (Jimenez et al. 2003, Delgado and Sendra 2004, Cipollini, et al. 2005).

Model testing and evaluation

Prototyping

One of the primary heuristics in model development is the necessity of rapid prototyping (Starfield and Bleloch 1991, Starfield, et al. 1994, Nicolson, et al. 2002). Only after one develops a prototype and views its output can one see how the model actually works, which allows one to think about the concept or system that one is trying to model. This leads to intermittently changing and testing the model, all the while incrementally improving the model as well as improving one's understanding of the problem at hand.

Sensitivity analyses

According to Nicolson et al. (2002), "sensitivity analysis is the only available means of determining what goes into the model and what level of detail is necessary." A sensitivity analysis is conducted by testing the influence of a single parameter or variable on model output by changing its value and running the model repeatedly until one understands how the model responds through the full range of that variable. This can be done with several variables in concert as well as a single variable. In addition to testing variables, one also needs to test the influence of the assumptions and educated guesses that are programmed into the model on how the model operates (Nicolson, et al. 2002). Sensitivity analyses are conducted after a working prototype is constructed, but rapid prototyping can also occur based upon the results of sensitivity analyses—if a sensitivity analysis indicates that the way a model responds to a specific variable needs to be modified, then a new prototype needs to be developed based upon these results.

Field testing

As this tool is designed for field use by a wide range of users, it was essential to both test it in the field under realistic conditions, and to get user feedback on the format of data entry. Field testing of the site descriptors and indicators, and what users thought of these variables, was conducted by Amy Richey during initial development of the tool, and Talise Dow conducted extensive field evaluations of the data forms in 2006 at numerous parks, with several surveyors working at multiple sites. This was not a field test of the computer application, but the data will be used for further prototyping of the model (field testing is frequently a part of prototyping). According to Sojda (Sojda 2007), decision support tools need to be empirically evaluated, especially to determine if they are actually useful for the end user, and to assess whether or not they address the intended purpose. Analysis of these data using the computer application will enable comparisons among users, comparisons between model output and user assessments of sites, and usefulness of the tool to the end user. Additional field sampling will be required to develop the RRAT for other habitat types, especially more terrestrial areas that do not have riverine or wetland influences.

Results and Discussion

Model description

Knowledge base / decision trees

My primary goal in constructing the logic of the RRAT was to use scientific as well as pragmatic principles that restoration ecologists, hydrogeological engineers, and practitioners use. In the interest of making the model broadly applicable, I did not include the level of detail or types of decisions that are unique to one park, state, or area of the country. The logic used to build the model is therefore based on broad concepts, and the model is strictly designed to use rapid assessment data for making comparisons between sites, not for selecting detailed, site-specific restoration treatments.

The challenge in doing this is that ecologists, engineers, and practitioners often focus on very different things. Ecologists typically focus on factors and processes that influence the biota. Engineers focus on parent material, channel morphology, stream flow rates (flood, minimum, and base flows), erosion, and sedimentation. Practitioners have to consider political, fiscal, and logistics of restoration, while trying to satisfy all parties and get the best “bang for the buck”. This is, of course, a simplification of what different professionals consider; anyone doing riparian or river restoration will be dealing with most of these issues on some level. It does, however, help illustrate the difficulty of determining common concepts. The principles that are hereafter described in this section are not necessarily applicable to all sites, but they give a basis for the decisions and provide the user with concepts that may guide their decisions.

One principle that is widely agreed upon is the relationship of the longitudinal location of the site on the river to the difficulty of restoring the site (Gordon, et al. 2004). Generally, areas within the headwaters of a river are highly erosional, which makes bank stability, sediment loads, and scouring difficult to deal with. On the other end, in the deposition zone of a river (typically slow-moving, meandering rivers), sedimentation processes are important. Since one is effectively dealing with all of the inputs (and problems) from upstream, restoration in these deposition areas is very challenging. The transfer zones, where sedimentation is roughly equal to deposition, are typically believed to be the easiest to restore.

Another common principle is the need to have a hydrological regime that can actually support riparian vegetation. Without this, seedings and plantings in a restoration project may fail. Soil moisture, which is at least partly determined by slope of the river channel and the adjacent upland, as well as aspect of the land, can be estimated using GIS models and has been used as a proxy for restoration potential (Harris et al. 1997).

The size of a site and its proximity to existing lightly impacted riparian areas (reference sites) are also seen as influencing the restoration potential of a site. In short, this relates to habitat fragmentation and proximity to native plant seed sources. Usually, the larger the site, and the closer it is located to a pristine site, the higher the restoration potential will be, both for plants (Wickham et al. 1999, Timm et al. 2004) and wildlife (George and Zack 2001, Lehtinen and Galatowitsch 2001).

I kept the decision trees (see the "Building the knowledge base" section in the methods) as simple and linear as I could in order to avoid circular reasoning, and because I could find few similarities in the order in which restoration decisions are made among restoration experts. The similarities among experts are mostly in the broad concepts that I mentioned above. Even though the decision trees seem to follow a linear progression of ideas, questions, and decisions, this is not necessarily the case when decisions are made in real life, and it is not necessarily the way the model deals with the information. As an example, even though the decision tree shows that the hydrologic potential of the soils has to be determined before the indicators are dealt with, this is not the case. They could be determined in any order.

I will not give a rule-by-rule breakdown of the entire model in sentence form, but instead I will rely on the flow charts and decision trees to explain the logic in the system (Appendix K). On the first page of Appendix K are the RRAT procedures, which follow an example of how the RRAT would be used by a park or an agency. The flow chart on the next page of Appendix K, titled Model Structure, shows how the variables, command blocks and logic blocks of the model all interact to create the indices. These are not steps taken by the end user, but by the program itself. The final two decision trees in Appendix K show the ***logic*** that is used to determine values for the indices of site value and restoration potential.

The purpose of the site value decision tree is to determine the degree of confidence in the need to either protect or restore the site. Basically, if a site is currently more valuable than it will likely be in the future, there is much to be gained from protecting the site (as opposed to restoring it after it has degraded). Conversely, if a site is not valuable now but it has the potential to be valuable in the future, the proper action is restoration (see information below for the protection-restoration confidence index).

The restoration potential decision tree outlines the logic used for a large portion of the RRAT, including how each visual indicator is dealt with, when stressors are selected for indicators, and how stressor removal efforts come into play in the model. Documentation of the logic and justification for the logic is found in the table on the last page of Appendix K.

Indices & weights

A single run of the RRAT analytic tool requires input for the 48 indicator variables, and the analytic output consists of seven indices developed to indicate overall restoration potential. These indices reflect the restoration concepts in the Introduction above (see the section Restoration Potential, Site Value, and Degree of Disturbance, subsection Restoration theory and practice). The derivation of these indices is fairly simple, at least in the version of the model available at the time of this report (Table 1). The indices are designed to be in the same numerical form as probabilities: ranging from zero to one (0-1). The exception is the Protection-Restoration confidence level, which ranges from -1 to 1. In order to facilitate the calculation of these indices within these ranges, the input variables are also converted into numbers from 0-1. The Degree of Disturbance is simply an average of all of the indicator values, which I decided upon to express the general degree of disturbance at each site. Site Value also uses a simple average of current conditions from the site value module. Restoration Potential mostly expresses

Table 1. Explanation and justification for derivation of the indices, including variables and terms used in the calculations of the indices.

Indices	Code	Explanation of variable or formula	Justification
Natural Revegetation Potential	NRP	This is the same thing as the 10^{th} indicator in the Native Plants section of the RRAT, titled "Potential for Natural Revegetation"	Revegetation potential is frequently referred to in restoration literature (Martin and Chambers 2002, Mulhouse and Galatowitsch 2003, Steed and DeWald 2003, Taylor and McDaniel 2004, Shafroth et al. 2005, Orr and Stanley 2006)
Hydrologic Potential	HP	Value derived from soil moisture content in watershed analysis, or estimated by user	Restoration potential relates to the hydrologic potential for supporting riparian vegetation (Harris and Olson 1997, O'Neill et al. 1997).
Stressor Removal effort	SR	Independent probability: $SR = 1 - ((1 - SR_1) \times (1 - SR_2) \times ...)$ (SR_1, SR_2, etc. are the stressor removal efforts required for each individual stressor)	Stress is additive instead of averaged (less stress of one kind does not necessarily reduce stress of another kind); independent probability allows for this.
Restoration Potential	RP	Average of values: $RP = \frac{NRP + HP + (1 - SR)}{3}$	Restoration potential relates to the natural ability for plants to return (NRP and HP), and the effort required to remove the stressors (Galatowitsch, pers. comm.)
Site Value	SV	Average of current site values: $SV = \frac{SV_1 + SV_2 + ... + SV_N}{N}$ (N = number of site values ranked)	Averaging is most intuitive way to summarize the value of a site
Degree of Disturbance	DD	Average of indicators: $DD = \frac{I_1 + I_2 + ... + I_N}{N}$ (N = number of indicators ranked)	Averaging is most intuitive way to summarize the overall degree of disturbance of a site
Protection-Restoration confidence	P-R	The Mycin technique is used (see explanation within text).	The Mycin technique is useful for ranking confidence values between two directly opposing concepts (Giarratano and Riley 2005).

the natural restoration potential (i.e., revegetation potential and hydrologic potential of soils to support vegetation) of the site and the degree of effort required to remove the stressors, and is calculated by averaging these values. The degree of effort required to remove stressors is determined by calculating an independent probability based upon the separate efforts (the efforts may or may not be independent, but in order to have the efforts additive but not exceed 1, the independent probability calculation was used).

The protection to restoration (P-R) continuum is on a continuous scale from -1 to 1: a value of -1 means the site should be protected, 1 means the site should be restored, and 0 means equal effort should be placed towards protection and restoration. Input values, which come from both the site stressors and the site values, are converted to values between -1 and 1, as is described in Appendix K for site values. These converted values are then used to calculate the P-R confidence, which is determined by the Mycin method, a technique of calculating degrees of confidence that was developed for use in early expert systems (Giarratano and Riley 2005). This method was chosen because it is commonly used in expert systems to determine the certainty with which one decision should be made over another. Here is how the P-R value is determined:

- If the current value is 1 and a -1 is assigned, the result is 0.
- If the current value is ≥ 0 and the value to assign is ≥ 0, then the new value is: (value to assign) + (current value × (1 – value to assign))
- If the current value is < 0 and the value to assign is < 0, then the new value is: (value to assign) + (current value × (1 + value to assign))
- Otherwise, the new value is: ((value to assign) + (current confidence)) / (1-min(abs(value to assign), abs(current confidence))

Here, min = minimum value, and abs = absolute value.

Weights are employed in the model at several locations. First, weights are placed upon erosion and deposition indicators when the site is in the headwater or deposition zone of a river, as these are highly influential processes within each zone. In these cases, the extra weight on an indicator will come into play if it has a high degree of departure from the expected natural condition, and it will put more importance on the stressors causing the departure of the indicator. Second, during the process of selecting stressors that are causing departure of the indicators, if an individual stressor is selected more than once, that stressor will have weight placed upon it.

Model testing

According to Nicolson et al. (2002), being able to run model simulations for sensitivity analyses within a minute or two is typically what allows the advancement of a model. Corvid has the capability of reading and writing to text files, which can allow you to rapidly run a simulation, to change a single variable in the text file easily, then quickly run a new simulation. Running model simulations by entering values separately, however, can easily take 10 or more minutes for each run. I was not able to run thorough sensitivity analyses during initial model development, as the read/write capability had not been fully worked out and incorporated into the model, but the issue has since been fixed and tests of the model output are currently being conducted. This report does not include results of running model simulations in the interest of getting the report out in a timely manner. The results of the model testing will be included in a manuscript that will be submitted for publication in a peer-reviewed journal.

Conclusions

This project will fulfill a vital role for the NPS, and hopefully beyond the NPS, especially as it is developed for use in additional habitats and ecoregions. The need for effective rapid assessment techniques for use in restoration planning, the availability of restoration experts and published information on restoration, and the motivation of natural resource agencies to put time, money and effort into restoration projects will help ensure the success of the RRAT.

Expert systems and decision support systems are very well suited for natural resource applications such as this. They have the analytical power to be able to make sense of complex logistical problems, and restoration projects often have many layers of complexity. One of the primary goals of the RRAT is to help resource managers think about the problem and make decisions based upon logic, science, and the best knowledge available.

The structure employed in the RRAT expert system, and the Corvid program, suit the problem very well. The ability to have the model be modular at any level desired not only follows good modeling heuristics (Nicolson, et al. 2002), but it also makes the model easy to modify and update, essential qualities for its future development. In addition, Corvid is very flexible in its methods of distribution to the end user, from web-based application (this requires a different licensing that we currently do not have, but this is a potential option) to an applet that the user can run from a CD or from their hard drive. It also is very flexible in the appearance of the application and in the links it can have to web sites and other external information sources.

Recommendations and Future Work

I highly recommend that the RRAT be developed further, not only by making improvements to the existing structure and the riparian/river module, but also by adding modules for other habitats and ecoregions. The current module must concurrently be tested frequently and critically, as errors are easily introduced to systems like this. The primary testing that I recommend is to test the module output against what an expert or several experts would recommend, and to modify the model if it is necessary to better match expert opinions. Expert systems are known to take quite a bit of time to develop: some sources claim that it can take several years just to develop a useful prototype (Greenwell 1988, Scott, et al. 1991, Jackson

1999) with adequate sensitivity analyses and field testing, and this project is not an exception. It could conceivably take equally long to add additional modules to the RRAT, but this will depend upon the resources that are available for the project.

Along with developing the RRAT, the indicators should also be changed or modified as new research highlights indicators that are sensitive to stress and have clear links to ecosystem processes (Whitford et al. 1998, Niemi and McDonald 2004). Many of the indicators in the RRAT are based on this kind of analysis, especially the ones carried over from Pellant et al. (2005), which include (numbering carried over from Pellant et al.):

1. Rills
2. Water-flow patterns
3. Pedestals and/or terracettes
4. Bare ground%
5. Gullies
6. Wind-scoured, blowouts, and/or deposition areas
7. Litter movement
8. Soil surface resistance to erosion
9. Soil surface loss or degradation
10. Plant community composition
12. Functional/structional groups
13. Plant mortality/decadence
14. Litter amount
16. Invasive plants
17. Reproductive capability of perennial plants

Several of these, including ones related to soil surface stability and plant cover, have been through rigorous experimental testing, like that done by Whitford et al. (1998). Some indicators in the RRAT that have not been through any testing include: channel morphology, soil contamination, plant functional/structural groups, native plant seedbank and germination, seedbank and external source of invasive non-native plants, native and invasive non-native herbivory, ecosystem engineering, and animal waste. This does not necessarily mean that they are not valid, but it would lend credence to the model if there were more science backing the indicator selection.

The automation team will have the opportunity to improve the RRAT greatly. The modifications that have been discussed include providing connectivity between the RRAT output and geospatial data, which would make the RRAT more powerful as a decision support tool. It will also be easy to incorporate results from other assessment methods, such as the Rapid Bioassessment Protocol used by the Environmental Protection Agency (Barbour et al. 1999), and other decision support tools if they are seen to be applicable to prioritization of restoration areas. The appearance and the output of the RRAT will also be greatly improved by providing an easy-to-understand format, which could include graphical representations of the model output (Figure 1), such as that employed in the Alien Plant Ranking System (Hiebert 1997, Benjamin and Hiebert 2004, Morse et al. 2004).

An additional product that would make the documentation and transfer of knowledge for the RRAT more secure would be a detailed RRAT Developers Manual. This manual should include instructions about how to properly modify the expert system, printouts of the actual code of the variables, logic blocks, and command blocks from Corvid. It should also provide a format for thoroughly documenting the justification for all the logic in the system. Without some built-

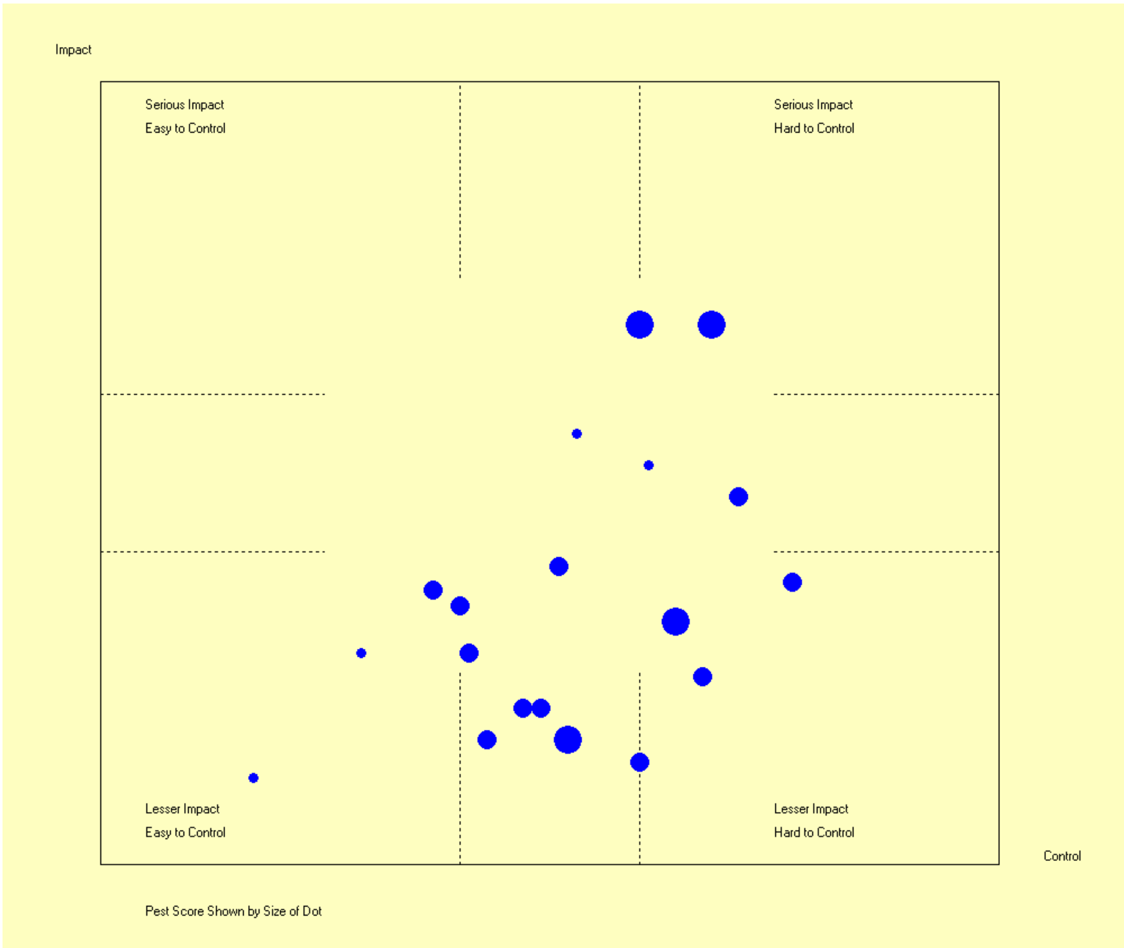

Figure 1. A screen shot of example output from the Alien Plant Ranking System. The x-axis is a rank of ease of control of the alien plant species at a site, the y-axis is the degree of impact from the alien plants at the site, and the size of the dots relates to the pest score. Each dot represents a different site. This style of visual representation could easily be applied to the RRAT.

in structure for maintaining continuity on the project as different people come and go, the institutional knowledge of the project will undoubtedly be lost.

Among the many aspects of restoration projects that are seen as critical for improving the science and practice of restoration, four that are repeatedly stressed are the importance of establishing realistic goals (Diamond 1987, Cairns 2000, Ehrenfeld 2000, Hobbs 2003, Ryder and Miller 2005), setting up experiments within restorations (Block et al. 2001), monitoring restoration projects (Kondolf 1995, Block, et al. 2001, Holl and Cairns 2002, Roni et al. 2005), and clearly identifying ways of measuring the success of restoration projects (Hobbs 2003, Palmer et al. 2005, Ryder and Miller 2005). A restoration project that is seen as successful is of minimal help outside of the restoration area unless the process is documented and the progress evaluated with respect to the goals. Funding for experiments and/or monitoring of restoration efforts is rarely incorporated into budgets, but this needs to change if we are to have any real progress in the field, and monitoring is critical to evaluating the progress or success of any restoration project.

One final recommendation is for the standardized documentation of restoration projects (including project goals, actions taken, and outcomes) and widespread dissemination of this information. Formats for documenting these kinds of data are currently inconsistent, and these data are scattered among many agencies, databases, and methods of distribution (Jenkinson et al. 2006). A recent effort to compile such data for the US, The National River Restoration Science Synthesis (NRRSS) (Bernhardt et al. 2005), highlights both the difficulties and the benefits of this kind of standardization, but the benefits, in the long run, will surely outweigh the costs of these efforts. While this is not an endorsement of the NRRSS per se, which has its own weak points (Gillilan et al. 2005), it would be very worthwhile to invest in documenting the information in a standardized format such as the one presented by Jenkinson et al. (2006).

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Appendix A. Supplementary river, stream, and riparian restoration information.

Journals:

Aquatic Conservation: Marine and Freshwater Ecosystems
Ecological Applications
Ecological Engineering
Ecological Management and Restoration
Ecological Restoration
Environmental Management
Environmental Monitoring and Assessment
Forest Ecology and Management
Freshwater Biology
Geomorphology
Hydrobiologia
Journal of Applied Ecology
Journal of Range Management
Journal of the American Water Resources Association
Journal of the North American Benthological Society
Land and Water
Landscape Ecology
North American Journal of Fisheries Management
Regulated Rivers – Research and Management
Restoration Ecology
River Research and Applications
Water Resources Bulletin
Water Science and Technology
Wetlands

Books & Reports:

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Web sites (all sites were accessed in September 2006):

US Government:

- United States Department of Agriculture, Natural Resources Conservation Service: http://www.nrcs.usda.gov/

- USDA Riparian Ecosystem Management Model (REMM): http://www.tifton.uga.edu/remmwww/

- The Riparian Ecosystem Management Model (REMM) is a computer simulation model. REMM is used to simulate hydrology, nutrient dynamics and plant growth for land areas between the edge of fields and a water body. Output from REMM will allow designers to develop buffer systems to help control non-point source pollution.

- USDA Agricultural Research Service, Rangeland Monitoring and Assessment: http://usda-ars.nmsu.edu/monit_assess/monitoring.php

- USDA Forest Service National Riparian Service Team: http://www.fs.fed.us/rangelands/ecology/riparian_serviceteam.shtml

- USDI Bureau of Land Management Riparian Recovery Initiative: http://www.blm.gov/riparian/index.htm

- US Fish and Wildlife Service, Partners for Fish and Wildlife, River Restoration Program: http://www.r6.fws.gov/pfw/r6pfw2h.htm

- US EPA, Bear Creek, Iowa Restoration: http://www.epa.gov/OWOW/NPS/Ecology/chap6bea.html

- Jordan River Restoration Project (U.S. Fish & Wildlife Service, Utah Ecological Services Field Office): http://www.r6.fws.gov/jordan/

State organizations:

- Minnesota Department of Natural Resources, Stream Habitat Protection and Restoration Program: http://www.dnr.state.mn.us/ecological_services/streamhab/index.html

- MNDNR Guidelines for managing and restoring natural plant communities along trails and waterways: http://www.dnr.state.mn.us/trails_plantcommunities/index.html

- Watershed Restoration Action Strategies (Maryland Department of Natural Resources): http://www.dnr.state.md.us/watersheds/wras/

- Kissimmee River Restoration Project (South Florida Water Management District): http://www.sfwmd.gov/site/index.php?

- Center for Watershed Protection (Pennsylvania): http://www.cwp.org/index.html

Nonprofit organizations:

- American Rivers: http://www.americanrivers.org/site/PageServer

- Great River Greening: http://www.greatrivergreening.org/

- Friends of the Mississippi River: http://www.fmr.org/index.html

- San Lorenzo River Restoration Institute: http://members.cruzio.com/~slriver/

- Salmon River Restoration Council: http://www.srrc.org/

- River Restoration Northwest: http://rrnw.org/

Private companies:

- Ellen River Partners LLC: http://ellenriverpartners.com/

- Wildland Hydrology Consultants: http://www.wildlandhydrology.com/index.htm

- Environmentally-Sensitive Streambank Stabilization (Salix Applied Earthcare): http://www.e-senss.com/

International:

- Department for Environment and Heritage (DEH) (Australia), Monitoring River Health Initiative: http://www.asdd.sa.gov.au/asdd/ANZSA1024000003.html

- River Landscapes: Restoring rivers and riparian lands all over Australia (Land & Water Australia): http://www.rivers.gov.au/

- River Styles (Land & Water Australia): http://www.riverstyles.com/index.php

- River Health (Australian Government, Department of the Environment and Heritage): http://www.deh.gov.au/water/rivers/index.html

- Cooperative Research Centre for Catchment Hydrology (Australia): http://www.catchment.crc.org.au/

- Romanian Centre for River Restoration: http://www.rcrr.org/

- European Centre for River Restoration: http://www.ecrr.org/

- Land & Water Australia: http://www.lwa.gov.au/

- Ontario's Stream Rehabilitation Manual: http://www.ontariostreams.on.ca/OSRM/toc.htm

- Canadian Angling (Upper Saugeen Habitat Restoration Association): http://www.canadianangling.com/news.php

Academic

- RestoringRivers.org (home of the National River Restoration Science Synthesis): http://www.restoringrivers.org/

- Restoration and Reclamation Review (University of Minnesota Department of Horticultural Science): http://horticulture.coafes.umn.edu/vd/h5015/rrr.htm

- National Center for Earth-surface Dynamics (NCED), StreamRestoration.net: http://www.nced.umn.edu/Stream_Restoration.html

- Iowa Vanes (The University of Iowa): http://www.iihr.uiowa.edu/projects/IowaVanes/index.html

- Streams: Stream restoration, ecology & aquatic management solutions (Ohio State University): http://streams.osu.edu/index.php

- Anacostia Watershed Network: http://www.anacostia.net/

- Wild Fish Habitat Initiative: http://wildfish.montana.edu/default.asp

- Klamath Resource Information System (KRIS): http://www.krisweb.com/

Appendix B. Restoration experts interviewed.

Name	Title & Affiliation	Contact information
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Appendix C. Questions for restoration experts.

Broad principles or ideas

As far as you know, are there major distinct philosophies or methodologies concerning restoration or riparian restoration? Or is it a bit more haphazard than this?

Are there any specific areas in river/riparian restoration that are particularly contentious, or where experts are likely to widely disagree?

How do you know when riparian restoration will require river or watershed restoration?

What are the major differences in restoration potential and prescription of rivers that are unregulated versus regulated?

What are the main things you consider at a site when first visiting it?

What are your thoughts on river classification and its use in restoration projects?

Prioritization

If there were limited funds for restoration at multiple sites, what primary factors would you use to decide which site(s) to put resources into first?

How would you "rate" these factors in different settings? In other words, are there weights you might place on some indicators in one setting that you would not in another?

How do you determine the restoration potential of a site?

How do you determine the benefits of doing a site restoration to the surrounding environment?

What things would lead you to determine that restoration is not feasible?

RRAT Questions/Review

What are your thoughts on the RRAT indicators and usefulness of using them for prioritization and restoration recommendations?

What information in the indicators would you use, and under what circumstances, for restoration recommendations?

Are there groups of indicators that would be more useful for this task? Which ones and why?

Can the RRAT indicators be used to determine:

1. Restoration potential: The incremental improvement at a site for a certain amount of effort and funds, i.e., how much are you going to get for what you put in?
2. What the benefit of the site restoration will be to the surrounding environment?

If so, how? Are there certain groups of indicators that would be used to determine each?

If not, how do you determine these two things? What factors do you look at?

Are there weights you might place on some indicators in one setting that you would not in another? Weights on groups of indicators?

How would you summarize indicator data for a site? Simplest option: sum all of the indicators. Does this make sense?

Do you think an approach similar to the APRS would be useful for site prioritization? If so, would it make sense to have axes based upon the groupings of indicators in the RRAT? If not, what kind of groupings would make sense? For example: degree of problem", "feasibility of fixing", "benefit of restoration to surrounding environment", "cost of fixing", and "overall site value".

If neither the simple addition nor the APRS technique make sense, do you envision another summarization of indicator data that would make sense for site prioritization?

Without thinking of the location, specific plant community, etc., what can be said about using the RRAT indicators for site prioritization? Is it useless out of context?

How would you envision information that's contained on the Site Value Module to influence outcome of the prioritization and restoration recommendations?

<u>Questions recommended by Scott et al. (1991):</u>

Do restoration solutions fall easily into basic categories? How would you categorize them?

Can restoration be broken down to a number of separate stages? Describe each stage as if it was a separate task. What is the interaction between the phases? Which phases are the more difficult and why?

What sort of complications arise during the task?

Do you sometimes have to backtrack and redo part of the process because of an error or unseen problem?

To what degree is creativity a component of the problem solving activity?

Do you call upon the advice or help of any other person during the task?

Appendix D. RRAT Field Data Sheet (Site Descriptors)

RRAT Field Data Sheet

Date ________ **Park** ________ **Site** ________
Recorders ________________
GPS:
UTM ________________
EPE ________ **DOP** ________ **Elevation** ________

Site size
____0.1-0.5 acres ____1.0-5.0 acres ____10-25 acres
____0.5-1.0 acres ____5.0-10.0 acres ____>25.0 acres

Disturbance size
____0.1-0.5 acres ____1.0-5.0 acres ____10-25 acres
____0.5-1.0 acres ____5.0-10.0 acres ____>25.0 acres

Disturbance notes: ________________

Site accessibility

Completely accessible by road (0) ________
Partially accessible by road with <0.5 mile hike (0) ________
0.6-1.0 mile hike (1) ________
1.1-3.0 mile hike (2) ________
3.1-5.0 mile hike (3) ________
>5 miles or in designated wilderness (4) ________
Other access issues: ________________

General Topography

1a. Approx. slope of river channel:		2a. Approx. slope of upland area:	
0-5% (0)	______	0-5% (0)	______
6-10% (1)	______	6-10% (1)	______
11-15% (2)	______	11-15% (2)	______
16-20% (3)	______	16-20% (3)	______
>20% (4)	______	>20% (4)	______

Riverbed slope direction:		Upland slope direction:	
Flat	______	Flat	______
North	______	North	______
Northeast	______	Northeast	______
East	______	East	______
Southeast	______	Southeast	______
South	______	South	______
Southwest	______	Southwest	______
West	______	West	______
Northwest	______	Northwest	______

Soils

Visual characterization of soil type (sandy, gravelly, loamy etc.): ________________

Hydrology

Zone of stream/river: Headwater ______ Transfer ______ Deposition ______
River / Stream Classification System: ________________
River / Stream Type: ________________

Appendix E. RRAT Indicators

RRAT Indicators

Rating Key:

Departure from expected natural condition or management goal:	Rating
None	0
Low	1
Moderate	2
High	3
Extreme	4

Category	Indicator	Current Rating	Desired Future Rating	Stressor	Notes
Hydrology/ Landform	1. Rills				
	2. Gullies				
	3. Bare ground				
	4. Pedestals/teracettes				
	5. Wind scour blowouts or deposition areas				
	6. Litter, debris, thatch movement/presence				
	7. Surface water flow				
	8. Channel morphology				
	9. Impervious surfaces and compaction				
Soil / Water Quality	1. Soil surface erodibility/stability				
	2. Soil loss or degradation				
	3. Plant rooting depth				
	4. Soil chemistry/nutrient alteration				
	5. Soil contamination				
	6. Sediment supply/ transport				
	7. Vegetation morphology				

Native Plants	1. Dominant plant composition and cover 2. Uncommon plant composition and cover 3. Functional / Structural groups 4. Soil crusts 5. Other non-vascular plant cover 6. Age class of major vegetation type/active recruitment 7. Native plant seedbank 8. Native plant germination 9. External sources of native plant propagules 10. Natural revegetation potential	
Invasive Non-native Plants	1. Presence of invasive nonnative plants 2. Type of impact of invasive nonnative plants 3. Availability of areas for invasive colonization 4. Seedbank of invasive nonnatives 5. External source of invasive nonnatives 6. Difficulty of control	
Native Fauna	1. Critical/keystone native fauna 2. Herbivory 3. Trampling and animal trails 4. Bioturbation 5. Ecosystem engineering 6. Animal waste 7. Microbial pathogens	

Invasive Non-native Fauna	1. Presence of invasive non-native fauna 2. Herbivory 3. Trampling and animal trails 4. Bioturbation 5. Ecosystem engineering 6. Animal waste 7. Microbial pathogens 8. Difficulty of control				

1511 # Appendix F. Indicator ranking explanations.

Hydrology/Landform					
Indicator	**Degree of departure from expected natural condition or from management goal**				
	Severe	**High**	**Moderate**	**Low**	**None**
1. Rills	Rill formation is severe and well defined throughout the site	Rill formation is moderately active and defined throughout most of site	Active rill formation is slight or at infrequent intervals, mostly in exposed areas	No recent rill formation; old rills have blunted or muted features	Current or past formation of rills are as expected for the site
2. Gullies	Gullies common with indications of active erosion/ downcutting; vegetation infrequent; headcuts numerous/ active	Gullies moderate to common w/ indications of active erosion; vegetation intermittent; headcuts active, no downcutting	Gullies moderate in number w/ indications of active erosion; vegetation intermittent; occasional headcuts may be present	Gullies uncommon w/ vegetation stabilizing ground/slopes; no signs of active headcuts, nickpoints or bed erosion	Drainages are represented as natural stable channels; no signs of erosion w/ vegetation common/ frequent
3. Bare ground	Much more extensive than expected	Moderate to much more than expected; large and connected patches of bare ground	Moderately to slightly more than expected; bare areas large and sporadically connected	Bare areas slightly different than expected	Bare ground is what is expected for area, matches that of similar communities
4. Pedestals / teracetettes	Abundant active pedestalling and numerous teracettes; exposed plant roots are common	Moderate active pedesatlling; terracettes common. Some rocks and plants are pedestalled with occasional exposed roots	Slight active pedestalling noted; most are within flow paths, interspaces or on exposed slopes; occasional terracettes present	Active pedestalling or terracette formation is rare; some evidence of past pedestal formation, especially in water flows and/or exposed slopes	Current or past evident of pedestalled plants or rocks as expected under natural conditions for the site. Teracettes absent or rare.
5. Wind scour blowouts or deposition areas	Extensive and well-connected areas of scour or deposition	Areas of scour or deposition are common and fairly well connected	Areas of scour or deposition are occasionally present	Infrequent or few signs of scour or deposition	Matches what is expected for site
6. Litter, debris, thatch presence and movement	Extreme departure from expected amounts of litter; only concentrated around obstructions; most size classes of litter have been displaced	High to extreme departure from expected amounts of litter; loosely concentrated around obstructions; moderate to small size classes displaced	Moderate departure from expected amounts of litter; movement of smaller size classes in scattered concentrations around obstructions	Slightly to moderately different from expected amounts of litter in the site w/ only small size classes of litter being displaced	Matches what is expected for the site under undisturbed conditions; fairly uniform distribution of litter

7. Surface water flow, including base flow, seasonal patterns, flooding regime, and water table	Extreme disruption to surface water flow(s); disturbance intercepts a stream or wash; significantly diverts, concentrates, or impedes surface water flow over all of site Natural flooding cycles are drastically altered or absent. Restoration of natural flooding is not likely due to technical or political limitation.	Severe disruption to surface water flow(s); disturbance intercepts a stream or wash, or severely diverts. Natural flooding regimes are significantly altered; flooding cycles may be partially restored by either natural or artificial means.	Moderate disruption to surface water flow; disturbance intercepts a small portion of stream; water flow is diverted, concentrated, or impeded on only a portion of the site. Natural flooding regimes have been moderately altered, but are likely to be restorable	Slight to moderate disruption of surface water flow. Natural flooding regimes have been slightly altered as a result of recent climatic condition and/or temporary circumstances	Surface water flow and seasonal patterns match what is expected for the site or NOT APPLICABLE (for example, in a non-aquatic terrestrial setting)
8. Channel morphology	Channel has severely departed from natural contours; is deeply incised, straightened, banks are armored, or channel severely altered by sediment deposition or absence; Flow paths highly altered from expected; unstable with active erosion;	Channel is highly departed from natural contours; eg; has been straightened, but banks not armored, Channel contact with floodplain and migration are limited by incision or levees; channel is chocked with sediment deposition or modified from absence; flow paths much different than expected; deposition and cut areas common; occasionally connected	Channel moderately departed from natural contours; contact with floodplain and migration are limited by levees or incision Moderate erosion with some instability and deposition	Channel somewhat departed from natural contours; some evidence of minor erosion; flow patterns are stable and short	Channel contours match what is expected for the site; minimal or no evidence of past or present deposition or erosion
9. Impervious surfaces and compaction	Extensive soil compaction and/or hydrophobic soils, impervious structures	Presence of compacted soils, hydrophobic soils, or impervious structures high	Moderate soil compaction or presence of hydrophobic soils	Low presence/ level of compacted soils, hydrophobic soils	Site fits within range of natural variability

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Soil / Water Quality					
Indicator	**Degree of departure from expected natural condition or from management goal**				
	Severe	**High**	**Moderate**	**Low**	**None**
1. Soil surface erodibility/ stability	Soil erodibility is extremely high throughout site; biological stabilizing agents including organic matter and biological crusts virtually absent	Soil erodibility is significantly increased in most plant canopy interspaces and moderately increased beneath plant canopies; stabilizing agents present only in isolated patches	Soil erodibility is significantly increased in at least half of the canopy interspaces, or moderately increased throughout the site	Some increase in soil erodibility in interspaces or slight increase throughout the site; stabilizing agents reduced below what is expected	Soil surface erodibility matches what is expected for the site; soil surface is stabilized by organic matter, decomposition products or a biological crust
2. Soil loss or degradation	Topsoil/surface horizon absent; soil structure at surface is similar to or more degraded than sub-surface horizons; and/or soil horizons completely mixed.	Topsoil/soil surface loss is severe throughout site; minimal differences in organic content & structure of the surface & subsurface layers.	Moderate soil loss or degradation in interspaces w/ some degradation beneath plant canopies; soil structure is degraded & organic matter significantly reduced.	Some soil loss has occurred and/or soil structure shows signs of degradation, especially in plant interspaces	Topsoil/soil surface is intact; soil structure and organic matter matches what is expected for the site.
3. Plant rooting depth	None; plants absent from site due to loss of soil	Sever limitations in plant rooting throughout site	Moderately limited throughout some to most of site	Slightly to moderately limited on some portions of the site	Rooting depth is good within top 12 inches and/or matches expected site conditions.
4. Soil Chemistry/ Nutrient Alteration	Drastic alteration to plant composition and/or successional processes has occurred as a result of unnatural levels of nutrients and salt deposition	Significant alteration to plant composition as a result of known unnatural levels of nutrient or salt deposition	Moderate alteration to plant composition as a result of known or suspected unnatural levels of nutrients or salt deposition	Slight alteration to expected plant composition as a result of known or suspected unnatural levels of nutrients or salt deposition	Plant composition matches what is expected for the site; no impacts resulting from unnatural levels of nutrients or salt deposition are suspected

5. <u>Soil Contamination</u>	Site has known land use history (mining, landfills, etc.) with use of hazardous materials; and/or contains extensive areas of soil discoloration; and/or site has been designated as hazardous	Site has known land use history that involved use of hazardous materials; and/or site contains large areas of soil discoloration	Site has known land use history that has moderate potential for site contamination as noted by multiple areas of soil discoloration acid runoff and/or presence of suspect containers	Site has know land use history that may have involved minor presence of hazardous materials; and/or minor soil discoloration in a very limited area	Site does not show any indication of soil contaminants
6. Sediment supply/ transport	System is showing extreme levels of unnatural erosion or sedimentation deposition that is not the result of a natural process (for example, erosion associated with construction, or deposition resulting from high sediment loads from construction)	System is showing high levels of unnatural erosion or sediment deposition that is not the result of natural processes	System is showing moderate levels of unnatural erosion or sediment deposition that is not the result of a natural process	System is showing minor signs of unnatural erosion or sediment deposition that is not the result of a natural process	System is in balance with the water and sediment being transported
7. Vegetation Morphology	Vegetation morphology severely modified from expected condition; dwarfed, chloritic, yellowing, or abnormal growths. (This may occur as a result of disease, parasites, soil chemistry, etc. Plant community composition or succession not necessarily altered.)	Vegetation morphology highly modified from expected	Vegetation morphology moderately modified from expected	Vegetation morphology slightly modified	Vegetation morphology matches what is expected for site

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Native Plants					
Indicator	**Degree of departure from expected natural condition or from management goal**				
	Severe	**High**	**Moderate**	**Low**	**None**
1. Dominant Plant Composition and Cover:	Plant community and cover are extremely different from desired or expected natural condition. Few if any native plants present	Plant community and cover are very different from desired or expected natural condition	Plant community and cover depart moderately from desired or expected natural condition	Plant community and cover depart slightly from desired or expected natural condition	Expected plant community and cover are present
2. Uncommon/Rare Plant Presence	There are no uncommon or rare native plants on the site	Uncommon or rare native plant presence departs highly from desired or expected community	Uncommon or rare native plant presence departs moderately from desired or expected community	Uncommon or rare native plant presence is close to what is desired or expected	Uncommon or rare native plant presence reflects that of an undisturbed reference condition
3. Plant Functional / Structural (F/S) Groups (i.e., legumes, forbs, warm season grasses, trees, etc.)	Number of F/S groups greatly reduced and/or relative dominance has been dramatically altered; and/or number of species with in F/S groups have been dramatically reduced	Significantly reduced; members of F/S groups NOT expected for site are present	Moderately reduced numbers of structural or functional group members present, relative dominance moderately altered	Slightly reduced numbers of F/S groups' numbers, relative dominance slightly altered	F/S groups closely match that expected for site
4. Soil Crusts	Found only in protected areas	Largely absent, occurring mostly in protected areas	In protected areas and a minor component in interspaces	Evident throughout the site, but community is broken	Largely intact and matches or nearly matches natural reference condition
5. Other Non-vascular Plant Cover (not ones considered as soil crust)	Mosses, lichens and others are severely impacted, stressed or absent from expected condition for site	Mosses, lichens and others are highly impacted and diverge markedly from desired or natural conditions	Mosses, lichens and others are moderately impacted by disturbances at the site	Mosses, lichens and others are slightly impacted from disturbance at the site	Mosses, lichens and others form a healthy community for the region
6. Age Class of Major Vegetation Type / Active Recruitment	Dramatic changes have occurred relative to age class distribution of most of the dominant/desired plant species. Active recruitment of	Significant changes have occurred relative to age class distribution of several of the dominant/ desired plant species. Active recruitment of	Moderate changes have occurred relative to age class distribution of most of the dominant/desired plant species. Active recruitment of	Dominant/desired species show slightly unequal age class distribution relative to reference conditions. Condition is expected to be naturally	Matches natural conditions

	younger age classes not evident.	younger age classes significantly reduced or absent;	younger age classes still evident.	recoverable and/or temporary	
7. Native Plant Seedbank	Seedbank of desired native species has been dramatically reduced or is absent. Active reseeding will be necessary to restore the site.	Seedbank of desired native species has been significantly reduced. Active reseeding is likely necessary to restore the site	Seedbank of desired native plants species has been moderately reduced and/or desired species have limited persistence or short-term viability within the soil	Seedbank of desired native species is only slightly reduced. Desired native species have known persistence or long-term viability within the soil	Seedbank of desired native plant species matches what is expected for the site
8. Microsites for Native Plant Germination	Drastically reduced; chances for native regeneration are slim	Significantly reduced; many of the native vegetation types will have trouble regenerating	Moderately reduced; two or more of the dominant species will have trouble germinating	Slightly impacted; a few of the major vegetation types may have a little trouble germinating	Matches natural conditions
9. External Source of Native Plants	Site is not within dispersal distance of native propagule sources	Site has only a few possible sources of surrounding native propagules	Site has a moderate number of surrounding native propagule sources	Site has a good number of native propagule sources surrounding it	Site is well surrounded with native propagule sources
10. Potential for Natural Revegetation	No potential for natural revegetation; active seeding/planting required and/or is limited to only a few dominant native species; less dominant components will remain absent	Low potential for natural revegetation active seeding/planting of most species required; some limitations to re-establishment of rarer species	Some potential for natural revegetation of a few species; moderate level of active seeding/planting very likely. Most species expected to re-establish	High potential for natural revegetation of most species; limited active seeding/planting of a few native species likely. All species are expected to re-establish	Very high potential for natural revegetation; no active seeding/replanting required. All species are expected to reestablish.

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Invasive Non-native Plants					
Indicator	**Degree of departure from expected natural condition or from management goal**				
	Severe	**High**	**Moderate**	**Low**	**None**
1. Presence of invasive nonnative plants	Infestations are extensive and dominate the vegetative cover.	Infestations are significant and co-dominate the vegetative cover.	Infestation is moderate yet a conspicuous component of the vegetative cover.	Infestations are relatively light.and constitute a minor portion of the vegetative cover.	No invasive non-native plants present on the site.
2. Type of impact of invasive nonnative plants	Consult list of invasive non-native plant impacts				
3. Availability of areas for invasive colonization	Disturbance has left extensive patches of mineral soil or other niches available for widespread invasive non-native plant colonization	Conditions at site are ripe for a significant invasive colonization event, with bare soil or other niches available	Conditions at site (bare ground, other spaces available for colonization) are such that a moderate invasion may be possible	There is a slight chance that invasive plants will find an opportunity to grow at the site (mineral soil or other niche slightly available)	Bare mineral soil or other available areas for colonization are occupied by desired plant community
4. Seedbank of invasive nonnatives	Seedbank of invasive non-native species is long-term (>10 yrs) Requires removal of topsoil to effectively reduce or control	Seedbank of invasive non-native species is long-term (>5 yrs) and requires multiple germination events to eliminate	Seedbank of invasive non-native species is moderate' and/or can be significantly reduced with a single artificial or natural germination event	Seedbank of invasive non-native species is low and/or has relatively short-term viability (1-3 yrs)	Seedbank of invasive non-native species is absent
5. External source of invasive nonnatives	Site is surrounded by severely invaded areas; invasion from these areas is almost certain	Site is surrounded by sites highly impacted with invasive non-native species; invasion from these sites highly likely	Site is moderately surrounded by infested sites; invasion from these sites moderately likely	Site is surrounded with a few invasive non-native species; invasion from surrounding sites relatively unlikely	Site is surrounded or impacted with almost no invasive non-native species
6. Difficulty of control	Invasive non-native species are extremely persistent; requires long-term multiple treatment over a series of years, requires use of restricted herbicides, and/or has never been known to be eradicated	Invasive non-native species are very persistent; requires long-term, multiple treatments over a series of years, but can be controlled with unrestricted herbicides or other tools	Invasive non-native species is moderately persistent; requires multiple, short-term treatments (1-2 years) to control and/or requires chemical use for effective control	Invasive species has low persistence; is relatively easy to control, but is likely to require more than one treatment	Invasive species is not persistent; is easy to control with a single treatment event

Native Fauna					
Indicator	Degree of departure from expected natural condition or from management goal				
	Severe	High	Moderate	Low	None
1. Critical/keystone native fauna	Critical/keystone native species or groups of organisms missing or severely stressed. Reintroduction of these organisms will be required for restoration.	Critical/keystone native fauna in low numbers or highly stressed. Will require significant management and/or reintroduction to stabilize populations.	Critical/keystone native fauna present but in moderate or declining numbers. Will require management to reestablish populations.	Critical/keystone native fauna mostly present and recruiting on site, but will require minor management for full recovery.	Native animal community is what is expected for the area.
2. Herbivory	Evidence of severe overbrowsing over entire area	Evidence of high herbivore usage that prevents vegetation from completing life cycle (browselines etc.)	Evidence of moderate herbivore usage that impacts vegetation	Evidence of low herbivore usage that slightly stresses the vegetation type	Area appears in healthy balance with herbivore community
3. Trampling and animal trails	Severely trampled and devoid of herbaceous and/or aquatic vegetation. Individual trails not discernable. Soils severely disturbed or compacted. Aquatic areas extremely turbid.	High level of trampling, with few vegetated areas undisturbed. Trails are heavily used and in a dense network over the entire site. Soils highly disturbed or compacted. Aquatic areas very turbid.	Moderate level of trampling, with patches of plants undisturbed. A well-used network of trails exists on site. Soils moderately disturbed or compacted. Aquatic areas show some signs of turbidity.	Low level of trampling, with most damage concentrated around trails or in a low level across site. Trails well-used but more sparse. Soils somewhat disturbed or compacted. Low aquatic turbidity from trampling.	Level of trampling is what is expected for the area. Animal trails in density and at use level that is expected.
4. Bioturbation (digging & burrowing by mammals, earthworms & invertebrates)	Soil extremely impacted by animal activity. Density of digging, burrows, and tunnels (mammals), and/or sign of soil organisms (earthworm castings, termite mounds, ant nests,	Soil highly impacted by animal activity. Density of digging, burrows, and tunnels (mammals), and/or sign of soil organisms (earthworm castings, termite mounds, ant nests, etc.) very	Soil moderately impacted by animal activity. Density of digging, burrows, and tunnels (mammals), and/or sign of soil organisms (earthworm castings, termite mounds, ant	Soil slightly impacted by animal activity. Density of digging, burrows, and tunnels (mammals), and/or sign of soil organisms (earthworm castings, termite mounds, ant nests, etc.) slightly	Level of bioturbation is what is expected for the site.

	etc.) extremely different than expected. Duff layer gone or greatly reduced (in forests).	different than expected. Duff layer reduced (in forests).	nests, etc.) somewhat different than expected.	different than expected.	
5. Ecosystem engineering (e.g., beaver dam building)	Animal activity has severely modified or disturbed site. Restoration would require removal of engineering organisms.	Animal activity has highly disturbed site. Restoration would require intensive control of engineering organisms.	Animal activity has moderately disturbed site. Some animal control / management will be necessary.	Animal activity has slightly modified site. Minor animal management may be necessary.	Animal activity is what is expected for the site.
6. Animal waste (feces, urine, etc.)	Animal waste highly impacting site. Very dense droppings. Very high level of soil / water eutrophication. Scent of feces or ammonia very noticeable.	High density of animal droppings. High degree of soil and water eutrophication. Noticeable scent.	Moderate density of droppings. Scent not very noticeable. Some soil and water eutrophication.	Low density of animal droppings. No noticeable scent. Little sign of soil or water eutrophication.	Animal waste as expected for the site.
7. Microbial pathogens	Viral or bacterial activity severely impacts ecosystem process, structure and/or composition	Viral or bacterial activity has a high impact on ecosystem structure and function	Viral or bacterial activity has a moderate impact on the ecosystem's structure and composition	Viral or bacterial activity has a slightly more than expected impact on the ecosystem	Viral or bacterial activity is within the cycle expected for the area

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Invasive Non-native Fauna					
Indicator	**Degree of departure from expected natural condition or from management goal**				
	Severe	**High**	**Moderate**	**Low**	**None**
1. Presence of invasive non-native fauna	Invasive non-native fauna dominant at site, with few native animals present	High density and/or diversity of invasive non-native animals present at site.	Moderate density and/or diversity of invasive non-native animals present at site.	Low density and/or diversity of invasive non-native animals present at site.	Invasive non-native fauna not present or very rare.
2. Herbivory	Evidence of severe overbrowsing over entire area	Evidence of high herbivore usage that prevents vegetation from completing life cycle (browselines etc.)	Evidence of moderate herbivore usage that impacts vegetation	Evidence of low herbivore usage that slightly stresses the vegetation type	Area appears in healthy balance with herbivore community
3. Trampling and animal trails	Severely trampled and devoid of herbaceous and aquatic vegetation. Individual trails not discernable. Soils severely disturbed or compacted. Aquatic areas extremely turbid.	High level of trampling, with few vegetated areas undisturbed. Trails are heavily used and in a dense network over the entire site. Soils highly disturbed or compacted. Aquatic areas very turbid.	Moderate level of trampling, with patches of plants undisturbed. A well-used network of trails exists on site. Soils moderately disturbed or compacted. Aquatic areas show some signs of turbidity.	Low level of trampling, with most damage concentrated around trails or in a low level across site. Trails well-used but more sparse. Soils somewhat disturbed or compacted. Low aquatic turbidity from trampling.	Level of trampling is what is expected for the area. Animal trails in density and at use level that is expected.
4. Bioturbation (digging & burrowing by mammals, earthworms & invertebrates)	Soil extremely impacted by animal activity. Density of digging, burrows, and tunnels (mammals), and/or sign of soil organisms (earthworm castings, termite mounds, ant nests, etc.) extremely different than expected. Duff layer gone or greatly reduced (in forests).	Soil highly impacted by animal activity. Density of digging, burrows, and tunnels (mammals), and/or sign of soil organisms (earthworm castings, termite mounds, ant nests, etc.) very different than expected. Duff layer reduced (in forests).	Soil moderately impacted by animal activity. Density of digging, burrows, and tunnels (mammals), and/or sign of soil organisms (earthworm castings, termite mounds, ant nests, etc.) somewhat different than expected.	Soil slightly impacted by animal activity. Density of digging, burrows, and tunnels (mammals), and/or sign of soil organisms (earthworm castings, termite mounds, ant nests, etc.) slightly different than expected.	Level of bioturbation is what is expected for the site.

5. Ecosystem engineering (e.g., gypsy moths modifying forest structure)	Animal activity has severely modified or disturbed site. Restoration would require removal of engineering organisms.	Animal activity has highly disturbed site. Restoration would require intensive control of engineering organisms.	Animal activity has moderately disturbed site. Some animal control / management will be necessary.	Animal activity has slightly modified site. Minor animal management may be necessary.	Animal activity is what is expected for the site.
6. Animal waste (feces, urine, etc.)	Animal waste highly impacting site. Very dense droppings. Very high level of soil / water eutrophication. Scent of feces or ammonia very noticeable.	High density of animal droppings. High degree of soil and water eutrophication. Noticeable scent.	Moderate density of droppings. Scent not very noticeable. Some soil and water eutrophication.	Low density of animal droppings. No noticeable scent. Little sign of soil or water eutrophication.	Animal waste as expected for the site.
7. Microbial pathogens	Viral or bacterial activity severely impacts ecosystem process, structure and/or composition.	Viral or bacterial activity has a high impact on ecosystem structure and function.	Viral or bacterial activity has a moderate impact on the ecosystem's structure and composition.	Viral or bacterial activity has a slightly more than expected impact on the ecosystem.	Viral or bacterial activity is within the cycle expected for the area.
8. Difficulty of control	Invasive non-native species are extremely persistent; requires long-term multiple removals or treatment over a series of years, and/or has never been known to be eradicated. May require use of restricted biocides.	Invasive non-native species are very persistent; requires long-term, multiple removals or treatments over a series of years, but can be controlled with established techniques or unrestricted biocides.	Invasive non-native species is moderately persistent; requires multiple, short-term treatments (1-2 years) to control and/or requires biocide use for effective control.	Invasive species has low persistence; is relatively easy to control, but is likely to require more than one treatment.	Invasive species is not persistent; is easy to control with a single treatment event.

Appendix G. Invasive non-native plant impact types.

List of invasive non-native plant impact types

Category	General Impact	Specific Impact
Community Structure	Plant community structure	Native plant biodiversity
Community Structure	Plant community structure	Native plant composition
Community Structure	Plant community structure	Native plant abundance
Community Structure	Plant community structure	Native plant size, growth, or biomass
Community Structure	Plant community structure	Available light for other plants
Community Structure	Plant community structure	Succession
Community Structure	Higher trophic levels	Native animal biodiversity
Community Structure	Higher trophic levels	Native animal composition
Community Structure	Higher trophic levels	Native animal abundance
Community Structure	Higher trophic levels	Native animal diet
Ecosystem processes	Nutrient cycling	Presence / density of N-fixing plants
Ecosystem processes	Nutrient cycling	Litter production
Ecosystem processes	Hydrology	Water table (phreatophytes)
Ecosystem processes	Hydrology	Soil moisture (shallow roots)
Ecosystem processes	Fire regimes	Fuel load
Ecosystem processes	Fire regimes	Fire intensity
Ecosystem processes	Fire regimes	Fire frequency

Appendix H. Site Values.

Site Value Module

Potential Future Condition assumes site protection and / or restoration

Rating Key:

Value	Rating
None	0
Minimal	1
Moderate	2
High	3
Extreme	4

	Conditions		
	Current	**Potential Future**	
Category	**Condition**	**Condition**	**Notes**
1. Threatened and Endangered Species			
2. Plant community / biodiversity			
3. Animal community / biodiversity			
4. Emblematic natural features			
5. Historical / Cultural / Archeological			
6. Recreation / Aesthetics			
7. Site role in landscape			
8. Habitat / Ecosystem rarity in landscape			

Appendix I. Site Stressors.

Restoration Rapid Assessment Tool Site History

Date:__________________Park ____________________ Site Name __________________

Recorder(s) Name and Title: __________________________________

Site subjected to the following human-related disturbances/stressors:
See stressor matrix for more detailed stressors
(check those that apply):

Anthropogenic Activities "Sources"	**Current degree of impact (high, medium, low)[1]**	**Past Activity**		**Projected future degree of impact (high, medium, low)[1]**	**Site Stressors (Please choose from stressor list)**	**If future use is projected for site, does desired future condition require removal of anthropogenic activity?**
		Degree of Impact[1]	**Time Since Use[2]**			
Agriculture						
Domestic Livestock Grazing						
Forestry/logging						
Industrialization						
Mining						
Recreation						
Urbanization in the landscape (roads/trails/structures)						
Utilities and Infrastructure (dam)						
Climate (flood/fire)						
Other (explain)						

1. High=3, Medium=2, Low=1 None=0
2. Less than 10 years=1, More than 10 years=2 More than 50 years=3

Appendix J. Source-Stressor Matrix.

Source-Stressor matrix

X indicates that the stressor occurs as a direct result of the human acitivity or natural cause

	SOURCES										
	Human Activities										
Stressor	Agriculture	Domestic Livestock Grazing	Forestry	Industrialization	Mining	Recreation	Urbanization	Utilities & Infrastructure	Natural causes	Climate	**Explanations**
Air pollution	X			X	X		X	X	X		Impacts plant and animal communities. Lichens are especially sensitive to air pollution.
Altered channels	X	X	X	X	X		X	X	X		Change in stream or river shape, meander, direction, etc.
Altered hydrology	X	X	X	X	X	X	X	X	X		Change in surface water or groundwater flow, availability, seasonal changes, etc.
Bridges	X		X	X	X	X	X	X			Bridges typically concentrate water flow and reduce opportunities for river meandering
Channelization	X	X		X	X		X	X	X		Straightening of streams or rivers, sometimes in association with river/streambank armoring. Drastically changes river hydrology and geomorphology.
Climate change	X	X	X	X	X		X	X	X	X	Change in the local climate, typically associated with changes due to human activities. Also known as global climate change or global warming.
Construction	X	X	X	X	X	X	X	X			Activities focused on land clearing and subsequent construction of buildings, structures, roads, etc.
Contaminants	X	X	X	X	X	X	X	X	X		Anything that pollutes the air, soil, or water.
Culverts	X	X	X	X	X	X	X	X			Drainage structures, especially used under roadways. Focus water flow, therefore changing water velocity and rates of flow.
Dams	X	X		X	X	X	X	X			Used for reservoirs, agriculture, hydroelectricity, etc. Can block natural movement of aquatic wildlife; change water temperature, seasonal flooding, erosion and deposition, etc.
Deposition	X	X	X	X	X	X	X	X	X	X	Buildup of silt or other material carried by water, typically due to reduction of water velocity. Can be problematic for some restoration efforts
Disease	X	X	X	X	X	X	X	X	X		Resulting from microbes or contaminants. Can harm or kill plants and animals.
Ditches	X		X	X	X		X	X			Drainage structures made to carry rainwater or runoff.
Drainage	X		X	X	X		X	X			Tiling, ditches, etc. used to drain wetlands or saturated soils (i.e., for agricultural fields)
Drought									X	X	Caused by storms, seasonal weather patterns, or climate change
Earthquakes									X		Can permanently change geomorphology and hydrology over large areas.
Erosion	X	X	X	X	X	X	X	X	X	X	Causes loss of soils, destabilizes riverbanks, increased sedimentation, etc.
Excessive cold									X	X	Caused by storms, seasonal weather patterns, or climate change. Can cause dieoffs of plants or animals
Excessive heat									X	X	Caused by storms, seasonal weather patterns, or climate change. Can cause dieoffs of plants or animals
Excessive precipitation									X	X	Caused by storms, seasonal weather patterns, or climate change. Can cause erosion, dieoffs of plants or animals
Exotic fauna	X	X	X				X		X	X	Can impact native flora and fauna, ecosystem processes

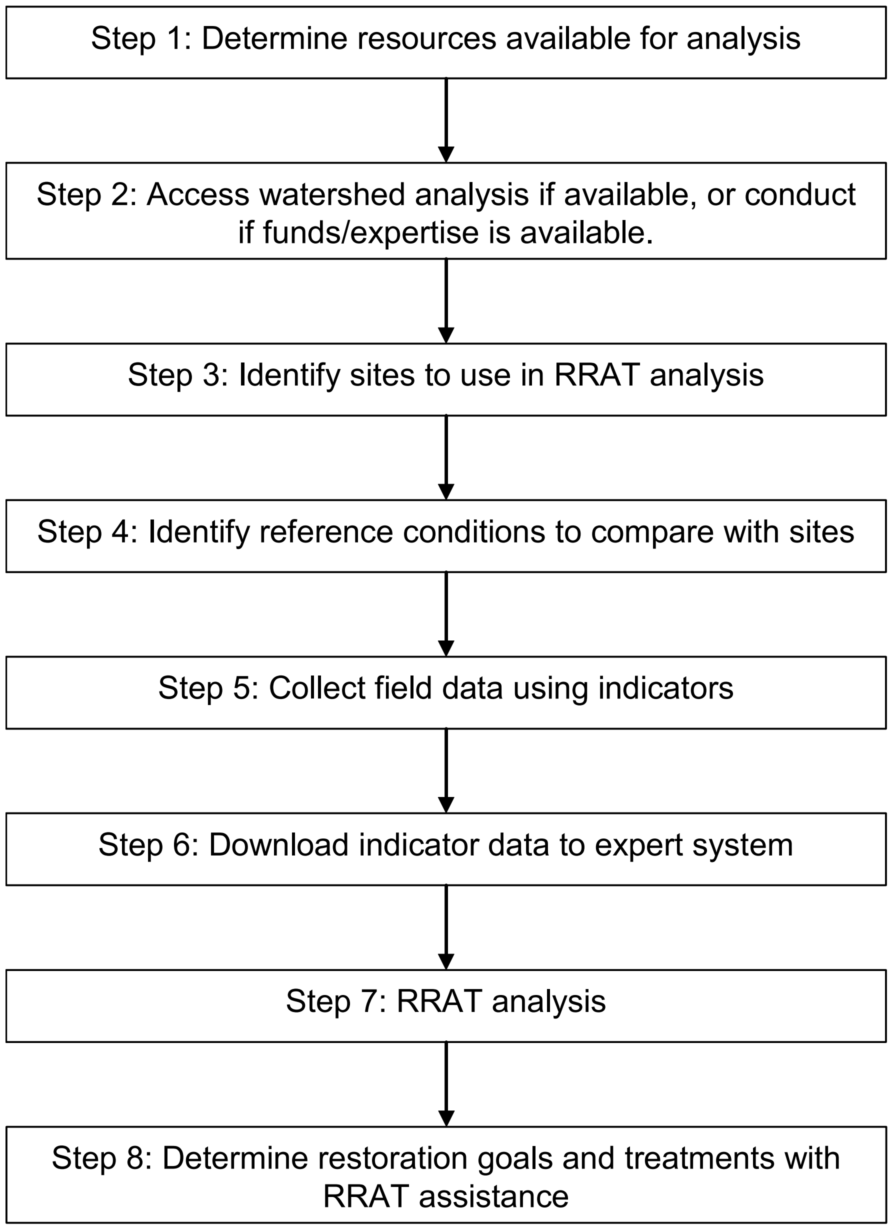
	SOURCES										
	Human Activities										
Stressor	Agriculture	Domestic Livestock Grazing	Forestry	Industrialization	Mining	Recreation	Urbanization	Utilities & Infrastructure	Natural causes	Climate	**Explanations**
Invasive non-native plants: external source	X	X	X			X	X		X	X	Provide propagules that can invade or re-invade adjacent areas
Invasive non-native plant presence	X	X	X			X	X		X	X	Can impact native flora and fauna, ecosystem processes
Invasive non-native plant seedbank	X	X	X			X	X		X	X	Provide future opportunities for germination and growth of plants for as long as seedbank is viable.
Fertilizers	X						X				Cause eutrophication of soils and water. Invasive non-native plants typically encouraged by fertilizers.
Fire	X		X	X	X	X	X	X	X	X	Impacts plant and animal communities
Fire management	X	X	X			X					Fire suppression, fuel management, subscribed burning, etc. Can drastically alter natural fire regimes.
Floods	X	X	X	X	X		X	X	X	X	Causes extreme erosion and deposition, change in channel morphology, etc. Impacts plant and animal communities
Fuel load	X	X	X						X	X	Dead plant material that does not degrade, providing fuel for future fires.
Hard surfacing	X			X	X	X	X	X			Artificial surfaces that do not absorb rainwater: roads, parking lots, rooftops, etc. Change duration and intensity of stormwater events, increase contaminant runoff
Herbivory	X	X	X						X	X	Consumption of plant material by herbivores (mammals, insects, etc.)
Hurricanes									X	X	High winds and flooding accompany hurricanes
Insects	X								X	X	Can cause intense plant damage (herbivory and when carriers of plant pathogens), impact animals (when carriers of animal pathogens)
Instream modifications	X	X	X	X	X	X	X	X	X		Structures such as artificial riffles, pools, deflectors, barriers, etc.
Irrigation	X										Water use for agriculture is one of the most significant
Land grading	X		X	X	X		X	X			Typically one of first steps in preparing land for human use.
Landslides			X		X		X	X	X	X	Deliver materials to river channels
Levees	X		X	X	X		X	X			Channel stabilization using riprap and levees interfere with riparian habitat development and maintenance
Lightning									X	X	Primary non-human ignition source for fires
Litter	X	X	X						X	X	Plant litter influences terrestrial and stream communities
Loss of vegetative cover	X	X	X	X	X	X	X	X	X	X	Vegetation cover protects soil from erosion
Microbes	X	X	X			X	X		X		Infection or disease from microbes can harm or kill plants and animals.
Native plants: lack of external source	X	X	X	X	X	X	X	X	X	X	Native plant propagules cannot enter from surrounding areas and aid restoration
Native plants: reduced presence or absence	X	X	X	X	X	X	X	X	X	X	Lack of native plants make restorations more difficult
Native plants: lack of seedbank	X	X	X	X	X	X	X	X	X	X	Native plant establishment will have to be through seeding or planting
Nitrogen	X	X	X	X	X		X	X	X		Primary element in fertilizers, also results from various forms of pollution.
Pesticides/Herbicides	X		X				X				Can be wind-blown, in soil, or in water

	SOURCES										
	Human Activities										
Stressor	Agriculture	Domestic Livestock Grazing	Forestry	Industrialization	Mining	Recreation	Urbanization	Utilities & Infrastructure	Natural causes	Climate	**Explanations**
Phosphorus	X			X	X		X				Results from various forms of pollution
Piped discharge/Controlled outlet	X	X	X	X	X		X	X			Return of water after human use. Can be source of pollution, change hydrology, etc.
Plowing/Tilling/Harvesting/etc.	X										Actions from row-crop agriculture. Results in habitat loss, fragmentation, increased erosion, increased nitrogen pollution, etc.
Reduction of floodplain	X			X	X		X	X			Reducing the opportunities for water to escape riverbanks during high flow events. Typically from levees, channelization, etc.
Removal of trees	X	X	X	X	X		X	X			Can greatly increase water runoff, erosion and sedimentation
River/stream regulation	X	X	X	X	X	X	X	X			Done using dams, water diversion structures, water abstraction, etc. Can impede movement of native fauna, alter stream hydrology, etc.
River/streambank armoring	X			X			X	X			Most common form is concrete channelization of streams in urban settings.
Roads and railroads	X	X	X	X	X	X	X	X			Can be a major source of fauna mortality. Can act as water impoundment structure, with only water outlets at culverts and bridges
Salinity	X	X		X	X		X	X	X		Soil and water salinity have a strong influence on occurrence of plants and animals.
Sediment	X	X	X	X	X	X	X	X	X		High load of silt and other fine particles in water. Can be problematic for aquatic species adapted to clear water.
Site preparation	X		X		X			X			Preparing a site for future human activities: grading, bulldozing, vegetation removal, etc.
Soil compaction/exposure	X	X	X	X	X	X	X	X	X		Reduces water infiltration rate, seed germination and establishment.
Soil contamination/pollution	X	X	X	X	X	X	X	X	X		May need to know site history for knowledge about contamination or pollution problems.
Soil disturbance	X	X	X	X	X	X	X	X	X		Can result in soil erosion, establishment of invasive plants, loss of habitat.
Storms									X	X	Can cause extensive vegetation damage from high winds (i.e., tree blowdown)
Stormwater inputs	X			X			X				Typically a major problem in urban settings with runoff from hardened surfaces.
Streambed disturbance	X	X	X	X	X	X	X	X	X	X	Can result in multiple water quality or hydrology problems, depending on degree and type of disturbance
Tornadoes									X		Can cause extensive vegetation damage from high winds (i.e., tree blowdown)
Trails						X	X				Hiking, horse, bike, ATV, snowmobile, etc. Cause soil compaction, disturb wildlife, and can be routes for invasive non-native plant introduction
Transportation of products	X		X	X	X		X	X			Roads, railroads, barges, etc. Creates air, noise, and/or water pollution. Can disturb or harm wildlife.

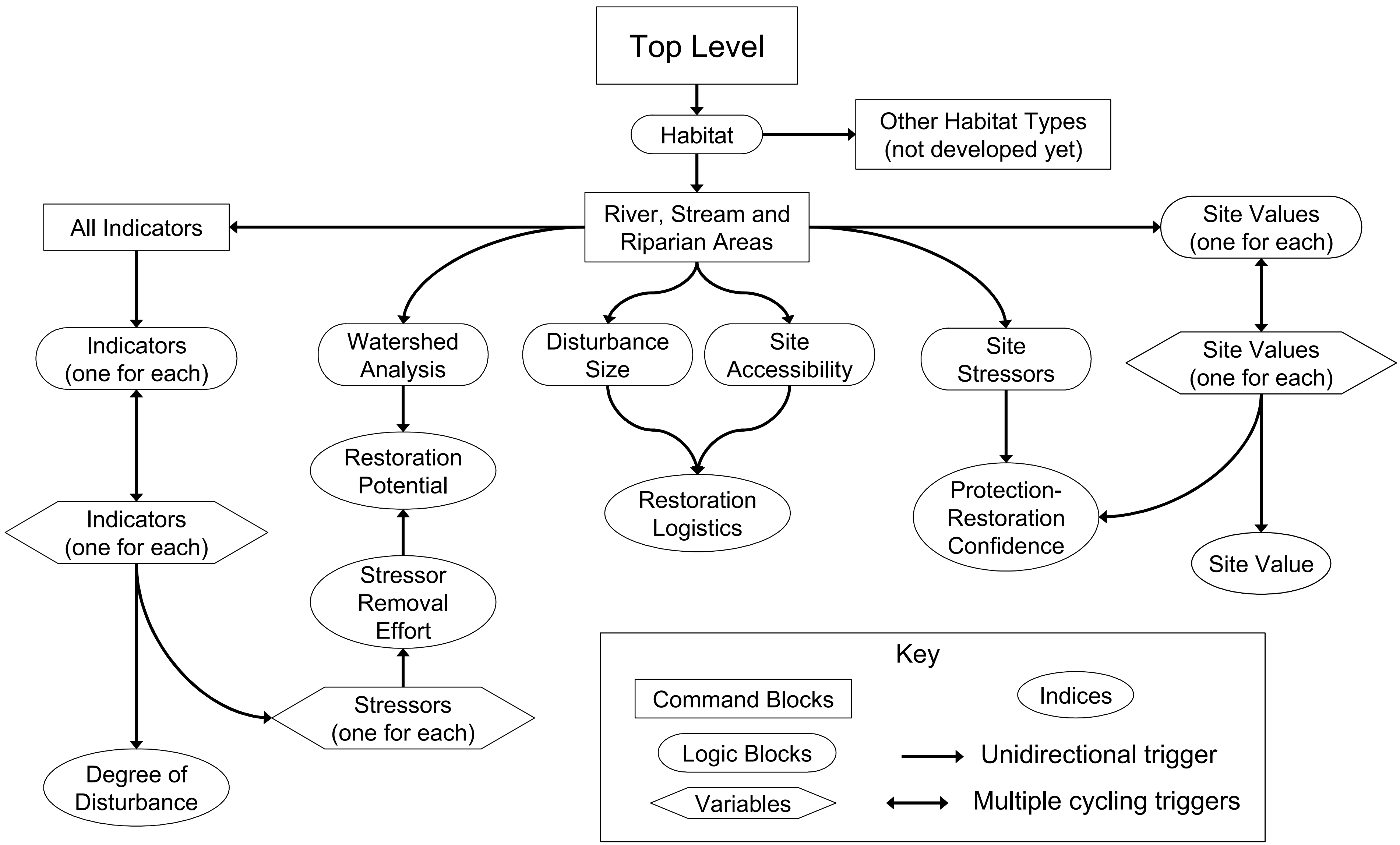
	SOURCES										
	Human Activities										
Stressor	Agriculture	Domestic Livestock Grazing	Forestry	Industrialization	Mining	Recreation	Urbanization	Utilities & Infrastructure	Natural causes	Climate	Explanations
Utility corridors/crossings	X		X	X	X	X	X	X			Powerlines, gaslines, etc. Can cause habitat fragmentation, introduction of invasive species, wildlife disturbance.
Clearing vegetation	X	X	X	X	X	X	X	X			Results from human disturbance; usually first step in preparing a site for future human activities.
Volcanic eruptions									X		Can permanently change geomorphology and hydrology over large areas.
Waste disposal	X			X	X		X	X			Usually ubiquitous with human activity. Can result in soil and water pollution, attracts some wildlife while negatively influencing most.
Water contamination/pollution											Can be difficult/impossible to identify source.
Water diversion structure	X	X	X	X	X	X	X	X			Designed for river/water regulation.
Water abstraction/removal	X	X		X	X		X	X			Usually for agriculture or urban use. Can reduce water levels (water bodies), water tables, and water flow rates (rivers).
Wildlife management	X	X	X			X	X				Usually relating to game animals: deer, fish, waterfowl, etc. Can result in wildlife concentration in reserves, parks, etc.
Woody debris removed	X	X	X			X					Woody debris is a very important component of some stream/riparian/river habitats, like in forests of the Pacific Northwest

Appendix K. Flow charts and decision trees.

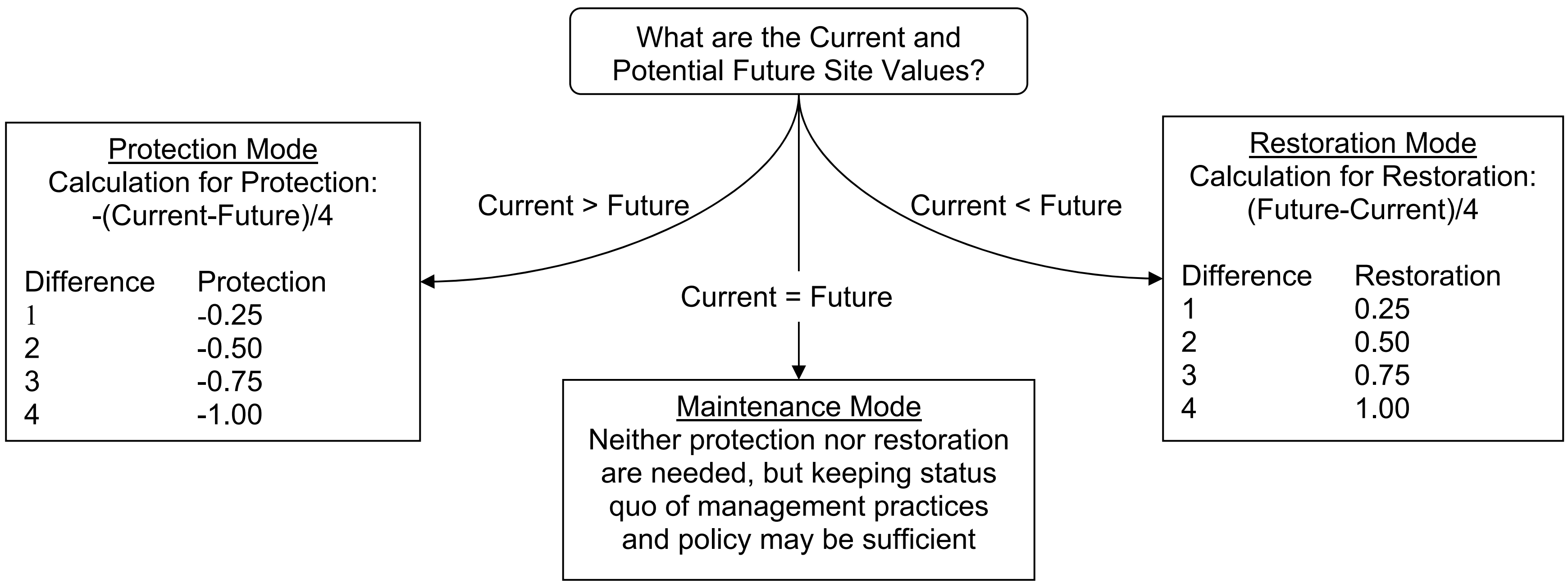
RRAT procedures



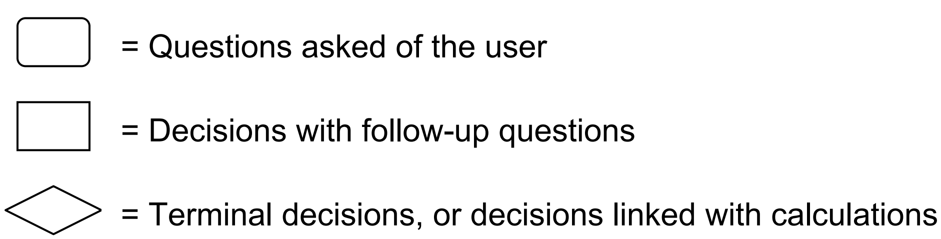
RRAT Model Structure



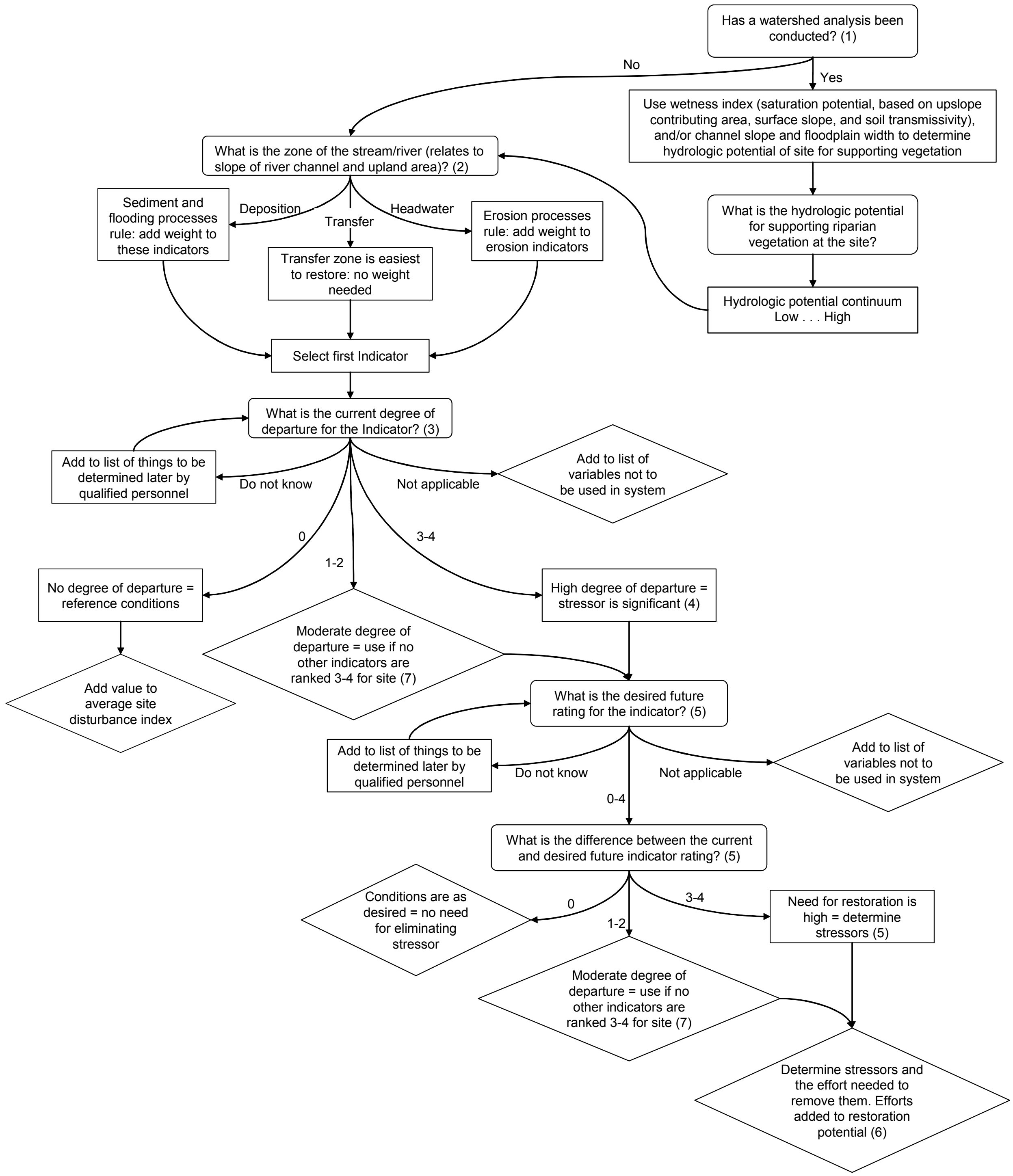
Site Value Decision Tree



Note: Current and Future are on a scale from 0-4, with 0 being not at all valuable, and 4 being extremely valuable.



Restoration Potential Decision Tree



Note: Departure from expected natural condition for indicators are on a scale from 0-4, with 0 being no departure, and 4 being severe departure.

Justification for logic in Restoration Potential decision tree

Number	Justification	Citation
1	A watershed analysis can be used to determine the hydrologic potential of site for supporting riparian vegetation. This potential can be ranked on a scale from low to high.	(Harris and Olson 1997, O'Neill, et al. 1997)
2	The zone of a river frequently relates to the restoration potential of a site. The transfer zone is typically the easiest in which to conduct restorations. The deposition zone is difficult because you are dealing with all of the problems from upstream, and the headwater zone is tricky due to high erosional processes.	(Galatowitsch, pers. comm.)
3	Degree of departure ratings are based upon rangeland health assessments and other rapid assessment techniques.	(Anonymous 2004, Pellant, et al. 2005)
4	In many cases one will only be paying attention to the high or extreme departures from the reference condition.	(Galatowitsch, pers. comm.)
5	The desired future rating is for the user to rank the realistic future management goal for indicators. If there is a large difference between the current condition and the management goal, the restoration need for that indicator is high and the stressors need to be ranked for that indicator.	Expert workshop 2006
6	Logic for stressor removal effort and restoration potential covered in the section describing indices	Indices results, this report
7	There may be cases where no indicators rank above a 2 for a site. In these cases, smaller degrees of departure can be analyzed similar to when they rank as 3-4, but the restoration need may not be as high.	N.A.