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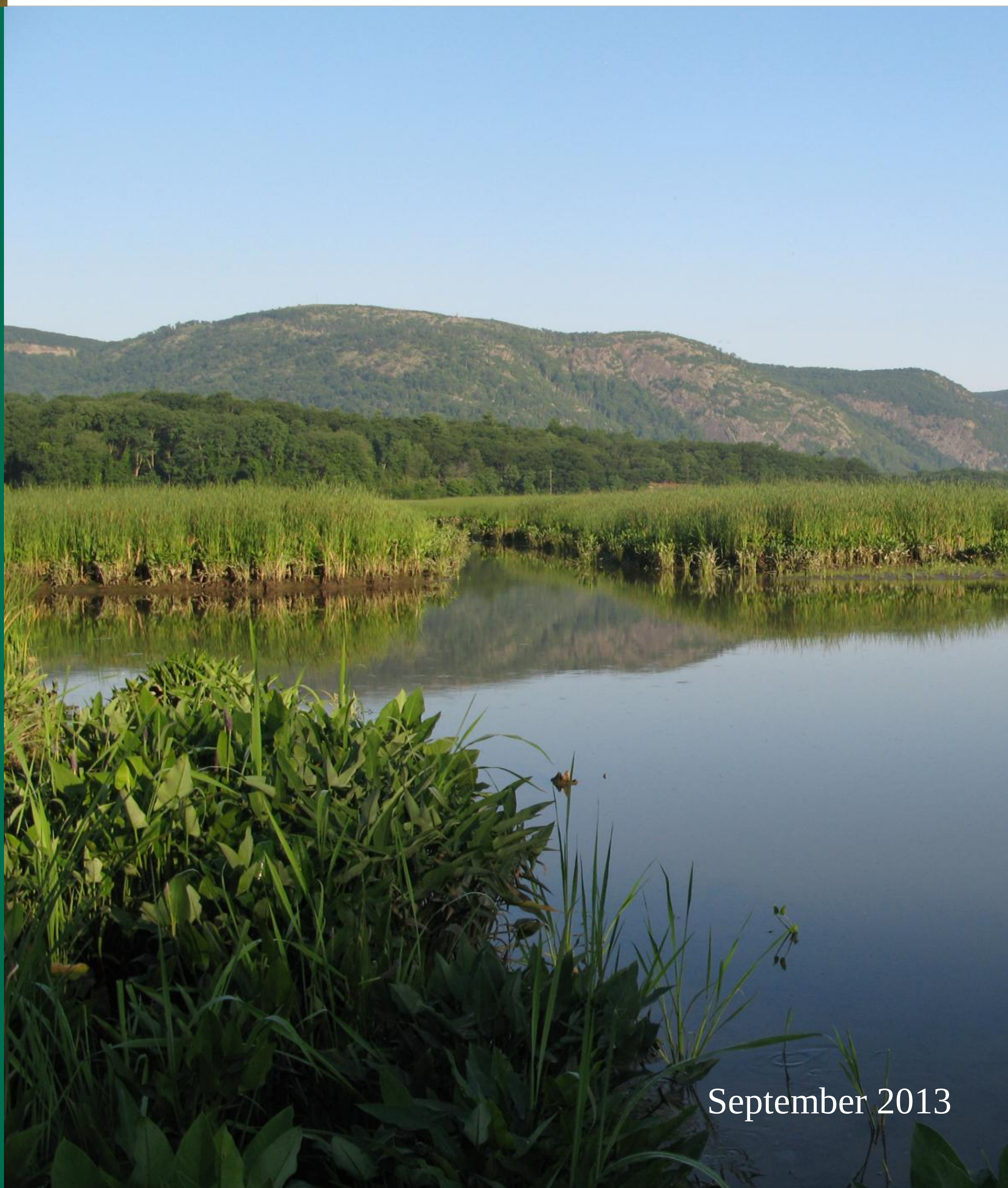
A HANDBOOK FOR PRIORITIZING WETLAND AND STREAM RESTORATION AND PROTECTION USING LANDSCAPE ANALYSIS TOOLS



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EXECUTIVE SUMMARY

Introduction

Renewable energy development and increased utilization of domestic energy reserves, particularly natural shale gas extraction, are poised to result in an expansion of aquatic resource impacts in the United States in the coming decades. Impacts to the nation's watersheds and landscapes from the potentially deleterious effects of these threats can be minimized through strategic planning and science-based cumulative impacts analysis, evaluation of avoidance and minimization options, and the selection of high-value compensatory options. Strategic prioritization of conservation opportunities can also identify suitable sites for aquatic resource restoration.

Landscape approaches to the prioritization of wetland and stream restoration and protection sites can provide a platform for integrating multiple, potentially complementary aquatic resource conservation efforts in a more holistic manner. These prioritization tools are designed for use in two general types of wetland and stream conservation programs:

- Regulatory programs requiring wetland or stream conservation as compensatory mitigation for permitted damages (e.g., Clean Water Act (CWA) §404).
- Voluntary non-regulatory programs that provide funding to landowners for wetland or stream restoration conservation activities (e.g., Wetlands Reserve Program).

This handbook was designed to provide states, tribes, and local governments with valuable information to guide the development, establishment, and refinement of geospatial tools for identifying restoration and protection prioritization priorities. It does so by:

- Defining landscape prioritization tools in terms of inputs, outputs, and target prioritization objectives.
- Describing how landscape prioritization tools are applied to evaluate potential wetland and stream restoration and protection sites across a range of objectives.
- Identifying the variety of component processes used upstream and downstream of landscape prioritization tools.
- Discussing the application of landscape prioritization tool outputs to regulatory and non-regulatory programs, the transferability of prioritization approaches to programs currently lacking such tools, and barriers currently limiting the development and implementation of landscape prioritization tools.
- Compiling an inventory of data and methods used by prioritization programs.

Definition of a landscape prioritization tool

Each prioritization program consists of one or more "prioritization tools." As defined for this study, each prioritization tool represents a landscape metric or index based on a set of data factor inputs and a corresponding output. Furthermore, landscape prioritization tools were only included in the analysis if the landscape unit of analysis used was no larger than the HUC-12 watershed scale. Two types of prioritization tools evaluated in this study included single-objective and multi-objective tools (see below).

Single-objective tool: As shown in Figure 1, below, a single-objective tool integrates a set of input factors to derive an output representing a *single* prioritization objective. Eighty-three of the 115 tools examined in this study were single-objective tools.

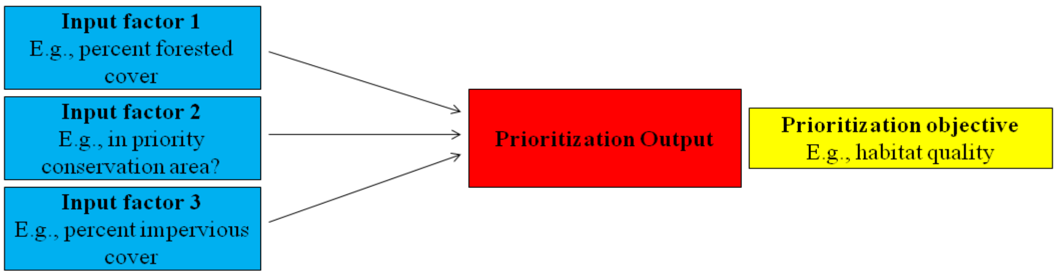


Figure 1. Single-objective tools integrate multiple input factors to produce a prioritization output that evaluates a *single* prioritization objective.

Multi-objective tool: Like single-objective tools, multi-objective tools integrate multiple input factors as part of their analysis. However, the prioritization output obtained using a multi-objective tool represents *multiple* prioritization objectives (Figure 2). Thirty-two of the 115 tools examined in this study were multi-objective tools.

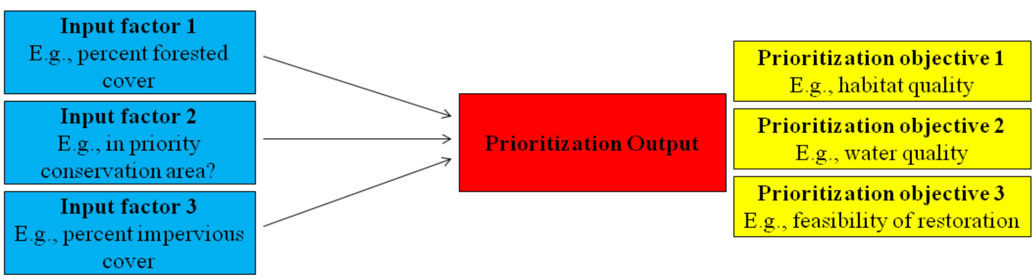


Figure 2. Multi-objective tools integrate multiple input factors to produce a prioritization output that evaluates *multiple* prioritization objectives.

A subset of multi-objective tools combines outputs of other single- and multi-objective tools to produce an output representing multiple objectives (Figure 3). For example, the Kramer et al. (2012) Potential Wetland Bank Site Index combines outputs from several other tools, such as the Kramer et al. (2012) Connectivity to Existing Conservation Lands Tool (which itself prioritizes for habitat quality and social values) to assess prioritization objectives that include habitat quality, water quality, flood mitigation, feasibility of restoration, and social values.

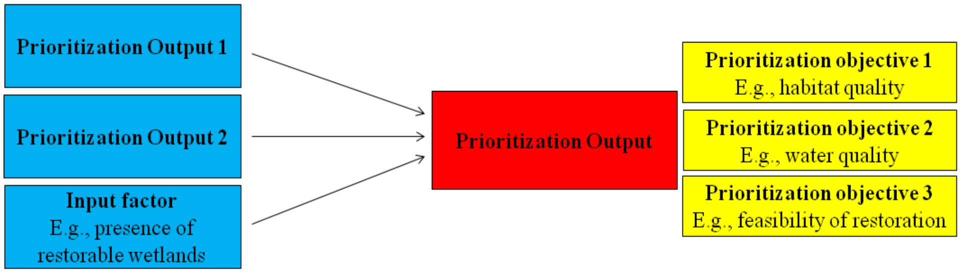


Figure 3. A subset of multi-objective tools integrate input factors that include the prioritization outputs of other prioritization tools to obtain a multi-objective output.

Application of landscape prioritization tools to specific objectives

Tools use inputs obtained from upstream processes (steps 1, 2, and 3, above) to generate output maps identifying and/or ranking individual hydrologic units (e.g., HUC-12s), wetland polygons, and pixels (e.g., $30m^2$ raster cells) in terms of one or more prioritization objectives. Objectives targeted by the programs studied for this handbook include:

• Aquatic resource condition	• Habitat quality
• Carbon storage	• Historic functional change
• Cost-effectiveness	• Social values
• Feasibility of restoration	• Suitability for preservation
• Flood mitigation	• Surface water supply
• Future impacts	• Sustainability of restoration
• Groundwater supply	• Water quality

For example, The Duck-Pensaukee Watershed Approach Pilot, led by The Nature Conservancy (TNC) and Environmental Law Institute (ELI), applied a variety of tools for identifying wetland sites suitable for wetland restoration (reestablishment) and preservation across a range of wetland services. These services included the provision of wildlife habitat, flood abatement, surface water supply, water quality protection, carbon storage, shoreline protection, and provision of fish habitat. In addition, to assess watershed needs for each wetland service, the tool applied a unique method for quantifying historical losses of each service across subwatersheds. Figure 4 compares the Pilot's output map for historic flood abatement service losses with its output map showing priority wetland sites for restoring and protecting flood abatement services.

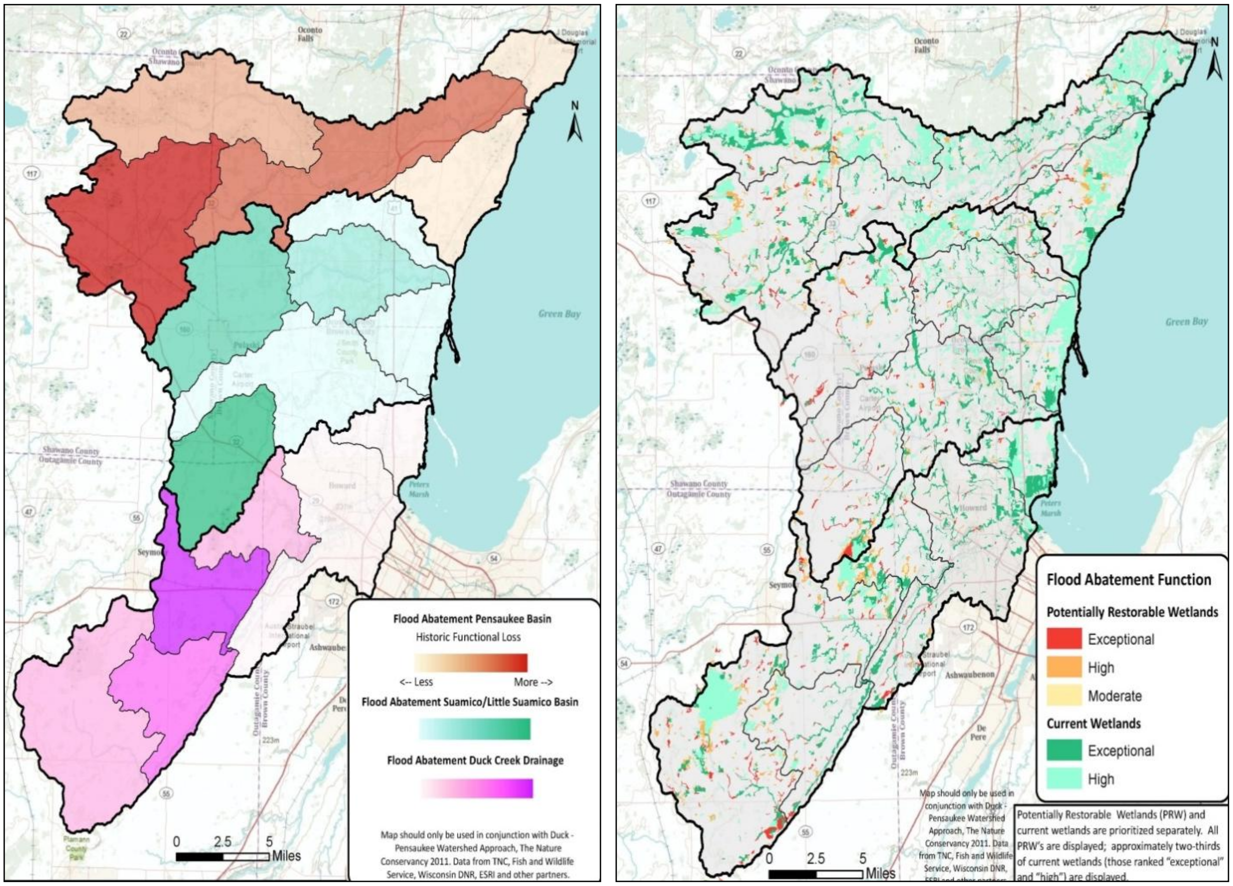


Figure 4. In their 2012 report, TNC and ELI provided output maps from its assessments of watershed needs (i.e., areas of historic functional loss) and tools for identifying site-specific priorities. For example, its assessment of flood abatement needs (*left*) identifies HUC-12s in which site-specific restoration and preservation priorities for flood abatement (*right*) might be targeted to promote a watershed approach to regulatory and non-regulatory wetland conservation.

Upstream and downstream processes

The programs examined for this handbook prioritize aquatic resource restoration or protection using a variety of processes. The generic sequence of processes that follows reflects the full range of processes observed by these programs. Note that this sequence is all encompassing and does not reflect the specific subset of processes that would be expected to be used by a given prioritization program.

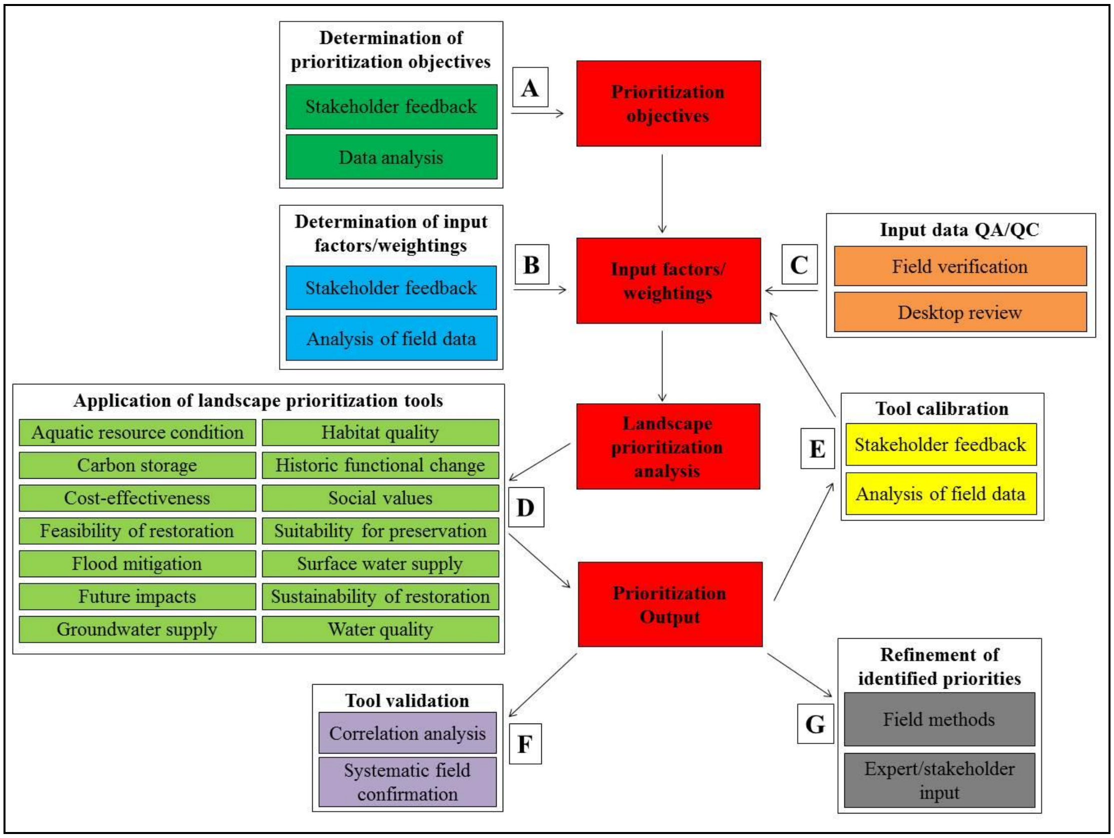


Figure 5. General process applied by the 30 landscape prioritization programs evaluated in this study. Methods applied by programs included: A) determination of prioritization objectives, B) determination of input factors/weightings, C) input data QA/QC, D) application of landscape prioritization tools, E) calibration of landscape prioritization tools, F) validation of landscape prioritization tools, and G) refinement of identified priorities.

Upstream processes

Determination of prioritization objectives (Figure 5(A))

- **Based on stakeholder feedback:** Five of the programs we reviewed determine prioritization objectives by soliciting stakeholder feedback on watershed/landscape priorities. For instance, prioritization objectives targeted by the National Oceanic and Atmospheric Administration (NOAA) Habitat Priority Planner Mississippi-Alabama Habitats Tool (HPP MAHT) were determined by a stakeholder group that included over 60 state and local representatives involved with habitat management in coastal Alabama. In the first of three meetings in which the group provided input for the tool, the group identified ten distinct habitat types to target for prioritization. The final habitat types identified by the group included freshwater wetlands, riparian buffers, longleaf pine, pine savannah, maritime forest, intertidal marshes and flats, beaches and dunes, submerged aquatic vegetation, oyster reefs, and rivers and streams.
- **Based on data analysis:** Two programs we reviewed integrate watershed/landscape data analysis as part of their process for identifying prioritization objectives. For example, as part of its Standard GIS Methodology for Wetland Analysis, the Arkansas Multi-Agency Wetland Planning Team identifies objectives specific to each of its Watershed Planning

Areas by evaluating readily available watershed-scale GIS datasets that capture basic wetland characteristics.[1]

Determination of input factors/weightings (Figure 5(B))

- **Based on stakeholder feedback:** Five of the programs we reviewed determine input factors/weightings using expert/stakeholders group collaboration. For example, in a series of workshops, the U.S. Army Corps of Engineers Sunrise River Watershed-Based Mitigation Pilot engaged a stakeholder team to develop a framework for selecting mitigation sites that would best meet watershed needs. This stakeholder team consisted of representatives from EPA, the Minnesota Pollution Control Agency (MNPCA), the Minnesota Department of Natural Resources (MNDNR), Minnesota Board of Water and Soil Resources (MNBWSR), and local agencies responsible for implementing the Minnesota Wetland Conservation Act.

  In workshops, this stakeholder team identified criteria that it considered to be most important for targeting wetland compensation mitigation efforts within each subwatershed, such as hydrologic connection to tributaries, land costs, potential to reconnect riparian buffers, etc. Following the workshops, stakeholders completed a web-based survey in which they ranked selected criteria against one another in a series of pairwise comparisons (Figure 6). The Corps applied the Analytic Hierarchy Process (AHP), a type of Multi-Criteria Decision Analysis (MCDA), to determine the weightings to use for each criterion as part of the spatial decision support system (SDSS) model. The Corps completed the survey online, rather than as a group, to minimize bias and avoid concerns related to group think.

Figure 6. The Corps used web-based surveys to solicit the stakeholder team for weightings to apply in the SDSS prioritization model for each criterion identified by the team in the workshops. Used with permission of U.S. Army Corps of Engineers.

- **Based on an analysis of field data:** Three of the programs we studied determine input factors and weightings using correlation analysis. These programs assemble field-based data, which are correlated with a wide variety of potential landscape metrics to determine which specific landscape metrics to include in their landscape analysis. For example, Weller et al. (2007) developed landscape assessment models that predicted wetland conditions for flat and riverine wetlands in the Nanticoke watershed. Researchers first applied EPA's Environmental Monitoring and Assessment Program sample design to obtain five different field-based Functional Capacity Index (FCI) scores (based on hydrogeomorphic, or HGM, variables) for riverine wetlands, with four of these five FCI scores obtained for flat wetlands. Researchers then used regression analysis to evaluate relationships between each of these nine FCI scores and 27 landscape indicators to identify nine sets of landscape indicators that best predicted FCI scores. Through this analysis the researchers generated nine equations (four for flat wetlands and five for riverine) that predicted scores for each of the nine FCI models. The underlying methods applied by these researchers can be reapplied to prioritize wetland restoration or conservation for wetland types of any watershed for which a random sample of Rapid Assessment Method (RAM) scores can be obtained.

Input data quality assurance/quality control (QA/QC) (Figure 5(C))

- **Using field verification:** Three methods we reviewed apply rapid or intensive on-the-ground assessment methods to confirm the accuracy of input spatial datasets. For example, when Arkansas Multi-Agency Wetland Planning Team (MAWPT) identifies obvious discrepancies in the input datasets it uses as part of its Standard GIS Methodology for Wetland Analysis, it groundtruths these datasets using windshield surveys, field visits, and local knowledge.[2]
- **Using desktop review:** Methods involved in desktop review included the application of predefined QA/QC guidelines, comparison of input data to other data sources, and examination of whether data inputs were integrated correctly by landscape prioritization tools. For instance, the Watershed Resource Registry (WRR) is in the process of developing a method for the field validation of various input data sources. These on-the-ground assessments will likely be rapid and will seek to confirm whether factors are present as described by the input maps. Other input data QA/QC includes completing a desktop review of the model outputs to ensure that they are being calculated correctly within the model.

Downstream processes

Tool calibration (Figure 5(E))

- **Based on stakeholder feedback:** Two prioritization programs calibrated their landscape prioritization tool(s) through stakeholder evaluation of outputs. Applied to the development of the NOAA HPP MAHT, output maps were visualized for the Mobile Bay National Estuary Program’s Coastal Habitats Coordination Team, a stakeholder group consisting of over 60 state and local resource professionals that had informed the initial parameterization of the tools. This stakeholder group drew upon its collective expertise and on-the-ground experience to provide feedback to refine parameters applied by the model and improve results. In a subsequent round of feedback, this stakeholder group again evaluated output maps to adjust inputs and weightings for the models and generate a final prioritization map.

- **Based on analysis of field data:** Two programs that rely on expert judgment to determine input factors established weightings for these factors by analyzing model outputs against field data. In addition, one program calibrates its model by using rapid assessment scores to determine which sites are more degraded than the model indicates, informing changes to the model. Virginia Institute of Marine Science Wetland Condition Assessment Tool (VIMS WetCAT) researchers developed input factors based on expert judgment and calibrated the model using data obtained from field surveys in which they counted the number of anthropogenic stressors within 30m and 100m buffer regions for 1,928 randomly-sampled wetland sites. VIMS correlated counts for the most frequently observed stressors (e.g., roads, brush cutting) with Level 1 scores and applied changepoint analysis to account for nonlinear thresholds in these relationships to establish a final scoring protocol.

Tool validation (Figure 5(F))

- **Based on systematic field confirmation:** Five prioritization programs apply systematic field confirmation to compare results of their tools against field data. For instance, to validate its Wetland Mitigation Site Suitability Tool, Michigan Tech Research Institute (MTRI) and Michigan Department of Transportation (MDOT) follow workflow procedures for the tool to compare site suitability rankings provided by the tool with rankings obtained based on field monitoring data. As a result, they found that the tool correctly assessed wetland suitability for 19 of the 20 sites. In demonstrating the tool's accuracy, the validation study also showed that the Wetland Mitigation Site Suitability Tool (WMSST) would produce substantial savings for MDOT, reducing costs for evaluating potential mitigation sites by 73%.
- **Based on correlation analysis:** Two prioritization programs apply more elaborate statistical methods to evaluate tool accuracy by validating tool outputs against rapid or intensively obtained data. For example, to validate outputs from its Landscape Integrity Model, the Colorado Natural Heritage Program (CNHP) correlates model results against three Level 2 assessments (Human Disturbance Index, Ecological Integrity Assessment, and Mean C assessment) and one Level 3 assessment (Vegetation Index of Biotic Integrity).[3] Because the CNHP found correlations to be strong for all three Level 2 assessments, it concluded the Landscape Integrity Model (LIM) to be an accurate tool for the assessment of landscape integrity. (Figure 7)

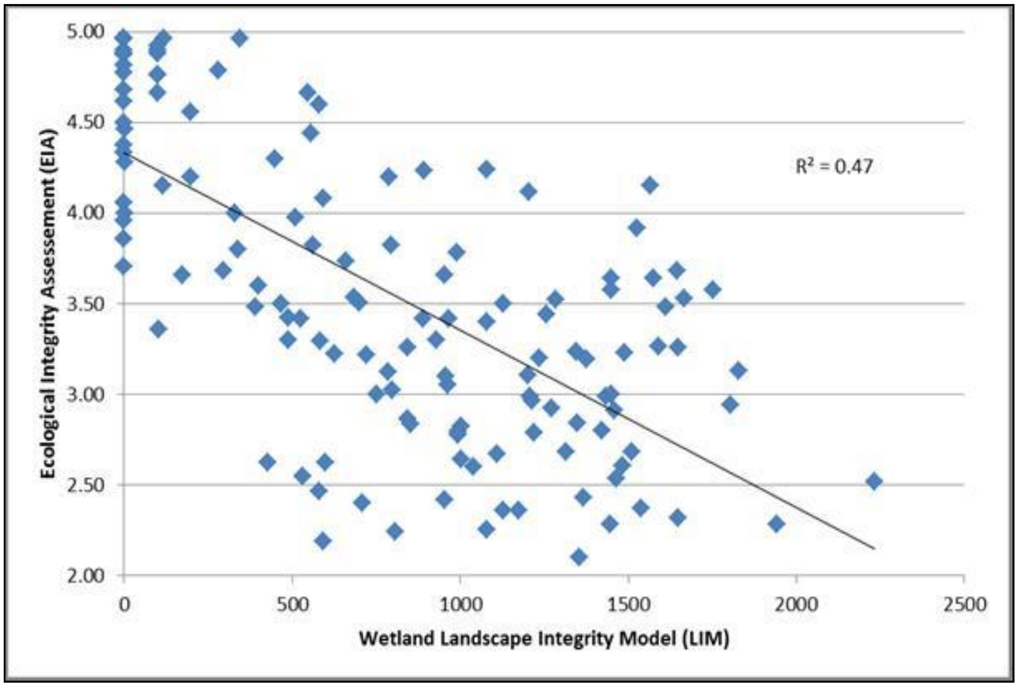


Figure 7. Rapid assessment results for EIA assessments correlate strongly with landscape prioritization LIM results. Strong correlations were also demonstrated between LIM and rapid assessment results for HDI and Mean C assessments. Used with permission of the Colorado Natural Heritage Program.

Refinement of identified priorities (Figure 5(G))

- **Using field methods:** Seven of the prioritization programs analyzed describe methods for refining the results of their tools using field data. Strager et al. (2012)'s method for refining priority sites, for example, was specifically developed for integration with the landscape prioritization process. The method scores potential wetland restoration sites based on Level 2 assessment criteria, collected in the field by wetland specialists, with weightings for each criteria derived by asking each specialist to evaluate a series of pairwise comparisons among criteria (i.e., the Analytical Hierarchy Process). Strager et al. (2012) then evaluates the three highest ranked sites within each HUC-10 watershed using extensive Level 3 on-site assessments to identify which sites are most feasible for combined wetland and stream mitigation banking.
- **Using expert/stakeholder input:** Five programs refine outputs of landscape prioritization tools based on expert/stakeholder input. For example, after applying its GIS screening analyses, the TNC Aquatic Ecoregional Assessment solicits feedback on prioritization results from aquatic resource experts from land/resource management agencies, academic institutions, private consulting firms, and local non-profits in a series of workshops. The TNC WBSP Union Portfolio, identifies Conservation Opportunity Areas (COAs) by incorporating recommendations from the public regarding the modification, addition, or removal of COAs. Members of the public use a nomination form and online mapping site to draw features over the Union Portfolio to indicate which COAs should be added or changed before submitting them to TNC (Figure 8). Contributors are instructed to make changes that support recovery of listed species or

protected habitat identified in the Oregon Conservation Strategy, address multiple conservation values, or improve ecosystem functions that benefit people.

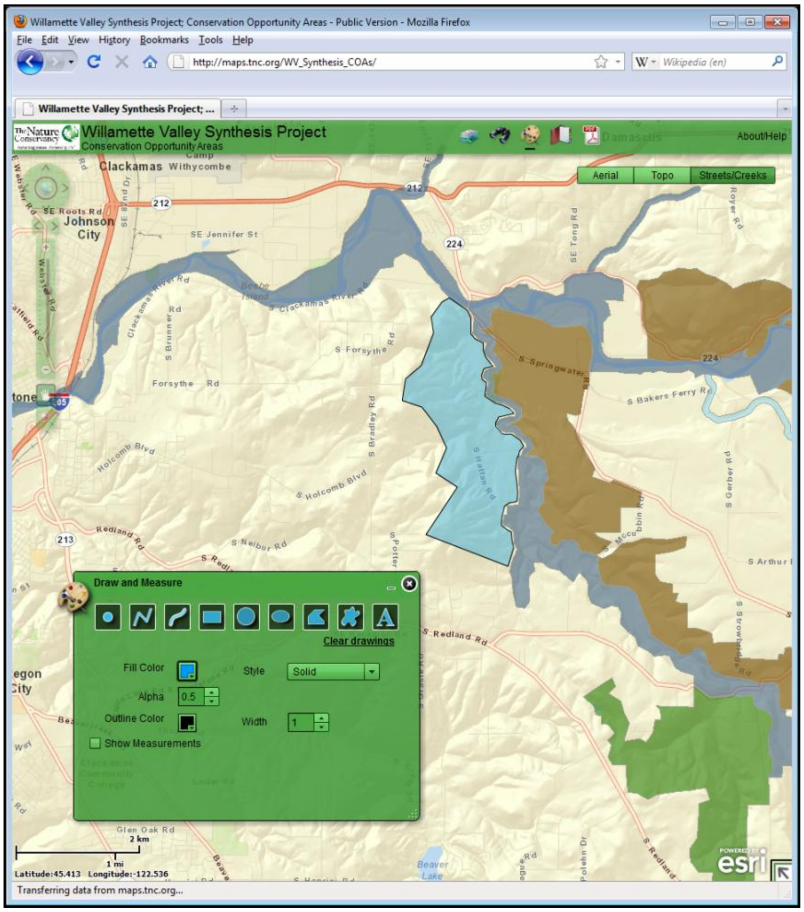


Figure 8. Using the WBSP online mapping tool, members of the public can draw recommended additions or changes to COAs identified in TNC's Union Portfolio. Members of the public can then print changes as a PDF for submission to TNC for incorporation into the Union Portfolio. Used with permission of The Nature Conservancy.

Application of landscape prioritization tools to meet program needs (Figure 5(D))

Application to specific regulatory/non-regulatory programs

We identified ten categories of regulatory/non-regulatory programs targeted by landscape prioritization programs.

- **Clean Water Act wetland mitigation:** The most common application of the landscape prioritization tools evaluated in this study was site selection for Section 401/404 wetland compensatory mitigation. Types of site selection undertaken by landscape prioritization programs included general site selection, in-lieu fee (ILF) site selection, bank site selection, watershed approach, and determination of permit requirements
- **Clean Water Act water quality programs:** Seven programs indicated that their tools could be used to guide the selection of wetland and stream restoration and conservation

projects to satisfy federal water quality regulations such as §303(d), total maximum daily loads (TMDL), §305(b), §319, and §402.

- **NRCS Wetland Reserve Program:** Six of the prioritization programs analyzed reported that their tools have been used as a criterion in the selection of Wetland Reserve Program (WRP) sites by the Natural Resource Conservation Service (NRCS). As part of its process for allocating WRP funding, NRCS may award points to applicants with proposed WRP sites that fall within priority areas identified by these prioritization programs.
- **State Wildlife Action Plans:** One of the prioritization programs reviewed supported development of a State Wildlife Action Plan (SWAP). Applicants to the Tennessee Wildlife Resources Agency (TWRA) Comprehensive Wildlife Conservation Strategy (Tennessee's SWAP) for State Wildlife Grants have an incentive to target areas that have been identified as priorities in the SWAP because TWRA gives preference for projects in these areas.
- **Endangered Species Act (ESA) §10 compensatory mitigation:** Five programs indicated that their tools could be used to site compensatory mitigation under ESA §10. For instance, the tools could be used to calculate predicted compensatory mitigation acreage requirements for various habitat types as a result of future road projects, which could be inputted into a MARXAN algorithm to identify priority parcels.
- **National Environmental Policy Act (NEPA) effects analysis:** Four of the programs reviewed suggested that their prioritization tools could be used to support NEPA effects analysis. For example, one prioritization program cited interest from its state department of transportation in using its prioritization results to assess cumulative effects of planned transportation corridors.
- **State/local wetland mitigation:** Nine prioritization programs described state/local wetland compensatory mitigation as a potential application of their prioritization tool(s).
- **State water quality programs:** Two of the prioritization programs reviewed apply their tools to state/local water quality programs. For instance, one program applies its tools to satisfy state regulations for riparian buffers and nutrient offsets in applicable river basins.
- **Non-regulatory markets for ecosystem services:** Two of the prioritization programs reviewed are used in non-regulatory markets for ecosystem services. Priority areas identified by the Willamette Basin Synthesis Project are used to inform the Willamette Partnership Ecosystem Marketplace, a non-regulatory market for ecosystem services.
- **Other non-regulatory restoration/protection:** Twenty-one of the prioritization programs analyzed are used to guide other types of non-regulatory restoration/protection, including federal programs that fund restoration/protection, state programs that fund restoration/protection, local programs that fund restoration/protection, and non-profit restoration/conservation.

<u>Transferability of landscape prioritization tools</u>

The prioritization programs reviewed for this study were asked to indicate whether or not their tools have specific characteristics that would lend themselves to being easily transferable. These responses fall into four categories, including:

- **Ease of use:** Seven prioritization programs examined in this study cited ease of use as an attribute that made their tool(s) transferable. For example, some programs that rely on raster calculation methods to determine aquatic resource restoration/conservation priorities felt that this approach made adoption of these tools particularly simple.
- **Use of readily available data:** Eight indicated that their tools have this characteristic. Many prioritization programs, for instance, rely on national datasets (e.g. soil survey geographic, or SSURGO, data) that can simply be reapplied if the model is transferred to other states.
- **Minimal funding limitations:** Three of the prioritization programs reviewed indicated that their tools are highly transferable because they are inexpensive to develop and apply.
- **Represents a readily adaptable framework:** Eight of the prioritization programs reviewed rely upon easily adaptable frameworks, which make them readily transferrable.
- **Limitations on tool transferability:** We also identified six rationales for why existing landscape prioritization tools may *not* be easily transferable, including:
    - The analysis is time-consuming to complete
    - The analysis is data intensive
    - Limited transferability to some geographic areas
    - The tool is technically sophisticated
    - The tool requires data inputs that are not widely available
    - Documentation for how to apply the tool is lacking

Barriers to development and implementation

Twenty-eight of the 30 prioritization programs evaluated identified barriers to developing and implementing their prioritization results. We categorized program responses into eight types of barriers including:

- **Data limitations:** Twenty-seven of the 30 prioritization programs evaluated here indicate that specific data gaps may limit the functionality of their tools. Overall, we identified 16 different types of data gaps, including:

• Aerial photography data	• Conservation lands data
• Resolution of elevation data	• Urbanization data
• Flood map data	• Agricultural data
• Wetland mapping data	• Local impacts data
• Stream data	• Habitat data
• Coastal data	• Parcel data
• Soils data	• Population data

- **Technical capacity:** Six prioritization programs cited technical capacity as a barrier to the development of their landscape prioritization tools. For other prioritization programs, the technical capacity necessary to develop their tools was initially available for tool development, but is no longer available for tool maintenance, updating, or implementation.

- **Funding and staff time:** Of the twenty-four prioritization programs that described limited funding and/or staff as barriers to the development of their tools, two identified limited staff or staff time to be the primary barrier. For other tools, barriers related to staff and funding were more directly rooted in the availability of funding.
- **Property rights concerns:** Eight prioritization programs identified property rights concerns as a barrier to development or implementation of their tools. For most of these programs, property rights issues associated with identifying specific priority sites on a map were a concern.
- **Promoting use of the tool:** For two prioritization programs, a need to market prioritization results served as a barrier to continued tool development and implementation. For example, developers of the NOAA Habitat Priority Planner Mississippi-Alabama Habitats Tool are currently striving to ensure the tool's availability, accessibility, and user-friendliness in order to maintain broad interest in the model outputs.
- **Bureaucratic obstacles:** Six existing prioritization programs have experienced bureaucratic obstacles related to data access, mitigation site selection, and available funding and staff time throughout the development and implementation of their tools. Other prioritization programs experienced bureaucratic barriers that limited available funding and staff time.
- **Stakeholder collaboration:** Four of the prioritization programs reviewed encountered issues with stakeholder collaboration throughout the development phases of their prioritization processes. In contrast, two programs encountered stakeholder-related obstacles during the implementation phase of their prioritization process.
- **Maintaining updated data:** Four prioritization programs characterized the maintenance of updated input data to be a significant obstacle. Representatives for the Kramer et al. (2012) tools, for example, expected that the most significant data-related concern going forward would be its ability to continuously update the tool's inputs with new datasets so that outputs would remain as relevant as possible.

Conclusion

<u>Benefits of landscape prioritization methods for siting aquatic resource conservation</u>

The programs examined for this handbook highlight the wide variety of ways in which landscape prioritization tools benefit wetland restoration and protection. Some particularly important benefits of landscape prioritization tools include:

- **Efficient identification of restoration and protection sites that address multiple conservation objectives:** Landscape prioritization tools can be designed to meet the objectives of multiple regulatory and non-regulatory programs that often have differing goals for the same or similar wetland or stream resources. Environmental managers can use landscape prioritization tools to visualize and identify projects or areas that are priorities for multiple programs or that achieve certain sets of functional benefits, allowing for more coordination of conservation and more cost-effective investments.
- **Advancement of regional conservation goals by prioritizing sites using a watershed approach:** Many of the landscape prioritization tools evaluated for this handbook are

used to support the selection of mitigation sites using a watershed approach. For example, the TNC-ELI Duck-Pensaukee Watershed Approach Pilot promotes the functional replacement of wetland benefits on a watershed basis by identifying areas in which to target mitigation through an analysis of historic functional losses within HUC-12 watersheds.

- **Streamlined permitting processes for transportation and natural resource agencies undertaking compensatory mitigation:** Landscape prioritization tools can support early collaboration and planning among agencies, which can reduce project delays, field visits, and time spent approving and monitoring compensation projects.
- **Reduced costs associated with field monitoring:** Long-term monitoring costs for programs that prioritize sites using landscape prioritization tools are low compared to costs for programs that prioritize sites based on field methods alone. While some landscape prioritization tools depend on field-based methods for some component processes (e.g., tool validation), costs associated with these methods are likely to be relatively small. In contrast, programs that determine priorities using field-based methods alone incur much higher costs as they carry out field assessments on a much larger scale.
- **Increased transparency in the selection of conservation sites:** The processes applied by landscape prioritization programs are often well documented and highly transparent. This is especially true of those that draw heavily upon stakeholder input. For instance, stakeholder teams representing state and local government agencies, non-profits, and private businesses were responsible for developing metrics used to model priority habitat patches as part of the NOAA Habitat Priority Planner Mississippi-Alabama Habitats Tool.
- **Offering considerable opportunities for cost-savings by enabling users to evaluate a large variety of potential conservation sites:** Since conservation costs vary throughout space and time based on component costs of conservation, such as land values and on-the-ground restoration work, prioritization can better target locations that will achieve high-quality environmental outcomes at lower costs. Consolidated conservation projects, such as those performed by mitigation banks, conservation banks, and in-lieu fee programs, can achieve economies of scale in land acquisition and on-the-ground restoration costs, reducing the marginal cost of these projects.
- **Allowing for effective cost-benefit analysis with respect to functional return on investment:** Practitioners can apply landscape prioritization tools to account for watershed-scale factors that inform assessment of functional return on investment when selecting aquatic resource restoration and protection sites. These include stressors, stream order, and proximity to existing conservation lands.
- **Reduced time required to locate project sites:** Results of landscape prioritization analyses for a given watershed can have a long shelf life, assuming that the rate of land use change within the watershed is slow. As needs arise for aquatic resource restoration and protection (e.g., through compensatory mitigation), practitioners can readily reference prioritization results to guide selection of areas in which to pursue projects. This is especially true when prioritization results are disseminated widely to potential users – e.g., using interactive web-based maps.
- **Decreasing development costs:** The costs required to obtain the hardware, software, and technical skills necessary to develop landscape prioritization tools are not insubstantial. However, as the programs evaluated in this handbook illustrate, once an agency or

organization has incurred these fixed up-front costs, additional costs for data acquisition are often negligible as many datasets are freely available.

Applying this handbook to promote more successful conservation outcomes

As agencies and organizations charged with restoring and protecting the nation's aquatic resources confront a variety of constraints, ranging from funding limitations to increasing calls for a watershed approach to the selection of mitigation sites, demand for information useful for guiding the development cost-effective prioritization methods will continue to grow. By analyzing the objectives and components of existing landscape prioritization tools and summarizing programmatic information for these tools, this handbook will provide a useful resource for practitioners seeking to capitalize on the opportunities offered by landscape prioritization methods. In this way, the information presented in this handbook will support the development of state and local capacity for the successful prioritization of wetland and stream restoration and conservation projects.

While states, tribes, and local governments currently lacking landscape prioritization tools face much greater technical, staffing, and financial barriers compared to those with programs currently in place, they can benefit from the learning opportunities presented by programs that have come before them. By promoting such learning opportunities, we hope that this handbook can play a role in improving the ability of states, tribes, and local governments to site projects on a landscape basis. Better project siting will lead to an overall improvement in both watershed and human health.

1 Introduction

Aquatic resource restoration and protection programs seek to achieve high-quality environmental results with limited resources. Many of the federal, state, and local wetland and stream restoration and protection programs make their investments on an ad hoc or opportunistic basis. However, we now have the opportunity to employ science-based tools to systematically analyze, compare, and prioritize among potential wetland or stream restoration and protection sites. By so doing, government agencies, nonprofit organizations, and for-profit businesses engaged in aquatic resource restoration or protection can optimize the selection of their projects and increase the likelihood that such projects provide better hydrologic, ecologic, economic, and/or social outcomes.

1.1 Purpose of handbook

ELI's handbook was designed to provide states, tribes, and local governments with valuable information to guide the development, establishment, and refinement of geospatial tools for identifying restoration and protection prioritization priorities. It does so by:

- Defining a standard framework for conceptualizing landscape prioritization programs, objectives, and tools (Section 3);
- Describing how landscape prioritization tools are applied to evaluate potential wetland and stream restoration and protection sites across a range of objectives (Section 4.4);
- Identifying the variety of component processes used upstream (Sections 4.1-4.3) and downstream (Sections 4.5-4.7) of landscape prioritization tools;
- Discussing the application of landscape prioritization tool outputs to regulatory and non-regulatory programs, the transferability of prioritization approaches to programs currently lacking such tools, and barriers currently limiting the development and implementation of landscape prioritization tools (Section 5); and,
- Compiling an inventory of data and methods used by prioritization programs (included as Appendices A and B, respectively).

1.2 Background and introduction

1.2.1 Historic aquatic resource losses and current threats

The contiguous United States has lost over half of the wetland acreage that was present when European settlers arrived in North America in the 1600s,[4] with six states estimated to have lost at least 85% of their original acreage.[5] Causes of wetland loss have changed throughout time, but generally, agricultural expansion, urban and suburban growth, infrastructure development, natural resource exploitation, and industrial growth have drained, dredged, filled, or otherwise modified aquatic ecosystems and the services they provide to society.

Many of these same threats persist today. Substantial infrastructure investment is likely throughout the United States in the coming decade, which often has significant impacts on wetlands and streams. A recent analysis conducted in conjunction with the American Recovery and Reinvestment Act of 2009 concluded that a number of highways, bridges, transit systems, dams, levees, piping systems, and wastewater and drinking water systems need construction or rehabilitation.[6] Further, renewable energy development and increased utilization of domestic energy reserves, particularly natural shale gas extraction, are poised to lead to an increase in aquatic resource impacts in the coming decades. Although residential construction has slowed during the current U.S. economic downturn, housing demand is sure to increase due to anticipated rapid increases in U.S. population in the next decade, and, with it, we can anticipate associated wetland and stream impacts.[7]

Impacts to the nation's watersheds and landscapes from the potentially deleterious effects of these threats can be minimized through strategic planning and science-based cumulative impacts analysis, evaluation of avoidance and minimization options, and the selection of high-value compensatory options. Strategic prioritization of conservation opportunities can also offset historic impacts to wetland and stream resources, and in some cases, can use analysis of historic impacts to locate suitable sites for aquatic resource restoration.

1.2.2 Landscape prioritization for meeting complementary conservation objectives

Landscape approaches to the prioritization of wetland and stream restoration and protection sites can provide a platform for integrating multiple, potentially complementary aquatic resource conservation efforts in a more holistic manner. These prioritization tools are designed for use in two general types of wetland and stream conservation programs:

- Regulatory programs requiring wetland or stream conservation as compensatory mitigation for permitted losses (e.g., Clean Water Act (CWA) §404)
- Voluntary non-regulatory programs that provide funding to landowners for wetland or stream restoration conservation activities (e.g., Wetlands Reserve Program)

Regulatory or non-regulatory conservation programs operating in the same states often have differing goals for the same or similar wetland or stream resources. These programs frequently pursue their objectives independently and without substantial coordination. For instance, delegated state agencies implementing Section 303(d) of the Clean Water Act, which identifies impaired waters and generates pollution reduction strategies (total maximum daily loads, or TMDLs), may not coordinate TMDL implementation with other state or federal programs that concurrently regulate or restore aquatic resources. This segregated, "stovepiped" approach to aquatic resource regulation and conservation has resulted in some agencies that are adept at fulfilling their explicit statutory mandates, but that may overlook opportunities to leverage investment from other programs and synthesize efforts to achieve better environmental results.

The spatially explicit nature of geospatial prioritization allows environmental managers to visualize and identify projects or areas that are priorities for multiple programs or that achieve certain sets of functional benefits, allowing for more coordination of conservation and more cost-effective investments. Powerful personal computers with GIS software (e.g., ArcGIS) are also now more accessible to environmental professionals, allowing more agencies and organizations to analyze the increasing volume and diversity of available geospatial data. ArcGIS can readily perform simpler geospatial analysis to identify priority wetland or stream sites; for example, the raster calculator function in ArcGIS can combine multiple datasets to find locations in the landscape that meet multiple favorable characteristics (e.g., hydric soils, favorable surrounding land cover, hydrologic sinks) for wetland restoration. The ArcGIS Spatial Analyst tool allows users to process data into layers useful for wetland and stream analysis; for instance, users can generate layers of slope and flow accumulation from existing DEMs. Hydrologic analysis tools that function within the ArcGIS Spatial Analyst allow further simple analyses, such as delineation of catchments and flowpaths, which can support identification of priority wetland or stream sites. ArcHydro, an ArcGIS hydrology plug-in, allows more detailed hydrologic analyses, and other plug-ins (e.g., ArcSWAT—Soil and Water Assessment Tool) allow for detailed hydrologic and water quality modeling within ArcGIS.

1.2.3 Level 1-2-3 framework for aquatic resource assessment

Under the Clean Water Act, states and tribes must monitor the condition of all "waters of the United States," including wetlands and streams regulated under the Act. EPA suggests that states and tribes conduct wetland monitoring and assessment at three integrated scales:

- **Level 1 assessments** include landscape analyses that are generally conducted with GIS and remote sensing data. Landscape assessment can provide valuable information for targeting field monitoring and assessment and to assess broader landscape trends and condition. For example, the National Wetlands Inventory (NWI) is a Level 1 data source.
- **Level 2 assessments** are rapid field evaluations of wetland sites and their surroundings. Rapid assessments use fairly simple indicators of aquatic resource condition or function, such as the presence of stressors (e.g., roads, development) nearby or in a wetland, and characteristics of a site's vegetation, hydroperiod, and hydrologic alteration. For example, the California Rapid Assessment Method (CRAM) for wetland and riparian habitats, is a Level 2 data source.
- **Level 3 assessments** include intensive field studies of wetland sites. Level 3 assessments generally consist of gathering detailed information on biological communities at wetland or stream sites (e.g., macroinvertebrate surveys) to test indicators used in rapid or landscape-scale assessments.[8] For example, an Index of Biological Integrity (IBI) is a Level 3 data source.

A properly designed Level 1-2-3 monitoring and assessment framework uses these three scales of data and analysis to complement each other, with each of the data categories being used to validate or calibrate the others. For instance, some aquatic resource conservation prioritization tools correlate landscape indicators of wetland condition with rapid or intensive assessment data to generate more accurate Level 1 predictors of wetland condition and to evaluate the accuracy of these Level 1 predictors (see Section 4.2.2). In practice, when rapid or intensive site assessments are not readily integrated with landscape-level assessments or data, these or other field assessments are used by practitioners to further refine prioritization maps and select conservation sites.

While wetland and stream functional and condition assessments have historically relied more on Level 2 and 3 data, the increasing availability and declining costs for hardware, software, and data acquisition required for Level 1 assessments have made these approaches more accessible to a broader audience of environmental professionals. Remote sensing data are increasingly collected by governmental agencies, conservation organizations, and private businesses, and the last decade has seen a dramatic increase in the computing power available for carrying out geospatial analysis. The federal government now collects and processes a number of national-level GIS datasets that are useful for aquatic resource identification and prioritization, such as the NWI, National Hydrography Dataset (NHD), Digital Elevation Models (DEM), the National Land Cover Dataset (NLCD), and the Watershed Boundary Dataset (WBD). State and local governments also commonly collect or purchase these types of GIS data, sometimes at higher resolution, which can be useful for analyzing wetland and stream restoration and protection priorities. Private, for-profit companies may contract with governments, conservation organizations, academic institutions, or other private entities to supply geospatial data useful for wetland and stream analysis, such as high-resolution LiDAR-derived elevation maps.

1.3 How to use this handbook

The sections that follow seek to provide practitioners with the resources they need to successfully use landscape prioritization tools to select restoration or protection sites that meet their specific objectives. Each section accomplishes this as follows:

Section 2 includes a discussion of the methods used to select the landscape prioritization programs and tools that formed the basis of the analysis, methods for developing research questions, and methods for completing interviews.

Section 3 provides definitions for key concepts used as part of the handbook, including "prioritization objective," "prioritization tool," "prioritization program," "single-objective tool," and "multi-objective tool." Readers of this handbook should be sure to familiarize themselves with these definitions.

Section 4 discusses the range of component processes applied by the landscape prioritization programs included in this research. For state and local water resource programs without such tools, this synthesis can serve as a valuable resource to guide the development of aquatic resource prioritization methods that best meet their needs.

- **Sections 4.1-4.3** cover upstream processes for identifying prioritization objectives, determining input factors and weightings, and applying input data QA/QC for the landscape prioritization tools described in Section 4.4. For example, for prospective programs seeking to determine input factors and weightings based on stakeholder input, the approach used by USACE SRWBMP could serve as a model (Section 4.2.1).
- **Section 4.4** addresses the application of landscape prioritization tools, using inputs derived from upstream processes (Sections 4.1-4.3), to prioritization objectives. This section may serve as a valuable resource for prospective state or local programs seeking to develop tools that prioritize for one or more specific objectives. For instance, for practitioners seeking to prioritize for water quality improvement, the WDNR Wetland Water Quality Assessment Tool may provide a model tool (Section 4.4.14).
- **Sections 4.5-4.6** discuss downstream processes used to calibrate, validate, and refine the outputs of the landscape prioritization tool discussed in Section 4.4. For example, for

prospective programs seeking to refine a coarse map of priority sites, the systematic field-based approach used by Strager et al. (2012) may serve as a useful model (Section 4.7.1).

- **Section 4.7** presents the various types of prioritization products used by landscape prioritization programs to visualize identified priorities. These include static maps, tables/graphs, data files, instructional materials for prioritization tool application, interactive web-based maps, and software tools.

Section 5 discusses the application of landscape prioritization tools to meet the needs of regulatory and non-regulatory programs. This evaluation could help prospective programs with prioritization needs in terms of specific target applications and constraints (i.e., limitations to transferability). In addition, by summarizing obstacles and data limitations encountered by previously developed tools, Section 6 could serve as a source of "lessons learned" for supporting the development of future prioritization tools and geospatial datasets.

- **Sections 5.1-5.2** examine the benefits of landscape prioritization tools for various regulatory and non-regulatory programs. For example, given the increased interest in the watershed approach to compensatory mitigation, TNC-ELI DPWAP, which identifies areas in which to target mitigation through an analysis of historic functional losses within HUC-12 watersheds, could serve as a model tool for the selection of mitigation sites.
- **Section 5.3** provides a discussion of how landscape prioritization programs may be transferable to other states. For example, prospective prioritization efforts with limited data resources are likely to find tools that only use readily-available data (e.g., the VDCR GIS Model) most desirable (Section 5.3.2).
- **Section 5.4** addresses data and programmatic barriers that have limited the development and implementation of landscape prioritization tools. An understanding of data limitations encountered by previous prioritization programs can be used to guide improvements in large spatial datasets to accommodate the needs of landscape prioritization programs. An understanding of other obstacles faced by prioritization programs could help prospective programs better anticipate potential barriers to tool development.

Section 6 concludes the handbook by summarizing the advantages and disadvantages of landscape prioritization methods. This section argues that wetland programs involved with aquatic resource restoration and protection decision-making should implement these tools in order to improve their ability to maximize achievement of their objectives on a landscape scale.

2 Methods

2.1 Identifying tools and programs for analysis

This handbook provides an in-depth look at 30 landscape prioritization tools and programs (see definition in Section 3) that represent a broad continuum of geospatial methods and data currently used in the United States to identify wetland and stream restoration or protection priorities at watershed or landscape scales (Table 1). In addition, it provides an overview of the barriers to developing such methods for states lacking the tools. The Environmental Law

Institute (ELI) enlisted the participation of an Advisory Committee (see Acknowledgements), which included leading thinkers on the prioritization of aquatic resource restoration and protection from academia, non-profit organizations, and federal and state agencies, to help identify the relevant programs for evaluation and the parameters by which to evaluate the programs.

In order to identify the range of existing prioritization tools to be evaluated, ELI relied upon direction provided by the Advisory Committee, existing published literature, and a web-based survey. An individual landscape prioritization tool was considered for evaluation if a prioritization program applied the method to identify priority sites meeting some prioritization objective (e.g., wetland condition, flood mitigation, habitat value, etc.) based on a combination of spatial data inputs. After compiling an extensive inventory of more than 60 prioritization programs and with the help of the Advisory Committee, we selected 30 landscape prioritization programs for further study (Table 1, see Appendix B for a list of programs not included in the analysis). We sought to maximize the breadth of our sample by including programs that represented diversity across each of the following criteria:

1. Geographic distribution
2. Regulatory/non-regulatory applications (e.g., wetland compensatory mitigation, land acquisition, etc.)
3. Prioritization objectives assessed (e.g., habitat quality, water quality improvement, cost-effectiveness, etc.)
4. Types of methods applied (ArcGIS raster/vector methods, complex modeling, spreadsheet-based analysis, etc.)
5. Data used

Table 1 Prioritization programs and associated landscape prioritization tools selected for evaluation.

Prioritization program	Landscape prioritization tool(s)	Factsheet
Arkansas Multi-Agency Wetland Planning Team (Arkansas MAWPT)	Standard GIS Methodology for Wetland Analysis	http://www.eli.org/pdf/wetlands/Factsheets/AR_MAWPT_GIS_Method_FactSheet.pdf
Kauffman-Axelrod and Steinberg (2010)	Restoration Consideration Areas Tool Tidal Wetland Restoration Prioritization Tool	http://www.eli.org/pdf/wetlands/Factsheets/AxelrodSteinberg_FactSheet.pdf
Caltrans Regional Advance Mitigation Planning (Caltrans RAMP)	Road Impact Footprint Analysis MARXAN Greenprint Analysis	http://www.eli.org/pdf/wetlands/Factsheets/Caltrans_RAMP_FactSheet.pdf
Colorado Natural Heritage Program (CNHP)	Landscape Integrity Model Wetland profile	http://www.eli.org/pdf/wetlands/Factsheets/CNHP_LIM_FactSheet.pdf
Ducks Unlimited (DU)	Forested Wetland Restoration Suitability Model	http://www.eli.org/pdf/wetlands/Factsheets/DU_ForestedWetland_FactSheet.pdf
Idaho Department of	Wetland condition tool	http://www.eli.org/pdf/wetlands/

Prioritization program	Landscape prioritization tool(s)	Factsheet
Fish and Game (IDFG)	Watershed condition tool	Factsheets/IDFG_LA_FactSheet.pdf
Kramer et al. (2012)	Jurisdiction	http://www.eli.org/pdf/wetlands/Factsheets/Kramer_Models_FactSheet.pdf
	Water quality and quantity index	
	Potential runoff index (PRI)	
	Connectivity to existing conservation lands	
	Terrestrial dispersal corridors between potential wetland banks	
	Hydrologic connectivity between wetlands	
	Natural upland habitat surrounding sites	
	Maintenance of high biodiversity streams	
	Potential wetland banking site index	
	Wetland Condition Index	
	Human Development Index	
Louisiana Coastal Protection and Restoration Authority Coastal Master Plan (LACPRA CMP)	Coastal Louisiana Risk Assessment (CLARA)	http://www.eli.org/pdf/wetlands/Factsheets/LACPRA_CMP_FactSheet.pdf
	Relative elevation sub-model	
	American Alligator Habitat Suitability Model (HSI)	
	Crawfish (wild caught) HSI	
	Eastern oyster HSI	
	Largemouth bass HSI	
	Spotted sea trout HSI	
	Muskrat HSI	
	River otter HSI	
	Roseate spoonbill (nesting) HSI	
	Roseate spoonbill (foraging) HSI	
	Brown shrimp HSI	
	White shrimp HSI	
	Mottled duck HSI	
	Green-wing teal HSI	
	Gadwall HSI	
	Nitrogen Uptake Spatial Statistical Approach	
	Storm surge/wave attenuation potential suitability index	
	Potential for freshwater availability tool	
	Nature Based Tourism Suitability Index	

Prioritization program	Landscape prioritization tool(s)	Factsheet
	Carbon sequestration potential tool	
Michigan Tech Research Institute (MTRI)	Wetland Mitigation Site Suitability Tool	http://www.eli.org/pdf/wetlands/Factsheets/MTRI_WMSST_FactSheet.pdf
Montana Natural Heritage Program (MTNHP)	Landscape Integrity Model	http://www.eli.org/pdf/wetlands/Factsheets/MTNHP_LIM_FactSheet.pdf
National Oceanic and Atmospheric Administration Habitat Priority Planner Mississippi-Alabama Habitats Tool (NOAA HPP MAHT)	Riparian buffers (conservation) tool	http://www.eli.org/pdf/wetlands/Factsheets/NOAA_HPP_FactSheet.pdf
	Riparian buffers (restoration) tool	
	Freshwater wetlands tool	
	Watersheds (river and stream conservation) tool	
	Watersheds (river and stream restoration) tool	
	Intertidal marshes and flats (flood hazard protection) tool	
	Intertidal marshes and flats (natural resource conservation) tool	
New Hampshire Department of Environmental Services Wetland Restoration Assessment Model (NHDES WRAM)	Site identification model	http://www.eli.org/pdf/wetlands/Factsheets/NHDES_WRAM_FactSheet.pdf
	Significant habitat tool	
	Ecological integrity tool	
	Sediment trapping and nutrient potential tool	
	Flood protection tool	
	Groundwater use potential tool	
	Restoration Sustainability Score	
	Landscape Position Score	
	Net Functional Benefit Tool	
	Site Prioritization Model	
North Carolina Ecosystem Enhancement Program (NCEEP)	HUC-14 Screening Tool	http://www.eli.org/pdf/wetlands/Factsheets/NCEEP_FactSheet.pdf
	Focus Area Identification Tool	
Playa Lakes Joint Venture Playa Lakes Decision Support System (PLJV PLDSS)	Landscape-scale model	http://www.eli.org/pdf/wetlands/Factsheets/PLJV_PLDSS_FactSheet.pdf
	Site-scale model	
Strager et al. (2011)	Wetland banking site selection model	http://www.eli.org/pdf/wetlands/Factsheets/Strager_BSST_FactSheet.pdf
	Stream banking site selection model	
Tennessee Wildlife Resources Agency Comprehensive Wildlife Conservation Strategy (TWRA CWCS)	HUC-12 aquatic resource prioritization tool	http://www.eli.org/pdf/wetlands/Factsheets/TWRA_CWCS_Model_FactSheet.pdf

Prioritization program	Landscape prioritization tool(s)	Factsheet
TNC Aquatic Ecoregional Assessment (TNC Aquatic EA)	Aquatic System Integrity GIS Model	http://www.eli.org/pdf/wetlands/Factsheets/TNC_AquaticEA_FactSheet.pdf
	Landscape Context GIS Model	
TNC and ELI Duck-Pensaukee Watershed Approach Pilot (TNC-ELI DPWAP)	Watershed profile tool	http://www.eli.org/pdf/wetlands/Factsheets/TNC_ELI_DPWAP_FactSheet.pdf
	Wildlife tool	
	Fish habitat tool	
	Water quality protection tool	
	Flood abatement tool	
	Shoreline protection tool	
	Surface water supply tool	
	Potentially Restorable Wetlands (PRW) tool	
	Wetland preservation tool	
	Carbon storage tool	
	Function variety tool	
University of Massachusetts Amherst Conservation Assessment and Prioritization System (UMass Amherst CAPS)	Index of Ecological Integrity (IEI)	http://www.eli.org/pdf/wetlands/Factsheets/MACAPS_FactSheet.pdf
USACE Baltimore District and USEPA Region III Maryland Watershed Resources Registry (Maryland WRR)	Wetland preservation tool	http://www.eli.org/pdf/wetlands/Factsheets/MD_WRR_FactSheet.pdf
	Wetland restoration tool	
	Upland Preservation tool	
	Upland Restoration tool	
	Riparian Zone Preservation tool	
	Riparian Zone Restoration tool	
	Preserving Natural Surface Hydrology for Stormwater tool	
	Restoring/Mimicking Natural Hydrology for Stormwater	
USACE St. Paul District Sunrise River Watershed-Based Mitigation Pilot (USACE SRWBMP)	Social Context Tool	http://www.eli.org/pdf/wetlands/Factsheets/USACE_SRWBMP_FactSheet.pdf
	Recovery Potential Integrated Tool	
USEPA Recovery Potential Screening (USEPA RPS)	Forest Breeding Bird Decision Support Model	http://www.eli.org/pdf/wetlands/Factsheets/EPA_RPS_FactSheet.pdf
	GIS Model	
	Wetland Condition Assessment Tool	
	Wetland Mitigation Targeting Tool	
USGS	Water delivery tool	http://www.eli.org/pdf/wetlands/Factsheets/USGS_ForestBirdToo

Prioritization program	Landscape prioritization tool(s)	Factsheet
		l_FactSheet.pdf
Virginia Department of Conservation and Recreation (VDCR)	Water storage tool	http://www.eli.org/pdf/wetlands/Factsheets/VDCR_GIS_Model_FactSheet.pdf
Virginia Institute of Marine Science (VIMS WetCAT)	Groundwater recharge tool	http://www.eli.org/pdf/wetlands/Factsheets/VIMS_WetCAT_FactSheet.pdf
Virginia Institute of Marine Science (VIMS WMTT)	Groundwater discharge tool	http://www.eli.org/pdf/wetlands/Factsheets/VIMS_WMTT_FactSheet.pdf
Washington Department of Ecology Watershed Characterization Tool (WSDOE WCT)	Overall watershed characterization tool	http://www.eli.org/pdf/wetlands/Factsheets/WSDOE_WCT_FactSheet.pdf
	Hydrology (flat wetlands)	
	Biogeochemistry (flat wetlands)	
	Plant community (flat wetlands)	
	Habitat (flat wetlands)	
Weller et al. (2007)	Hydrology (riverine wetlands)	http://www.eli.org/pdf/wetlands/Factsheets/Weller_WCA_FactSheet.pdf
	Biogeochemistry (riverine wetlands)	
	Plant community (riverine wetlands)	
	Habitat (riverine wetlands)	
	Landscape (riverine wetlands)	
	Willamette Valley Synthesis Map	
	Potentially Restorable Wetlands Tool	
	Wetland Preservation Tool	
	Habitat Quality Index	
The Nature Conservancy Willamette Basin Synthesis Project (TNC WBSP)	Wetland Water Quality Assessment Tool	http://www.eli.org/pdf/wetlands/Factsheets/TNC_WBSP_FactSheet.pdf
Wisconsin Department of Natural Resources (WDNR)	Flood Storage Decision Support Tool	http://www.eli.org/pdf/wetlands/Factsheets/WDNR_FactSheet.pdf
	Relative Need Tool	
	Potential Opportunity Tool	
	Potentially Restorable Wetlands	

States that do not have wetland and stream programs that prioritize sites for restoration or protection were selected through deduction. Eleven state wetland programs were determined to exist that have limited access to landscape prioritization methods (see Table 2).

Table 2 States, and associated wetland programs, with limited access to prioritization methods.

State	Wetland program
Alaska	Department of Environmental Conservation
Arizona	Department of Environmental Quality
Connecticut	Department of Environmental Protection
Kentucky	Department of Water Resources
New Jersey	Department of Environmental Protection
New Mexico	Environmental Department
New York	Department of Environmental Conservation
South Carolina	Department of Health and Environmental Control
South Dakota	Department of Environment and Natural Resources
Texas	Council on Environmental Quality
Wyoming	Department of Environmental Quality

2.2 Development of research questions

With input from the Advisory Committee, ELI developed a set of research questions for states that both have and lack such prioritization methods. These questions are provided in Appendix A.

The questions for the 30 landscape prioritization programs were designed to provide information about methods (including Level 2/3 methods), regulatory/non-regulatory applications, transferability, and barriers to development of existing landscape prioritization tools. The questions were organized into categories that included:

- General program information (e.g., "what is the status of your program/tool?")
- The general purpose of the tool (e.g., "list all regulatory/non-regulatory programs to which the tool is intended to be applied")
- Landscape prioritization tool components (e.g., "what aquatic resource functions or values…or other factors…are evaluated?," "at what scale is the tool applied?," etc.)
- Associated Level 2 and Leve1 3 methods (e.g., "what type of Level 2 assessment do you perform?," "is your Level 3 method documented?," etc.)
- Data gaps (e.g., "are there any data gaps that limit the functionality of the tool?")
- Present status and future development of the prioritization program (e.g., "is your prioritization tool transferable to other states?," "has the program been applied to inform actual aquatic resource restoration or conservation decisions?"

Ten questions were developed to gather information for states lacking prioritization tools. Examples of these questions included those designed to elicit information about the characteristics of prioritization tools they find the most appealing, the obstacles they have encountered in seeking to develop landscape prioritization tools, and types of investments by federal, state, or local governmental agencies, or the private/nongovernmental community that would be particularly helpful in facilitating adoption of a landscape prioritization approach.

2.3 Interviews

Between July 2011 and May 2012 ELI interviewed 30 programs that had developed landscape prioritization tools and 11 state programs lacking tools. In addition to the 30 programs listed in our interviews, which were conducted with staff from programs that had developed tools, three previously included programs were ultimately excluded from our sample because methods applied by these programs overlapped substantially with other tools in our study sample (inclusion of these tools would have added little additional variety).[9] Interviews with program representatives lasted about 1.5 hours each.

3 Definitions

Prioritization objective: Prioritization objectives represent the aquatic resource function(s), value(s), condition metric(s), or opportunity metric(s) that are assessed by each prioritization tool/program. The specific prioritization objectives targeted by the tools and programs examined in this study included the following:

• Aquatic resource condition	• Habitat quality
• Carbon storage	• Historic functional change
• Cost-effectiveness	• Social values
• Feasibility of restoration	• Suitability for preservation
• Flood Mitigation	• Surface water supply
• Future impacts	• Sustainability of restoration
• Groundwater supply	• Water quality improvement

Prioritization program: A prioritization program includes any agency, organization, or researcher that developed one or more landscape prioritization tools that prioritized for one or more prioritization objectives. For example, "Michigan Tech Research Institute," which developed the Wetland Mitigation Site Suitability Tool, was considered the prioritization program corresponding to the tool. Additionally, for the tools presented in the Kramer et al. (2012) research article we considered "Kramer et al. (2012)" to be the prioritization program. In some cases, we also identified the prioritization program to include a specific program implemented by the tool developer that facilitated development of the prioritization tool or toolset. For example, the Louisiana Coastal Protection and Restoration Authority (LACPRA) developed its prioritization tools as part of its Coastal Management Plan (CMP). In this case, the prioritization program was defined as "LACPRA CMP."

Prioritization tool: Each prioritization program consists of one or more "prioritization tools." As defined for this study, each prioritization tool represents a landscape metric or index based on a set of data factor inputs and a corresponding output.[10] Furthermore, landscape prioritization tools were only included in the analysis if the landscape unit of analysis used was no larger than the HUC-12 watershed scale. Two types of prioritization tools evaluated in this study included single-objective and multi-objective tools (see below).

Single-objective tool: As shown in Figure 1, below, a single objective tool integrates a set of input factors to derive an output representing a *single* prioritization objective. Eighty-three of the 115 tools examined in this study were single-objective tools.

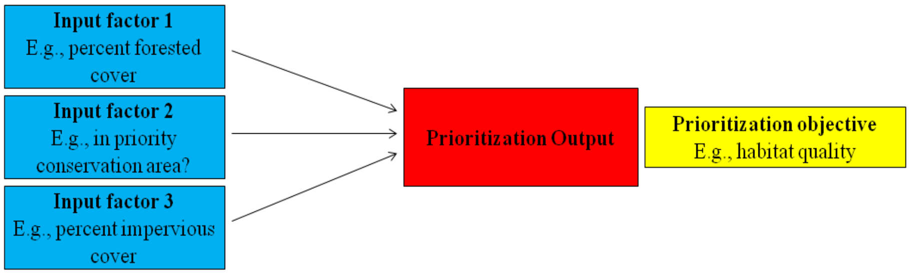


Figure 1. Single-objective tools integrate multiple input factors to produce a prioritization output that evaluates a *single* prioritization objective.

Multi-objective tool: Like single-objective tools, multi-objective tools integrate multiple input factors as part of their analysis. However, the prioritization output obtained using a multi-objective tool represents *multiple* prioritization objectives (Figure 2). Thirty-two of the 115 tools examined in this study were multi-objective tools.

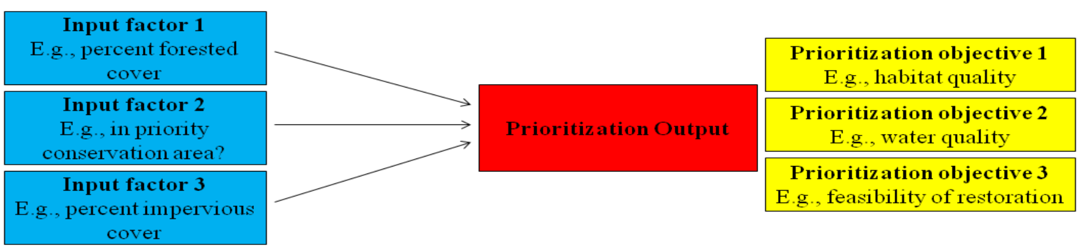


Figure 2. Multi-objective tools integrate multiple input factors to produce a prioritization output that evaluates *multiple* prioritization objectives.

A subset of multi-objective tools combines outputs of other single- and multi-objective tools to produce an output representing multiple objectives (Figure 3). For example, the Kramer et al. (2012) Potential Wetland Bank Site Index combines outputs from several other tools, such as the Kramer et al. (2012) Connectivity to Existing Conservation Lands Tool (which itself prioritizes for habitat quality and social values) to assess prioritization objectives that include habitat quality, water quality, flood mitigation, feasibility of restoration, and social values.

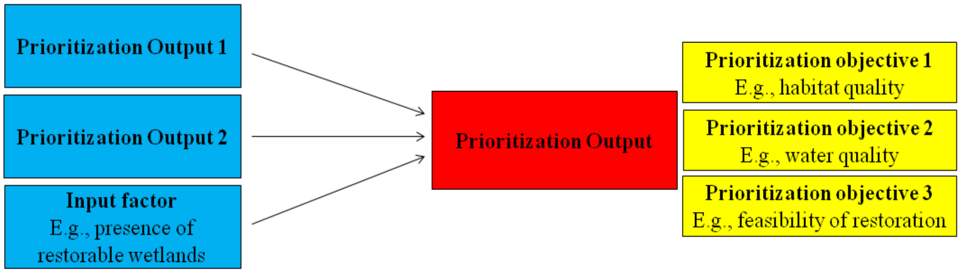


Figure 3. A subset of multi-objective tools integrate input factors that include the prioritization outputs of other prioritization tools to obtain a multi-objective output.

4 Processes applied by landscape prioritization programs

The landscape prioritization programs examined for this handbook prioritize aquatic resource restoration or protection using a variety of processes. The generic sequence of processes that follows reflects the full range of processes observed by these programs. Note that this sequence is all-encompassing and does not reflect the specific subset of processes that would be expected to be used by a given prioritization program.

1. **Determination of prioritization objectives** (e.g., habitat quality, water quality improvement, etc.) based stakeholder feedback or data analysis (Figure 4A; Section 4.1).
2. **Determination of input factors/weightings** based on an analysis of field data or stakeholder feedback (Figure 4B; Section 4.2). In this step, stakeholders may develop input factors or weightings as either an initial step in the prioritization process or based on prioritization objectives determined in the preceding step.
3. **Input data Quality Assurance/Quality Control (QA/QC)** using either field verification or desktop review (Figure 4C; Section 4.3). Methods involved in desktop review included the application of predefined QA/QC guidelines, comparison of input data to other data sources, or examination of whether data inputs were integrated correctly by landscape prioritization tools.
4. **Application of landscape prioritization tools** by using inputs obtained from upstream processes (steps 1, 2, and 3, above) to generate output maps identifying and/or ranking individual hydrologic units (e.g., HUC-12s), wetland polygons, and pixels (e.g., $30m^2$ raster cells) in terms of one or more prioritization objectives (Figure 4D; Section 4.4).
5. **Tool calibration** through an examination of outputs by stakeholders or an analysis of outputs against field data (Figure 4E; Section 4.5).
6. **Tool validation:** Some programs validate the accuracy of their prioritization methods using systematic field confirmation or correlation analysis (Figure 4F; Section 4.6).
7. **Refinement of identified priorities** using field methods (e.g., Rapid Assessment Methods) or expert/stakeholder input (Figure 4G; Section 4.7).

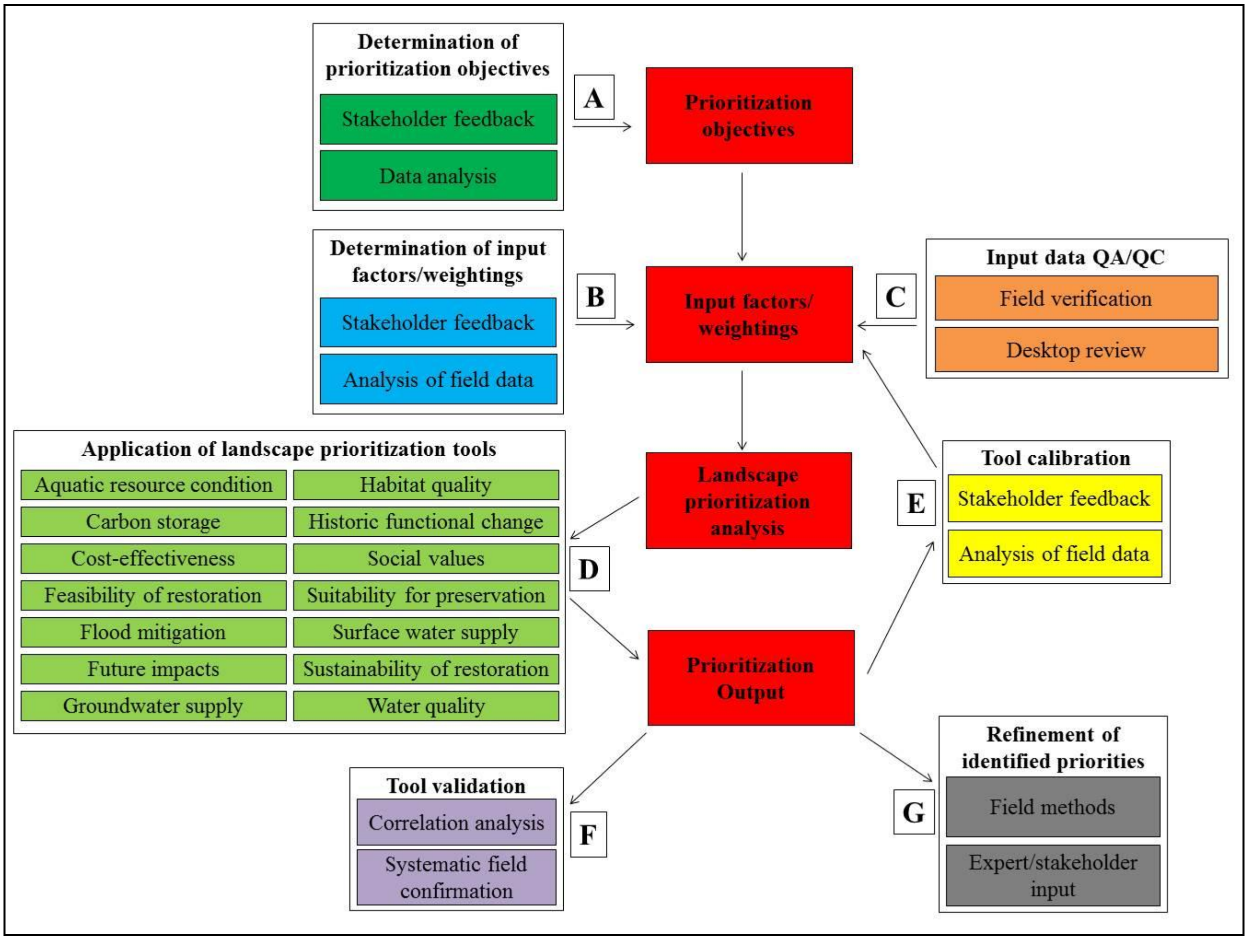


Figure 4. General process applied by the 30 landscape prioritization programs evaluated in this study. Methods applied by programs included: A) determination of prioritization objectives, B) determination of input factors/weightings, C) input data QA/QC, D) application of landscape prioritization tools, E) calibration of landscape prioritization tools, F) validation of landscape prioritization tools, and G) refinement of Level 1 priorities.

4.1 Determination of prioritization objectives

In total, seven of the programs reviewed apply a method for identifying prioritization objectives, five identify objectives by soliciting stakeholders for watershed/landscape needs, and two identify objectives based on watershed/landscape needs using data analysis (Figure 4A; Table 3). In most cases, however, no method for identifying prioritization objectives is used; rather, the tool developer predetermines the method. For example, because the programmatic focus of Ducks Unlimited is migratory waterfowl, Ducks Unlimited developed its Forested Wetland Restoration Suitability Model to prioritize wetland areas for the benefit of waterfowl habitat.[11] Similarly, for Caltrans RAMP prioritization objectives were determined based on Caltrans' regulatory needs (e.g., under the Endangered Species Act) to compensate for losses of wildlife habitat due to transportation projects).[12]

Table 3. Prioritization programs evaluated in this study identified prioritization objectives using two different methods.

	Stakeholder feedback	Data analysis
AR MAWPT		X
Kramer et al. (2012)	X	
NCEEP	X	
NOAA HPP MAHT	X	
TNC Aquatic EA		X
TNC-ELI DPWAP	X	
USEPA RPS	X	

4.1.1 Stakeholder feedback

Five of the programs reviewed determine prioritization objectives by soliciting stakeholder feedback on watershed/landscape priorities. NCEEP's Watershed Needs Assessment Team identified water quality, hydrology, and habitat quality as prioritization objectives, ranking potential areas based on these objectives as part its HUC-14 Screening and Focus Area Identification Tools.[13] For the TNC-ELI DPWAP program, a planning team identified seven wetland services to target as part of its prioritization process based on "(1) their relative importance to humans; (2) the degree to which wetlands, specifically, perform them; and (3) the extent to which we can distinguish their performance at a landscape scale, using available spatial datasets."[14] In addition, during the development of the NOAA HPP MAHT, a stakeholder group developed and agreed upon ten distinct habitat types to target for prioritization.[15] EPA's RPS generally uses input from stakeholder workgroups as part of a roundtable facilitation approach to identify initial prioritization objectives.[16]

Kramer et al. (2012) identified prioritization objectives by soliciting input from a technical steering committee led by GAEPD and including representatives from state and federal agencies, non-governmental organizations, and forest product industry groups.[17] This stakeholder group identified prioritization objectives to be targeted for compensatory wetland mitigation based on regulatory, planning, and management considerations. In contrast to the methods discussed above that used stakeholder feedback to derive objectives for specific watersheds/landscapes, this stakeholder group identified general prioritization objectives that should be used as the basis for prioritization for all watersheds in the state.

4.1.2 Data analysis

Finally, two programs integrated watershed/landscape data analysis as part of their process for identifying prioritization objectives. Arkansas MAWPT's planning team evaluated readily available watershed-scale GIS datasets that capture basic wetland characteristics to identify prioritization objectives for meeting specific needs within each of its Watershed Planning Areas (restoration of riparian corridors to address sedimentation issues).[18] The TNC Aquatic Ecoregional Assessments determine prioritization objectives as a set of "conservation targets" composed of priority ecosystems, communities, and species identified at both fine scales (e.g., rare and endangered species) as well as coarse scales (e.g., large river systems) within each of its Ecological Drainage Units (EDUs).[19]

4.2 Determination of input factors/weightings

Ten of the prioritization programs that we evaluated apply methods for selecting input factors and weightings. Of these, seven obtain input factors and weightings using stakeholder feedback and three derive input factors and weightings based on an analysis of field data (Figure 4B; Table 4). For most of the landscape prioritization programs analyzed, however, input factors and weightings for the landscape prioritization analysis were determined based on the judgment of technical staff (i.e., the tool developer), without use of stakeholder feedback or field data.

Table 4. Programs evaluated in this study applied two different methods for determining input factors/weightings.

	Stakeholder feedback	Analysis of field data
AR MAWPT	X	
Caltrans RAMP	X	
IDFG		X
MD WRR	X	
MTNHP		X
NOAA HPP MAHT	X	
TNC-ELI DPWAP	X	
USACE SRWBMP	X	
USEPA RPS	X	
Weller et al. (2007)		X

4.2.1 Stakeholder feedback

Prioritization objectives translated into input factors using stakeholder feedback: Among the programs that apply stakeholder feedback, four determine input factors/weightings by translating pre-identified prioritization objectives – identified, for example, using the processes described in Section 4.1, above – into data factors (Figure 4). For example, after identifying prioritization objectives for a Wetland Planning Area (WPA), Arkansas MAWPT draws from a set of spatial datasets to develop quantitative factors that will represent each objective in the GIS model. For instance, if the planning team identifies water quality as a prioritization objective, it may use a map of riparian corridors to design an input layer that rates $30m^2$ pixels higher as potential sites for wetland protection or restoration that are adjacent to riparian corridors.[18] Caltrans RAMP inputs habitat conservation targets into the MARXAN tool that targets landscape needs defined by local stakeholders. For example, in its analysis of the Elkhorn Slough watershed, RAMP parameterized its MARXAN reserve selection algorithm using habitat coverage percentages that the Elkhorn Slough Foundation considered to be ecologically desirable for protection (e.g., 30% freshwater wetlands).[12] After identifying initial stakeholder objectives as part of its roundtable facilitation approach, EPA solicits stakeholder feedback to identify relevant input factors and weightings to be applied by its RPS prioritization tool.[16] For NOAA's HPP MAHT, a stakeholder group met to develop prioritization selection criteria identified for each of its ten priority habitat types (four of which are aquatic).[20]

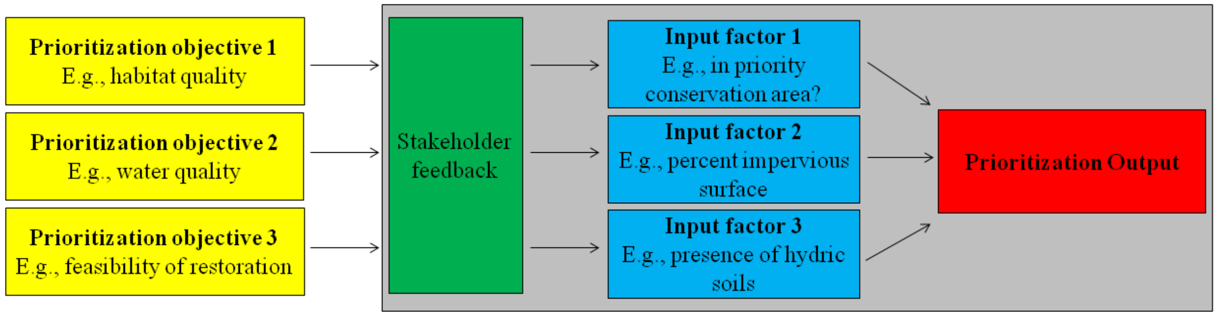


Figure 5 . Stakeholder feedback was used to determine input factors and weightings by directly translating pre-identified prioritization objectives, as shown above. Stakeholder feedback was also used to determine input factors without prioritization objectives explicitly stated (gray box).

Input factors used to evaluate prioritization objectives identified using stakeholder feedback: With three of the programs reviewed, stakeholders or experts collaborated to identify input factors and weightings for their landscape prioritization analysis that were not derived from explicitly-stated prioritization objectives (gray box in Figure 5). For instance, using a multi-partner technical advisory committee that met regularly from 2008-2013, the Maryland WRR selected data inputs and weightings for each of its GIS tools.[21] In contrast, the USACE SRWBMP determined input factors and weightings analytically by using a stakeholder team to interpret results of a baseline analysis and identify a set of important criteria for focusing wetland compensation within each subwatershed. In an online survey, the stakeholders ranked the importance of each criterion, with results analyzed using the Analytic Hierarchy Process (a type of Multi-Criteria Decision Analysis) to determine appropriate weightings for each criterion.[22] The TNC-ELI DPWAP Wildlife Tool used expert input to rate the strength of association between priority habitats (derived from the Wisconsin Wildlife Action Plan) and representative SGCNs.[14] Experts also identified several "proximity factors" to account for landscape-level requirements of each species (e.g., Canada warblers require extensive forested habitat surrounding their primary forested swamp habitat).

4.2.2 Analysis of field data

Three prioritization programs – Weller et al. (2007), IDFG, and MTNHP – determine input factors and weightings using correlation analysis. Weller et al. (2007) applied a systematic field data collection approach to obtain rapid assessment data for nine Functional Capacity Indices (FCIs) across wetlands throughout the Nanticoke watershed. FCI results for this set of wetlands were correlated one-by-one with each of 27 landscape indicators of wetland condition that included percent deciduous forest, mean percent impervious surface coverage, and distance to nearest stream, among others. Those landscape indicators for which the correlations were most significant were then selected to form the basis of a multivariate model for that FCI dataset, resulting in the selection of nine sets of landscape indicators for each of the nine FCI datasets. The researchers found that these multivariate models produced a strong relationship between landscape variables and FCI scores; even the poorest performing models explained nearly 50% of the variability.[23]

Similarly, to parameterize its Landscape Assessment Model, IDFG assembled field-based data, which were correlated with a wide variety of potential landscape metrics (69 total) to determine which landscape metrics to include in its landscape analysis. In contrast to Weller et al. (2007), these field data sources were derived largely from existing Level 2 datasets, though IDFG did collect some additional rapid assessment data to ensure that the final Level 2 dataset used to select landscape analysis metrics represented the variety of wetland environments across the landscape. Based on these correlations, the IDFG produced two landscape analysis models, one composed of 19 metrics and representing a northern region and the other composed of 41 metrics and representing a southern study site.[24]

MTNHP also attempted to find landscape-level predictors of wetland condition to serve as input factors in its analysis. MTNHP derived potential indicators from the literature and expert judgment and applied a Classification and Regression Tree (CART) analysis to select those that best predicted Montana Department of Environmental Quality Rapid Assessment Method (MTDEQ-RAM) scores for wetlands throughout the state. Because MTNHP found few landscape predictors to be valuable in predicting MTDEQ-RAM scores, in the end MTNHP built its LIM based primarily on metrics for landscape-level stressors shown by the scientific literature to have important impacts on wetland condition in addition to those derived using its CART analysis.[25,26]

4.3 Input data QA/QC

Several prioritization programs applied QA/QC (Quality Assurance/Quality Control) methods to ensure that input data were valid prior to using them as input factors in their landscape prioritization analyses (Figure 4C). These methods included a variety of approaches for the field verification and desktop review of data inputs. Those that applied desktop review did so using methods including application of predefined QA/QC guidelines, comparison of input data with other data sources, and examination of the quality with which data inputs were integrated in prioritization processes.

4.3.1 Field verification

Ducks Unlimited field-verified the accuracy of input variables used for two counties as part of its Forested Wetlands Restoration Suitability Model by confirming that areas identified as having high soil moisture by its Soil Moisture Index GIS data layers actually contained high soil moisture. In addition, the Maryland WRR is currently developing rapid on-the-ground assessment methods that will be used to confirm the accuracy of its input spatial data.[21] When obvious discrepancies exist, Arkansas MAWPT applies windshield surveys, field visits, and local knowledge to groundtruth input data that include NRCS soils data, GAP analysis data, NHD data, and other hydrologic data.[27]

4.3.2 *Desktop review*

Application of predefined QA/QC guidelines: NHDES applied comprehensive GIS data quality standards to all datasets used in its analysis. These included using only GIS data of known origin, obtaining the most updated version of each dataset from its original source, and using only datasets properly documented to Federal Geographic Data Committee (FGDC) standards.[28] In addition, all projects using EPA's RPS develop and follow a QA/QC plan that involves an evaluation of input data sources[16] while MTRI follows recommended workflow guidelines for examining input data layers prior to running its analysis.[29] NCEEP ensures that important datasets, particularly aerial photography and land use data, are up-to-date prior to its LWP prioritization analyses.[13]

Comparison of input data with other data sources: Ducks Unlimited applied map agreement analysis to its Soil Moisture Index (SMI) data by comparing areas indicated to contain high moisture in the SMI dataset with areas indicated by SSURGO data to contain hydric soils.[11] Likewise, MTRI compared input data (e.g. soils data) with visualization data such as NWI data and aerial photography.[29] In developing the PRW v.2.1 layer, WDNR instituted a hierarchical subtraction method starting with hydric soils, subtracting out existing wetlands and then subtracting out areas in urban land use. USACE SRWBMP updated its roads data in some areas and removed some mapped roads that were no longer present. It also excluded areas from its hydric soils dataset that had been classified as containing hydric soils but were actually forested to avoid inadvertently advocating conversion of forested areas to wetlands.[30]

Examination of data input integration: Maryland WRR examines the accuracy with which inputs are combined within each of its models to ensure that outputs are calculated correctly.[21] UMass Amherst CAPS researchers put "considerable effort" into integrating data in ways that maximized accuracy to minimize error resulting from the fact that CAPS input data come from a variety of sources and have variable quality. UMass Amherst CAPS researchers are unable to quantify the effects that input data errors have on final results but believe them to be negligible.[31]

4.4 Application of landscape prioritization tools

The 115 tools analyzed in this study targeted a wide variety of prioritization objectives that included biophysical functions (e.g., water quality improvement), social values (e.g., nature-based tourism), opportunity metrics (e.g., feasibility of mitigation), and condition metrics (e.g., based on stressors inferred from surrounding land use). Overall, we categorized prioritization objectives assessed by tools into the 14 categories listed below (Figure 4D):

• Aquatic resource condition	• Habitat quality
• Carbon storage	• Historic functional change
• Cost-effectiveness	• Social values
• Feasibility of restoration	• Suitability for preservation
• Flood mitigation	• Surface water supply
• Future impacts	• Sustainability of restoration
• Groundwater supply	• Water quality

As discussed in Section 2.1, above, 83 tools are single-objective tools while 32 are multi-objective tools. Objectives prioritized by each tool are indicated in Table 4. See http://www.eli.org/Program_Areas/wetland_prioritization.cfm for a detailed inventory of the methods applied by each tool.

Table 5. In this study, we identified a total of 14 different prioritization objectives targeted by landscape prioritization tools. The objectives or sets of objectives prioritized by each of the 115 tools evaluated in this study are indicated below.

	Aquatic resource condition	*Carbon storage*	*Cost-effectiveness*	*Feasibility of restoration*	*Flood mitigation*	*Future impacts*	*Groundwater supply*	*Habitat quality*	*Historic functional change*	*Social values*	*Suitability for preservation*	*Surface water supply*	*Sustainability of restoration*	*Water quality*
AR MAWPT Standard GIS Methodology for Wetland Analysis								X						X
Caltrans RAMP Greenprint Analysis			X					X						
Caltrans RAMP Road Impact Footprint Analysis						X								
CNHP Landscape Integrity Model	X													
CNHP Wetland profile	X													
DU Forested Wetland Restoration Suitability Model				X										
IDFG Watershed Condition Tool	X													
IDFG Wetland Condition Tool	X													
Kramer et al. (2012) Connectivity to Existing Conservation Lands								X		X				
Kramer et al. (2012) Human Development Index						X								
Kramer et al. (2012) Hydrologic Connectivity Between Wetlands					X			X						X
Kramer et al. (2012) Jurisdiction Tool											X			
Kramer et al. (2012) Maintenance of High Biodiversity Streams Tool								X						
Kramer et al. (2012) Natural Upland Habitat Surrounding Sites Tool								X						
Kramer et al. (2012) Potential Runoff Index					X									X
Kramer et al. (2012) Potential Wetland Banking Site index				X	X			X		X				X
Kramer et al. (2012) Terrestrial Dispersal Corridors Between														
Kramer et al. (2012) Water Quality and Quantity Index					X									X
Kramer et al. (2012) Wetland Condition Index					X			X		X	X			X
LACPRA CMP American Alligator Habitat Suitability Index								X						
LACPRA CMP Brown Shrimp Habitat Suitability Index								X						
LACPRA CMP Carbon Sequestration Potential Tool		X												
LACPRA CMP Coastal Louisiana Risk Assessment					X									
LACPRA CMP Crawfish Habitat Suitability Index								X						
LACPRA CMP Eastern Oyster Habitat Suitability Index								X						
LACPRA CMP Gadwall Habitat Suitability Index								X						
LACPRA CMP Green-wing teal Habitat Suitability Index								X						
LACPRA CMP Largemouth bass Habitat Suitability Index								X						
LACPRA CMP Mottled Duck (Foraging) Habitat Suitability Index								X						
LACPRA CMP Muskrat Habitat Suitability Index								X						
LACPRA CMP Nature Based Tourism Suitability Index										X				
LACPRA CMP Nitrogen Uptake Spatial Statistical Approach														X
LACPRA CMP Potential for Freshwater Availability Tool							X							
LACPRA CMP Relative Elevation Sub-Model					X									
LACPRA CMP River Otter Habitat Suitability Index								X						
LACPRA CMP Roseate Spoonbill (Foraging) Habitat Suitability								X						
LACPRA CMP Roseate Spoonbill (Nesting) Habitat Suitability Index								X						
LACPRA CMP Spotted Sea Trout Habitat Suitability Index								X						
LACPRA CMP Storm Surge/Wave Attenuation Potential Suitability Index					X									
LACPRA CMP White Shrimp Habitat Suitability Index								X						
MD WRR Wetland Preservation								X			X			X

	Aquatic resource condition	Carbon storage	Cost-effectiveness	Feasibility of restoration	Flood mitigation	Future impacts	Groundwater supply	Habitat quality	Historic functional change	Social values	Suitability for preservation	Surface water supply	Sustainability of restoration	Water quality
MTNHP Landscape Integrity Model	X													
MTRI Wetland Mitigation Site Suitability Tool				X										
NCEEP Focus Area Identification Method					X			X						X
NCEEP HUC-14 Screening Method					X			X						X
NHDES WRAM Ecological Integrity Tool								X						
NHDES WRAM Flood Protection Tool					X									
NHDES WRAM Groundwater Use Potential Tool							X							
NHDES WRAM Landscape Position Score														
NHDES WRAM Net Functional Benefit Score					X		X	X						X
NHDES WRAM Restoration Sustainability Tool													X	
NHDES WRAM Sediment Trapping and Nutrient Potential Tool														X
NHDES WRAM Significant Habitat Tool								X						
NHDES WRAM Site Identification Model				X										
NHDES WRAM Site Prioritization Model					X		X	X					X	X
NOAA HPP Freshwater Wetlands Tool								X						
NOAA HPP Intertidal Marshes and Flats (Flood Hazard Protection) Tool					X									
NOAA HPP Intertidal Marshes and Flats (Natural Resource Conservation) Tool								X			X			
NOAA HPP Riparian Buffers (Conservation) Tool								X			X			
NOAA HPP Riparian Buffers (Restoration) Tool				X				X						
NOAA HPP Watersheds (River and Stream Conservation) Tool								X			X			
NOAA HPP Watersheds (River and Stream Restoration) Tool				X				X						
Kauffman-Axelrod and Steinberg (2010) Restoration Consideration Areas Tool				X										
Kauffman-Axelrod and Steinberg (2010) Tidal Wetland Restoration Prioritization Tool				X				X						X
PLJV PLDSS Landscape-Scale Model								X						
PLJV PLDSS Site-Scale Model								X						X
Strager et al. (2011) Stream Banking Site Selection Model				X										X
Strager et al. (2011) Wetland Banking Site Selection Model				X										
TNC Ecoreginal Assessment Landscape Context Tool	X													
TNC Ecoregional Assessment Wetland Condition Tool	X													
TNC-ELI DPWAP Carbon Storage Tool		X												
TNC-ELI DPWAP Fish Habitat Tool								X						
TNC-ELI DPWAP Flood Abatement Tool					X									
TNC-ELI DPWAP Function Variety Tool		X		X	X			X			X	X		X
TNC-ELI DPWAP Potentially Restorable Wetlands Tool				X										
TNC-ELI DPWAP Shoreline Protection Tool					X									
TNC-ELI DPWAP Surface Water Supply Tool												X		
TNC-ELI DPWAP Water Quality Protection Tool														X
TNC-ELI DPWAP Watershed Profile Tool									X					
TNC-ELI DPWAP Wetland Preservation Tool											X			
TNC-ELI DPWAP Wildlife Tool								X						
TWRA CWCS HUC-12 aquatic resource prioritization tool								X						
UMass Amherst CAPS Index of Ecological Integrity								X						
USACE SRWBMP Baseline Assessment														
USACE SRWBMP Spatial Decision Support System			X					X						X
USEPA RPS Ecological Capacity Tool								X						
USEPA RPS Recovery Potential Integrated Tool	X			X				X					X	X
USEPA RPS Social Context Tool				X									X	
USEPA RPS Stressor Exposure Tool	X													
USGS Forest Breeding Bird Decision Support Model								X						
VDCR GIS Tool for Identifying Wetland Restoration Opportunities								X						X

	Aquatic resource condition	Carbon storage	Cost-effectiveness	Feasibility of restoration	Flood mitigation	Future impacts	Groundwater supply	Habitat quality	Historic functional change	Social values	Suitability for preservation	Surface water supply	Sustainability of restoration	Water quality
VIMS Wetland Condition Assessment Tool	X													
VIMS Wetland Mitigation Targeting Tool				X										
WADOE Overall Watershed Characterization Tool							X					X		
WADOE WCT Groundwater discharge tool							X							
WADOE WCT Groundwater Recharge Tool							X							
WADOE WCT Water Delivery Tool												X		
WADOE WCT Water Storage Tool												X		
WBSP Union Portfolio								X						
WDNR Flood Storage Decision Support Tool					X									
WDNR Habitat Quality Index								X						
WDNR Potential Opportunity Tool				X										
WDNR Potentially Restorable Wetlands Tool				X										
WDNR Relative Need Tool									X					
WDNR Wetland Preservation Tool											X			
WDNR Wetland Water Quality Assessment Tool														X
Weller et al. (2007) Biogeochemistry (Flat Wetlands)	X													X
Weller et al. (2007) Biogeochemistry (Riverine Wetlands)	X													X
Weller et al. (2007) Habitat (Flat Wetlands)	X							X						
Weller et al. (2007) Habitat (Riverine Wetlands)	X							X						
Weller et al. (2007) Hydrology (Flat Wetlands)	X													
Weller et al. (2007) Hydrology (Riverine Wetlands)	X													
Weller et al. (2007) Landscape (Riverine Wetlands)	X													
Weller et al. (2007) Plant Community (Flat Wetlands)	X													
Weller et al. (2007) Plant community (Riverine Wetlands)	X													

4.4.1 Aquatic resource condition

The nineteen tools that assess aquatic resource condition do so by applying three different types of metrics (Table 6). These include:

- Metrics calculated for buffer regions surrounding wetlands
- Metrics calculated for watershed units
- Metrics derived based on strength of correlation between prospective metrics and field measures

Table 6. Prioritization methods used three different approaches to calculate aquatic resource condition.

	Metrics calculated for buffer region surrounding wetland	Metrics calculated for watershed units	Metrics derived based on strength of correlation between prospective metrics and field measures
CNHP Landscape Integrity Model	X		
CNHP Wetland Profile		X	
IDFG Wetland Condition Tool			X
IDFG Watershed Condition Tool		X	
MTNHP Landscape Integrity Model			X
TNC Aquatic EA Aquatic System Integrity GIS Model		X	
TNC Aquatic EA Landscape Context GIS Model		X	
USEPA RPS Recovery Potential Integrated Tool		X	
USEPA RPS Stressor Exposure Tool		X	
VIMS Wetland Condition Assessment Tool	X		
Weller et al. (2007) Biogeochemistry (Flat Wetlands)			X
Weller et al. (2007) Biogeochemistry (Riverine Wetlands)			X
Weller et al. (2007) Habitat (Flat Wetlands)			X
Weller et al. (2007) Habitat (Riverine Wetlands)			X
Weller et al. (2007) Hydrology (Flat Wetlands)			X
Weller et al. (2007) Hydrology (Riverine Wetlands)			X
Weller et al. (2007) Landscape (Riverine Wetlands)			X
Weller et al. (2007) Plant Community (Flat Wetlands)			X
Weller et al. (2007) Plant community (Riverine Wetlands)			X

Metrics calculated for buffer regions surrounding wetlands: Two tools assess wetland condition for individual wetlands based on landscape metrics calculated for buffer regions surrounding each wetland (Table 6). These landscape metrics often accounted for stressors resulting from surrounding land use such as roads, urbanization, or agriculture. For example, VIMS scored each wetland in coastal Virginia in terms of factors that included land use type, road density, wetland size, and wetland type.

Metrics calculated for watershed units: Six tools calculate wetland condition based on landscape metrics for hydrologic units. For example, the TNC Aquatic EA Aquatic System Integrity GIS Model identified the most intact HUC-12s within Ecological Drainage Units by ranking each HUC-12 in terms of land cover and road impacts (impacts due to roads, urbanization, and agriculture), dam and drinking water supply impacts (impacts caused by altered hydrologic regimes and creation of migration barriers to due dams), and point source impacts (potential chemical threats due to point sources).[19]

Metrics derived based on strength of correlation between prospective metrics and field measures: Eleven tools calculate wetland condition by combining 30m^2 resolution raster datasets, each representing a landscape metric, for the entire study landscape (Table 6). These tools inform their selection of input metrics using an analytic process in which each prospective metric was correlated with field measurements of wetland condition (e.g., RAM scores). Metrics significantly correlated with field indicators were incorporated into landscape prioritization models predicting wetland condition (see Section 4.2.2).

4.4.2 Carbon storage

Three of the tools assess the capacity of wetlands for carbon storage potential based on landscape indicators of the quantity of organic material present (Table 5). The TNC-ELI DPWAP tool drew directly from SSURGO and NWI/NWI+ data to evaluate carbon storage, incorporating factors such as prevalence of high biomass vegetation and the potential of wetlands to serve as carbon sinks based on the inflow of water.[14] In contrast, the LACPRA CMP tool drew upon outputs from its wetland morphology model, such as soil bulk density, organic matter, and percent land. The TNC-ELI DPWAP Function Variety Assessment prioritized for carbon storage potential by incorporating the output of its Carbon Storage Tool along with outputs of several other functional assessment tools.[14]

4.4.3 Cost-effectiveness

Two programs (Caltrans RAMP and USACE SRWBMP) incorporate cost-effectiveness into their prioritization process. In one of its study watersheds, Caltrans RAMP estimated parcel cost for all land parcels within the watershed based on parcel cost data for two counties by developing a function relating parcel cost and size. Caltrans RAMP incorporated these parcel costs into its Marxan greenprint analysis to ensure that the tool prioritized parcels that met mitigation goals in addition to minimizing parcel costs.[12]

For the USACE SRWBMP, stakeholders incorporate land cost, derived from real estate sales data, into a raster calculator model to rank the suitability of each 30m^2 pixel for mitigation. Stakeholders weight land cost against nine other landscape metrics used in the analysis by applying the Analytic Hierarchy Process, a type of Multi-Criteria Decision Analysis, to results of an online survey that assessed stakeholder perceptions of each metric's relative importance.[32]

Needs of programs lacking landscape prioritization tools: In our interviews with states lacking landscape prioritization tools, three of the 11 states (New Jersey, New Mexico, and New York) identified prioritization of aquatic resource restoration and conservation sites in terms of cost-effectiveness (i.e., inclusion of budget constraints) as an important objective of potential landscape prioritization tools.[33,34,35]

4.4.4 Feasibility of restoration

Of the 17 tools that assess feasibility of restoration, nine are single-objective tools (i.e., assess feasibility of restoration alone) and eight are multi-objective tools. Of the nine single-objective tools, eight combine raster or polygon spatial factors (e.g. presence of hydric soils, flood probability, presence of adjacent wetlands, etc.) in ArcGIS to evaluate the likelihood for a wetland to develop successfully at specific locations throughout the landscape. For instance, TNC-ELI DPWAP and WDNR both applied Potentially Restorable Wetlands (PRWs) tools that combined spatial indicators to prioritize areas based on presence of appropriate land cover (e.g., hydric soils, agriculture, etc.) as well as absence of inappropriate landcover (e.g., no existing wetlands, not located in urban areas, etc.).[14]

Two tools for prioritizing feasibility (MTRI Wetland Mitigation Site Suitability Tool and VIMS Wetland Mitigation Targeting Tool) include web or software tools to help users visualize and apply prioritization results.[29,36] For example, MTRI programmed and embedded an interface into ArcGIS to enable MDOT (for whom the tool was designed) to identify watershed or ecoregional boundaries and indicate input layers/weightings to include when applying MTRI's Wetland Mitigation Site Suitability Tool. Using this ArcGIS interface, MDOT is able to visualize the output from the analysis – a site suitability map for the selected watershed or ecoregion – which is produced using standard GIS formats of transportation agencies.[29]

4.4.5 Flood mitigation

We identified a total of 18 landscape prioritization tools that applied two different types of analyses for prioritizing aquatic resources in terms of flood mitigation. These analyses evaluated flood mitigation in terms of:

- Flood benefits from riverine wetlands.
- Flood benefits from marine coastal wetlands.

Needs of programs lacking landscape prioritization tools: In our interviews with states lacking level 1 prioritization tools, four of the 11 states (New Jersey, New Mexico, New York, and South Carolina) identified prioritization of aquatic resource restoration and conservation sites in terms of flood mitigation needs as an important objective of potential landscape prioritization tools.[33,35,37] New York described prioritization for flood mitigation to be an especially important characteristic of any prospective landscape prioritization tool.[35]

Flood benefits from riverine wetlands: Fourteen single- and multi-objective tools target the flood mitigation benefits provided by riverine wetlands. For example, the NHDES WRAM Flood Protection Tool determined the potential for each NWI wetland site to act as a natural flood control buffer based on factors such as storage (e.g., the amount of water that the wetland can hold), outlet flow rate, percentage of the site located within a FEMA floodplain, and the dominant wetland class.[38] The Kramer et al. (2012) Water Quality and Quantity Index evaluated the capacity of wetlands within $30m^2$ cells to limit flooding by multiplying the proportion of runoff following a large storm event (i.e., Potential Runoff Index) by a measure representing the ability of potential restoration sites to limit non-point source pollution based on landscape position (i.e., Distance to Impairment Index).[17] One tool – the TNC-ELI DPWAP Shoreline Protection Tool – evaluated the ability of riverine wetlands to protect shorelines from erosion due to storm surges based on criteria such as river adjacency and presence of densely-rooted vegetation.[14]

Flood benefits from marine coastal wetlands: The other five tools (LACPRA CMP Storm Surge/Wave Attenuation Potential Suitability Index, LACPRA CMP CLARA, LACPRA CMP Relative Elevation Sub-Model, and NOAA HPP Intertidal Marshes and Flats (Flood Hazard Protection) Tool) are single-objective tools that estimate flood attenuation services provided by marine coastal wetlands. For example, the LACPRA CMP Storm Surge/Wave Attenuation Potential Suitability Index estimates the beneficial effects in terms of flood attenuation for $500m^2$ cells that would result from wetland projects within 100- and 500-year flood zones based on wetland location, percent land, vegetation type, and elevation inputs.[39] In addition, the LACPRA CMP CLARA estimates the effect of wetland restoration projects on flood depths and damage for each of the approximately 35,500 census blocks that make up coastal Louisiana.[40] Based on an evaluation of flood elevation for protected (e.g., extensive hurricane protection), semi-protected (incomplete levee/floodwall protection), and unprotected areas (lacking levees/floodwalls), the LACPRA CMP CLARA calculates the total economic damage and risk within each census block due to flooding based on storms of category 3 or higher.

4.4.6 Future impacts

We identified two tools that evaluate future impacts – the Caltrans RAMP Road Impact Footprint Analysis and the Kramer et al. (2012) Human Development Index (HDI). Caltrans RAMP estimates future habitat impacts resulting from planned road projects by applying buffer distances to planned road corridors reflecting the ecological spatial extent of impact for each road classification (e.g., a road 30.5m wide impacted a 10m buffer).[12] Caltrans RAMP then sums the total area affected for each habitat type across all projects in the study region. This assessment of future impacts is used together with anticipated mitigation ratios for each habitat type to estimate Caltrans' future mitigation needs.

In contrast, Kramer et al. (2012) quantifies the presence of current and future threats within each HUC-12 by reclassifying eight datasets representing aquatic resource threats to a scale of one to nine and adding them to obtain a final HDI score.[17] Examples of threats used to calculate the HDI include stream fragmentation, percent impaired streams and rivers, and the change in wetland density between 1974 and 2008.

It is worth noting that no projects examined in this study integrated future impacts related to climate change as part of their Level 1 analysis – e.g., by using expected changes in runoff intensity as a data input. However, the VDCR GIS Model considered the potential integration of climate change by indicating plans to use data on expected sea level rise obtained from the Sea Level Affecting Marshes (SLAM) model (see Section 5.4.1). If the goal of approaches that prioritize wetland restoration and protection in terms of future impacts is to achieve sustainable long-term watershed management, then climate change impacts must be addressed.

4.4.7 Groundwater supply

Four of the six tools that evaluate groundwater supply services produced by wetlands did so by targeting groundwater supply alone. Two of these estimate groundwater supply as a service to humans by ranking individual wetlands based on proximity to public or private water supply wells (NHDES WRAM Groundwater Use Potential Tool)[38] or ranking $500m^2$ cells based on proximity to industrial or municipal freshwater users (LACPRA CMP Potential for Freshwater Availability Tool).[41] LACPRA CMP also evaluates freshwater availability by simulating the effects of salinity.

Two other single-objective tools – WSDOE WCT Groundwater Recharge Tool and WSDOE WCT Groundwater Discharge Tool – specifically evaluate importance and impairment of hydrologic units for groundwater supply without considering the location of beneficiaries.[42] For example, WSDOE's Recharge Tool estimates the importance of a hydrologic unit for recharge based on permeability of the soil and annual average precipitation. It also estimates the impairment of an area for recharge by adjusting the total recharge value based on the intensity of land use within each hydrologic unit.

Two of the multi-objective tools (WSDOE WCT Overall Watershed Characterization Tool and NHDES WRAM Potential Functional Uplift Tool) prioritize for groundwater supply by incorporating the outputs of the aforementioned groundwater supply analyses to produce an output that addresses groundwater as well as other objectives.[38]

4.4.8 Habitat quality

Needs of programs lacking landscape prioritization tools: Five of 11 states without landscape prioritization tools (New Jersey[33], New Mexico[34], New York[35], South Carolina[37], and Texas[44]) identified prioritization of aquatic resource restoration and conservation sites in terms of habitat needs as an important objective of potential landscape prioritization tools.

We identified a total of 36 landscape prioritization tools that apply eight different types of analyses for prioritizing aquatic resources in terms of habitat quality (Table 7). These analyses evaluate habitat quality in terms of:

• Specific Species	• Connectivity
• Groups of related species	• Connectivity to conservation lands
• Diverse species groups	• Streams
• Overall ecological condition	• Riparian buffers

Table 7. The 36 tools prioritizing habitat quality applied eight different approaches.

	Specific species	Groups of related species	Diverse species groups	Overall ecological condition	Connectivity to wetlands or terrestrial habitat	Connectivity to conservation lands	Streams	Riparian buffers
Kramer et al. (2012) Connectivity to Existing Conservation Lands Tool						X		
Kramer et al. (2012) Hydrologic Connectivity Between Wetlands						X		
Kramer et al. (2012) Maintenance of High Biodiversity Streams Tool							X	
Kramer et al. (2012) Natural Upland Surrounding Site Tool					X			
Kramer et al. (2012) Potential Wetland Bank Site Index						X		
Kramer et al. (2012) Wetland Condition Index						X		
LACPRA CMP American Alligator Habitat Suitability Index	X							
LACPRA CMP Brown Shrimp Habitat Suitability Index	X							
LACPRA CMP Crawfish Habitat Suitability Index	X							
LACPRA CMP Eastern Oyster Habitat Suitability Index	X							
LACPRA CMP Gadwall Habitat Suitability Index	X							
LACPRA CMP Green-wing teal Habitat Suitability Index	X							
LACPRA CMP Largemouth bass Habitat Suitability Index	X							
LACPRA CMP Mottled Duck (Foraging) Habitat Suitability Index	X							
LACPRA CMP Muskrat Habitat Suitability Index	X							
LACPRA CMP River Otter Habitat Suitability Index	X							
LACPRA CMP Roseate Spoonbill (Foraging) Habitat Suitability Index	X							
LACPRA CMP Roseate Spoonbill (Nesting) Habitat Suitability Index	X							
LACPRA CMP Spotted Sea Trout Habitat Suitability Index	X							
LACPRA CMP White Shrimp Habitat Suitability Index	X							
NHDES WRAM Ecological Integrity Tool				X				
NOAA HPP Riparian Buffers (Conservation) Tool								X
NOAA HPP Riparian Buffers (Restoration) Tool								X
NOAA HPP Watersheds (River and Stream Conservation) Tool							X	
NOAA HPP Watersheds (River and Stream Restoration) Tool							X	
PLJV PLDSS Landscape-Scale Model		X			X			
Strager et al. (2011) Stream Banking Site Selection Model							X	
TNC-ELI DPWAP Fish Habitat Tool		X						
TNC-ELI DPWAP Wildlife Tool			X					
TWRA CWCS HUC-12 Aquatic Resource Prioritization Model			X					
UMass Amherst CAPS Index of Ecological Integrity				X				
USEPA RPS Ecological Capacity Tool				X				
USGS Forest Breeding Bird Decision Support Model		X			X			
WDNR Habitat Quality Index			X					
Weller et al. (2007) Habitat (Flat Wetlands) Tool				X				
Weller et al. (2007) Habitat (Riverine Wetlands) Tool				X				

Specific species: Fourteen Habitat Suitability Index (HSI) tools, applied as part of LACPRA's Coastal Master Plan, prioritized habitat areas for specific species (Table 7). HSI scores represented the effects of wetland projects on individual species known to inhabit the Louisiana coast and were calculated for $500m^2$ landscape units based on habitat factors known to align with habitat preferences of each species evaluated. For example, LACPRA ranked $500m^2$ landscape units higher for American alligator habitat that contained larger amounts of edge habitat (an indicator of more plentiful prey) and lower salinity (the American alligator is a freshwater species).[45]

Groups of related species: Three tools identified priority habitat areas for groups of related species (Table 7). For example, the TNC-ELI DPWAP Fish Habitat Tool ranks the ability of potential wetland restoration and preservation sites to serve as fish habitat based on factors reflecting fish habitat "opportunity" (e.g., connectivity with lakes and stream) and "effectiveness" (e.g., wetland not 303(d) listed).[14] Additionally, the USGS Forest Breeding Bird Decision Support Model rates 30m^2 raster cells throughout the Mississippi Alluvial Valley in terms of their ability to benefit forest-breeding birds through restoration of bottomland hardwood forest habitat.[46] The PLJV PLDSS Landscape-Scale Model prioritizes migratory waterfowl habitat highest where playa complexes occurred containing multiple, densely-distributed playas as well as fewer, larger, isolated playas based on known relationships between dabbling duck abundance and playa density.[47]

Diverse species groups: Of the three tools that prioritized habitat areas for diverse species groups (Table 7), two identify priority habitat areas for Species of Greatest Conservation Need (SGCN) derived from State Wildlife Action Plans. For priority habitats, the TNC-ELI DPWAP Wildlife Tool identify restoration and protection sites important to SGCN species by combining values representing the strength of association between these habitats and SGCN species and proximity factors (derived based on expert input; see Section 4.2.1).[14] In contrast, the TWRA CWCS HUC-12 Aquatic Resource Prioritization Model calculates an overall priority score for each HUC-12 throughout Tennessee for each SGCN species from its Comprehensive Wildlife Conservation Strategy.[48] This score was calculated based on a rarity score, calculated as the species global rank added to its state rank, and a viability score, calculated by multiplying species size, condition, and landscape context. An overall priority score was calculated for Tier 1, Tier 2, and Tier 3 SGCN species to obtain prioritization maps of HUC-12 watersheds for species of varying conservation significance. The WDNR Habitat Quality Index prioritized for habitat quality through an analysis of "suites of species with shared habitat requirements" or "umbrella species."[49] This tool associates 13 wetland habitat types (e.g., wetlands near woodlands) with umbrella species (e.g., wood frog) so that each species accounts for the habitat requirements of several other species sharing the same habitat type. WDNR then scores 15 land cover types in terms of their importance for each umbrella species based on input from an expert group in addition to several proximity factors. WDNR uses this expert-provided information to parameterize a GIS model that identified potential habitat for each species. Results for each species are then combined to produce a final Habitat Quality Index score.[50]

Overall ecological condition: Five tools prioritized habitat quality based on an assessment of overall ecological condition (Table 7). While these tools apply many of the same data inputs as other tools for assessing habitat quality described in this section (e.g., factors related to the upland context of a site), they are distinguished from other habitat tools by their focus on prioritizing for ecological condition generally, rather than more specific habitat characteristics (e.g., specific species). For example, the NHDES WRAM Ecological Integrity Tool scores each wetland in terms of the capacity of surrounding upland to provide a buffer from human activity.[38] Additionally, the UMass Amherst CAPS Index of Ecological Integrity uses raster processing to score each 30m^2 area in terms of its ability to support the long-term sustainability of biodiversity. It does so for 22 different aquatic community types by drawing upon indicators of ecological condition including nutrient loading, intensity of nearby road traffic and effects of development on habitat connectivity.[51] The USEPA RPS Ecological Capacity Tool evaluates the ecological condition of hydrologic units in terms of their physical/biotic structure and key natural processes. In doing so, it accounts for factors such as watershed natural structure, corridor and shorelands stability, flow and channel dynamics, biotic community integrity, aquatic connectivity, and ecological history.

Connectivity to wetlands or terrestrial habitat: Three tools prioritized wetlands based on their connectivity to other wetlands or important terrestrial habitat (Table 7). For example, the USGS Forest Breeding Bird Decision Support Model scores $30m^2$ cells throughout the Mississippi Alluvial Valley in terms of the potential benefit they provide to forest-breeding birds if restored to bottomland hardwood forest habitat.[46] The tool scores potential restoration areas based on their proximity to forest core areas, with proximity scores weighted based on core area size. The Kramer et al. (2012) Natural Upland Surrounding Site Tool ranks $30m^2$ areas in terms of their connectivity to vegetated upland habitats, which provide important benefits to wetland-dependent wildlife – in particular, amphibians disperse through upland habitat connecting neighboring wetlands and forage and breed in upland forests.[17] This tool evaluates sites in terms of percentage of upland vegetation within a 500-meter radius to capture the amphibian range of movement in addition to that of more vagile species.

Connectivity to conservation lands: Four multi-objective tools included connectivity as a factor in their prioritization analysis. For example, the Kramer et al. (2012) Connectivity to Existing Conservation Lands Tool uses an area-weighted connectivity function to rank areas higher where they are located in closer proximity to conservation areas identified in the Georgia Conservation Lands Database.[17] These rankings are generated for several conservation area layers, which are summed so that final rankings indicate potential sites that would enhance connectivity among multiple conservation areas.[52]

Streams: Four tools addressed habitat quality for rivers and streams. For example, for the NOAA HPP Watersheds (River and Stream Conservation) Tool, stakeholders collaborated to identify a set of parameters that would effectively prioritize watershed units for river and stream conservation.[15] Stakeholder-derived parameters include impervious surface coverage and presence of impaired streams. The Strager et al. (2011) Stream Banking Site Selection Model identifies potential stream and wetland mitigation banking sites by first delineating subwatershed boundaries around individual stream segments between stream confluences and tributaries.[53] Those stream segments with drainage areas ranging from 1 to 130 km^2, and which were biologically impaired due to sedimentation, temperature, or animal waste runoff (i.e., listed on WVDEP's 303d list of impaired waters), are identified as priorities for mitigation banking.

Riparian buffers: Two tools evaluated habitat quality for riparian buffers (Table 7). For example, in developing the NOAA HPP Riparian Buffers (Restoration) Tool, a stakeholder group selected metrics for buffer width, buffer vegetation, buffer length, and buffer landscape position to prioritize riparian buffer restoration.[15]

4.4.9 Historic functional change

Two tools – TNC-ELI DPWAP Watershed Profile Tool and WDNR Relative Need Tool – prioritized aquatic resources for historic functional change.[14] For example, the TNC-ELI

DPWAP Watershed Profile Tool measures the historic change in magnitude and distribution of four wetland services – water quality protection, flood abatement, surface water supply, and carbon storage.[14] It does so using NWI+ LLWW modifiers (Landform, Landscape position, Waterbody type, and Water flow path), which can be applied to NWI wetland maps to identify the highest performing wetlands for each service based on known "functional correlations" between each LLWW classification and each service. For each wetland service, the team calculated historic change in functional performance for each HUC-12 watershed by comparing the current acreage of high functioning wetlands with the historic acreage of high functioning wetlands within each HUC-12.

The WDNR Relative Need Tool assesses historic functional change by scoring HUC-12 by measuring the extent to which wetland restoration has the potential to improve wetland functions (e.g., flood storage, water quality, and habitat) within a subwatershed. The tool scores HUC-12 watersheds highest that have lost large amounts of wetland acreage but have few restored or remaining acres and have a large original wetland acreage relative to the total size of the HUC-12. The tool does not evaluate specific functions, but rather assumes that wetland restoration will produce general functional improvement.

4.4.10 Social values

One tool – LACPRA Nature Based Tourism Suitability Index – prioritizes potential benefits of wetland projects in terms of social values.[54] This tool measures the potential for a wetland project to provide habitat suitable for nature-based tourism by scoring each 500m^2 cell based on factors that include distance from major population centers, distance from points of interest, land cover type, distance to beaches, barrier island percent land, type of beach polygon, and quantity and quality of various species habitat. For example, 500m^2 cells closer to points of interest (e.g., wildlife refuges), closer to beaches, and more than 90% developed or agricultural land cover are ranked higher in the model.

In addition, three multi-objective tools – Kramer et al. (2012) Connectivity to Existing Conservation Lands Tool, Potential Wetland Bank Site Index, and Wetland Condition Index – prioritize potential wetland restoration and conservation sites for recreation, education, and scenic value based on the connectivity with existing conservation areas.[17] Using an area-weighted connectivity function, the Kramer et al. (2012) Connectivity to Existing Conservation Lands Tool ranks areas higher where they were located in closer proximity to conservation areas identified in the Georgia Conservation Lands Database. This analysis was carried out for several conservation area layers, which were summed such that higher ranks indicate sites that enhance connectivity among multiple conservation areas.

4.4.11 Suitability for protection

Two of the tools reviewed prioritize wetlands for suitability of protection. The TNC-ELI DPWAP Wetland Preservation Tool identifies potential wetland protection sites as both existing wetlands in the Duck-Pensaukee watershed as well as areas along the Lake Michigan coast that alternate between upland and wetland conditions.[14] The Kramer et al. (2012) Jurisdiction Tool prioritizes potential sites that are less vulnerable to development because they are within the

Savannah Corps District's definition of jurisdiction for wetlands ("within 100 feet of navigable waters or within the 100 year floodplain") under §404 of the Clean Water Act.[17]

Seven of the multi-objective tools reviewed include wetland preservation as a primary objective.[55] For example, the Maryland WRR Wetland Preservation Tool scores 30m^2 cells higher for wetland preservation that satisfies preservation suitability criteria such as 'cannot already be protected,' 'is a Wetland of Special State Concern,' and 'is in a Sensitive Species Project Review Area,' to name a few.[43] Additionally, two multi-objective tools prioritize riparian buffers for preservation – e.g., the NOAA HPP Riparian Buffers (Conservation) Tool scores 30m^2 areas classified as riparian buffers higher that meet criteria such as '30m wide on both sides,' 'composed of intact natural vegetation,' and 'at least 500m in length.'[15] One multi-objective tool – the NOAA HPP Watershed (River and Stream Conservation) Tool – prioritizes HUC-12 watersheds in terms of quality for river and stream preservation based on factors including 'contains less than 10% impervious surface' and 'contains no impaired streams.'[15]

4.4.12 Surface water supply

Of the three single-objective tools that prioritize for surface water supply, two were developed by WSDOE. The WSDOE WCT Water Delivery Tool and WSDOE WCT Water Storage Tool rank user-defined hydrological units in terms of "importance" and "impairment" for water delivery and water storage (i.e., surface water supply).[42] For the Water Delivery Tool, WSDOE considers hydrologic units to have a higher importance if they have higher annual precipitation and larger coverage by rain-on-snow and snow-dominated zones. On the other hand, the tool scores these units higher for "impairment" if they had poorer timing of water delivery caused by high percent coverage by either non-forest vegetation or impervious surfaces. In contrast, for its Water Storage Tool, WSDOE considers hydrologic units to have higher importance if they have a higher percentage of depressional wetlands and higher percentage unconfined and moderately confined floodplains. The tool ranks hydrologic units higher for impairment if they had larger areas of storage wetlands lost in urban and agricultural areas and more miles of channelized stream in unconfined and moderately unconfined floodplain. The third tool prioritizing for surface water storage alone is the TNC-ELI DPWAP Surface Water Supply Tool, which evaluates the ability of individual potential restoration and preservation sites to provide surface water supply services based on their ability to meet a number of preservation criteria.[14] Criteria include one "opportunity" criterion ('site is in a headwater setting') and two "effectiveness" criteria ('site is in a floodplain or fringe setting' and 'site is a pond or lake with perennial throughflow or outflow').[56]

4.4.13 Sustainability of restoration

One tool – NHDES WRAM Restoration Sustainability Tool – prioritizes NWI wetlands for sustainability of restoration alone by scoring potential restoration wetlands higher where they are covered by a low percentage of unfragmented landscape, are located within conservation management areas, and have a low human2 score.[38,57] Sites scoring lower for restoration sustainability using NHDES's tool are less likely to be sustainable over the long-term (e.g., those near urban areas), while those scoring higher are more likely to retain improvements in function (e.g., those located within conservation areas).[38] The output from this tool is used as an input factor for the NHDES WRAM Site Prioritization Tool, which prioritizes sustainability for restoration in addition to habitat quality, flood mitigation, groundwater supply, and water quality.

USEPA RPS Social Context Tool prioritizes for sustainability of restoration, among other objectives, by scoring each user-defined hydrologic unit based on several factors known to influence restoration success. These include leadership, organization, and engagement; protective ownership or regulation; level of information, certainty, and planning; restoration cost, difficulty, or complexity (as indicated by the number of landowners per river mile); socioeconomic considerations; and human health, beneficial uses, recognition and incentives.[58]

Needs of programs lacking landscape prioritization tools: In our interviews with states lacking landscape prioritization tools, seven of the 11 states (Kentucky[59], New Jersey[33], New Mexico[34], New York[35], South Carolina[37], Texas[44], and Wyoming[60]) identified development or persistence of sustainable aquatic resources as an important objective of potential landscape prioritization tools. South Carolina and New Mexico considered the identification of sustainable restoration/conservation sites to be especially important.[34,37]

4.4.14 Water quality

Of the four tools that prioritize for water quality improvement alone, two tools – NHDES WRAM Sediment Trapping and Nutrient Attenuation Tool and WDNR Wetland Water Quality Assessment Tool – focus specifically on trapping and storing sediments and nutrients.[38] The NHDES WRAM Sediment Trapping and Nutrient Attenuation Tool scores each NWI wetland in terms of its ability to improve water quality based on the opportunity to capture pollutants (e.g., average slope of contributing watershed), potential to capture sediment (e.g., riparian buffer width of the site), potential for nutrient attenuation (e.g., dominant wetland class), and sediment loading potential (e.g., soil erodibility of upslope drainage).[38] In addition, WDNR Wetland Water Quality Assessment Tool assigns a relative score to each catchment (HUC-14) based on the degree to which its wetlands protect downstream water quality by trapping sediment. The relative amount of sediment trapped by wetlands in each catchment is determined using a sediment loading grid and P-8 model and a variety of data inputs (e.g., elevation, hydrography, and land use) to calculate the relative sediment loading in each catchment multiplied by the relative wetland trapping efficiency. By adding wetland area to the input wetland map representing locations of potential wetland restoration projects, planners can estimate the relative increase in sediment trapping that can be gained in a catchment through wetland restoration.[61]

In contrast, the LACPRA CMP Nitrogen Uptake Spatial Statistical Approach estimates nitrogen removal due to denitrification resulting from wetland protection or restoration projects. It does so by first estimating nitrogen removal for vegetation for saline, brackish, intermediate, and freshwater habitat before then calculating benthic rates of denitrification by adjusting denitrification rates for vegetation by salinity and temperature for each project site.[62]

A fourth tool, the TNC-ELI DPWAP Water Quality Protection Tool, evaluates the capacity of sites to protect water quality based on "opportunity" (e.g., 'point source discharge upstream or directly into the site'), "effectiveness" (e.g., 'site has seasonally fluctuating water levels'), and "social significance" (e.g., 'wetland occurs in or above a catchment containing 303(d) waters') criteria.[14]

Needs of programs lacking landscape prioritization tools: Six of the 11 states without landscape prioritization tools (Kentucky[59], New Jersey[33], New Mexico[34], New York[35], South Carolina[37], and Texas[44]) identified prioritization of aquatic resource restoration and conservation sites in terms of water quality needs as an important objective of potential landscape prioritization tools.

4.5 Tool calibration

Needs of programs lacking landscape prioritization tools: In our interviews with states lacking landscape prioritization tools, we found that five of the 11 states (Kentucky[59], New Jersey[33], New Mexico[34], South Carolina[37], and Wyoming[60]) identified calibration/validation as an important characteristic of potential landscape prioritization tools. For Kentucky, calibration/validation was cited as one of the most important characteristics that a landscape prioritization tool should have.[59]

Methods for calibrating the results of landscape prioritization tools were applied by four programs (Figure 4E; Table 8). These methods included:

- Calibration based on stakeholder feedback.
- Calibration based on an analysis of field data.

Table 8. Programs evaluated in this study applied two different methods for calibrating landscape prioritization tools.

	Stakeholder feedback	*Analysis of field data*
NHDES WRAM	X	
UMass Amherst CAPS		X
USACE SRWBMP	X	
VIMS WetCAT		X

4.5.1 Stakeholder feedback

Two prioritization programs – NOAA HPP MAHT and USACE SRWBMP – calibrated their landscape prioritization tool(s) through stakeholder evaluation of outputs. Applied to the development of the NOAA HPP MAHT tools, output maps were visualized for the Mobile Bay National Estuary Program's Coastal Habitats Coordination Team, a stakeholder group consisting of over 60 state and local resource professionals that had informed the initial parameterization of the tools.[15] This stakeholder group drew upon its collective expertise and on-the-ground experience to provide feedback to refine parameters applied by the model and improve results.[20] In a subsequent round of feedback, this stakeholder group again evaluated output maps to adjust inputs and weightings for the models and generate a final prioritization map.[15] Similarly, the output map resulting from the USACE SRWBMP prioritization process was evaluated by stakeholders and adjusted based on a final round of feedback before a final prioritization map was generated.[22] The Corps expects this process to be iterative, with stakeholder feedback used to adjust inputs and weights for the model on a periodic basis. The SDSS will be rerun by the St. Paul District as necessary to update model results.

4.5.2 Analysis of field data

Methods for using field data to calibrate the ability of tools to accurately identify areas or sites in which aquatic resource restoration or protection will most effectively target prioritization objectives are essential for improving tool effectiveness. In this study, two programs that relied on expert judgment to determine input factors established weightings for these factors by analyzing model outputs against field data. VIMS WetCAT researchers developed input factors based on expert judgment and calibrated the model using data obtained from field surveys in which they counted the number of anthropogenic stressors within 30m and 100m buffer regions for 1,928 randomly-sampled wetland sites. VIMS correlated counts for the most frequently observed stressors (e.g., roads, brush cutting) with Level 1 scores and applied changepoint analysis to account for nonlinear thresholds in these relationships to establish a final scoring protocol.

In addition, UMass Amherst CAPs researchers calibrate their IEI model by comparing Index of Biological Integrity (IBI) scores obtained on the ground using site level assessment methods (SLAMs) with IBI scores derived from IEI scores. This approach tells them whether sites are actually more degraded than their landscape prioritization models are indicating, thus informing changes to the models.[31]

4.6 Tool validation

While calibration based on field data can be used to improve the accuracy and effectiveness of landscape prioritization tools, validation methods may be applied to document the accuracy of landscape prioritization tools. Of the seven programs that apply a method for validating priorities (Figure 4F; Table 9), five utilize methods involving systematic field validation while two adopted methods based on correlation analysis.[63]

Table 9. Programs evaluated in this study applied two different methods for validating landscape prioritization tools.

	Systematic field confirmation	Correlation analysis
CNHP		X
MTNHP	X	
MTRI	X	
USACE SRWBMP	X	
USGS	X	
VIMS WetCAT		X
WDNR	X	

Among programs that did not apply a validation method, three offered rationales for their decision not to validate their tool(s). UMass Amherst CAPS considered the use of Level 2 Rapid Assessment Methods (RAMs) to verify their Level 1 model to be inappropriate due to the fact that RAMs essentially represent unsophisticated models based on field data.[31] Because validating based on Level 2 RAM data would essentially mean verifying one model based on another, and because a sophisticated Level 1 assessment might be expected to perform better than a RAM in the first place, UMass Amherst CAPS applied a Level 1 approach alone. NHDES stated that it did not validate its Level 1 outputs using Level 2/3 methods because Level 2/3 methods are too costly and landscape prioritization tools are more accessible to stakeholders than Level 2/3 methods.[28] The USEPA RPS considers validation to be infeasible, citing the large variability among recovery watersheds with screening results, the limited opportunities to validate among these watersheds, and the insufficient time since restoration for projects informed by USEPA RPS tools.[16]

4.6.1 Systematic field validation

Five prioritization programs – USACE SRWBMP, USGS, MTRI, WDNR, and MTNHP – apply systematic field confirmation methods. For example, the USACE SRWBMP utilizes rapid field surveys (more rapid than traditional RAMS) to validate results of its SDSS tool for two sites within each of the ten subwatersheds of the Sunrise River watershed.[30] Sites selected for validation have all been identified as high priorities by the tool and are generally representative of wetlands within the watershed. Results show that priorities identified by the model generally match field observations. In contrast, the WDNR Potentially Restorable Wetlands Tool relies upon a random stratified sampling method to assess the accuracy of its PRW layer across three watersheds.[64] By evaluating randomly-selected points within PRWs and non-PRWs, WDNR found the accuracy of the tool to be "very acceptable," exceeding 80% in the three watersheds. To validate its Wetland Mitigation Site Suitability Tool, MTRI and MDOT follow workflow procedures for the tool to compare site suitability rankings provided by the tool with rankings obtained based on field monitoring data.[65] As a result, they found that the tool correctly assessed wetland suitability for 19 of the 20 sites. In demonstrating the tool's accuracy, the validation study also showed that the WMSST would produce substantial savings for MDOT, reducing costs for evaluating potential mitigation sites by 73%.

4.6.2 Correlation analysis

Two prioritization programs – VIMS WetCAT and CNHP – apply more elaborate statistical methods to evaluate tool accuracy. To validate outputs from its Landscape Integrity Model (LIM), CNHP correlates model results against three Level 2 assessments (Human Disturbance Index, Ecological Integrity Assessment, and Mean C assessment) and one Level 3 assessment (Vegetation Index of Biotic Integrity).[66] Because CNHP found correlations to be strong for all three Level 2 assessments, it concluded the LIM to be an accurate tool for the assessment of landscape integrity. In addition, the VIMS Wetland Condition Assessment Tool validates the ability of its Level 1 land cover scores and Level 2 stressor counts to predict a direct measure of habitat provision – acoustic signatures obtained using sound recording devices at 27 sampling sites. VIMS then uses an "analysis of similarity" to demonstrate that its Level 1 and 2 methods accurately reflected habitat provision. VIMS also uses Pearson correlation to demonstrate the relationship between land use metrics (percent pasture, percent rowcrops) and water quality measures (total dissolved nitrogen, total suspended sediment, incision ratio).

4.7 Refinement of identified priorities

Twelve of the prioritization programs reviewed here apply methods for refining the results of their landscape prioritization analysis. Seven of these apply field methods (e.g., Rapid Assessment Methods) to narrow down priority sites while five draw upon expert/stakeholder input to refine output maps (Figure 4G; Table 10).[67]

Table 10. Programs evaluated in this study applied two different methods for refining outputs from landscape prioritization tools.

	Field methods	Expert/stakeholder input
Caltrans RAMP	X	
CNHP	X	
LACPRA CMP		X
MD WRR	X	
MTRI		X
NCEEP		X
Strager et al. (2011)	X	
TNC Aquatic EA	X	X
UMass Amherst CAPS	X	
WSDOE	X	
TNC WBSP		X

4.7.1 Field methods

Seven of the prioritization programs analyzed describe methods for refining the results of their tools using field methods (Table 10). Strager et al. (2012)'s method for refining priority sites, for example, was specifically developed for integration with the landscape prioritization process. The method scores potential wetland sites based on rapid assessment criteria, collected in the field by wetland specialists, with weightings for each criteria derived by asking each specialist to evaluate a series of pairwise comparisons among criteria (i.e., the Analytical Hierarchy Process). Strager et al. (2012) then evaluates the three highest ranked sites within each HUC-10 watershed by using intensive on-site assessments to identify which sites are most feasible for combined wetland and stream mitigation banking.[53]

In addition, after selecting potential parcels to target for compensatory mitigation using its Marxan Greenprint Analysis, Caltrans RAMP uses the California Rapid Assessment Method (CRAM)[68] to field-verify sites as part of its final site selection process. It also applies intensive data collection methods as appropriate for particular areas of California that may include species surveys developed by FWS or CDFG, depending on species offset assessment requirements (for example, if eradication of invasive species is a mitigation objective, then intensive vegetation assessments might be used).[69]

The TNC Aquatic Ecoregional Assessment GIS models provide further examples of tools for which prioritization results are refined using Level 2/3 methods. TNC refines priority conservation areas (PCAs) identified in its Aquatic EA by developing a Conservation Action Plan (CAP) which relies upon field data in PCAs to identify specific locations and strategies for implementing aquatic resource restoration and conservation projects. TNC does not use a standard Level 2/3 method for its field-based assessments, but instead relies on a variety of techniques including simple walkthroughs, sophisticated site feasibility analyses, and detailed parcel analyses that identify priority tracts of land. Furthermore, as part of its CAP, TNC also projects the demand for credits within each service area (service areas are similar to EDUs for the ILF program) to understand where credits could be pooled to enable larger and more effective projects. Using this information, TNC develops strategies for implementing on-the-ground restoration and conservation activities that would meet the goals it had set for each target.[70,71]

CNHP will use LIM results as a coarse filter to identify high and low quality wetlands to determine where to apply more detailed targeted assessment methods. In this way, the LIM supports CNHP's broader conservation planning program, which primarily involves field-based assessments that are used to rank wetlands in terms of a "biodiversity significance rank" (B-rank) by conducting surveys at the county level. However, the method can also be used to rank wetlands at the watershed, planning area, and ecoregional scale. CNHP stores survey data in its Biotics database and uses the data to rank wetlands and uplands in terms of their biodiversity significance.[72]

4.7.2 Expert/stakeholder input

Five of the prioritization programs reviewed here refine outputs of landscape prioritization tools based on expert/stakeholder input (Table 10). For example, after applying its Level 1 GIS screening analyses (see above), the TNC Aquatic Ecoregional Assessment solicited feedback on prioritization results from aquatic resource experts from land/resource management agencies, academic institutions, private consulting firms, and local non-profits in a series of workshops. The experts delineated areas of aquatic biological significance on the prioritization maps, including written descriptions of the identified areas based on their professional knowledge of the area. TNC also requested that experts identify river systems within each Ecological Drainage Unit (EDU) that ranked the highest, in their judgment, for a number of ecological criteria. These included identifying those river systems that were most intact, in best condition, most free from exotic species, contained the highest presence of rare species, contained the most native fish communities, and contained the most stream invertebrates.[19]

Additionally, after identifying candidate watersheds using its NCEEP HUC-14 Screening Method, NCEEP refines its selection by completing windshield surveys, gathering input from local resource professionals, gauging local interest, and assessing whether appropriate restoration opportunities are likely to exist. As a result of this process, NCEPP produces a refined short list of candidate watersheds. Based on further feedback from local interests, NCEEP designates a final selection of HUC-14 watersheds in which conservation actions should be targeted in order to ensure that the largest possible functional benefits are obtained. As part of its Local Watershed Planning (LWP) process, NCEEP then identifies priority subwatershed "focus areas" within each of these targeted watersheds using its Focus Area Identification Tool and draws upon further GIS assessments, field assessments, and stakeholder input to identify potential project sites at which to target mitigation. With a set of potential project sites identified, NCEEP proceeds to develop a final Project Atlas that ranks projects based on ecological, feasibility, and stakeholder-defined criteria.[13] As another product of this process, NCEEP summarizes data gathered for the targeted HUC-14 watershed in a Watershed Management Plan.

A third example, the TNC WBSP Union Portfolio, identifies Conservation Opportunity Areas (COAs) using Level 1 methods by incorporating recommendations from the public regarding the modification, addition, or removal of COAs. Members of the public use a nomination form and online mapping site to draw features over the Union Portfolio to indicate which COAs should be added or changed before submitting them to TNC. Contributors are instructed to make changes that support recovery of listed species or protected habitat identified in the Oregon Conservation Strategy, address multiple conservation values, or improve ecosystem functions that benefit people.[73]

4.8 Prioritization products

Once the landscape prioritization programs we studied had ranked, rated, or otherwise identified priority pixels or polygons, they proceeded to visualize their results in a variety of ways. Types of prioritization products used by these programs included:

- Static maps (Section 4.8.1)

- Tables/graphs (Section 4.8.2)
- Data files (Section 4.8.3)
- Instructional materials for prioritization tool application (Section 4.8.4)
- Interactive web-based maps (Section 4.8.5)
- Software tools (Section 4.8.6)

4.8.1 Static maps

Three programs – Arkansas MAWPT, NCEEP, and USEPA RPS – continuously generate new static maps as they apply their tools to different geographic areas. For example, prioritization maps resulting from Arkansas MAWPT prioritization efforts are available in reports that MAWPT produces for each of its Wetland Planning Areas (e.g., for the Big Creek Watershed; (Figure 6). MAWPT's WPA reports, and their associated prioritization results, can be obtained by contacting MAWPT directly. NCEEP generates maps of prioritized project sites for each Local Watershed Plan (LWP) it completes in a final Project Atlas, which includes a large-scale map of all priority projects, site-specific maps, and detailed information for at least the highest ranking projects (e.g., the Bald Creek Watershed; Figure 7). All LWPs completed by NCEEP to date are available on its website at http://www.nceep.net/services/lwps/. Furthermore, the USEPA RPS uses static maps to visualize spatial relationships among HUC-12s based on scores generated using its ecological, stressor, and social context assessment tools. Using such maps, RPS users can identify HUC-12s in which restoration may be most effective for building larger, healthy watershed patch sizes and establishing healthy corridors (e.g., for Maryland: Figure 8).

In contrast, most other prioritization programs develop static maps illustrating priority areas as part of technical reports or research articles for their tools. For example, as part of its 2010 technical report, IDFG released maps illustrating wetland condition assessment results from its Landscape Assessment Tool for both the wetland and watershed level at its north and south study sites (Figure 9). Similarly, results from an application of the Caltrans RAMP Marxan Greenprint Analysis to the Elkhorne Slough and Pleasant Grove watersheds are presented in Thorne et al. (2009) (Figure 10). The UMass Amherst CAPS generates high resolution PDF maps that rank the top 50% of 30m^2 pixels in terms of IEI (Index of Ecological Integrity) score for all counties in Massachusetts (Figure 11) and identify areas within the state containing Important Habitat. It also makes available maps that visualize outputs for individual metrics used by its IEI tool (Figure 12). UMass Amherst CAPS has made a large collection of these maps available for download from its website at http://www.umass.edu/landeco/research/caps/data/caps_data.html.

Other prioritization programs that present results as static maps include Kramer et al. (2012)[74] (Figure 14), TNC Aquatic EA (Figure 13), VDCR (Figure 15), MTNHP (Figure 16), Strager et al. (2011) (Figure 17), Kauffman-Axelrod and Steinberg (2007) (Figure 18), USACE SRWBMP (Figure 19), DU Forest Breeding Bird Decision Support Model (Figure 20), TNC-ELI DPWAP (Figure 21), TWRA CWCS (Figure 22), and WSDOE (Figure 23).

4.8.2 Tables/graphs

The USEPA RPS approach provides recovery potential scores for each HUC-12 analyzed using bubble plots that graph ecological index against stressor index, with the size of the dot for each graphed HUC-12 related to social index score (Figure 24). Users of USEPA RPS may also view a simple rank-ordering of HUC-12 scores from its Ecological Capacity Tool, Stressor Exposure Tool, and Social Context Assessment, and the Integrated Assessment. VDCR instructs users of its GIS Model to use attribute tables of its spatial products to summarize prioritization results.

4.8.3 Data files

Many prioritization programs make the GIS data used in their analysis publicly available. For instance, UMass Amherst CAPS makes Arc grid and georeferenced TIFF (geoTIFF) data for Important Habitat and IEI results available for download from its website at http://jamba.provost.ads.umass.edu/web/caps2011/CAPS2011data.htm. Data files are available for a variety of scales (e.g., watershed; Figure 11) and for a variety of underlying metrics (e.g., aquatic connectivity; Figure 12).

4.8.4 Instructional materials for prioritization tool application

EPA includes detailed step-by-step instructions for applying its RPS tool on its website at: http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/recovery/index.cfm. In addition, to support potential efforts to repeat its prioritization analysis for different areas, as part of its technical report VDCR provides detailed step-by-step instructions that describe how its analysis was carried out in ArcGIS.[75]

4.8.5 Interactive web-based maps

Some prioritization programs made outputs available as interactive web-based maps. These are described in Table 11, below.

Table 11 Interactive-web based maps developed by landscape prioritization programs.

Program	Interactive web-based map description
VIMS WetCAT	VIMS will make results from its Wetland Condition Assessment Tool available as part of its Nontidal Wetlands Viewer web tool, which will allow users to study individual wetlands throughout Virginia using a variety of map overlay and geoprocessing tools. For instance, users will be able to overlay impaired waters, priority conservation areas, and sites that have received VDEQ permits, among other features, over NWI wetland maps. In addition, one geoprocessing tool will allow users to select a point on the landscape and observe cumulative effects to wetland habitat and water quality within 1 kilometer of that point (Figure 6). Other geoprocessing options will allow users to trace the downstream flow path from a point and visualize the contributing watershed to a point. Availability of the VIMS WetCAT online mapping tool is forthcoming.
TNC Willamette Basin Synthesis Project	The TNC WBSP uses a web-based interactive map not only to visualize prioritization results for the public but also to facilitate refinement of its Union Portfolio of priority sites (see Section 4.7.2). Using this online map, members of the public draw features over TNC's Union Portfolio to indicate which Conservation Opportunity Areas should be added or changed (Figure 27). The map can be accessed at: http://maps.tnc.org/WV_Synthesis_COAs/.
NOAA HPP Mississippi-Alabama Habitats Tool	Outputs from the models used by the NOAA HPP MAHT are depicted on MBNEP's online, interactive Habitat Mapper (Figure 28). In addition to displaying priority habitat area, users can overlay maps identifying the locations of planned, existing, and in-progress restoration and conservation activities throughout the estuary. The Habitat Mapper is accessible at http://habitats.disl.org/.
Maryland Watershed Resource Registry	Users of the online tool developed by the Maryland WRR can query each of program's eight suitability maps by specifying a 12-digit subwatershed, a county, a size criterion (e.g., >5 acres), and a rating criterion (e.g., "higher than three stars") to interactively highlight wetlands that meet those criteria. This online tool can be accessed at: http://watershedresourcesregistry.com.
Colorado Natural Heritage Program	CNHP's map of wetland landscape integrity can be viewed using an online interactive map developed by CNHP in collaboration with CPW (Figure 29), which can be accessed at: http://www.cnhp.colostate.edu/wetlandinventory/index.asp. In addition to displaying the LIM stressor map, users of the interactive tool can overlay boundary data for river basins, counties, and ecoregions as well as other features of interest (e.g., a variety of wetland and riparian GIS datasets).
TNC-ELI Duck-Pensaukee Watershed Approach Project	The TNC-ELI DPWAP Coastal Wetland and Tributary Decision Support Tool allows users to view outputs from its wetland service assessments (Figure 21). Users of this tool can overlay TNC-ELI DPWAP prioritization results with a variety of other layers, including EPA Areas of Concern, county tax parcels, and areas at risk of fish habitat degradation, among many others. The tool is available for viewing at http://maps.tnc.org/duckpentool/.

4.8.6 *Software tools*

MTRI designed its Wetland Mitigation Site Suitability Tool to be applied in the field using a field-ready notebook connected to a GPS unit, on which ArcGIS and the WMSST dockable window interface have been installed. MTRI distributes the WMSST for installation on field computers as a Microsoft Windows dynamic-link library. Users of the WMSST software tool complete an analysis by using a sequence of four tab controls (Figure 30):

1. Under the “Start” tab, users specify the extent of the analysis as either watershed or ecoregion boundaries. Users can also retrieve previously saved analyses, allowing modeling tasks to be reviewed later as part of the project planning process.

2. Under the “Analysis” tab, users select the weights to be applied to calculate the weighted mean for input layers in the WMSST. In addition, checkboxes allow users to indicate which layers to include or exclude in the analysis. Once weightings and layers to be included are set, the user runs the analysis.

3. After the site suitability map is displayed, users may use the “Results” tab to save the results of the analysis, print the results, create a new analysis, or navigate to a finer scale for a more detailed analysis of the results.

4. Under the “Navigate” tab, users can easily navigate to study area sites using Public Land Survey System (PLSS) Township, Range, and Section numbers, which are also used to reference project areas under MDOT project standards. This feature allows MDOT Environmental Section users to quickly view project areas within suitability model results. Users can also specify the latitude/longitude or address of the project area.

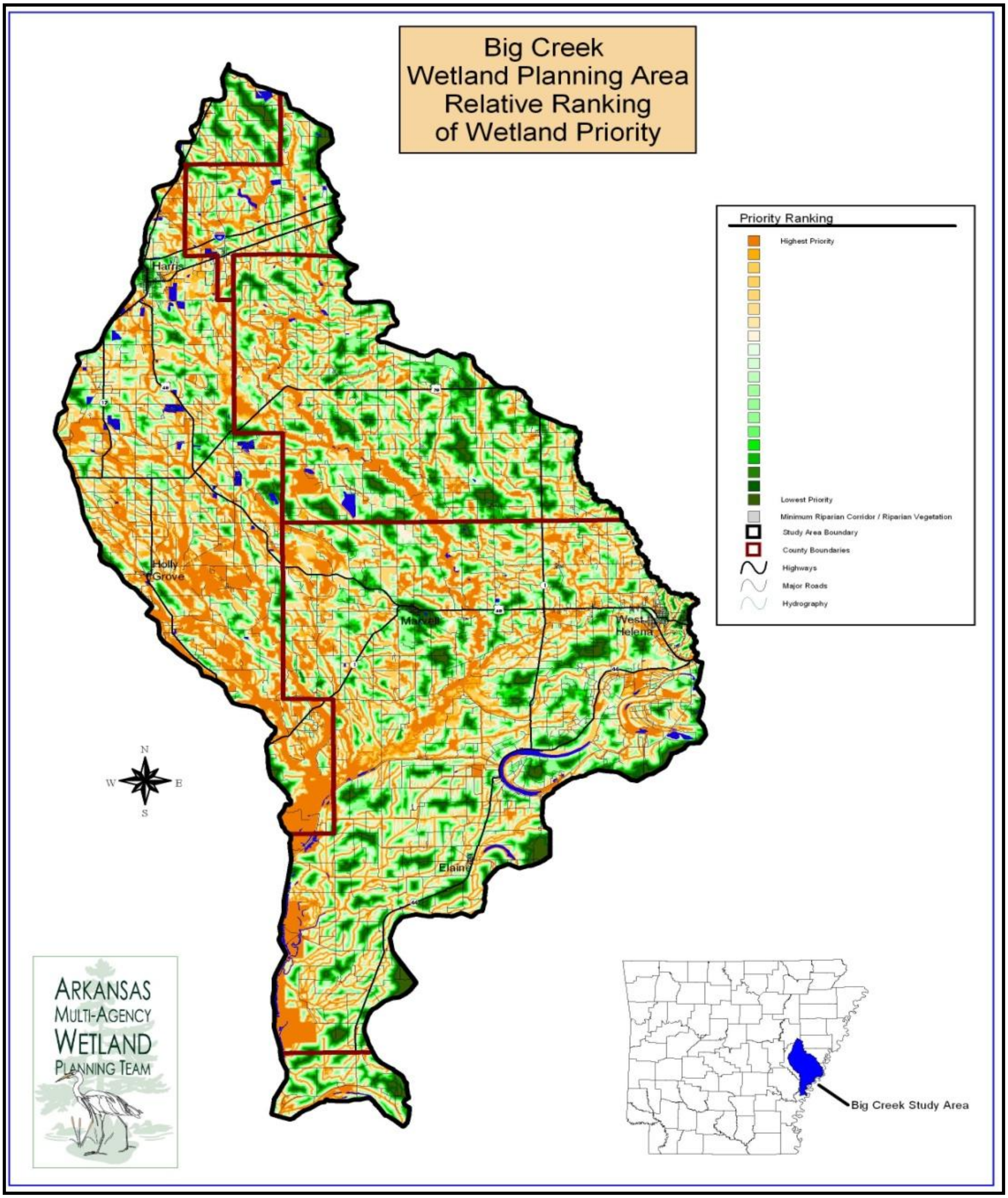


Figure 6. Output map identifying priorities for wetland restoration and protection for the Big Creek WPA. Orange areas indicate high priority areas and green areas indicate low priority areas. Used with permission from Arkansas MAWPT.

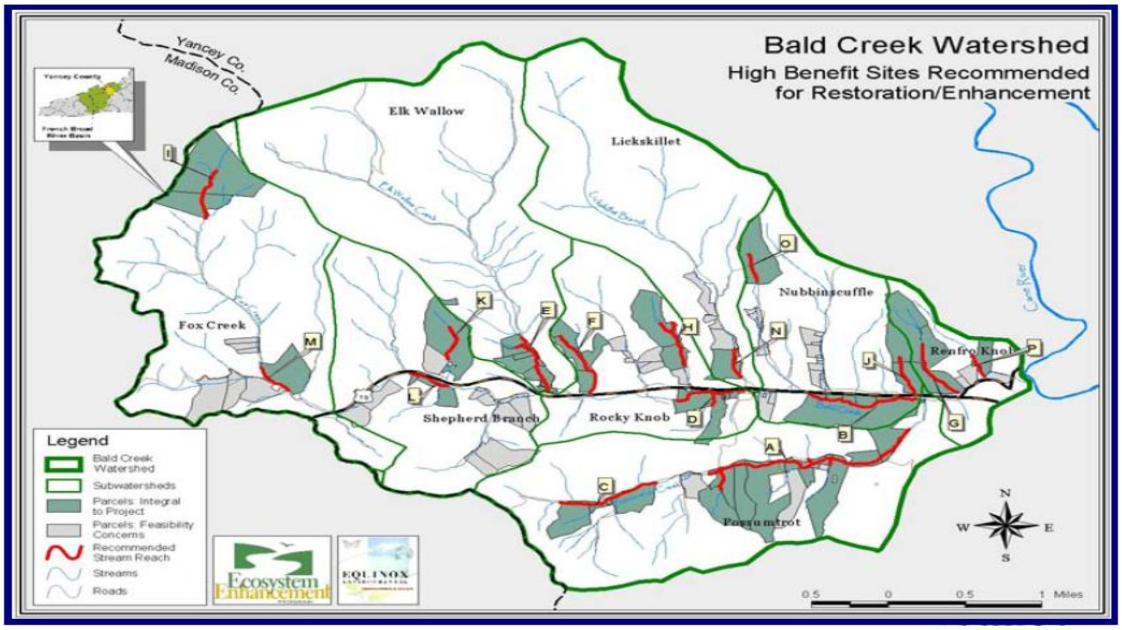


Figure 7. Priority sites for restoration/enhancement identified in the Bald Creek LWP. Map obtained from: http://www.nceep.net/services/lwps/Bald_Creek/NEW_baldcreek.pdf, used with permission.

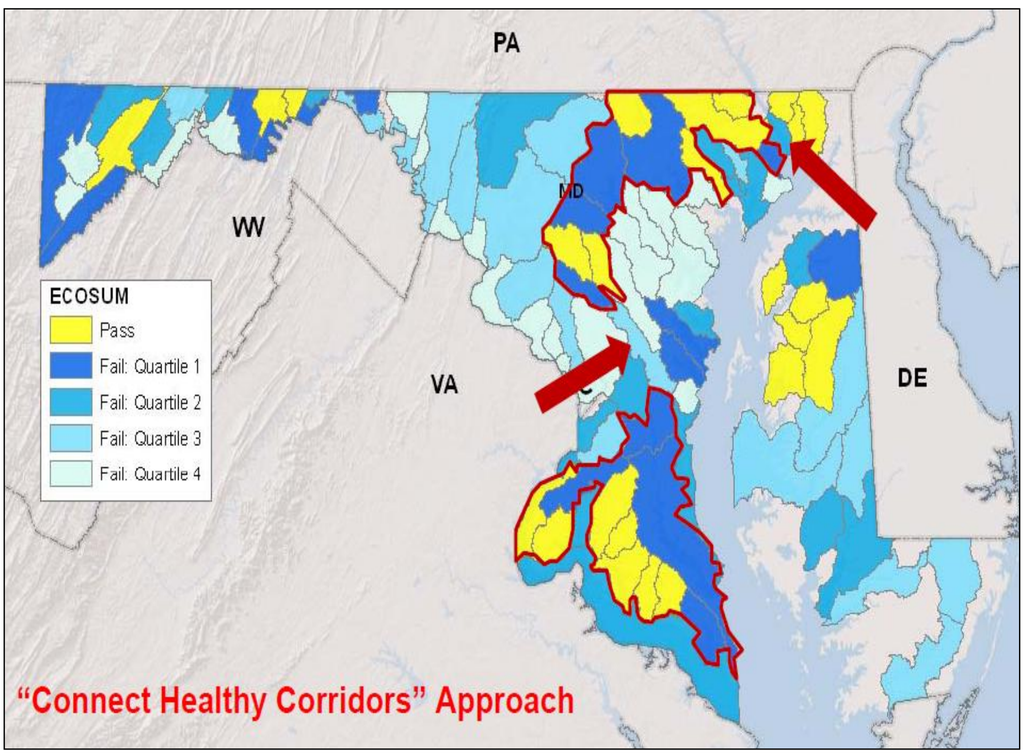
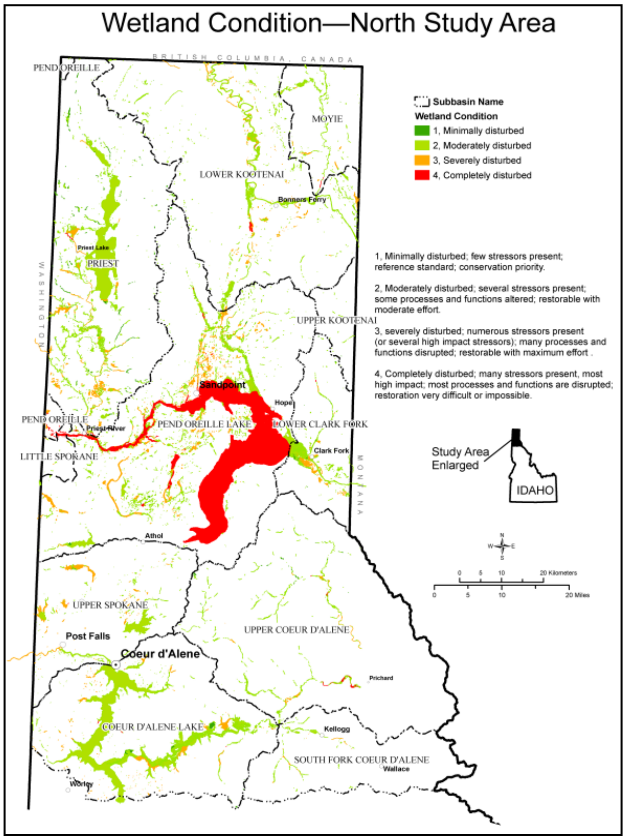


Figure 8. Output scores from the recovery potential screening tool can be visualized using color-coded maps. For example, this map for Maryland shows "passing" watersheds (yellow) as well as those that "failed" in field-based assessments (blue) but display various degrees of recovery potential (darker blue = better recovery potential). Visualizing watersheds in this way allows users to identify watersheds in which restoration may be most effective in increasing the size of contiguous healthy watershed patches and connecting healthy patches into large-scale corridors by targeting impaired but restorable watersheds in key locations (indicated by the red arrows). Used with permission from U.S. EPA.



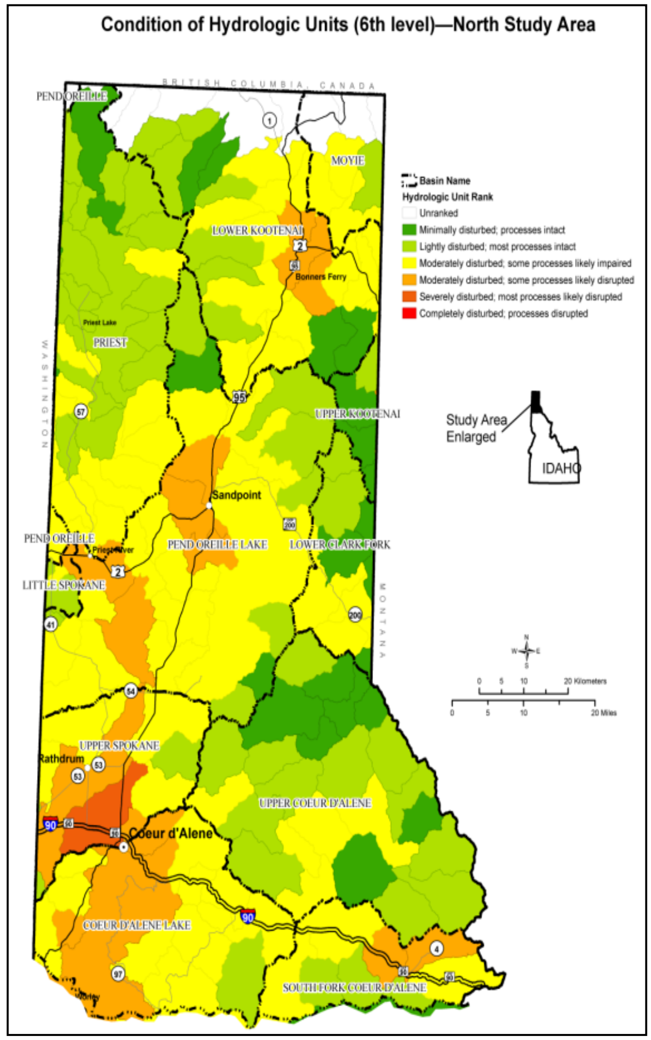


Figure 9. In the north study site, IDFG's landscape assessment tool ranked individual wetland polygons (*left*) and HUC-12 watersheds (*right*) in terms of overall landscape disturbance. IDFG also completed a similar analysis for the southern study site. Used with permission of IDFG.

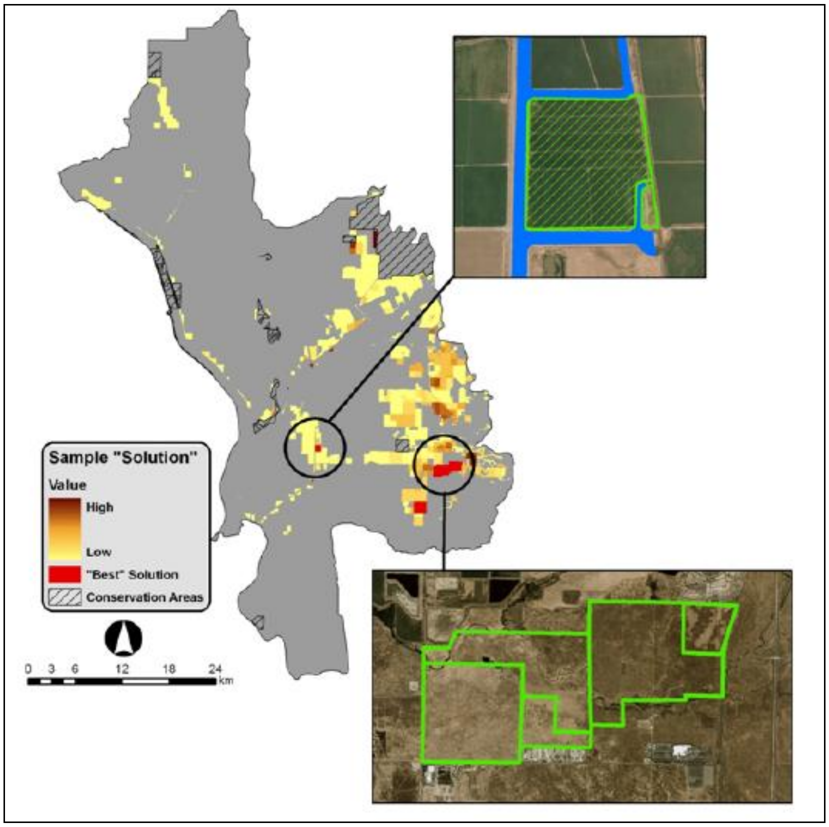


Figure 10. RAMP applies MARXAN to identify priority parcels for mitigation of agency infrastructure projects. In the above map, dark brown colored parcels represent those most likely to meet Caltrans' mitigation need, while red parcels are "best" solutions that meet mitigation needs at low cost. Used with permission from California Department of Transportation (Caltrans).

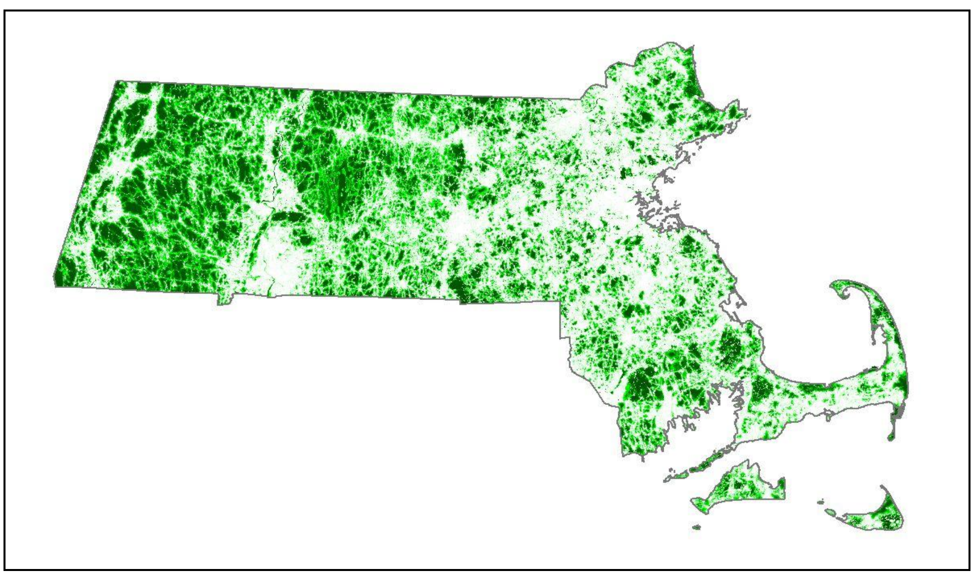


Figure 11. UMass Amherst CAPS makes Arc grid and geoTIFF files available that scale IEI scores by watershed for natural communities (forest, shrubland, freshwater wetland and aquatic, coastal wetland, and coastal upland) throughout Massachusetts (darker green = higher IEI rank). Used with permission from Massachusetts CAPS.

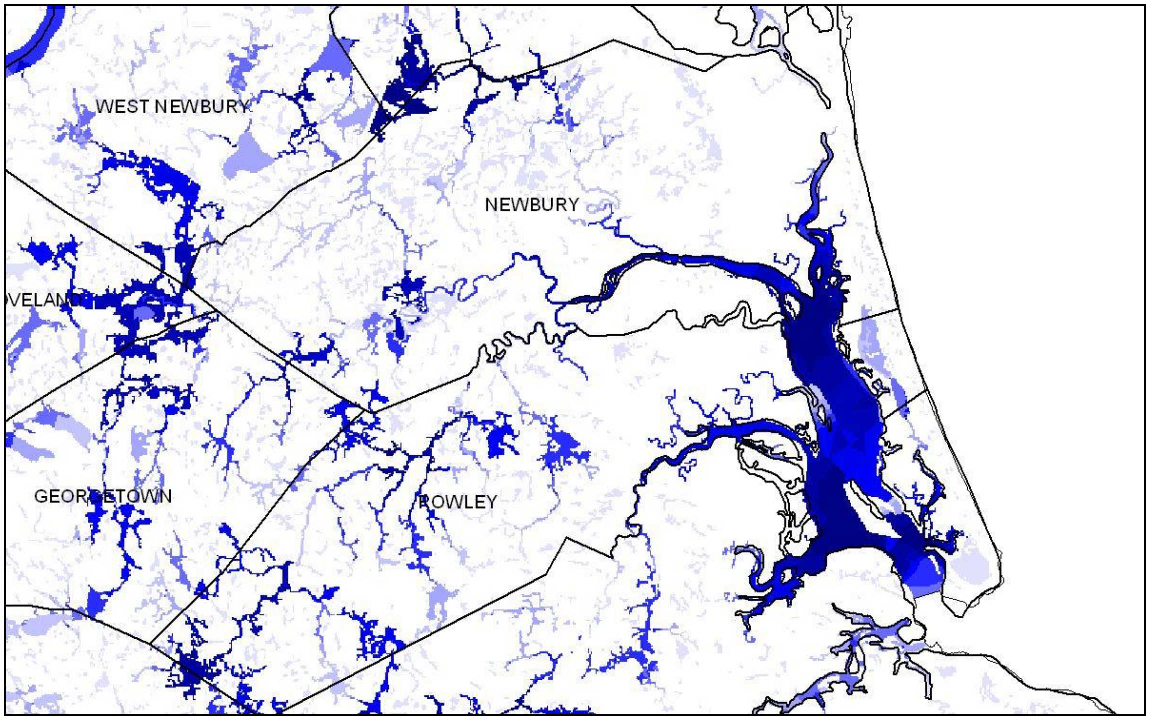


Figure 12. On its website, UMass Amherst CAPS makes Arc grid and geoTIFF data files available for individual metrics. For example, the data output for the aquatic connectedness metric, which ranks wetland and aquatic communities in terms of their interconnectedness with similar areas (darker blue = more interconnected), is available for download. Used with permission from Massachusetts CAPS.

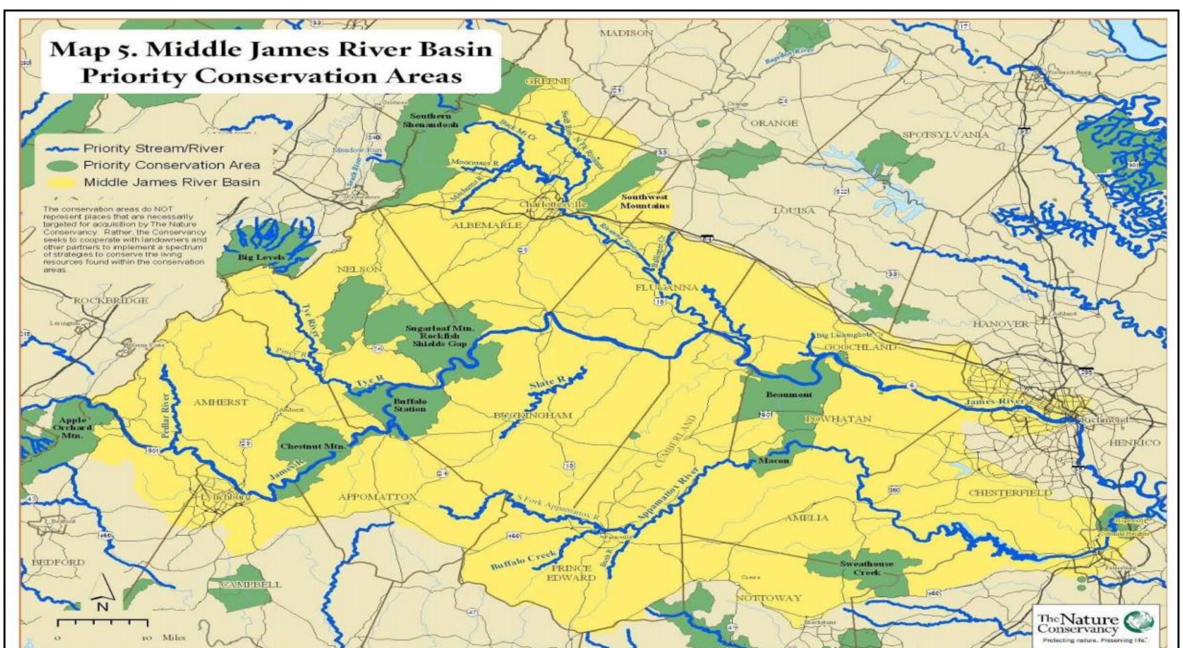


Figure 13 TNC's Aquatic Ecoregional Assessment prioritization process identified Priority Conservation Areas within 14 EDUs, such as those shown above for the Middle James River Basin. Used with permission from TNC Virginia Aquatic Restoration Trust Fund.

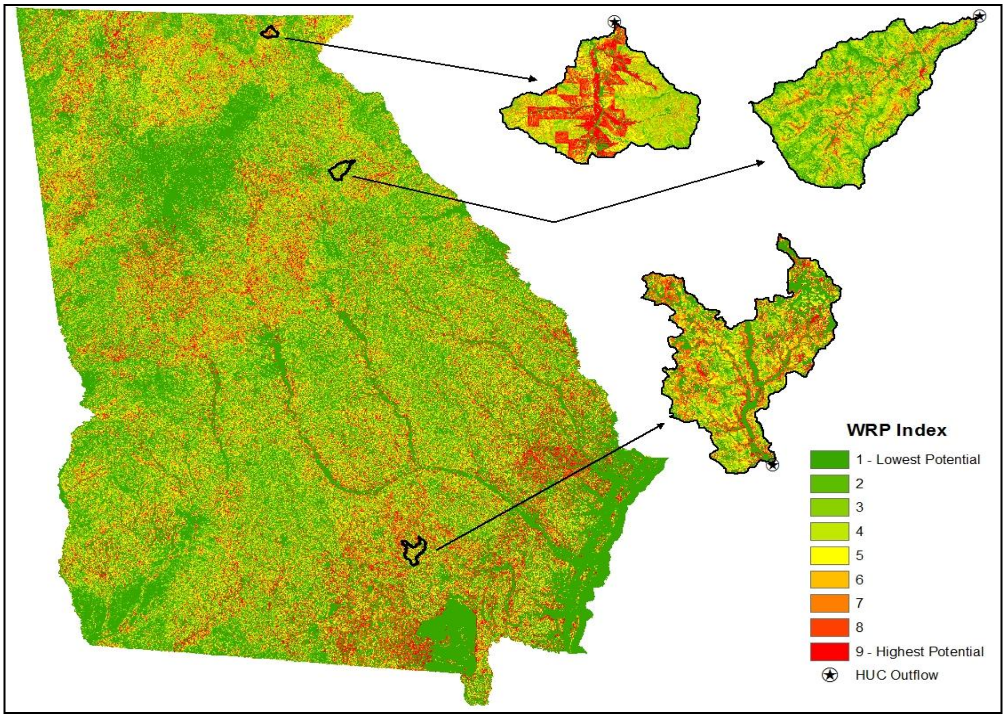


Figure 14. Output map from Kramer et al. (2012)'s PWBSI model including HUC-12 representative watersheds. Used with permission from University of Georgia.

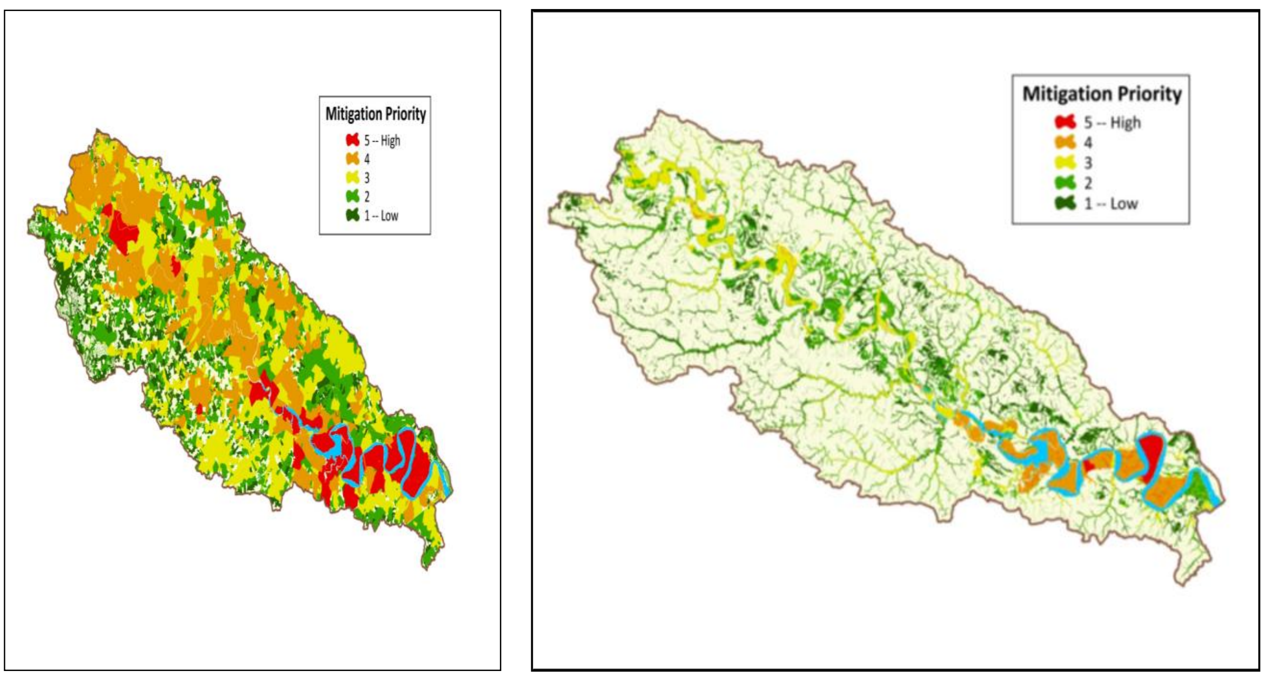


Figure 15. The VDCR GIS Model assigned mitigation priority scores to all identified wetlands (*top*), as well as individual parcels (*bottom*), in 11 subwatershed of the Pamunkey River watershed. Used with permission of Jason Bulluck, Virginia Department of Conservation and Recreation.

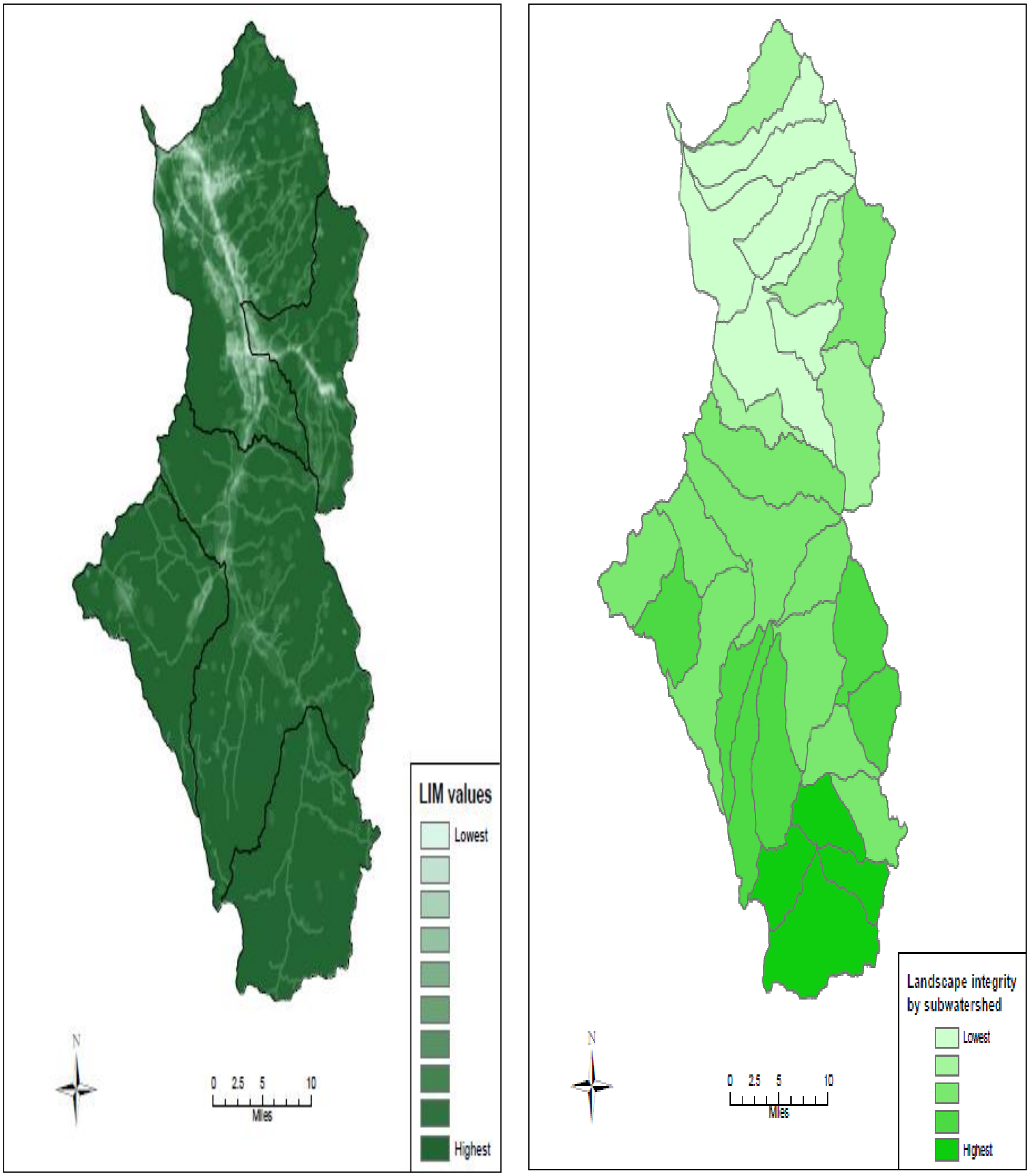


Figure 16. Users seeking to prioritize wetland restoration or conservation can use the MTLIM output to visualize wetland condition at the pixel (*left*) watershed (*right*) levels. Used with permission from the Montana Natural Heritage Program.

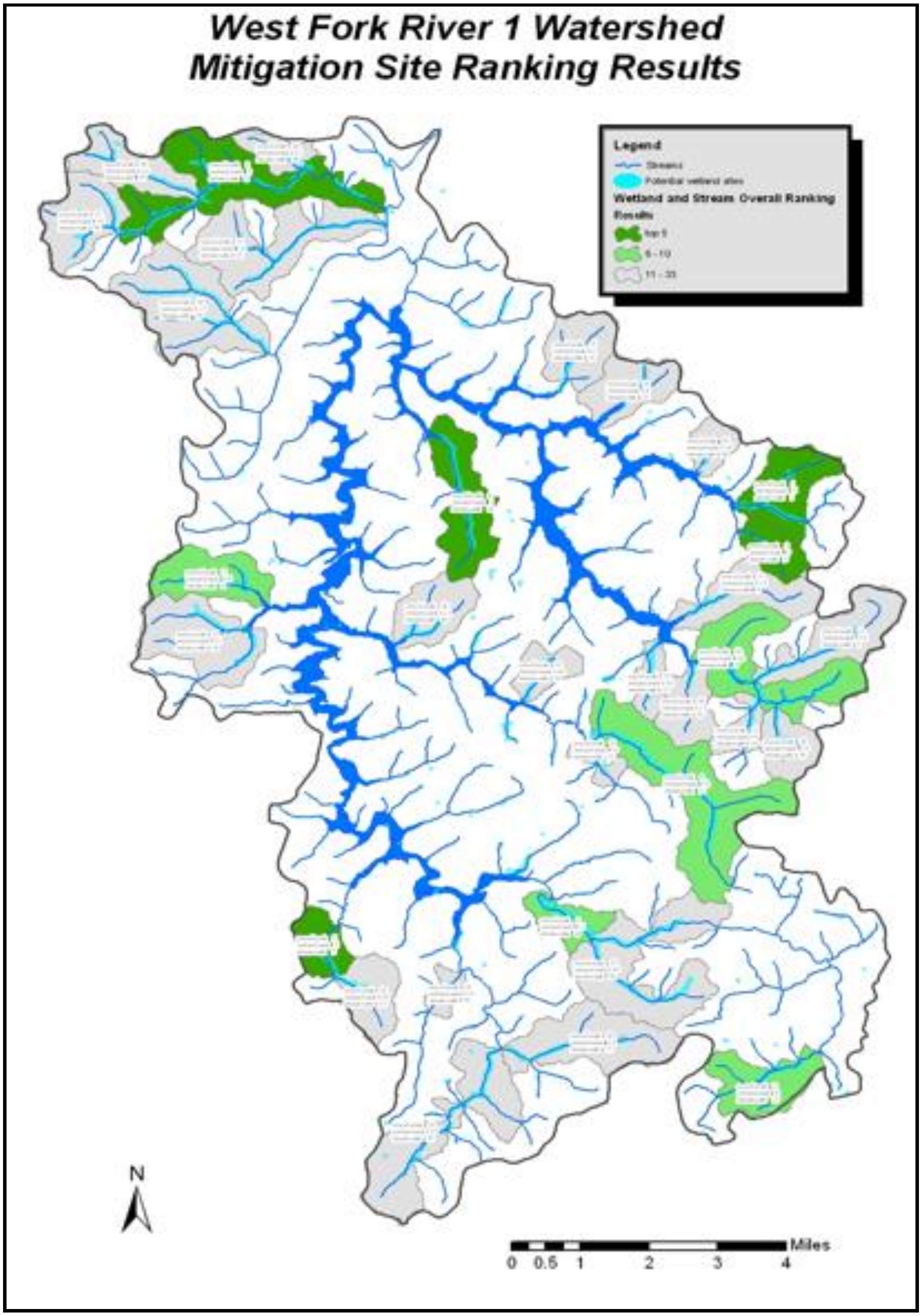


Figure 17. In the West Fork River watershed, Strager et al.'s Level 1 analysis identified potential wetland and stream mitigation sites (all shaded areas above). In the Level 2 analysis, each of these areas was scored, weighted, and ranked based on a variety of criteria. Highest ranked sites are indicated by the most darkly shaded areas above. Used with permission from Dr. Michael Strager.

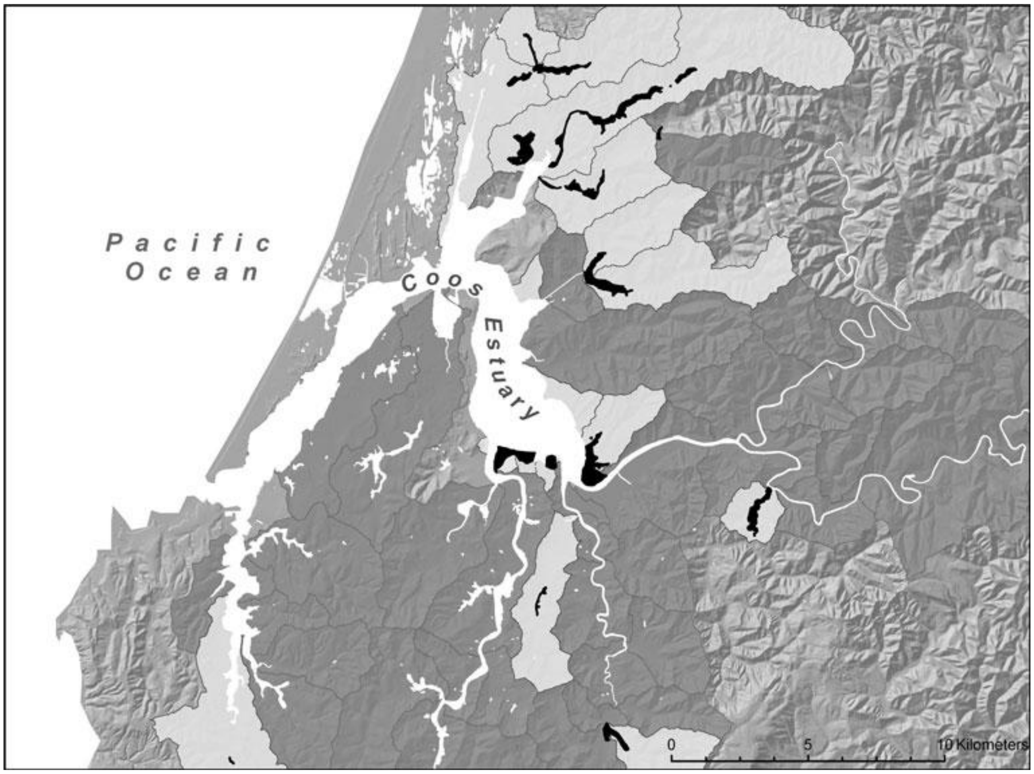


Figure 18. Top 10% of prioritized restoration sites (black) and the catchments in which they reside (light gray). Reprinted from Kauffman-Axelrod and Steinberg (2010).

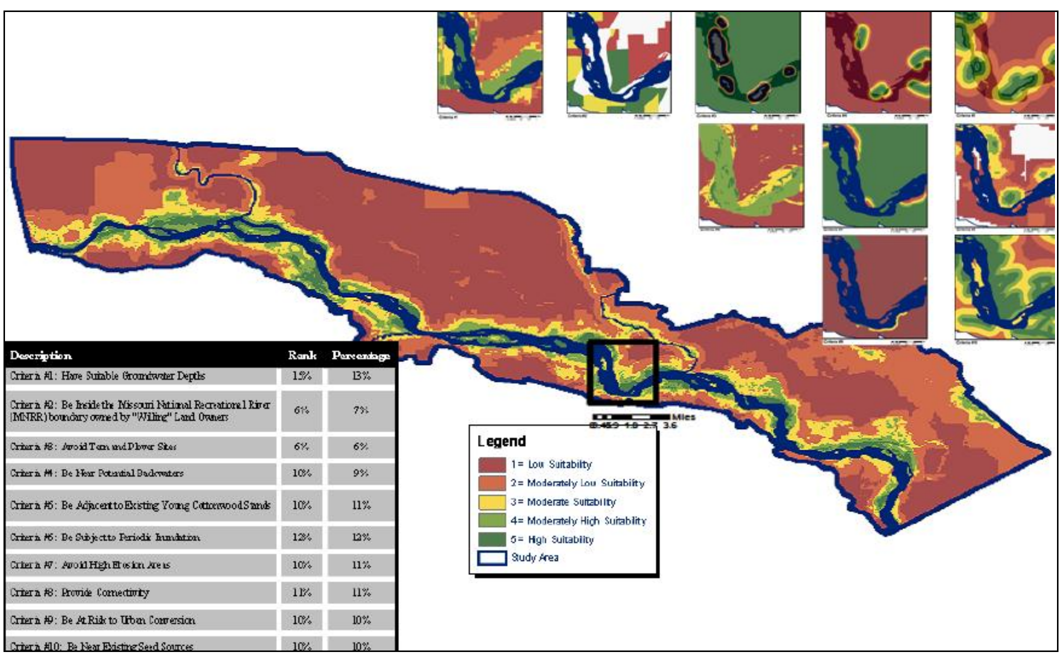


Figure 19. An example SDSS prioritization map produced for a segment of the Missouri River. Similar maps that provide suitability scores for areas of the Sunrise River watershed will soon be made available by the Corps St. Paul District. Used with permission from U.S. Army Corps of Engineers.

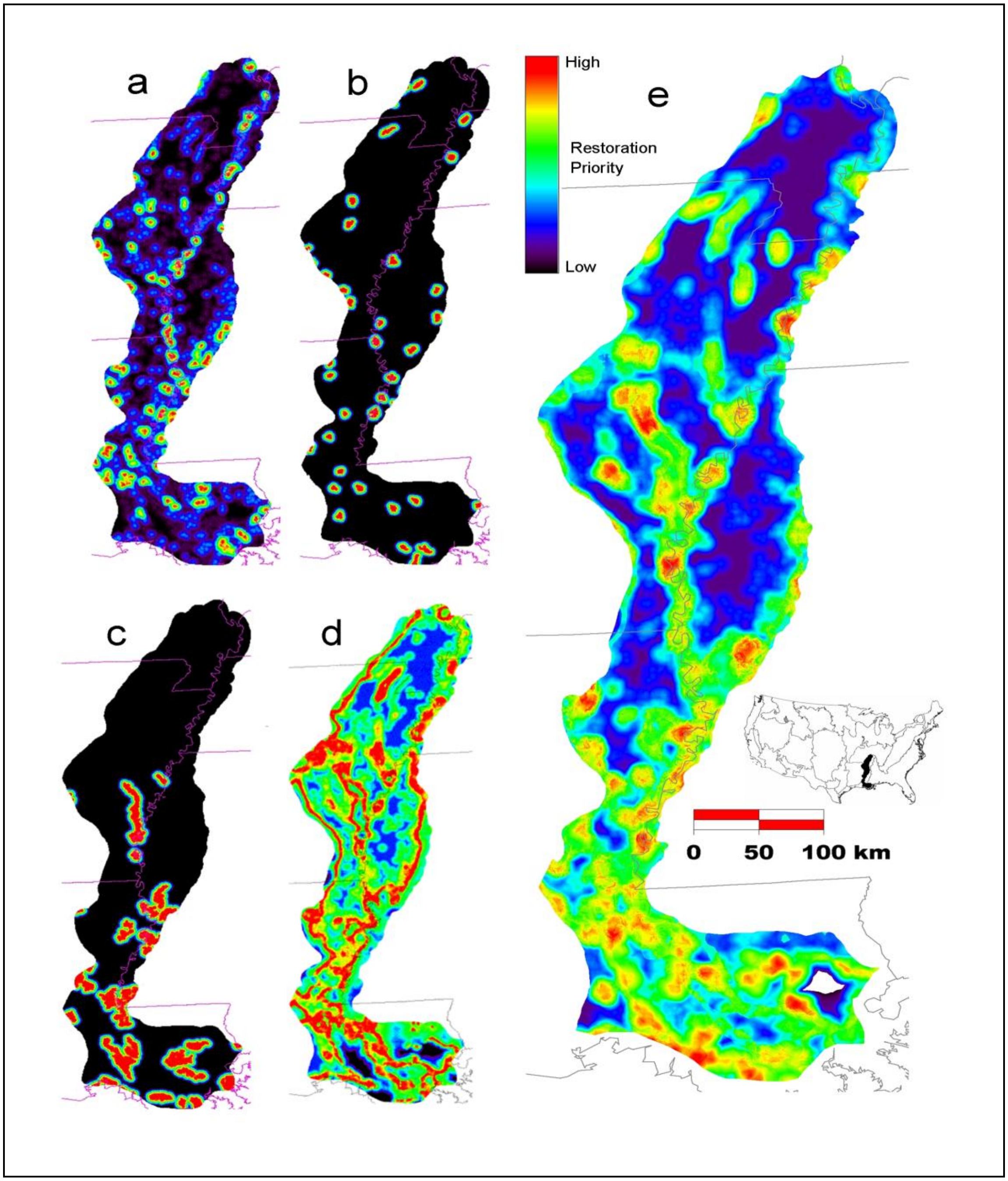


Figure 20. The prioritization outputs of the Forest Breeding Bird Decision Support Model rate areas throughout the MAV for their ability to benefit forest birds as restoration sites. These include: (a) creating forest patches with >2000 ha core area, (b) creating forest patches with > 5000 ha core area, (c) adding to forest core areas already >5000 ha, (d) increasing percentage forest cover in local landscapes to >60%, and (e) combining scores for all of these criteria and emphasizing higher-elevation sites. Figure from Twedt et al. (2006).

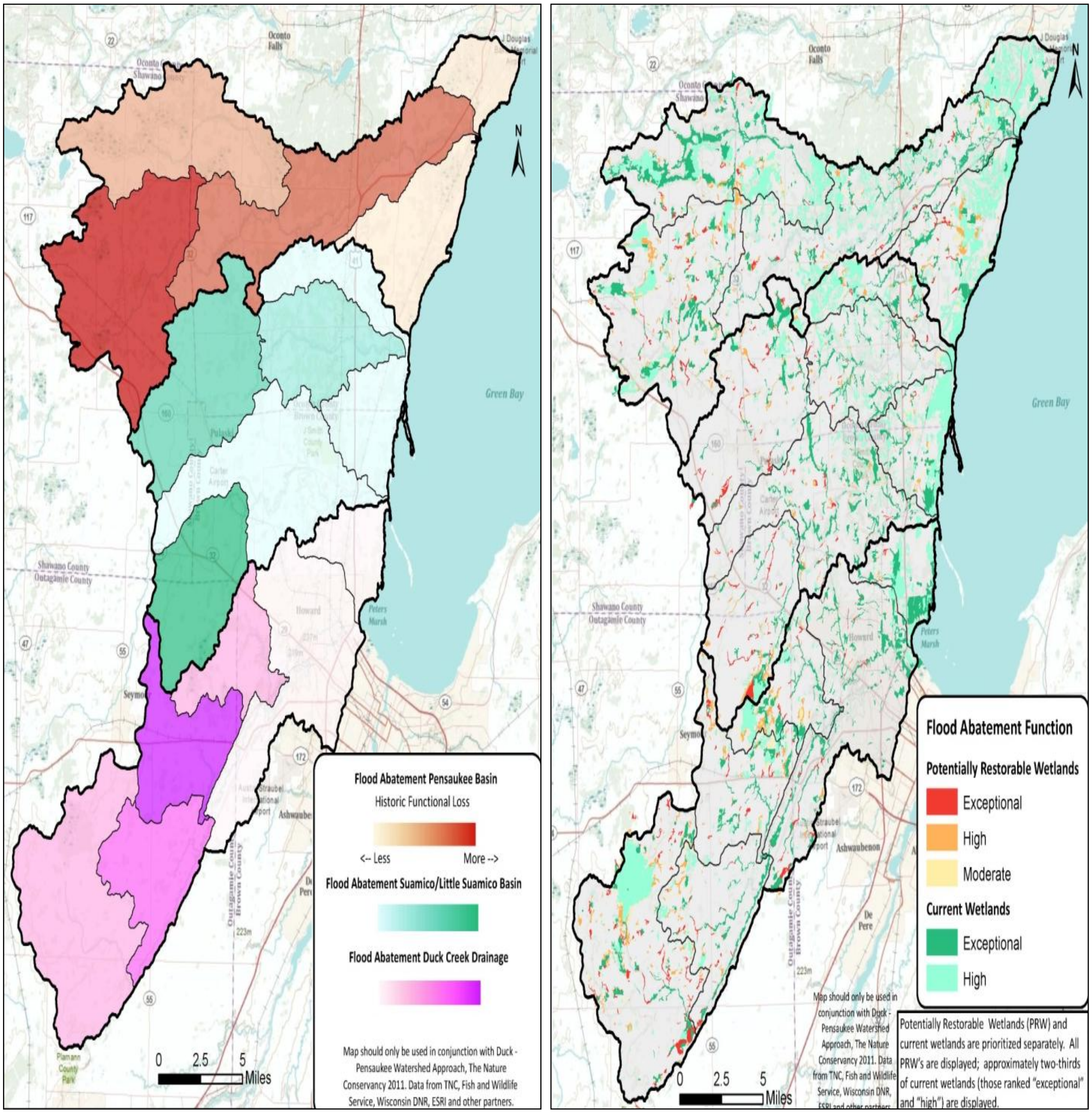


Figure 21. In its 2012 report, TNC-ELI provided output maps from its assessments of watershed needs (i.e., areas of historic functional loss) and tools for identifying site-specific priorities. For example, its assessment of flood abatement needs (*left*) identifies HUC-12s in which site-specific restoration and preservation priorities for flood abatement (right) might be targeted to promote a watershed approach to regulatory and non-regulatory wetland conservation.

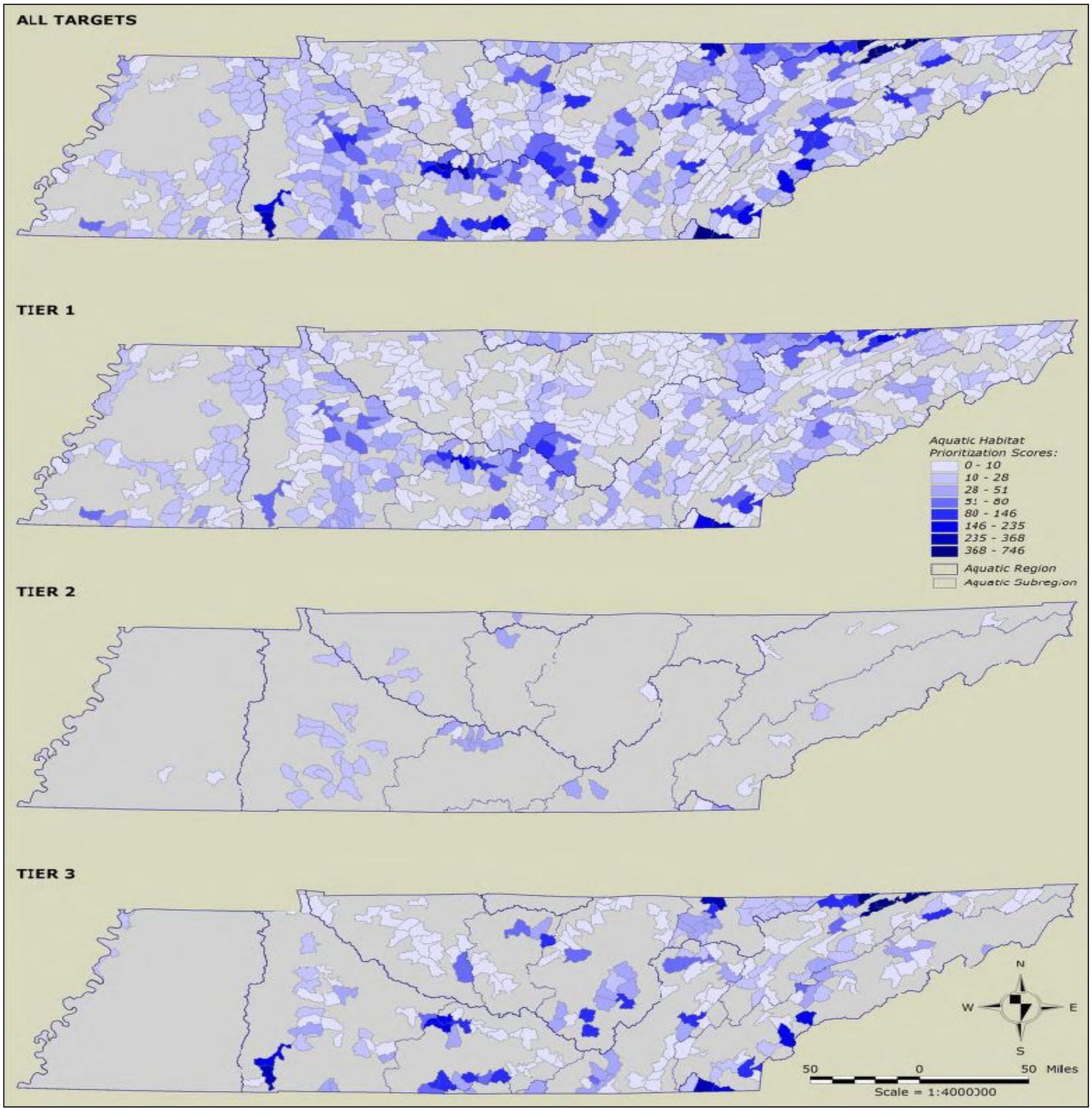
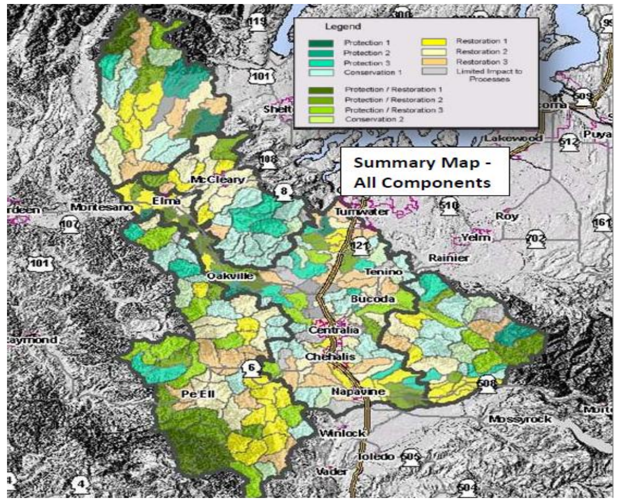


Figure 22. Prioritization of HUC-12 watersheds by the CWCS model based on occurrences of riparian species can inform aquatic resource restoration and conservation efforts throughout Tennessee. Used with permission of the Tennessee Wildlife Resources Agency.

Figure 23. Output maps from the WSDOE Watershed Characterization Tool for the Upper and Lower Chehalis Basins showing priorities for restoration (yellow), protection (green), and conservation (light yellow/light green), in addition to areas in which future disturbances are likely to have less impact (orange). An output map is generated that summarizes overall priorities for the particular watershed process analyzed – in this case, an overall hydrologic priorities map (Figure 23A). In addition, other output maps show priorities for individual component processes, which are here represented by water delivery (Figure 23B), surface water storage (Figure 23C), and ground water discharge (Figure 23D) and recharge (Figure 23E). Used with permission of Washington State Department of Ecology.

A



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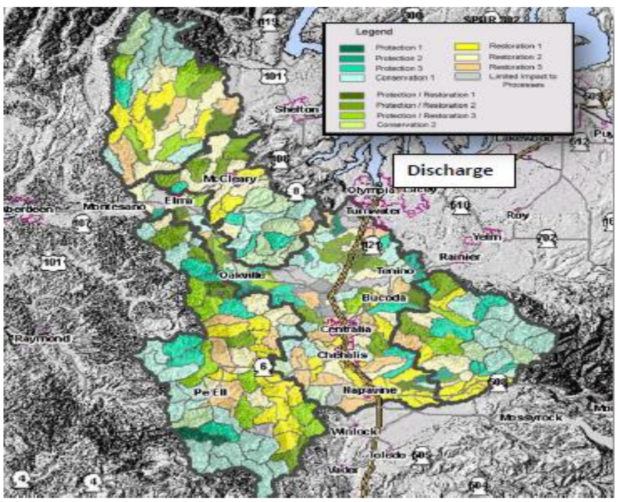

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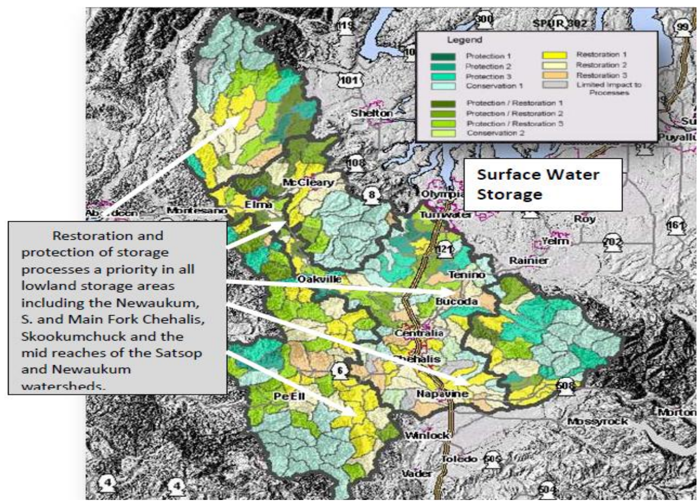

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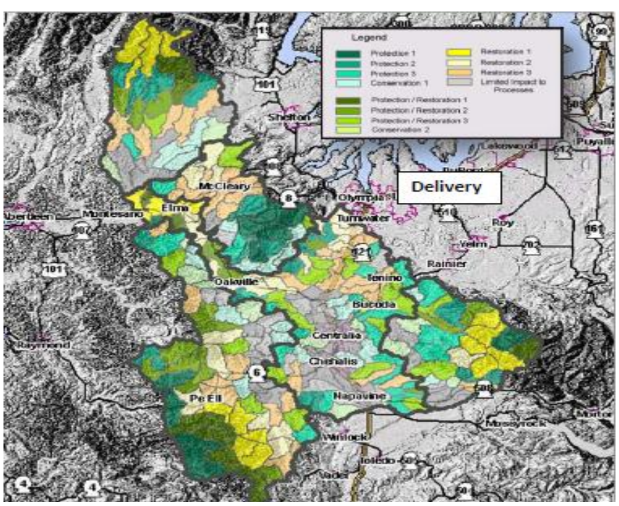
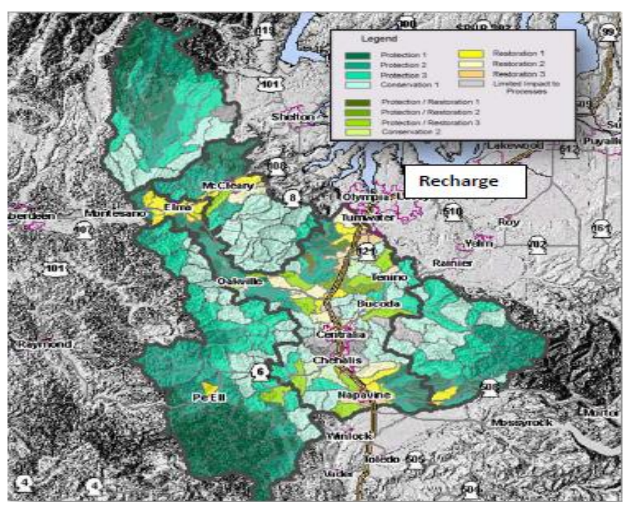
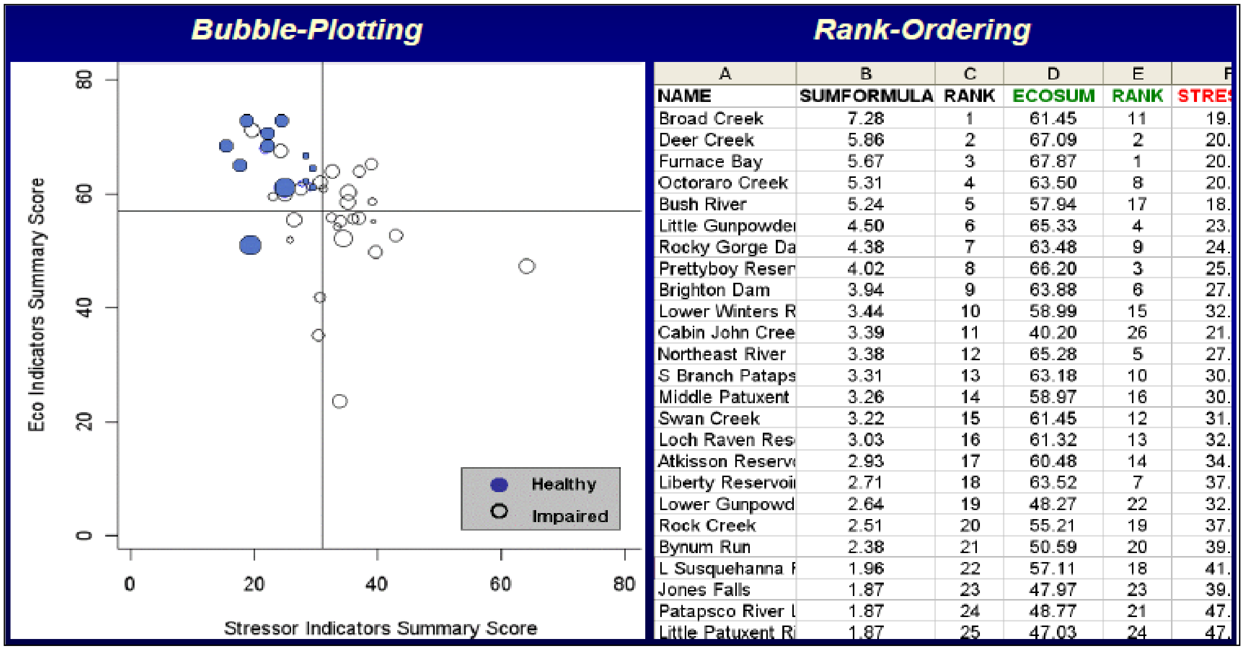


E





A	B	C	D	E	F
NAME	SUMFORMULA	RANK	ECOSUM	RANK	STRES
Broad Creek	7.28	1	61.45	11	19.
Deer Creek	5.86	2	67.09	2	20.
Furnace Bay	5.67	3	67.87	1	20.
Octoraro Creek	5.31	4	63.50	8	20.
Bush River	5.24	5	57.94	17	18.
Little Gunpowder	4.50	6	65.33	4	23.
Rocky Gorge Da	4.38	7	63.48	9	24.
Prettyboy Reser	4.02	8	66.20	3	25.
Brighton Dam	3.94	9	63.88	6	27.
Lower Winters R	3.44	10	58.99	15	32.
Cabin John Cree	3.39	11	40.20	26	21.
Northeast River	3.38	12	65.28	5	27.
S Branch Pataps	3.31	13	63.18	10	30.
Middle Patuxent	3.26	14	58.97	16	30.
Swan Creek	3.22	15	61.45	12	31.
Loch Raven Res	3.03	16	61.32	13	32.
Atkisson Reserv	2.93	17	60.48	14	34.
Liberty Reservoi	2.71	18	63.52	7	37.
Lower Gunpowd	2.64	19	48.27	22	32.
Rock Creek	2.51	20	55.21	19	37.
Bynum Run	2.38	21	50.59	20	39.
L Susquehanna I	1.96	22	57.11	18	41.
Jones Falls	1.87	23	47.97	23	39.
Patapsco River I	1.87	24	48.77	21	47.
Little Patuxent Ri	1.87	25	47.03	24	47.

Figure 24. The recovery potential screening tool generates rank-ordered scores for ecological, stressor, and social context indicators for each HUC12 watershed (*right*). These may be used to visualize restorability differences among impaired watersheds using bubble plots (*left*), which may also display reference healthy watersheds as determined from field-based assessment data.

ParID	WSID_1	WSID_2	WSID_3	WSID_4	PS1W	PS2W	PS3W	PS4W	PS5W	WetOver	MitPrior	CompPrior	Reclass5
127-584	NWI99332	NHD02080106006070	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5
127-584	NWI99332	NHD02080106006075	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5
127-584	NWI99332	NHD02080106006076	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5
127-584	NWI99332	NHD02080106006070	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5
127-584	NWI99332	NHD02080106006075	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5
127-584	NWI99332	NHD02080106006070	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5
127-584	NWI99332	NHD02080106006076	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5
127-584	NWI99332	NHD02080106006075	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5
127-584	NWI99332	NHD02080106006076	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5
127-584	NWI99332	NHD02080106006070	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5
127-584	NWI99332	NHD02080106006075	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5
127-584	NWI99332	NHD02080106006076	DFIRM2134	SSURGO21133	2	3	1	0	3	4	9	13	5

Figure 25. Attribute tables from VDCR spatial products, such as that shown above, provide values for wetland likelihood overlay, mitigation value, and composite prioritization scores. Wetland likelihood overlay (columns with "WSID…" header) and mitigation values (columns with "PS#W" header) are weighted and used in a calculation to assign the composite prioritization score (CompPrior), which is classified into 5 classes for map display from 1-Low to 5 – High. Tabular output tables and the algorithm can be manipulated by GIS desktop users to generate varying map outputs with emphasis on different mitigation values. Used with permission of Jason Bulluck, Virginia Department of Conservation and Recreation.

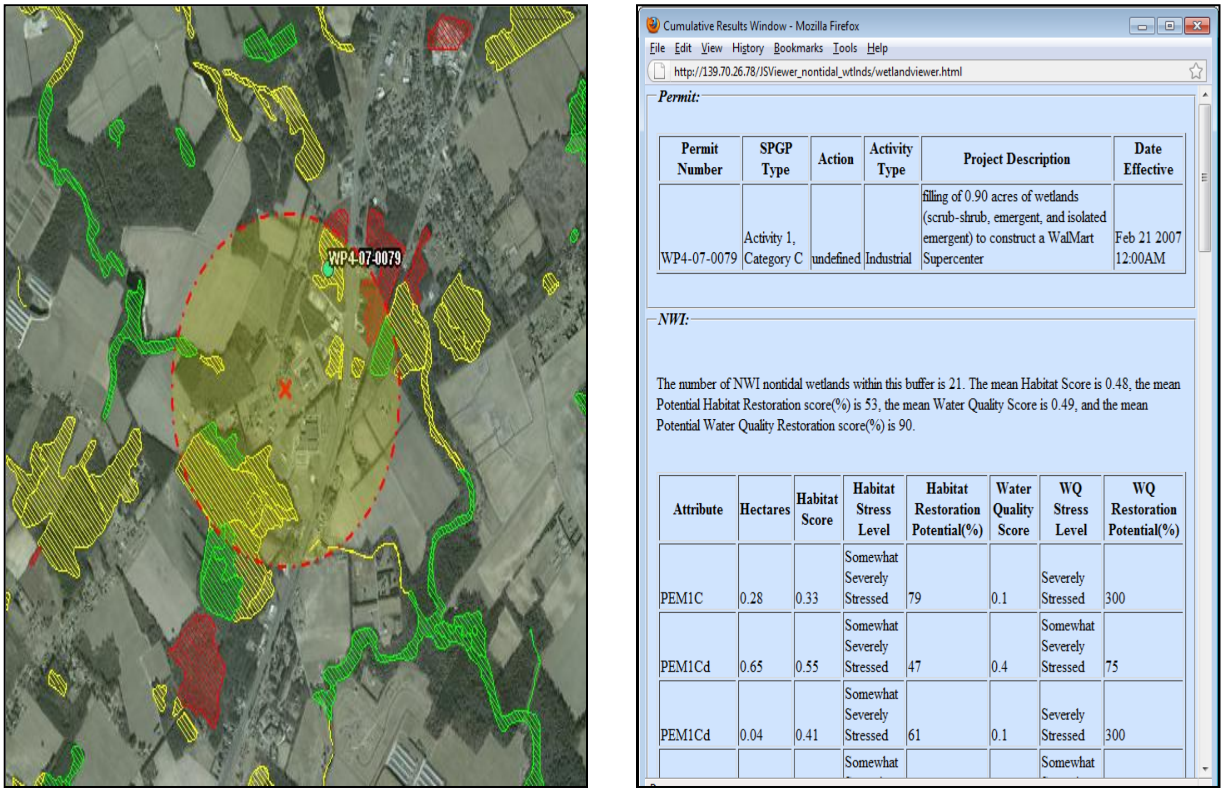


Figure 26. The Nontidal Wetlands Viewer Tool includes geoprocessing tools, such as this cumulative effects analysis, which reports stress levels for wetland habitat and water quality within a 1km radius. It also reports point source impairments, such as DEQ General Permit location (blue dot). Used with permission of Virginia Institute of Marine Science.

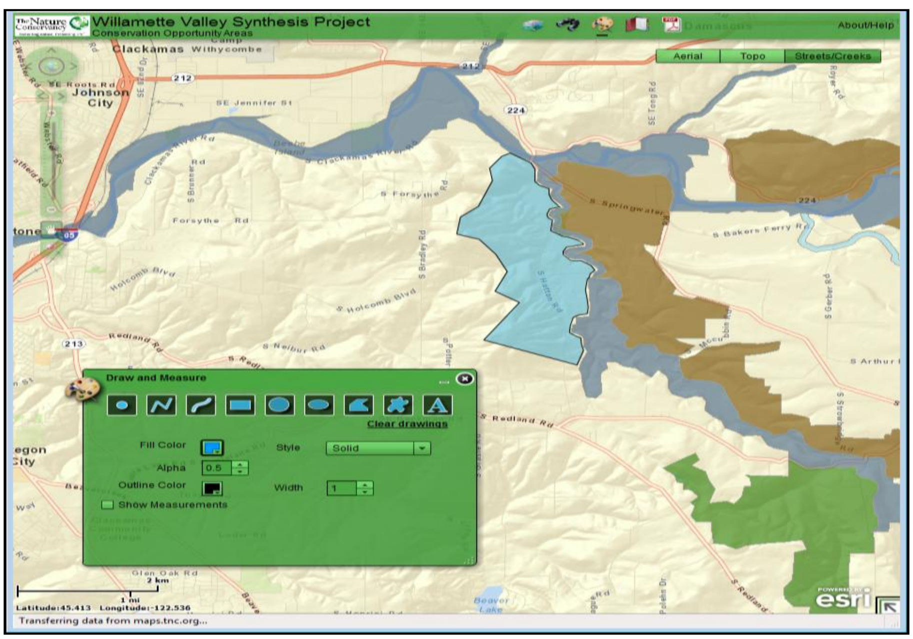


Figure 27. Using the WBSP online mapping tool, members of the public can draw recommended additions or changes to COAs identified in TNC's Union Portfolio. Members of the public can then print changes as a PDF for submission to TNC for incorporation into the Union Portfolio. Used with permission of The Nature Conservancy.

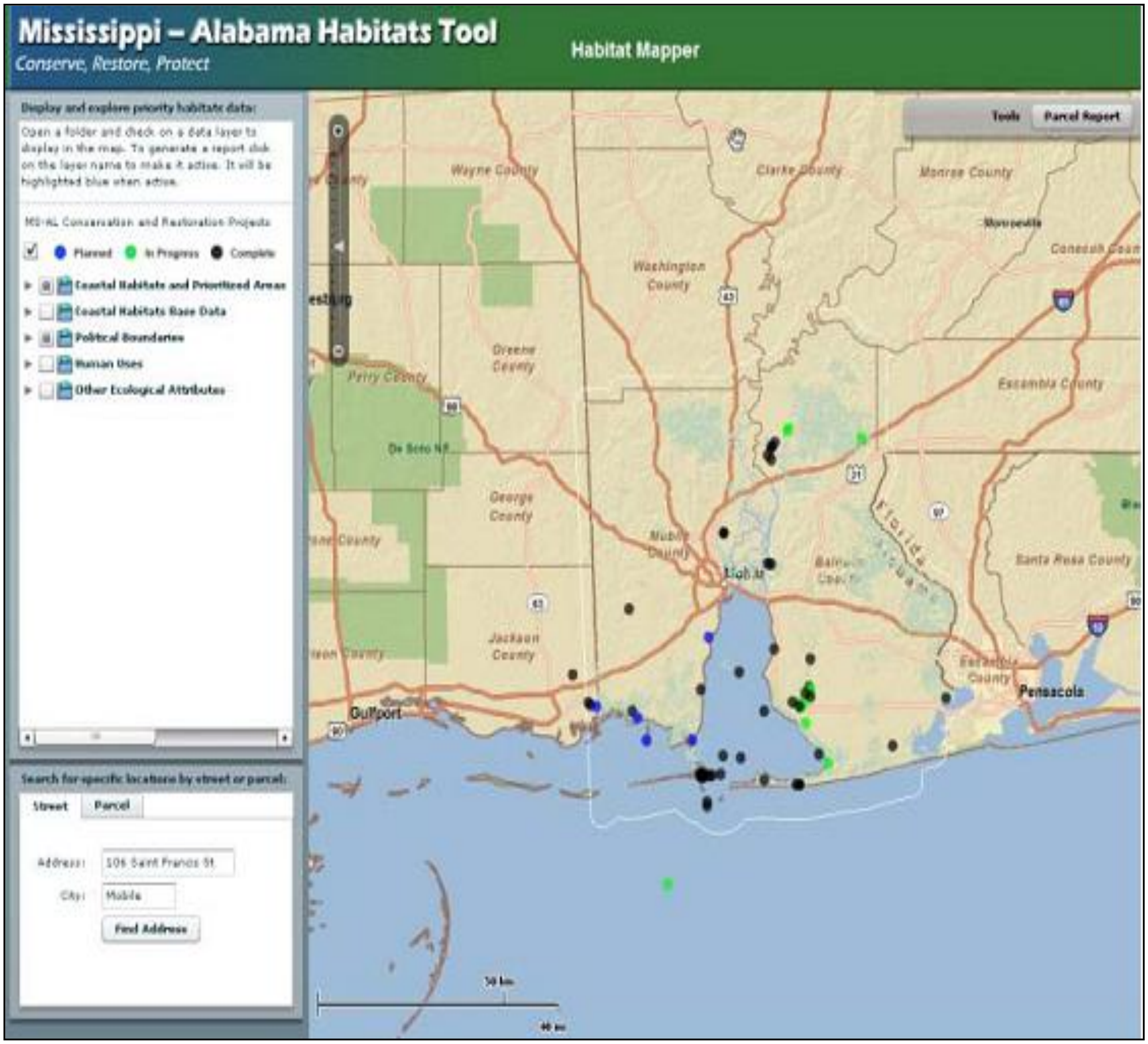


Figure 28. MBNEP's Habitat Mapper Tool includes a user interface that identifies planned and completed conservation and restoration projects relative to habitat priorities. In addition, users can enter addresses or parcel numbers to examine priority habitats that specific lands support and can identify locations of existing wetland restoration and conservation efforts. Used with permission from MBNEP.

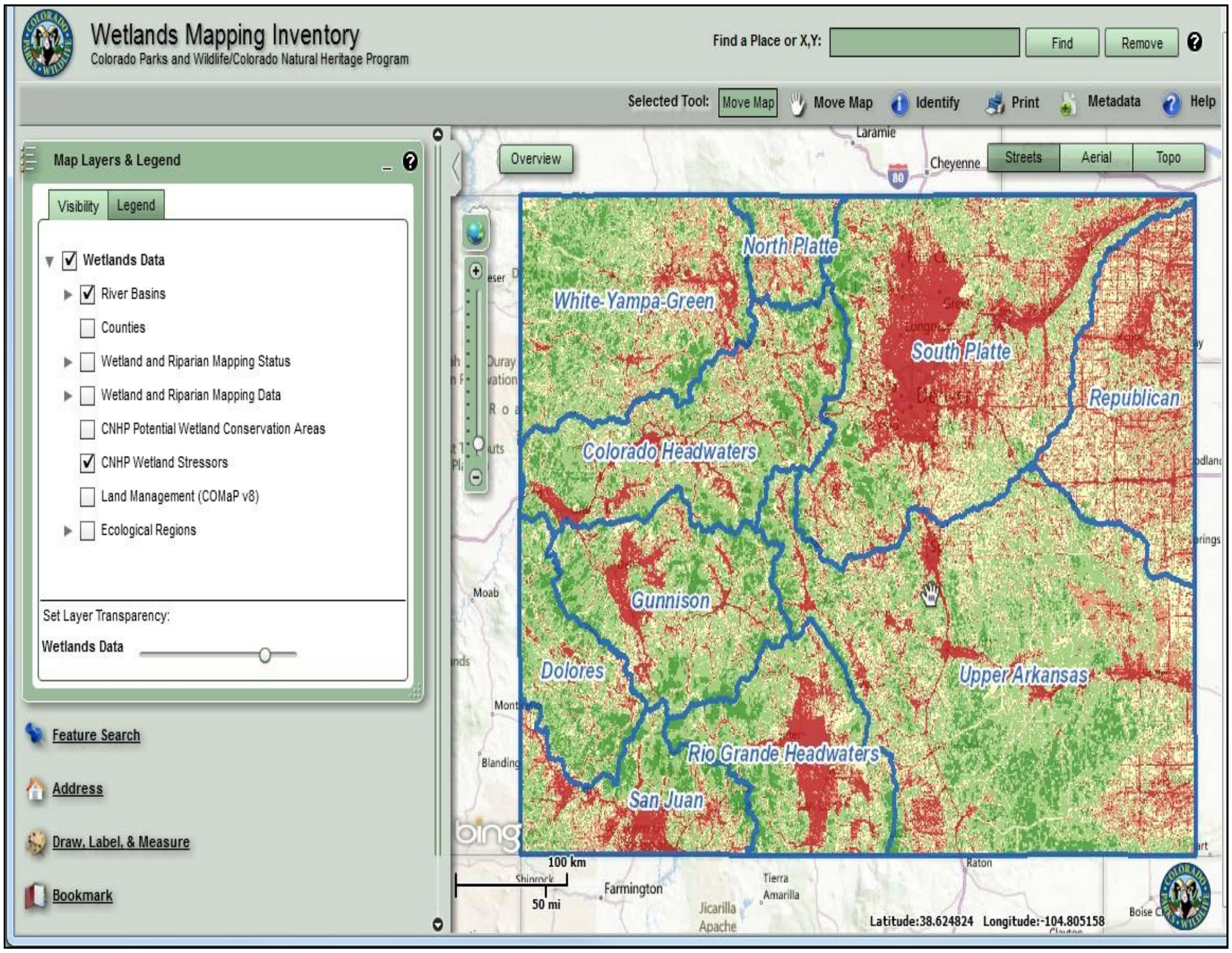


Figure 29. CNHP and CPW support an interactive map that the public can use to visualize LIM results overlaid with other spatial data of interest. Used with permission of Colorado Natural Heritage Program.

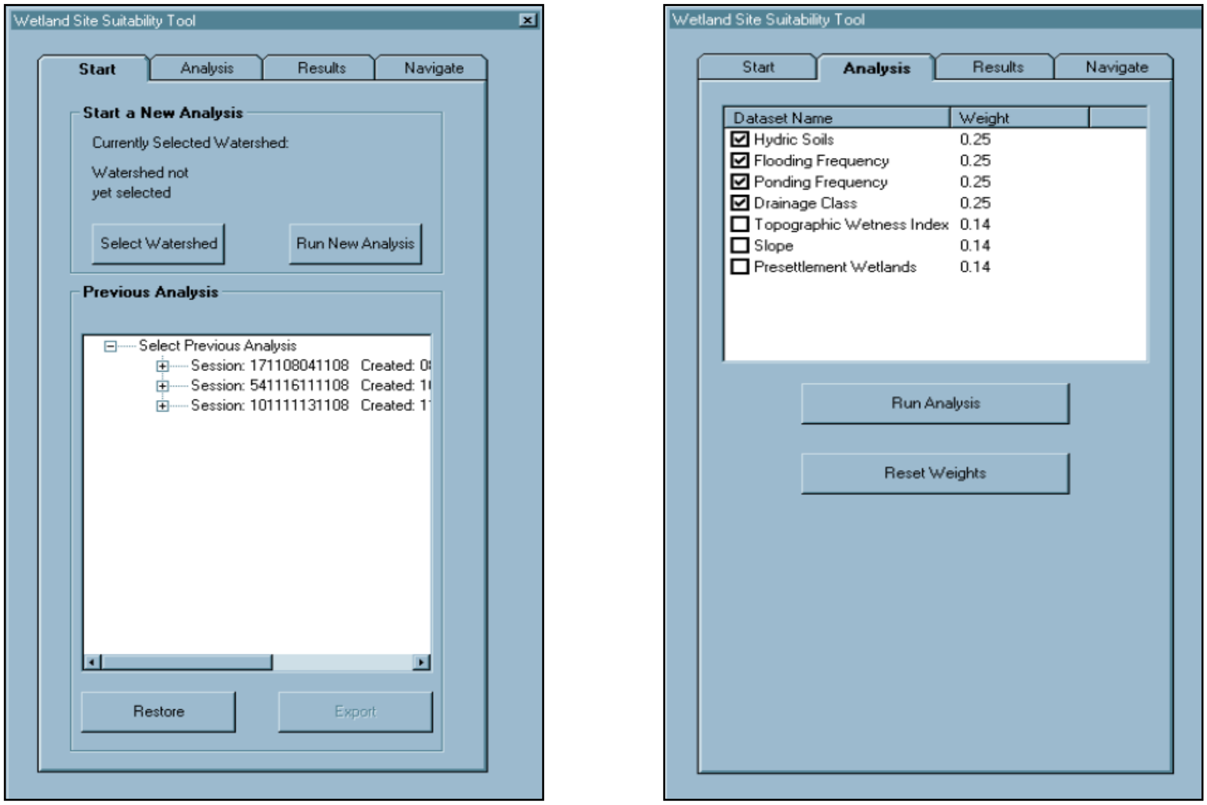


Figure 30. Users of the WMSST specify the watershed or ecoregion in which the analysis will be run (*left*) before indicating which of eight possible input layers, and their weights, should be included in the analysis (*right*).

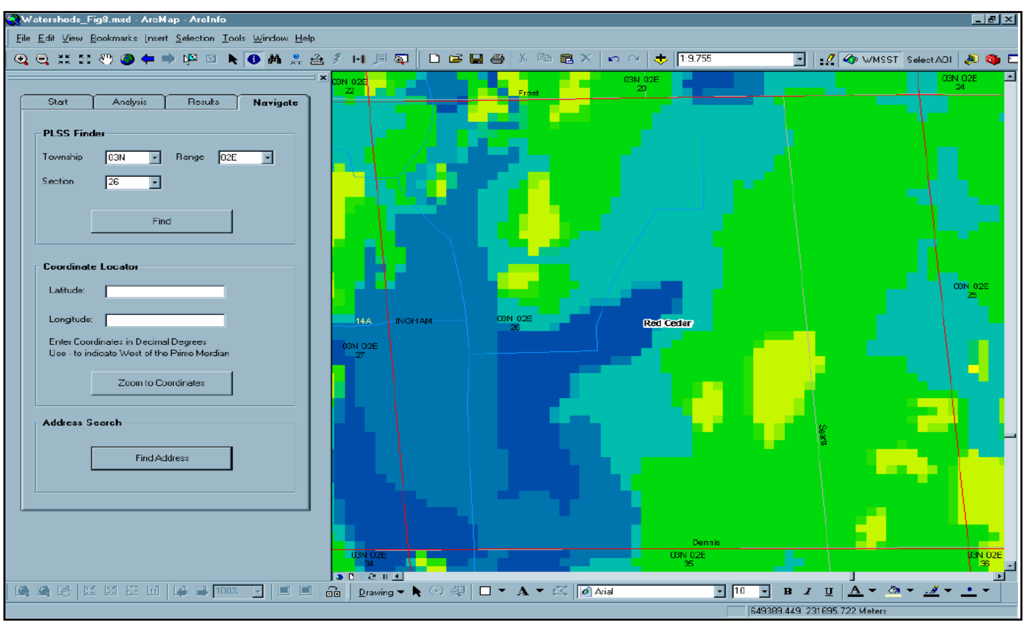


Figure 31. Users of the WMSST can locate their project site within the site suitability map by specifying PLSS Township, Range, and Section codes, which are used to reference projects under MDOT project standards.

5 Application of landscape prioritization tools to meet program needs

The following subsections address the application of landscape prioritization tools to meet the needs of regulatory and non-regulatory programs:

- Section 5.1 details how the use of landscape prioritization tools may benefit six particularly prominent regulatory and non-regulatory programs.
- Section 5.2 examines how the landscape prioritization tools examined in this study are applied to meet the needs of regulatory/non-regulatory programs.
- Section 5.3 discusses characteristics of the landscape prioritization programs that make them transferable to other states.
- Section 5.4.1 highlights data limitations encountered by landscape prioritization programs in the course of developing and applying landscape prioritization tools.
- Section 5.4 describes programmatic barriers that have limited the development and implementation of landscape prioritization tools.

5.1 Federal programs that may benefit from landscape prioritization methods

In this section, we highlight prominent federal programs involved with wetland and stream restoration and protection for which landscape prioritization tools may be particularly relevant. We highlight these programs because, though they exhibit variety in their implementation at the state and territorial level, they are carried out in every state. In addition, federal laws, regulations, and policies establish requirements for these programs, which may provide for some level of standardization across states. This list of programs is not intended to be comprehensive or indicative of the variety of programs that can utilize aquatic resource prioritization tools.

Major regulatory/non-regulatory programs that could potentially benefit from landscape prioritization tools include:

- Clean Water Act wetland mitigation (Section 5.1.1)
- Clean Water Act water quality protection (Section 5.1.2)
- Farm Bill conservation programs (Section 5.1.3)
- State Wildlife Action Plans (Section 5.1.4)
- NAWCA grants (Section 5.1.5)
- Partners for Fish and Wildlife (Section 5.1.6)

5.1.1 Clean Water Act wetland mitigation

Landscape prioritization programs that identified priority sites for use in wetland mitigation decision-making under the Clean Water Act are discussed in Section 5.2.1.

The Section 404 regulatory program: Section 404 of the CWA establishes a permitting program for discharges of "dredged or fill material" in "waters of the United States," which include many types of wetlands, streams, and other aquatic resources. The §404 program is administered by the U.S. Army Corps of Engineers' (Corps) 38 regulatory districts, though the U.S. Environmental Protection Agency (EPA) shares responsibility for developing the environmental criteria by which the Corps evaluates §404 permit applications, has veto authority over §404 permits, and shares other responsibilities for the program. Since the jurisdiction of the CWA over "waters of the United States" does not cover some geographically isolated wetlands and non-perennial streams, states, tribes, or territories may also regulate impacts to aquatic resources beyond federal jurisdiction or may establish additional requirements for permitting of impacts to "waters of the U.S." within their state. States and tribes also may review and condition/deny §404 permits through §401 water quality certification.

Proposed impacts to wetlands, streams, or other aquatic resources must satisfy the three-pronged mitigation process, which encompasses avoidance, minimization, and lastly, compensation to offset unavoidable aquatic resource impacts. Section 404 policy instructs Corps regulators to evaluate proposed impacts to ensure that:

1. All impacts are avoided to the maximum extent possible.
2. Unavoidable impacts are minimized, to the extent possible.
3. Compensation is provided for all remaining unavoidable impacts. Compensation can be satisfied through a variety of methods, including aquatic resource restoration or protection.

Avoidance and minimization using landscape prioritization: Applied to aquatic resource permitting under §404, landscape analyses that assess wetland and stream condition and function can inform considerations of avoidance and minimization. Regulators can use such information to identify wetlands or streams of high value and recommend that permittees avoid or minimize impacts in those locations. Once regulators deem that certain impacts are unavoidable and have fulfilled requirements for conducting avoidance and minimization, prioritization can help permittees, regulators, and restoration entities identify high-quality wetland or stream restoration or protection projects that offset impacts and contribute to broader ecosystem needs.

Selection of sites for compensatory mitigation using landscape prioritization: Compensatory mitigation generates substantial investment in ecological restoration or conservation and is the principal basis for the U.S. market for wetland and stream offsets. A 2007 study estimated that $2.9 billion is invested annually in wetland or stream offsets under CWA §404.[76]

Based primarily on the recommendations of a National Academy of Sciences report released in 2001[77] that reviewed the effectiveness of wetland compensatory mitigation, in 2008 federal §404 regulations codified a preference for compensation projects that are selected based on a "watershed approach" to compensatory mitigation. Historically, wetland and stream compensatory mitigation required under §404 was regulated under a strict preference to replace aquatic resources on or adjacent to impact sites (on-site) and with the same resource type (in-kind).[78] However, development often modifies hydrology at and around impact sites, and since site hydrology is a primary determinant of wetland development and persistence and ecosystem structure and function, hydrologic modification can severely limit the potential for high-quality resources to develop. In addition, on-site mitigation in heavily degraded locations or watersheds will likely impair the ultimate success of aquatic resource conservation projects, as they will be placed in areas with degraded soils, water quality, vegetation, faunal communities, or hydrology.

Accordingly, a number of scientific studies of the ecological performance of on-site mitigation indicated that these compensation projects often generated poor quality restoration projects, if restoration was accomplished at all.[79]

Further, a strict preference for on-site aquatic resource compensation likely misses promising restoration or protection opportunities elsewhere in the watershed or landscape that can better and more cost-effectively replace impacted aquatic resources or provide higher quality aquatic resource functions. The landscape position and surroundings of wetland and stream restoration, creation, enhancement, or preservation are critical to determining the quality of functions provided at a site, such as water quality improvement, flood desynchronization, and wildlife habitat provision. For instance, for a wetland to provide meaningful sediment retention functions, it should be located topographically lower in a drainage area than a source of sedimentation (e.g., a farm), and wetlands within terrestrial habitat hubs or corridors provide improved habitat functions for certain species. Specific wetland types in certain landscape positions may be particularly valuable for providing certain functions; for instance, riparian wetlands supply substantial functions for stream water quality, flood attenuation, and ecological health. Stream functions generated through restoration or conservation are also heavily dependent upon their location in a stream network, watershed, and landscape. For instance, headwater streams remove disproportionately more nitrogen and phosphorus than higher-order, downstream rivers through hydrological and biogeochemical processes (e.g., uptake in plant materials, denitrification).[80]

Expanding the geographic scope of conservation options to a watershed or landscape scale necessarily increases the number of possible conservation options and provides more opportunity to optimize the selection of compensatory mitigation projects. Geospatial prioritization tools can support the watershed approach by providing the means to systematically analyze a fuller suite of these options and support selection of conservation projects that can develop, persist, and contribute important aquatic resource functions.

5.1.2 Clean Water Act water quality programs

Landscape prioritization programs that identified priority sites for use by water quality programs under the Clean Water Act are discussed in Section 5.2.2

Clean Water Act §303(d) and associated regulations require state agencies to establish and maintain lists of waters that are impaired by specific pollutants under the Act and that necessitate development of a Total Maximum Daily Load. A TMDL is an estimate of the maximum quantity of a particular pollutant that a river, stream, lake, or other waterbody can receive from point sources and nonpoint sources, as applicable, and still attain water quality standards for that pollutant. States develop TMDLs for waterbodies impaired by an identified pollutant and implement restoration activities that support attainment of water quality standards. Though some states require development of implementation plans in TMDLs, doing so is not required and, as a result, many states do not include implementation strategies in every TMDL.

Historically, consent-decree agreements between state water quality agencies, EPA, and environmental groups have stipulated certain quantities of TMDLs that some states had to develop by certain dates. As a result of these settlement agreements, many state programs are driven to develop more TMDLs—irrespective of their quality—instead of focusing on developing more meaningful TMDLs that better support implementation of restoration in priority watersheds or areas (though all TMDL must be approved by EPA). Many states and EPA are now beginning to satisfy or renegotiate the requirements of their consent-decree agreements, which may allow them to focus more on developing TMDLs that bolster restoration. A central component of a more restoration-driven TMDL program may necessitate broader use of geospatial prioritization for development and implementation of restoration activities that better support attainment of water quality standards.

EPA and various states are piloting a geospatial prioritization tool that identifies watersheds (generally at the HUC-12 scale) with the highest potential for restoring impaired waters and protecting healthy watersheds. This tool can steer development and implementation of TMDLs to watersheds with more likelihood of ultimate success.[81] Further, as some state agencies begin to place more emphasis on implementation plans associated with impaired waters and TMDLs, the need for watershed-based prioritization approaches and technical tools that identify spatially explicit restoration or conservation priorities may expand.[82] While the §303(d) program is generally focused on one category of aquatic resource function—water quality—geospatial prioritization can play a significant role in identifying top locations for wetland and stream restoration or protection that advance water quality goals.

Implementation plans for TMDLs can include a bevy of options for water quality restoration, some of which may not result in direct physical stream or wetland restoration or protection activities. For instance, TMDL implementation plans may recommend educational programs for particular nonpoint source pollution sectors, such as agricultural operations, while others establish pollution limits for point source dischargers. However, some implementation plans included within TMDLs or watershed-based plans for nonpoint source pollution that are developed externally to implement TMDLs may explicitly identify physical restoration opportunities in specific stream segments or wetlands. Section 319 of the Clean Water Act provides funding for states, territories, and tribes to implement restoration and protection projects and develop watershed plans and associated technical tools that support reductions in nonpoint source pollution, along with funding technical assistance, education, training, and other projects that address nonpoint source pollution.

One application of §319 funding that is particularly relevant to prioritization of aquatic resource restoration or conservation projects is development of watershed-based plans that are designed to reduce nonpoint source pollution in §303(d) impaired waters. States, tribes, or territories can award §319 funds to local governments or nonprofit conservation organizations (e.g., watershed groups) to develop watershed-based plans. EPA stipulates nine specific elements that must be included in §319-funded watershed-based plans, one of which is "[a] description of the NPS management measures that will need to be implemented to achieve the load reductions…and an identification (using a map or a description) of the *critical areas* in which those measures will be needed to implement this plan" (emphasis added).[83] This required component of §319 watershed-based plans provides an opportunity to use and fund geospatial prioritization techniques that identify top wetland or stream conservation projects for reduction of nonpoint source pollution.

5.1.3 *Farm Bill conservation programs*

A suite of Farm Bill programs that provide technical assistance and funding to farmers to implement conservation practices on farms can fund wetland and stream restoration and protection. Most relevant to aquatic resource restoration and protection are the Wetlands Reserve Program (WRP), Conservation Reserve Program (CRP), Environmental Quality Incentives Program (EQIP), and the Wildlife Habitat Incentives Program (WHIP). All four programs fund a combination of restoration, land improvement, and land protection activities. With the exception of WRP, these Farm Bill programs fund a suite of different types of projects in addition to wetland or stream-related efforts. Most of these programs use a competitive bidding process to rank proposed conservation projects, and areas that are identified as significant by geospatial prioritization tools may be given more favorable rankings in some instances.

Wetlands Reserve Program: The Wetlands Reserve Program is administered by the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS). It is the most directly related to aquatic resource restoration and conservation, providing funding and technical support for preservation, enhancement, and rehabilitation of wetlands and upland areas that support wetlands. Mechanisms for wetland preservation, enhancement, and restoration under WRP include permanent or 30-year easements on wetland properties or cost-shares with landowners for wetland restoration. NRCS also funds maintenance activities associated with permanent easements or wetlands restoration funded under WRP. Each of these WRP payment programs are subject to geographic caps on payments that are established in different regions of the nation.[84] In addition to WRP, the Wetlands Reserve Enhancement Program (WREP) provides an opportunity to states, nongovernmental organizations, and other partners to work with NRCS to fund wetland conservation projects in "state-designated priority wetland restoration areas such as floodplains or riparian areas."[85] In 2009, WRP provided $62 million for wetland protection, enhancement, and restoration nationally.

WRP funding is distributed through a competitive application process so various prioritization criteria may be applied to evaluations of proposed WRP projects (Table 1). Geospatial prioritization can provide a basis for identifying wetland restoration or protection projects that support state or regional conservation objectives or that meet environmental suitability criteria by systematically analyzing a suite of possible conservation areas and comparing them. WRP proposals are often evaluated using state-specific ranking systems which may include these criteria, and in some instances, proposed WRP projects in geospatially prioritized areas may receive more points in the project proposal ranking process.

Landscape prioritization programs that identified priority sites for use by the NRCS Wetland Reserve Program are discussed in Section 5.2.3.

Conservation Reserve Program: The Conservation Reserve Program is administered by the U.S. Department of Agriculture Farm Service Agency (FSA). The program funds a variety of environmentally beneficial conservation practices on working farms and is subdivided into three programs: the general sign-up Conservation Reserve Program, the Continuous Conservation Reserve Program (CCRP), and the Conservation Reserve Enhancement Program (CREP). As a whole, these three parts of the Conservation Reserve Program provided the most funding of any

Farm Bill conservation program in 2009, distributing nearly $1.9 billion for conservation projects. Each of the three Conservation Reserve Program subdivisions include some element of geographic limitation or prioritization and rankings for these projects may reflect general or specific prioritization criteria.

CRP can provide funding for wetland restoration projects or other projects that reduce nutrient or sediment runoff. Landowners are only eligible for CRP funding if they are located in a "national or state CRP conservation priority area." CRP projects are selected on a competitive basis using an Environmental Benefits Index (EBI), which FSA uses to rank and compare proposed CRP projects (Table 1).

CCRP, which is funded through a noncompetitive process, provides financing for "high-priority conservation practices" that support ecological protection or restoration on "environmentally desirable lands." Types of aquatic resource improvement projects that can be funded through CCRP include "riparian buffers; wildlife habitat buffers, wetland buffers, filter strips, and wetland restoration." Examples of initiatives designated as high-priority conservation practices under CCRP include wetland restoration projects in the 100-year floodplain; wetland restoration projects outside of the 100-year floodplain that benefit wildlife, water quality, groundwater, or store carbon; wetland restoration for duck nesting in the U.S. prairie pothole region that provides duck nesting habitat; bottomland hardwood floodplain restoration; and the State Acres for Wildlife Enhancement (SAFE) initiative, which funds projects in geographically targeted areas that support particular wildlife species. For example, the objective of Tennessee's SAFE is to restore 500 acres of "habitat for amphibians, reptiles, crustaceans, waterfowl, and shorebirds."

Finally, CREP encourages partnerships between federal agencies (FSA, NRCS), state agencies, and sometimes private groups to perform conservation activities that are deemed high-priority and promote conservation projects of national or state importance. The specific types of projects and the conservation priorities or geographic areas supported by CREP vary by state and region. CREP projects must be sited "[w]ithin the boundaries of the CREP project areas located in specific geographic areas defined by the state and able to support the specific conservation practices required to address identified conservation issues."

The EBI point scoring system, the designation of "environmentally desirable lands" for CCRP projects, and the designation of high-priority conservation activities or geographic areas under CREP are mechanisms by which conservationists may institute incentives for selecting geospatially prioritized wetland or stream conservation sites.

Environmental Quality Incentives Program (EQIP): EQIP, administered by NRCS, provides funding and technical assistance to support conservation projects that manage impacts to soil, water, air, and related resources. The program supports a wide variety of environmental improvement projects, including riparian buffer restoration, wetland restoration, in-stream habitat restoration, and other projects that can promote water quality improvement. These resources can finance conservation activities, along with compensating for lost farm income from implementation of conservation activities. EQIP had the second highest budget of any Farm Bill conservation program in 2009, distributing $666 million.

As with proposed CRP and WRP projects, EQIP applications are ranked on a competitive basis based on national, state, and local project criteria (Table 1). In order to receive funding for conservation projects under EQIP, applicants have to fulfill at least one national priority. Subsequently, once proposed EQIP projects are determined to meet one or more national EQIP funding priorities, they are ranked based on how they fulfill state priority criteria. Further, with the consultation of a State Technical Committee that includes relevant federal and state agencies, private for-profit or nonprofit conservation entities, and members of the public, NRCS state conservationists can "establish special ranking pools for specific geographic areas or resources of concern such as a wildlife migration corridor, at-risk species, watershed, airshed or other area of special significance." Geographic prioritization may play an important role in the ranking procedures for EQIP funding at national and state levels, and may be particularly key in establishing specific priority geographic areas for focusing EQIP funding. In addition, the NRCS National Water Quality Initiative, as funded for FY2012, will require that at least 5% of each state's EQIP funding be spent in priority watersheds (identified at the HUC-12 scale) as identified by local partners and state water quality agencies.[86]

Wildlife Habitat Incentives Program (WHIP): WHIP, also administered by NRCS, provides technical support and funding to agricultural landowners to protect and restore fish and wildlife habitat of national, regional, and local importance. Specifically, WHIP's FY2012 program objectives include habitat restoration, enhancement, development, or protection for important or declining native fish and wildlife, at-risk species, and wildlife migration corridors. Among other types of fish and wildlife conservation projects, WHIP funds aquatic resource projects such as riparian buffer restoration, wetland restoration, in-stream habitat restoration, and management measures for nutrient and sediment runoff. The 2008 Farm Bill dedicated $85 million annually to fund WHIP projects.

WHIP holds high potential to utilize geospatial prioritization, as NRCS can prioritize proposed habitat projects that complement goals or objectives set in existing national, regional, or state conservation plans such as State Wildlife Action Plans. The criteria used to rank competitive bids for WHIP funding are set at both the national and state levels, and may include criteria that are conducive to use of geospatial prioritization (Table 1).

Table 12. Ranking criteria relevant to geospatial prioritization for Farm Bill conservation programs with competitive bidding process.[87]

Farm Bill conservation program	Ranking criteria relevant to geospatial prioritization
Wetlands Reserve Program	• Priority geographic areas where restoration supports state/regional objectives (states identify these areas) • Provides higher conservation value • Most cost-effective for environmental benefits gained • Best achieve the purposes of the program • Have lower on-farm and off-farm threats such as development of nearby land
Conservation Reserve Program	**Environmental Benefits Index (EBI)** • Wildlife habitat benefits from natural cover on contract acreage (0 to 100 points; includes 0 to 30 points for location in a wildlife priority zone) • Water quality benefits from reduced erosion, runoff and leaching (0 to 100 points; includes 0 to 30 points for location in an approved water quality zone) • Erosion factor point score (0 to 100 points) • Enduring benefits factor (0 to 50 points) • Air quality benefits from reduced wind erosion (0 to 45 points; includes 3 to 10 points for carbon sequestration) • Cost (varying point range)
Environmental Quality Incentives Program	**National Priorities** (must meet one) • Promotes at-risk species habitat conservation • Reduces nonpoint source pollution, surface and groundwater contamination, or contamination from concentrated animal feeding operations **State Priorities** (may vary by state) • Cost-effectiveness • Priority of resource concerns being addressed • How effectively and comprehensively the project addresses the identified concerns • Degree of expected environmental benefit • Long-term value and sustainability of the practices • Potential of project to improve existing conservation practices or systems or complete a conservation system **Special Initiatives** (may vary by state) • State conservationist can create individual ranking pools for specific geographic areas or resources of concern such as wildlife migration corridors, at-risk species, watersheds, airsheds, or other areas of special significance
Wildlife Habitat Incentives	• NRCS can prioritize projects that address state, regional, and

Farm Bill conservation program	Ranking criteria relevant to geospatial prioritization
Program	national conservation plans (e.g., State Wildlife Action Plans, North American Waterfowl Management Plan) **National Priorities** • Restore declining or important native fish and wildlife habitats • Protect, restore, develop or enhance habitat to benefit at-risk species such as candidate species and state-listed threatened and endangered species • Reduce the impacts of invasive species on fish and wildlife habitats • Protect, restore, develop or enhance declining or important aquatic wildlife habitats **State Priorities** (may vary by state) • State conservationist can sometimes set priority areas or habitats for WHIP funding • Contribution to resolving a national, regional or state habitat concern • Inclusion in an established wildlife priority area • Long-term benefits obtained from the project • How self-sustaining the proposed practices are • Restoration cost

5.1.4 State Wildlife Action Plans

Landscape prioritization programs that identified priority sites for use by State Wildlife Action Plans are discussed in Section 5.2.4.

In 2000, Congress established the State Wildlife Grants Program, which is administered by the U.S. Fish and Wildlife Service (FWS), to fund development and implementation of programs that support wildlife and their habitats. FWS distributes State Wildlife Grants for two broad categories of conservation activities: planning and implementation. Planning grants fund the development of State Wildlife Action Plans (SWAPs), while implementation grants fund projects that implement the activities contained in the SWAPs.[88] For states to qualify for State Wildlife Grant funding, they were required to generate a State Wildlife Action Plan (SWAP) that comprehensively addresses the following eight elements by October of 2005:

1) “Information on the distribution and abundance of species of wildlife, including low and declining populations as the state fish and wildlife agency deems appropriate, that are indicative of the diversity and health of the state’s wildlife;
2) Descriptions of extent and condition of habitats and community types essential to conservation of species identified in (1);
3) Descriptions of problems which may adversely affect species identified in (1) or their habitats, and priority research and survey efforts needed to identify factors which may assist in restoration and improved conservation of these species and habitats;

4) Descriptions of conservation actions proposed to conserve the identified species and habitats and priorities for implementing such actions;
5) Proposed plans for monitoring species identified in (1) and their habitats, for monitoring the effectiveness of the conservation actions proposed in (4), and for adapting these conservation actions to respond appropriately to new information or changing conditions;
6) Descriptions of procedures to review the plan at intervals not to exceed ten years;
7) Plans for coordinating the development, implementation, review, and revision of the plan with federal, state, and local agencies and Indian tribes that manage significant land and water areas within the state or administer programs that significantly affect the conservation of identified species and habitats;
8) Broad public participation is an essential element of developing and implementing these plans, the projects that are carried out while these plans are developed, and the species in greatest need of conservation."[89]

As such, when done in a comprehensive and spatially explicit manner, SWAPs can be valuable resources for siting compensatory mitigation or voluntary conservation projects that advance habitat and wildlife objectives. Given the required elements of SWAPs, particularly element four's requirement for describing conservation actions and priorities for implementing these actions, geospatial prioritization can advance the utility of SWAPs for environmental and natural resource agencies, conservation organizations, or other private restoration entities (e.g., mitigation banks). As of 2009, an estimated 31 SWAPs incorporated spatially explicit maps of terrestrial protection opportunity areas,[90] and some of these plans included maps of opportunity areas for aquatic habitat conservation. However, few SWAPs include spatially explicit maps of prioritized restoration opportunities that support habitat and wildlife objectives. All states have now at least finalized their first SWAP, and some states are presently revising their SWAPs to include more extensive mapping or analyses.

After states develop SWAPs, FWS distributes implementation grants to state wildlife agencies. However, as indicated above, SWG implementation grants do not fund conservation or restoration projects; rather, these grants fund monitoring, evaluation, and data-gathering projects that operationalize SWAPs. Even so, spatially explicit SWAPs may provide a promising platform for indicating where wildlife conservation investment priorities exist, and may help to target monitoring and evaluation of the progress of any subsequent conservation.

5.1.5 NAWCA grants

The North American Wetlands Conservation Act (NAWCA) establishes competitive standard and small grant programs that fund organizations, government agencies, land trusts, and landowners to conserve, restore, or enhance wetlands for the benefit of migratory birds and other wildlife supported by wetlands. Both the standard and small grant programs require cost-sharing between federal administrators of the programs and project implementers, and the grant programs are facilitated by the FWS Division of Bird Habitat Conservation. The standard and small grants programs are very similar, except that the maximum size of a small grant is $75,000. Congressional reauthorization of NAWCA in 2006 continued the grant programs, authorizing expenditures of up to $75 million per year until 2012 on wetland conservation projects for all types of habitats and birds that depend upon wetlands; the small grants program accounted for $3-5 million of this total amount.

Standard grants, which generally fund larger-scale wetlands restoration, enhancement, or conservation initiatives, are awarded by the Migratory Bird Conservation Commission, a commission of cabinet-level representatives, Senators, and Representatives. Prior to this review, staff in the FWS Division of Bird Habitat Conservation, coordinators for Joint Ventures, and the staff of the North American Wetlands Conservation Council conduct a preliminary review of applications, with the Council subsequently submitting a ranked list of suggested projects to the Commission. For small grants, the Division, Joint Venture coordinators, and Council review and rank proposals, and the Council selects wetlands projects to fund.

In some cases, geospatial prioritization may play a role in ranking and ultimately selecting NAWCA projects to fund, and where these geospatial techniques are not currently used, landscape-level prioritization has the potential to systematize rankings of projects' ecological benefits for wetland-dependent bird species.[91]

5.1.6 Partners for Fish and Wildlife Program

FWS administers the Partners for Fish and Wildlife Program, a voluntary habitat improvement program operated under the authority of the Fish and Wildlife Coordination Act, the Fish and Wildlife Act of 1956, and the Partnerships for Wildlife Act. Similar to Farm Bill conservation programs such as CRP, the Partners program supplies funding and technical assistance to landowners for habitat improvement activities that support "migratory bird species; anadromous fish species of special concern to FWS; endangered, threatened, or candidate species; species proposed for listing; and other declining or imperiled species."[92] Habitat improvement projects funded under the Partners program include restoration, enhancement, and preservation projects for wetlands, streams, riparian areas, and uplands. In FY2010, the Partners program received $60.2 million in funding for habitat improvement projects.

FWS policy for the Partners program indicates that conservation planning and geospatial prioritization could play a significant role in selection of priority sites. A driving objective for the Partners program includes implementing restoration, enhancement, and preservation projects that support "[FWS] plans and programs including, but not limited to, the National Wildlife Refuge System; the North American Waterfowl Management Plan; the North American Bird Conservation Initiative; the National Invasive Species Management Plan; threatened and endangered species recovery plans; Coastal Program management plans; Partners in Flight plans; fisheries management and restoration plans; ecosystem management plans; and other habitat plans."[93] Financing and technical assistance through the Partners program is awarded competitively, and so FWS has established a priority system that chooses particular habitat improvement projects. At a national scale, FWS policy sets generic primary and secondary priorities for consideration in selection of habitat improvement projects, and FWS field staff refine habitat priorities and focus areas at state or local levels to guide selection of projects.[94]

The Partners program provides the highest priority status to potential habitat improvement projects that "complement activities on National Wildlife Refuge System lands or contribute to the resolution of problems on refuges that are caused by off-refuge land use practices" or support at-risk species. Secondary factors which may give potential projects additional consideration include:

- **Ecoteam priorities:** Projects identified by Service ecosystem teams or in collaboration with State fish and wildlife agencies, conservation districts, and other partners.
- **Links and augmentation:** Projects that reduce habitat fragmentation.
- **Globally or nationally imperiled:** Projects that conserve or restore a natural community that a State Natural Heritage Program or Heritage Database has designated as globally or nationally imperiled.
- **Self-sustaining:** Projects that result in self-sustaining systems that are not dependent on artificial structures. If such structures are necessary for project success, they must be designed to blend with the natural landscape and to minimize future operational and maintenance costs.
- **Buffers:** Projects that serve as buffers for other important State or Federal conservation lands.[95]

Other general ranking criteria may be considered, including longer duration projects, projects with greater cost-sharing, or projects with greater cost-effectiveness. Finally, the Partners' guiding policy notes that "[h]abitat improvement projects targeting fisheries and other instream aquatic communities must focus on areas that will show a marked improvement in water quality and habitat values in both the project area and in downstream reaches. High priority should be given to projects that restore stream courses, restore riparian buffers, and remove constructed barriers."[96]

5.2 Application to specific regulatory/non-regulatory programs

We identified ten categories of regulatory/non-regulatory programs targeted by landscape prioritization programs.

- Clean Water Act wetland mitigation (Section 5.2.1)
- Clean Water Act water quality programs (Section 5.2.2)
- NRCS Wetland Reserve Program (Section 5.2.3)
- State Wildlife Action Plans (Section 5.2.4)
- Endangered Species Act §10 compensatory mitigation (Section 5.2.5)
- National Environmental Policy Act effects analysis (Section 5.2.6)
- State/local wetland mitigation (Section 5.2.7)
- State water quality programs (Section 5.2.8)
- Non-regulatory markets for ecosystem services (Section 5.2.9)
- Other non-regulatory restoration/protection (Section 5.2.10)

In addition, we identified further regulatory/non-regulatory program sub-categories for two of the categories listed above – "Clean Water Act wetland mitigation" and "other non-regulatory restoration/protection." Table 13 indicates the potential regulatory/non-regulatory applications, including sub-categories, of each of the landscape prioritization tools examined in this study.

Table 13 Actual and potential regulatory/non-regulatory applications of each landscape prioritization tool. An asterisk (*) indicates tools that have been applied to a particular regulatory/non-regulatory application.

	§404 mitigation site selection	§404 ILF site selection	§404 bank site selection	§404 watershed approach	§401/§404 permit requirements	CWA water quality programs	NRCS WRP	State Wildlife Action Plans	ESA §10 mitigation	NEPA effects analysis	State/local wetland mitigation	State water quality programs	Non-reg markets for ESS	Other non-reg conservation
AR MAWPT Standard GIS Methodology for Wetland Analysis	X		X*				X*					X*		X*
Caltrans RAMP Greenprint Analysis	X			X					X					X
Caltrans RAMP Road Impact Footprint Analysis				X	X				X					X
CNHP Landscape Integrity Model	X			X					X	X				X
CNHP Wetland profile														
DU Forested Wetland Restoration Suitability Model	X	X*					X							X*
IDFG Watershed Condition Tool	X					X		X*						X
IDFG Wetland Condition Tool	X					X		X*						X
Kramer et al. (2012) Connectivity to Existing Conservation Lands	X	X	X	X		X	X*							
Kramer et al. (2012) Human Development Index	X	X	X	X		X	X*							
Kramer et al. (2012) Hydrologic Connectivity Between Wetlands	X	X	X	X		X	X*							
Kramer et al. (2012) Jurisdiction Tool	X		X	X		X	X*							
Kramer et al. (2012) Maintenance of High Biodiversity Streams Tool	X	X	X	X		X	X*							
Kramer et al. (2012) Natural Upland Habitat Surrounding Sites Tool	X	X	X	X		X	X*							
Kramer et al. (2012) Potential Runoff Index	X	X		X		X	X*							
Kramer et al. (2012) Potential Wetland Banking Site index	X		X	X		X	X*							
Kramer et al. (2012) Terrestrial Dispersal Corridors Between	X	X	X	X		X	X*							
Kramer et al. (2012) Water Quality and Quantity Index	X		X	X		X	X*							
Kramer et al. (2012) Wetland Condition Index	X	X		X		X	X*							
LACPRA CMP American Alligator Habitat Suitability Index	X	X	X											X*
LACPRA CMP Brown Shrimp Habitat Suitability Index	X	X	X											X*
LACPRA CMP Carbon Sequestration Potential Tool	X	X	X										X	X*
LACPRA CMP Coastal Louisiana Risk Assessment	X	X	X											X*
LACPRA CMP Crawfish Habitat Suitability Index	X	X	X											X*
LACPRA CMP Eastern Oyster Habitat Suitability Index	X	X	X											X*
LACPRA CMP Gadwall Habitat Suitability Index	X	X	X											X*
LACPRA CMP Green-wing teal Habitat Suitability Index	X	X	X											X*
LACPRA CMP Largemouth bass Habitat Suitability Index	X	X	X											X*
LACPRA CMP Mottled Duck (Foraging) Habitat Suitability Index	X	X	X											X*
LACPRA CMP Muskrat Habitat Suitability Index	X	X	X											X*
LACPRA CMP Nature Based Tourism Suitability Index	X	X	X											X*
LACPRA CMP Nitrogen Uptake Spatial Statistical Approach	X	X	X										X	X*
LACPRA CMP Potential for Freshwater Availability Tool	X	X	X											X*
LACPRA CMP Relative Elevation Sub-Model	X	X	X											X*
LACPRA CMP River Otter Habitat Suitability Index	X	X	X											X*
LACPRA CMP Roseate Spoonbill (Foraging) Habitat Suitability	X	X	X											X*
LACPRA CMP Roseate Spoonbill (Nesting) Habitat Suitability Index	X	X	X											X*
LACPRA CMP Spotted Sea Trout Habitat Suitability Index	X	X	X											X*
LACPRA CMP Storm Surge/Wave Attenuation Potential Suitability Index	X	X	X											X*
LACPRA CMP White Shrimp Habitat Suitability Index	X	X	X											X*
MD WRR Wetland Preservation	X			X	X	X	X*							X*

	§404 mitigation site selection	§404 ILF site selection	§404 bank site selection	§404 watershed approach	§401/§404 permit requirements	CWA water quality programs	NRCS WRP	State Wildlife Action Plans	ESA §10 mitigation	NEPA effects analysis	State/local wetland mitigation	State water quality programs	Non-reg markets for ESS	Other non-reg conservation
MTNHP Landscape Integrity Model	X			X		X			X	X				X
MTRI Wetland Mitigation Site Suitability Tool	X			X							X			
NCEEP Focus Area Identification Method	X			X		X					X	X*		
NCEEP HUC-14 Screening Method	X			X		X					X	X*		
NHDES WRAM Ecological Integrity Tool	X													
NHDES WRAM Flood Protection Tool	X													
NHDES WRAM Groundwater Use Potential Tool	X													
NHDES WRAM Landscape Position Score	X													
NHDES WRAM Net Functional Benefit Score	X													
NHDES WRAM Restoration Sustainability Tool	X													
NHDES WRAM Sediment Trapping and Nutrient Potential Tool	X													
NHDES WRAM Significant Habitat Tool	X													
NHDES WRAM Site Identification Model	X													
NHDES WRAM Site Prioritization Model	X	X*												
NOAA HPP MAHT Freshwater Wetlands Tool														X*
NOAA HPP MAHT Intertidal Marshes and Flats (Flood Hazard														X*
NOAA HPP MAHT Intertidal Marshes and Flats (Natural Resource														X*
NOAA HPP MAHT Riparian Buffers (Conservation) Tool														X*
NOAA HPP MAHT Riparian Buffers (Restoration) Tool														X*
NOAA HPP MAHT Watersheds (River and Stream Conservation) Tool														X*
NOAA HPP MAHT Watersheds (River and Stream Restoration) Tool														X*
Kauffman-Axelrod and Steinberg (2010) Restoration Conideration Areas Tool	X													
Kauffman-Axelrod and Steinberg (2010) Tidal Wetland Restoration Prioritization Tool	X													
PLJV PLDSS Landscape-Scale Model							X							X
PLJV PLDSS Site-Scale Model							X							X
Strager et al. (2011) Stream Banking Site Selection Model	X			X						X				X*
Strager et al. (2011) Wetland Banking Site Selection Model	X			X						X				X*
TNC Aquatic EA Landscape Context Tool	X	X*		X*			X*				X			X*
TNC Aquatic EA Aquatic System Integrity GIS Model	X	X*		X*			X*				X			X*
TNC-ELI DPWAP Carbon Storage Tool	X	X	X	X				X*						
TNC-ELI DPWAP Fish Habitat Tool	X	X	X	X				X*						
TNC-ELI DPWAP Flood Abatement Tool	X	X	X	X				X*						
TNC-ELI DPWAP Function Variety Tool	X	X	X	X				X*						
TNC-ELI DPWAP Potentially Restorable Wetlands Tool	X	X	X	X				X*						
TNC-ELI DPWAP Shoreline Protection Tool	X	X	X	X				X*						
TNC-ELI DPWAP Surface Water Supply Tool	X	X	X	X				X*						
TNC-ELI DPWAP Water Quality Protection Tool	X	X	X	X				X*						
TNC-ELI DPWAP Watershed Profile Tool	X	X	X	X				X*						
TNC-ELI DPWAP Wetland Preservation Tool	X	X	X	X				X*						
TNC-ELI DPWAP Wildlife Tool	X	X	X	X				X*						
TWRA CWCS HUC-12 Aquatic Resource Prioritization Tool								X*						X*
UMass Amherst CAPS Index of Ecological Integrity	X*			X	X					X	X*			X*
USACE SRWBMP Baseline Assessment							X				X			X
USACE SRWBMP Spatial Decision Support System	X						X				X			X
USEPA RPS Ecological Capacity Tool	X					X								X*
USEPA RPS Recovery Potential Integrated Tool	X					X								X*
USEPA RPS Social Context Tool	X					X								X*

	§404 mitigation site selection	§404 ILF site selection	§404 bank site selection	§404 watershed approach	§401/§404 permit requirements	CWA water quality programs	NRCS WRP	State Wildlife Action Plans	ESA §10 mitigation	NEPA effects analysis	State/local wetland mitigation	State water quality programs	Non-reg markets for ESS	Other non-reg conservation
USEPA RPS Stressor Exposure Tool	X					X								X*
USGS Forest Breeding Bird Decision Support Model	X	X					X*		X				X	X*
VDCR GIS Tool for Identifying Wetland Restoration Opportunities	X	X		X					X		X			X
VIMS Wetland Condition Assessment Tool	X				X					X	X			
VIMS Wetland Mitigation Targeting Tool	X										X			X*
WADOE WCT Overall Watershed Characterization Tool	X	X*	X*	X*		X	X				X*			X*
WADOE WCT Groundwater discharge tool	X	X*	X*	X*		X	X				X*			X*
WADOE WCT Groundwater Recharge Tool	X	X*	X*	X*		X	X				X*			X*
WADOE WCT Water Delivery Tool	X	X*	X*	X*		X	X				X*			X*
WADOE WCT Water Storage Tool	X	X*	X*	X*		X	X				X*			X*
WBSP Union Portfolio													X*	
WDNR Flood Storage Decision Support Tool	X													X*
WDNR Habitat Quality Index	X													X*
WDNR Potential Opportunity Tool	X													X*
WDNR Potentially Restorable Wetlands Tool	X		X*											X*
WDNR Relative Need Tool	X													X*
WDNR Wetland Preservation Tool	X													X*
WDNR Wetland Water Quality Assessment Tool	X													X*
Weller et al. (2007) Biogeochemistry (Flat Wetlands)	X			X										
Weller et al. (2007) Biogeochemistry (Riverine Wetlands)	X			X										
Weller et al. (2007) Habitat (Flat Wetlands)	X			X										
Weller et al. (2007) Habitat (Riverine Wetlands)	X			X										
Weller et al. (2007) Hydrology (Flat Wetlands)	X			X										
Weller et al. (2007) Hydrology (Riverine Wetlands)	X			X										
Weller et al. (2007) Landscape (Riverine Wetlands)	X			X										
Weller et al. (2007) Plant Community (Flat Wetlands)	X			X										
Weller et al. (2007) Plant community (Riverine Wetlands)	X			X										

5.2.1 Clean Water Act wetland mitigation

The most common application of the landscape prioritization tools evaluated in this study was site selection for Section 401/404 wetland compensatory mitigation. Types of site selection undertaken by landscape prioritization programs included the following:

- General site selection
- ILF site selection
- Bank site selection
- Watershed approach
- Determination of permit requirements

General site selection: Eleven of the prioritization programs reviewed characterized their tools as generally applicable to the selection of wetland or stream mitigation sites under §404 wetland compensatory mitigation (Table 13). The UMass Amherst CAPS tools, for example, have been applied to the development of mitigation plans[31] and the IDFG Landscape Assessment is useful for improving the effectiveness of §404 mitigation.[97] In addition, MTRI described how its Wetland Mitigation Site Suitability Tool could help staff select wetland mitigation sites more efficiently compared to traditional methods that demand large amounts of staff time.[98] NHDES described how its WRAM tool can be highly effective at informing mitigation site selection for specific functions.[28] For example, by prioritizing functional uplift in floodwater wetlands, the NHDES WRAM could be used to help states enhance economic, water quality, and wildlife functions through compensatory mitigation.

ILF site selection: Nine of the programs analyzed described specific applications of their tool(s) to inform mitigation site selection as part of in-lieu fee (ILF) mitigation programs (Table 13). For instance, the output maps of the DU Forested Wetland Restoration Suitability Model are used by Ducks Unlimited to select offset sites as part of its ILF program.[99] Applicants to the NHDES Aquatic Resource Mitigation (ARM) ILF program use outputs from the NHDES WRAM as part of their project site selection process. The state's ILF program gives priority to proposed sites that are based on WRAM priorities.[28] The TNC Virginia Aquatic Resource Trust Fund ILF program uses priorities identified using TNC Aquatic Ecoregional Assessment to guide its ILF site selection process.[70] Additionally, three programs – Kramer et al. (2012) Wetland Condition Index,[100] the VDCR Model,[101] and the LACPRA Coastal Master Plan[102] – indicated ILF site selection to be a potential application of their tool(s).

Bank site selection: Six of the programs reviewed detailed applications of tools for selecting wetland mitigation banking sites (Table 13). The Arkansas MAWPT GIS Methodology for Wetland Analysis, for example, is commonly used to inform mitigation site selection by the State Wetland Mitigation Banking Program (operated by the Arkansas State Highway and Transportation Department and the Arkansas Natural Resources Commission).[103] In addition, Kramer et al. (2012)'s Potential Wetland Banking Site Index can be used by Interagency Review Teams (IRTs) to select potential sites for mitigation banks, select service areas for mitigation banks, and determine the number of credits to allocate to mitigation banks.[100] Moreover, the WSDOE Watershed Characterization Tools and WDNR Potentially Restorable Wetlands Tool have been used by mitigation bankers to guide selection of bank sites.[104,105]

Watershed approach: Fourteen of the programs reviewed indicated that their tool(s) could be used to support the watershed approach to wetland compensatory mitigation site selection (Tqable 13). For example, the TNC-ELI DPWAP promotes the functional replacement of wetland benefits on a watershed basis by identifying areas in which to target mitigation through an analysis of historic functional losses within HUC-12 watersheds.[14] NCEEP, on the other hand, applies a rigorous approach to identifying priority sites that benefit overall watershed function by first applying its River Basin Restoration Priorities analysis to identify priority HUC-14s within HUC-8 watersheds.[106] With these targets identified, NCEEP then applies its Focus Area Identification Method to identify priority subwatersheds within each HUC-14 unit. The Weller et al. (2007) wetland condition assessment tools may be used to inform a watershed approach to wetland mitigation site selection by providing a fairly precise estimate of average condition of wetlands within watersheds.[107] These assessments of watershed condition can be used to evaluate how different watershed units might benefit from wetland restoration or conservation.

Determination of permit requirements: Kentucky suggested that landscape prioritization tools might be helpful in permitting decisions as part of its §401 certification program by improving its ability to analyze cumulative effects.[59] Three prioritization programs cited applications for their tools related to determination of §401/§404 permit requirements (Table 13). For instance, by allowing users to estimate individual or cumulative effects of wetland impacts (e.g., by incorporating the habitat stress level of surrounding wetlands, locations of DEQ general permits, etc.) the VIMS Wetland Condition Assessment Tool supports efforts to determine wetland permitting requirements.[108]

Needs of states lacking landscape prioritization tools: Eight of the 11 states without such landscape prioritization tools – Alaska,[109] Arizona,[110] Connecticut,[111] Kentucky,[59] New Jersey,[33] New York,[35] South Carolina,[37] and Texas[44] – stated that such tools could be applied in the §404 compensatory mitigation context. South Carolina described how the tools could inform the selection of mitigation banking sites by the South Carolina Department of Transportation, which has a continual demand for mitigation sites.[37] New Mexico stated that landscape prioritization methods could support implementation of a watershed approach to mitigation in that state.[34]

5.2.2 Clean Water Act water quality programs

In our evaluation of prioritization programs, seven programs indicated that their tools could be used to guide the selection of wetland and stream restoration and conservation projects to satisfy federal water quality regulations such as §303(d), TMDL, §305(b), §319, and §402 (Table 13). The EPA Recovery Potential Screening method, for instance, informs the development of TMDL/§303(d) prioritized schedules through a number of applications, such as providing input to statewide nutrient reduction strategies and guiding the implementation of TMDLs for best results.[16] The USEPA RPS is also used to guide the prioritization of wetland/stream projects under CWA §319 by, for example, helping to inform phase 1 and 2 planning processes and revealing suitable criteria for §319 evaluations.[16] Another program that has been applied to §319 restoration and conservation projects is NCEEP. North Carolina's Clean Water Management Trust Fund evaluates potential aquatic resource restoration and conservation projects for funding based on a point system. In scoring projects, CWMTF awards additional points if projects are located in NCEEP priority areas.[106] Additionally, the IDFG Landscape Assessment,[97] Maryland WRR,[21] and WSDOE Watershed Characterization Tool,[104] can all be applied to support the development of TMDLs, with the MD WRR also applicable to other federal water quality regulatory purposes, such as §305(b) and §402.[21]

Needs of states lacking landscape prioritization tools: Seven of the 11 states without prioritization tools – Connecticut,[111] Kentucky,[59] New Jersey,[33] New Mexico,[34] New York,[35] South Carolina,[37] Texas,[44] indicated that such tools could be used to guide water quality programs Level 1. Such programs included Total Maximum Daily Load (TMDL) programs, §303(d) listing of impaired waterbodies, §305(b) water quality reporting, and §319 grant programs. For example, Wyoming stated that a landscape prioritization tool could be used to allocate funding for §319 grant programs.[60] Kentucky cited possible applications for decisionmaking regarding distribution of funding for §303(d) restoration projects and TMDL establishment.[59]

5.2.3 NRCS Wetland Reserve Program

Six of the prioritization programs analyzed reported that their tools have been used as a criterion in the selection of Wetland Reserve Program (WRP) sites by the Natural Resource Conservation Service (NRCS) (Table 13). As part of its process for allocating WRP funding, NRCS may award points to applicants with proposed WRP sites that fall within priority areas identified by these prioritization programs. For instance, WRP applicants with projects located within Conservation Priority Areas identified by the TNC Aquatic Ecoregional Assessment are often favored by the NRCS.[70] In addition, multiple states throughout the Mississippi Alluvial Valley use prioritization results from the USGS Forested Breeding Bird Decision Support Tool to award WRP points, though the scoring system used to incorporate prioritization results into the WRP scoring system varies across states.[112]

In contrast to these programs, the prioritization output for one program – the TNC WBSP Willamette Valley Synthesis Map – is weighted much more heavily as part of the NRCS WRP program. In the Willamette Valley, NRCS only pursues prospective WRP easements that are located within Conservation Opportunity Areas identified by the Willamette Valley Synthesis Map.[73]

Three additional programs – Ducks Unlimited, PLJV PLDSS, and WSDOE WCT – indicated that their tools could be integrated into the NRCS WRP scoring process. Ducks Unlimited, however, expressed concern that use of its prioritization maps to guide selection of WRP sites would not necessarily result in satisfying conservation outcomes due to the fact that NRCS distributes it conservation funding evenly throughout states.[99] For example, if DU's tool identified one specific county that represented a particularly high priority for wetland or stream conservation, Ducks Unlimited predicted significant obstacles would prevent large amounts of WRP resources from being targeted in that location.

5.2.4 State Wildlife Action Plans

One of the prioritization programs reviewed supported development of a State Wildlife Action Plan (SWAP). The TWRA Comprehensive Wildlife Conservation Strategy (Tennessee's SWAP) included a tool for prioritizing aquatic resources by HUC-12 watershed. Applicants to TWRA for State Wildlife Grants have an incentive to target areas that have been identified as priorities in the SWAP because TWRA gives preference for projects in this areas. Furthermore, to receive research funding under the TWRA State Wildlife Grant program, TWRA requires that applicants demonstrate how their research fits criteria developed by TWRA based on the prioritization results.[113] In addition, two prioritization programs – TNC-ELI DPWAP and IDFG – were used to inform the development of SWAPs.[114]

5.2.5 Endangered Species Act §10 compensatory mitigation

Five programs indicated that their tools could be used to site compensatory mitigation under ESA §10 (Table 13). For instance, the tools could be used to calculate predicted compensatory mitigation acreage requirements for various habitat types as a result of future road projects, which could be inputted into a MARXAN algorithm to identify priority parcels. One such example is California RAMP, which is used to address mitigation needs under ESA §10.[69] In addition, the USGS Forest Breeding Bird Decision Support Tool may be applied to identify high quality mitigation sites for forest bird species (e.g., ivory-billed woodpecker).[112] On the other hand, the CNHP Landscape Integrity Model guides the identification of high biodiversity sites as part of CNHP's targeted assessment process that could be prioritized for ESA §10 mitigation.[115]

5.2.6 National Environmental Policy Act effects analysis

Four of the programs reviewed suggested that their prioritization tool could be used to support NEPA effects analysis (Table 13). For example, the Virginia Department of Transportation has expressed interest in using the VIMS WetCAT Tool to assess cumulative effects of planned transportation corridors on wetlands.[108] Strager et al. (2011)'s method applies network connectivity analysis to stream segments and segment-level watersheds to identify headwater watersheds and pass-through watersheds, an approach that facilitates cumulative effects analysis.[116]

5.2.7 State/local wetland mitigation

Nine prioritization programs described state/local wetland compensatory mitigation as a potential application of their prioritization tool(s) (Table 13). For example, priority areas identified by the USACE SRWBMP could be applied to the selection of mitigation sites as required by the Minnesota Wetland Conservation Act. However, because state wetland regulations are administered by several local governments within the watershed, each of which have individual obligations and preferences for mitigation siting within their boundaries, USACE expects application of its SDSS tool to guide state-required mitigation to be challenging.[30] In addition, the UMass Amherst CAPS Index of Ecological Integrity plays an important role in determining whether proposed wetland impacts should trigger regulatory review by the Department of Environmental Protection (DEP).[31] It does so by determining areas containing "Habitat of Potential Regional and Statewide Importance." In the future, UMass Amherst CAPS expects that "Important Habitat" maps will be fully incorporated into state wetlands regulations. Development of the WSDOE Watershed Characterization Tool has been driven by a requirement under Washington State's Shoreline Management Act that local governments characterize watersheds.[117]

Needs of states lacking landscape prioritization tools: Six of the 11 states without prioritization tools – Connecticut,[111] New Jersey,[33] New Mexico,[34] New York,[35] South Carolina,[37] and Texas[44] – indicated that such tools would be ideally suited to guiding state/local wetland regulation. For example, New Jersey described how its state DEP could potentially apply a landscape prioritization method to direct permittees to appropriate mitigation sites.[33]

5.2.8 State water quality programs

Two of the prioritization programs reviewed apply their tools to state/local water quality programs (Table 13). The Arkansas Department of Environmental Quality uses priority areas identified by the Arkansas MAWPT Standard GIS Methodology for Wetland Analysis to target riparian restoration or protection projects that address water quality impairments from sedimentation.[103] NCEEP applies its tools to satisfy state regulations for riparian buffers and nutrient offsets in applicable river basins.[106]

5.2.9 Non-regulatory markets for ecosystem services

Two of the prioritization programs reviewed are used in non-regulatory markets for ecosystem services (Table 13). Priority areas identified by the Willamette Basin Synthesis Project are used to inform the Willamette Partnership Ecosystem Marketplace, a non-regulatory market for ecosystem services. The Willamette Partnership uses the Basin Synthesis Project map as part of its Ecosystem Marketplace program to adjust mitigation ratios for mitigation/impact sites located within priority areas. The Partnership awards more credits for mitigation projects located within priority areas and requires that more credits be purchased to compensate for impacts within these areas.[118] In addition, the LACPRA Coastal Master Plan includes models for carbon sequestration and nutrient uptake that could provide basic information for developing a nutrient credit program.[102] The USGS Forested Breeding Bird Decision Support Tool could potentially be used to assess carbon sequestration and thus inform the allocation of offset credits in carbon markets that incentivize investment in reforestation and wetland restoration.[112]

5.2.10 Other non-regulatory restoration/protection

This category describes all actual or potential applications of landscape prioritization programs to non-regulatory programs other than those described for the NRCS Wetland Reserve Program (Section 5.2.3) and non-regulatory markets for ecosystem services (Section 5.2.9). Twenty-one of the prioritization programs analyzed are used to guide non-regulatory restoration/protection programs (Table 13). The programs that rely upon these tools fall into four general categories:

- Federal programs that fund restoration/protection
- State programs that fund restoration/protection
- Local programs that fund restoration/protection
- Non-profit restoration/conservation

Federal programs that fund restoration/protection: Several of the prioritization programs reviewed indicate that federal programs designed to restore or protect aquatic resources use them. For example, the Maryland WRR and USGS Forest Breeding Bird Decision Support Tool are used by the USFWS Partners for Fish and Wildlife program to guide site selection for restoration/protection.[21,112] The EPA Recovery Potential Screening Tool is used as part of the EPA Healthy Waters Initiative to evaluate watersheds in terms of various criteria, such as their ability to improve water quality and support successful wetland restoration projects.[16] Priority wetland restoration and protection projects identified by the LACPRA Coastal Master Plan will inform the identification of projects to address environmental degradation caused by the Deepwater Horizon oil spill. The state will use these sites to guide the allocation of $400-500 million in funding from the Deepwater Horizon Oil Spill Natural Resource Damage Assessment and other sources (e.g., fines under CWA or other payments to state agencies).[119] The PLJV PLDSS identifies priority wetland areas for migratory bird conservation that could be used to inform the selection of projects to receive funding from the North American Wetland Conservation Act grant program.[120]

State programs that fund restoration/protection: Other prioritization programs indicated that they are or could be used to guide state-level restoration or protection programs. Priority habitats identified by the NOAA HPP Mississippi-Alabama Habitats Tool are used to inform the acquisition of parcels for conservation by Alabama's Forever Wild program.[121] In addition, the University of West Virginia researchers that produced the Strager et al. (2011) Banking Site Selection Tool have made their individual site rankings available to the West Virginia Department of Natural Resources (WVDNR). WVDNR has combined these site rankings with information from field-based wetland assessments and wildlife models to support voluntary project planning.[116] The researchers have also provided WVDNR with an ArcGIS extension that allows WVDNR to alter model rankings by manipulating underlying criteria and weightings using an ArcGIS toolbar.[116] Washington Fish and Game uses output maps from the WSDOE Watershed Characterization Tool to identify priority sites for species protection under state habitat protection laws.[104] Colorado Parks and Wildlife (CPW) administers the Wetland Wildlife Conservation Program, which funds over $1 million annually in wetland habitat restoration. The LIM and associated targeted field assessments help CPW prioritize wetland types and geographic areas most in need of restoration.[122]

Local programs that fund restoration/protection: Several of the programs reviewed indicated that the tools are used to identify priority sites for aquatic resource restoration/conservation programs undertaken by local governments. For instance, Arkansas MAWPT coordinates its prioritization work with municipalities to provide city-level wetlands information based on results of its Standard GIS Methodology for Wetland Analysis.[103] Counties obtain funding from the Coastal Impact Assessment Program to protect priority areas within their boundaries based on priorities identified by the NOAA HPP Mississippi-Alabama Habitats Tool. This program only awards funding for land protection if the selection of land to protect is supported by a federally-approved plan – maps generated using the MAHT represents such a federally-approved plan.[121] Additionally, the WSDOE Watershed Characterization tool is used by local governments to ensure that they remain in compliance with the treaty rights of Indian tribes requiring that local governments must ensure that salmon are adequately provided.[104] Because the tool facilitates restoration of waterways important for salmon, it helps local governments avoid possible conflict with tribes.

Non-profit restoration/conservation: Several of the programs analyzed are used to guide the restoration and conservation activities of private non-profit conservation organizations. WDNR's tools, for example, are used by the Ozaukee Land Trust to inform its selection of protection sites.[105] Similarly, NGOs involved in land acquisition in Tennessee occasionally approach TWRA to inquire about the results of its CWCS HUC-12 prioritization tool for lands they are considering for acquisition.[113] Non-profit wetland restoration programs, such as The Nature Conservancy and Joint Venture Conservation Delivery Network, use priorities identified by the Arkansas MAWPT Standard GIS Methodology for Wetland Analysis to identify potential conservation investments.[103] Furthermore, the Lower Mississippi Valley Joint Venture, which operates a conservation delivery network, is using the DU Forested Wetland Restoration Suitability Tool in combination with 5-6 other models to target bird habitat restoration.[99] VDCR and Caltrans RAMP described how their tools, which identify specific privately owned parcels with high quality habitat, could be very helpful in supporting the parcel-based protection and acquisition activities of conservation organizations.[101,69]

Three states – Alaska,[109] Connecticut,[111] and New Jersey[33] – identified land acquisition by non-profits as a potential application of landscape prioritization tools. Connecticut, for example, described how conservation organizations with limited resources might be able to achieve a larger return on investment by guiding land acquisition decisions using a landscape prioritization tool.[111] Other states without prioritization tools indicated that such tools could be used to guide non-profits in selecting Level 1 restoration/conservation projects. For example, Kentucky reported that landscape prioritization tools could be applied to help guide Ducks Unlimited's efforts to select wetland restoration sites throughout Kentucky.[59]

5.3 Transferability of landscape prioritization tools

The prioritization programs reviewed for this study were asked to indicate whether or not their tools have specific characteristics that would lend themselves to being easily transferable. These responses fall into five categories (Table 14):

- Ease of use (Section 5.3.1)
- Use of readily available data (Section 5.3.2)
- Minimal funding limitations (Section 5.3.3)
- Represents a readily adaptable framework (Section 5.3.4)
- Limitations on tool transferability (Section 5.3.5)

Table 14. Programs with landscape prioritization programs cited four types of rationales for why their tools are transferable to programs lacking tools.

	Ease of use	Use of readily available data	Minimal funding limitations	Tool represents a readily adaptable framework
AR MAWPT	X			
Caltrans RAMP		X	X	
IDFG	X			
Kramer et al. (2012)	X			
LACPRA CMP	X			
MD WRR	X	X		
MTNHP		X		
Kauffman-Axelrod and Steinberg (2010)	X		X	
Strager et al. (2011)				X
TNC Aquatic EA				X
TNC-ELI DPWAP	X	X		
UMass Amherst CAPS				X
USEPA RPS				X
VDCR	X	X	X	X
VIMS WetCAT		X		
VIMS WMTT		X		
WSDOE				X
WDNR	X			X
Weller et al. (2007)		X		X

5.3.1 Ease of use

In total, seven prioritization programs examined in this study cited ease of use as an attribute that made their tool(s) transferable (Table 14). Three programs that rely on raster calculation methods to determine priorities for aquatic resource restoration and protection felt that this approach made adoption of these tools particularly simple. Kramer et al. (2012), for instance, explained that because its raster models are based on datasets that can be readily interchanged, the approach can be easily adopted by many potential users.[100] Arkansas MAWPT explained that because its method is based on simply raster stacking in ArcGIS, the method is particularly transferable to other states in the process of establishing a new prioritization program.[103] Furthermore, because Kauffman-Axelrod and Steinberg (2010)'s tool was developed using

ArcGIS ModelBuilder, it would be easy for practitioners familiar with GIS to manipulate by changing input parameters and weightings.[123]

In contrast to tools for which ease of use derives from dependence on simplistic raster-based approaches, LACPRA Coastal Master Plan indicated that its tools would be easily transferable because of its method for visualizing prioritization outputs in support of decisionmaking to refine the landscape prioritization results.[102] The LACPRA Planning Tool is highly effective at using model outputs to evaluate different preferences for actions given multiple datasets and constraints. Additionally, VDCR considered its tool to be easy to use because it makes high quality documentation available describing how to develop and apply the tool.[101] For example, in its technical report, VDCR documents step-by-step GIS procedures for building its prioritization model. Other states could use this documentation to identify opportunities to tailor the model specifically for their needs.

Needs of states lacking landscape prioritization tools: Seven of the 11 states without prioritization tools – Alaska, Connecticut, Kentucky, New Jersey, New Mexico, New York, and South Carolina – cited "ease of use" as an important characteristic that a landscape prioritization tool would need were it to be successfully adopted. New Jersey, New York, and South Carolina considered ease of use to be an especially important characteristic.[33,35,37]

5.3.2 Use of readily available data

Needs of states lacking landscape prioritization tools: Four states without prioritization tools – Connecticut, New Jersey, New York, and Wyoming – indicated that tools that rely upon readily available data would be most desirable.

Of the landscape prioritization programs examined in this study, eight indicated that their tools have this characteristic (Table 14). Many datasets used by the VDCR GIS Model, for instance, are national datasets (e.g. SSURGO data) that can simply be reapplied if the model is transferred to other states.[101] Other datasets used in the VDCR model are state-level datasets that may not necessarily be the same as those needed in other states, though substitutable datasets are likely to be available in most states. In addition, the basic method underlying the VIMS WetCAT is readily transferable to any state with NWI and land cover data. In fact, VIMS has already helped to transfer the basic method to the mid-Atlantic region.[108] The VIMS WMTT is readily transferable because it uses national and regional datasets – states would just need to replace some input datasets to apply it themselves.[124]

In evaluating mitigation needs as part of its Road Impact Footprint Analysis, RAMP's MARXAN technique draws on transportation planning documents that are readily available to all state DOTs to estimate footprints for infrastructure projects in advance of impacts. Using information from state DOTs, any state can reapply RAMP's MARXAN Greenprint Analysis method to identify parcels that should be targeted in advance for compensatory mitigation.[69]

The Weller et al. (2007) Wetland Condition Analysis is capable of identifying priorities within any area for which a readily available, spatially distributed sample of field-based wetland condition assessment data exist. Weller et al. (2007) notes: "Our method could be applied wherever a large group of field assessments (say 50 or more) can be matched with appropriate digital geographic data."[23]

5.3.3 Minimal funding limitations

Three of the prioritization programs reviewed indicated that their tool(s) are highly transferable because they are inexpensive to develop and apply (Table 14). For instance, Kauffman-Axelrod and Steinberg (2010) indicate that the Tidal Wetland Restoration Prioritization Tool is easily transferable due to its limited funding requirements.[123] Programs interested in applying the Kauffman-Axelrod and Steinberg (2010) method would only need to be licensed to use ModelBuilder in ArcGIS. In contrast, although Caltrans RAMP's prioritization method for planning advance mitigation does have substantial funding needs, its application would be limited in those states with DOTs that have complete or nearly complete control over transportation funding (e.g., North Carolina).[69] Such states in particular stand to gain both financially and ecologically from implementing RAMP's MARXAN prioritization method as part of an advance mitigation planning framework. The VDCR GIS Model's capacity for long-term mitigation planning may make its approach more cost-effective than the piecemeal approach commonly used by some government agencies and developers to address their mitigation obligations (e.g., by paying into an in-lieu fee program). This benefit is particularly relevant for state/federal transportation agencies.[125,126]

5.3.4 Tool represents a readily adaptable framework

Eight of the prioritization programs reviewed rely upon easily adaptable frameworks, which make them readily transferrable (Table 14). For example, EPA's Recovery Potential Screening Tool is broadly applicable across different states due to its emphasis on flexible and efficient use of systematic comparisons to identify user-driven screening objectives, indicators and weightings, and screening scenarios.[16] In addition, under the U.S. Fish and Wildlife Service Landscape Conservation Cooperatives Program, UMass Amherst CAPS researchers are currently working to adapt the Index of Ecological Integrity for use in other states.[31] UMass Amherst researchers currently have pilot projects underway in Maine and Virginia and expect the Index of Ecological Integrity to eventually be used in all North Atlantic states. The TNC Aquatic EA is based on TNC's broader ecoregional assessment approach, which has been applied in all 50 states.[70]

Some programs described their tool(s) as readily adaptable, but clarified under what conditions this would be the case. For example, the WSDOE Watershed Characterization Tool is transferable to other areas of the country, provided they are adapted by regional experts for each unique region in which they are applied.[117] Furthermore, the Weller et al. (2007) wetland condition tools are capable of extending field-based Level 2/3 assessment programs into landscape prioritization tools that can be applied broadly throughout the landscape given that investment already exists in a rapid assessment program.[107] The WDNR tools are especially transferable to local entities (e.g., county-level) because data collected at the local scale are very usefully applied by the tools – adoption of the tools by local communities, in particular, could extend the usefulness of the tools substantially. In fact, where local data are higher resolution than data used by WDNR, local results could be more precise than those used by WDNR.[105]

5.3.5 Limitations on tool transferability

In our evaluation of existing prioritization programs and tools, we identified six limitations on tool transferability:

- **The analysis is time-consuming to complete:** NCEEP described the transferability of its tools as limited due to the fact that its fine-scale Local Watershed Planning analysis is time consuming to complete, requiring substantial dedicated staff time and intensive data collection efforts.[106]
- **The analysis is data intensive:** NCEEP's process for identifying priority sites is limited because of the large amount of data that must be collected to support it.[106] For the NOAA HPP MAHT, because the data used are very place-specific, the transferability of the tool may be limited for some users due to the substantial investment in data mining required.[121]
- **Limited transferability to some geographic areas:** Transferability of NCEEP's RBRP HUC-14 Screening Method may be limited for particularly small/fragmentary states (e.g., Hawaii), in which very small subdivisions of drainages could complicate the application of NCEEP's tiered watershed-based approach. For this reason, a direct application of the LWP process might be more appropriate for particularly small states or regions.[106]
- **The tool is technically sophisticated:** Transferability of the UMass Amherst CAPS Index of Ecological Integrity is limited by the fact that the modeling approach underlying the tool is sophisticated. Only sophisticated GIS users can use the CAPS software, which requires extensive GIS data, GIS expertise, and data processing capability.[31] Other programs include sophisticated components that limit their transferability – e.g., programs seeking to replicate the VIMS WetCAT Level 2 and 3 steps and web-based interactive tool would require substantial funding and expertise.[108]
- **The tool requires data inputs that are not widely available:** For example, although the MTRI Wetland Mitigation Site Suitability Tool primarily uses national data inputs (e.g., DEM data, SSURGO data, aerial photography), MTRI's use of presettlement data as a data input to assess whether a site was once covered by wetland could limit the tool's transferability. Because presettlement data, which are based on 1800s county surveys, are readily available for states in the Midwest (e.g., Wisconsin and Minnesota) but not for most other states, the WMSST may be most successfully reapplied for the Midwest.[98] Similarly, the GIS data used by Strager et al. (2011) as part of their Level 1 site selection method must be available for other geographic areas considering adopting the method.[116]
- **Documentation for how to apply the tool is lacking:** A lack of comprehensive documentation for some tools limits their potential for reapplication. For example, the developer of the Kauffman-Axelrod and Steinberg (2010) Tidal Wetland Restoration Prioritization Tool noted that if a novice GIS analyst wanted to reapply the approach to other parts of Oregon, limited guidance documentation would exist for them to do so. Development of a user guide was beyond the scope of the original work.[123]

5.4 Barriers to development and implementation of existing tools

Twenty-eight of the 30 prioritization programs evaluated identified barriers to developing and implementing their prioritization results (Table 16). We categorized programs responses into eight types of barriers including:

• Data limitations	• Promoting use of the tool
• Technical capacity	• Bureaucratic obstacles
• Funding and staff time	• Stakeholder collaboration
• Property rights concerns	• Maintaining updated data

5.4.1 Data limitations of existing tools

Twenty-seven of the 30 prioritization programs evaluated here indicate that specific data gaps may limit the functionality of their tools (Table 15). Overall, we identified 16 different types of data gaps, including:

• Aerial photography data	• Conservation lands data
• Resolution of elevation data	• Urbanization data
• Flood map data	• Agricultural data
• Wetland mapping data	• Local impacts data
• Stream data	• Habitat data
• Coastal data	• Parcel data
• Soils data	• Population data

Aerial photography data: Three of the programs reviewed indicated that limitations of aerial photography data limit application of their tools, including NCEEP, Strager et al. (2011), and VIMS WMTT. NCEEP reported that because aerial photography data are so critical to its process, maintaining up-to-date land use and aerial data is always an issue.[106] A common data gap for NCEEP occurs when aerial data are rectified and the resulting map is patchy or the tiles comprising an area are from different years. Because NCEEP's LWPs are conducted in HUC-14s, which tend to cover small land areas (10-100 mi^2), these errors can be problematic for LWPs when they require that a large number of data gaps be filled.[106] For Strager et al. (2011), high-resolution multi-spectral leaf-off data from the National Agriculture Imagery Program (NAIP) would have been helpful for mapping wetlands for the Level 1 analysis. Strager et al. (2011) describes how limitations in mapping data available at the start of the Level 1 analysis present the most significant limitation to their approach.[116] Finally, VIMS WMTT indicates that higher resolution aerial imagery would yield land cover datasets with a higher resolution than that of the NLCD data currently used in the model.[124]

Resolution of elevation data: Nine of the prioritization programs reviewed – Arkansas MAWPT, Kramer et al. (2012), USGS, VIMS WetCAT, UMass Amherst CAPS, Maryland WRR, PLJV PLDSS, VIMS WMTT, and WSDOE WCT – indicate that the availability of high resolution elevation data is a limitation. These data serve as a particularly important component of the hydrological analysis for many tools. UMass Amherst CAPS, for example, describes how the quality of existing DEMs represents a significant limitation. In some cases, UMass Amherst CAPS has created metrics only to discard them because DEM quality was insufficient.[31] For the Maryland Watershed Resources Registry, tool developers indicated that higher resolution DEM data would allow hydrology to be modeled, facilitating analyses of whether particular points drain into impaired waters.[21] VIMS WMTT is aware of available higher resolution DEM data, though they sparsely cover their study area. For VIMS WMTT, finer-scale datasets are needed because data currently in use are regional while the target area for assessments is local.[124]

Table 15. Sixteen types of data gaps were cited by prioritization programs.

	Aerial photography data	*Resolution of elevation data*	*Flood map data*	*Wetland mapping data*	*Stream data*	*Coastal data*	*Soils data*	*Conservation lands data*	*Urbanization data*	*Agricultural data*	*Local impacts data*	*Land use/land cover data*	*Habitat data*	*Parcel data*	*Population data*
AR MAWPT		X		X											
Caltrans RAMP				X	X				X				X		
CNHP				X											
IDFG				X							X	X			
Kramer et al. (2012)		X													
LACPRA CMP															
MD WRR		X										X		X	
MTNHP				X					X	X	X	X			
MTRI														X	
NCEEP	X								X	X			X		X
NHDES WRAM				X	X										
NOAA HPP MAHT						X		X	X				X		
PLJV PLDSS		X		X								X			
Strager et al. (2011)	X														
TNC Aquatic EA				X	X										
TNC-ELI DPWAP												X			
TWRA CWCS				X											
UMass Amherst CAPS		X			X	X			X		X		X		
USACE SRWBMP											X			X	X
USEPA RPS					X										
USGS		X	X	X			X	X		X					
VDCR						X	X						X		
VIMS WetCAT		X						X							
VIMS WMTT	X	X		X										X	
WADOE		X		X			X					X			
WDNR			X	X									X		
Weller et al. (2007)					X										

For other prioritization programs, limitations on the resolution of elevation data stemmed from the type of the terrain being analyzed. For example, WSDOE requires high resolution Landsat data to model the complex hydrological functions of eastern Washington.[104] On the other hand, existing elevation data used by the PLJV PLDSS are poor quality because terrain within the playa region is very shallow.[120] For the USGS Forest Breeding Bird Decision Support Tool, existing DEM data were unable to resolve small differences in local elevation within the Mississippi alluvial floodplain.[112]

Flood map data: Two prioritization programs – USGS and WDNR – identify limitations posed by flood map data. Flood maps used by the USGS Forest Breeding Bird Decision Support Tool are limited in coverage and do not distinguish flood duration, with information particularly limited for Missouri.[112] In addition, county floodplain data used by Wisconsin DNR are not up to date. Counties are updating their floodplain data as part of the WDNR's Map Modernization Project, but many still have not done so. As the Modernization Project proceeds, WDNR expects flood data to continue to become available.[105]

Wetland mapping data: Thirteen of the programs reviewed here - Arkansas MAWPT, CNHP, TNC Aquatic EA, Caltrans RAMP, IDFG, MTNHP, NHDES, PLJV, TWRA CWCS, VIMS WMTT, WSDOE, WDNR, and USGS – indicated that lack of access to wetland mapping data presented the most significant data gap. Many of these data gaps were attributed to insufficient National Wetland Inventory (NWI) data. For instance, IDFG stated that the wetland data used as part of its Landscape Assessment model were not accurate or recent enough to be useful for locating wetlands in the field.[97] In addition, for the MTNHP Landscape Integrity Model, a lack of statewide NWI data prevented development of a distance layer for altered wetlands, which are likely important indicators of overall wetland condition.[26] A lack of comprehensive NWI data also limited the NHDES WRAM Net Functional Benefit, Restoration Sustainability, and Landscape Position tools, which all depend on NWI data to serve as base maps.[28] Other programs for which incomplete NWI data were a limitation included Caltrans RAMP, PLJV PLDSS, and the WSDOE Watershed Characterization Tool. For one program – CNHP – hard copy NWI data are available but are not comprehensively digitized, limiting their usefulness as part of CNHP's Landscape Integrity Model. Because digitized wetland data are essential for ensuring that it obtains high quality results, CNHP is currently seeking the funding its needs to digitize Colorado's NWI maps.[115]

Other programs indicated that the lack of specific types of wetland data were a hurdle. Arkansas MAWPT described a need for wetland subclass mapping data, which it is currently obtaining for its Delta and Coastal Plan ecoregions, a process that has revealed additional geomorphology data gaps.[103] Caltrans RAMP requires location data for jurisdictional waters from the Corps, FWS, and CDFG.[69] For its PLDSS tools, PLJV would benefit from playa functionality data. Although many playas have been mapped, information is lacking for which ones are still functional – e.g., many have likely been filled by agricultural practices, etc.[120]

Two programs reported that historical wetland data is lacking in their states. For the TNC Aquatic EA, TNC described a lack of comprehensive datasets documenting the locations of historical wetlands within Virginia that no longer exist or are no longer functional.[70] For its prioritization process, TNC also requires information describing factors contributing to these losses and indicating whether restoration is feasible at each site. A National Wetland Inventory (NWI) dataset documenting lost-but-repairable wetlands was once available but is now out of date – an updated version of this dataset would be very useful for TNC's Aquatic EA.[70] In addition, the VIMS WMTT indicated that data documenting the locations of Prior Converted

Wetlands (PCWs) would have been the most valuable layer that it could have incorporated to improve its prioritization results. VIMS WMTT was unable to develop a PCW data layer itself due to budget limitations.[124]

Stream data: Of the six prioritization programs reviewed that commented upon data on streams – TNC Aquatic EA, USEPA RPS, UMass Amherst CAPS, Weller et al. (2007), Caltrans RAMP, and NHDES WRAM – two indicated that spatial data for stream coverage was limited. For example, stream location and coverage data used by Caltrans RAMP are flawed in some parts of the state.[69] Additionally, the NHDES WRAM tool is limited by its dependence on the NHD dataset, which serves as the base map for the tool but is not comprehensive, especially with regard to small headwater streams.[28]

Other prioritization programs reported data gaps with regard to stream condition data. Weller at al. (2007) found that better maps for stream condition (e.g., indicating whether streams are excavated or ditched) that cover a broader geographic region would be useful for broadening the applicability of its wetland condition assessment tools.[23] These maps were available as part of the NWI dataset for the Weller et al. (2007) study area (i.e., the Nanticoke watershed) but are not widely available. Similarly, the EPA Recovery Potential Screening method would be more widely applicable if measures of flow alteration and channelization were nationally available.[16] Furthermore, the TNC Aquatic EA reported that it would benefit from an improved §303(d) stream list that, in addition to listing impaired streams, linked stream impairments to specific functional stressors (e.g., channelization, culverts) and detailed these stressors.[70] Such a dataset would enable TNC to target degraded sites within degraded river systems for system-wide functional improvement. UMass Amherst CAPS researchers indicated that important river and stream data for water temperature, groundwater contributions to stream flow, water salinity (for tidal rivers), dam attributes (e.g., height), and the location/effectiveness of fish passage structures is lacking.[31]

Coastal data: Three prioritization programs – NOAA HPP MAHT, UMass Amherst CAPS, and VDCR – reported a variety of data gaps in terms of coastal data. The NOAA HPP MAHT lacked data for high resolution salinity regimes, armored shorelines, and inshore and offshore sediment.[15] In addition, the UMass Amherst CAPS IEI lacked field-based data on the severity of tidal restrictions as well as data on groundwater contributions to coastal wetlands in the glaciated coastal plain.[31] To integrate the effects of climate stressors (e.g., sea level rise) into its model, VDCR is considering using sea level rise data from the Sea Level Affecting Marshes (SLAM) model. It is also considering using predicted precipitation/temperature data from recently downscaled climate models developed by the Virginia Department of Game and Inland Fisheries and from Intergovernmental Panel on Climate Change (IPCC) step-down climate models.[125]

Soils data: Three programs – WSDOE, VDCR, and USGS – indicated that NRCS soils data are insufficient for their purposes. A major data gap for WSDOE is its lack of soil data for federal lands – NRCS soils data do not cover Forest Service lands, which comprise about half the land in the state.[104] Because the Forest Service is unlikely to fill this data gap, and because obtaining soil data is resource-intensive, WSDOE does not believe that it is ever likely to obtain these data. Similarly, the NRCS SSURGO soils data used by VDCR as part of its prioritization process are incomplete.[101] However, because NRCS continues to obtain more soils data in

Virginia, VDCR considers a complete soils dataset to be forthcoming. USGS considers the STATSGO soils dataset used in its Forest Breeding Bird Decision Support Tool to be a poor predictor of soil characteristics because soil associations within STATSGO soils data include multiple soil types.[112]

Additionally, MTRI was unable to generate one input for its Wetland Mitigation Site Suitability Tool – the Soil Moisture Index – for the entire state of Michigan. Instead, it substituted this metric with its Topographic Wetness Index map, which effectively filled gaps in the SMI.[98]

Conservation lands data: Three programs – USGS, VIMS WetCAT, and NOAA HPP MAHT – reported gaps in conservation lands data. While developing its Forest Breeding Bird Decision Support Tool, USGS was unable to access a database documenting NRCS Conservation Reserve Program lands due to property rights concerns.[112] In addition, to supplement use of the VIMS WetCAT in permitting to assess proposed wetland impacts, VDEQ indicated it would benefit from a data layer visualizing conservation easements – these data are available but just need to be transferred to GIS.[108] Data used by NOAA HPP MAHT for protected lands and acquisition boundaries need to be updated and improved.[15]

Urbanization data: Data gaps related to development and urbanization were cited by five programs, including NCEEP, MTNHP, UMass Amherst CAPS, NCEEP, NOAA HPP MAHT, and Caltrans RAMP. NCEEP cited a need for fine-scale imperviousness data – although imperviousness data can be derived simply from land use and aerial photography, these data sources result in only coarse-scale imperviousness data, with fine-scale data available only at high cost.[106] Additionally, MTNHP's spatial data for roads do not include some unofficial but heavily used roads or any roads added in the state since the last census.[25] UMass Amherst CAPS reported data gaps in terms of detailed urbanization data, citing a need for more field assessments of road-stream crossing as well as location data for areas of development that rely on on-site wastewater treatment (e.g. septic systems), areas that are sewered, areas that rely on private wells, and areas served by a public water supply.[31] NOAA HPP MAHT explained that its prioritization tool would benefit from updated and improved data on construction control lines that currently do not extend to the edge of the boundaries for Mobile and Baldwin counties.[15] Caltrans RAMP described how its approach could support a more holistic consideration of future impacts if it had access to data for projected ecological impacts of DWR water infrastructure development projects.[69]

Agricultural data: Three of the prioritization programs reviewed reported limitations with regard to agricultural data, including NCEEP, MTNHP, and USGS. NCEEP's prioritization process would benefit from GIS data maintained by USDA on the aerial extent and number of animals on larger farms that are required to have USDA permits, such as Concentrated Animal Feeding Operations (CAFOs).[106] Because these are intermediate-scale data, they would be useful for incorporation into NCEEP's LWP analyses in addition to NCEEP's recently initiated effort to produce Regional Watershed Plans (RWPs). However, for privacy reasons, USDA currently does not make these data widely available.[106] Other instances of agricultural data gaps include a lack of large-scale GIS grazing data for use in the MTNHP Landscape Integrity Model[15] as well as inadequate crop type data for predicting forest types (along with soil moisture data) as part of the USGS Forest Breeding Bird Decision Support Tool.[112]

Local impacts data: Four programs – IDFG, UMass Amherst CAPS, MTNHP, and USACE SRWBMP – identified data gaps in terms of local impacts derived from a variety of sources. IDFG lacked several potentially important indicators of wetland condition that would have been useful in its analysis, including data for beaver presence, herbicide or pesticide use, non-native species abundance, nutrient loading, off-highway vehicle use, recreational and boating impacts, and sediment accumulation.[127] Impact data lacking for UMass Amherst CAPS included data on the location of water pollution sources (point-source discharges, stormwater outfalls) and quantity of pollutant discharged, especially for nutrients.[31] UMass Amherst CAPS also lacked data on the location of water withdrawals and discharges, including amounts of water withdrawn or discharged. Furthermore, some water rights point-of-use data used as part of the MTNHP Landscape Integrity Model represented a data gap as they were simply located at the central point of public land survey sections rather than precisely identified. MTNHP's data needs also included energy infrastructure spatial data, which were current through the summer 2008, but now need to be updated, in addition to abandoned mines data that do not fully represent the extent of mining impacts.[26]

Finally, one program – USACE SRWBMP – indicated that a lack of information on wetland impact data made some of its baseline analyses (e.g. assessing cumulative impacts, analyzing trends) more difficult. USACE SRWBMP largely attributed this limitation to the fact that Minnesota does not maintain a digital database for permitted wetland impacts.[30]

Land use/land cover data: Six of the programs reviewed indicated that they encountered limitations for land use/land cover data, including Maryland WRR, WSDOE, TNC-ELI DPWAP, MTNHP, IDFG, and PLJV PLDSS. Programs indicated that in some cases, data existed but were out of date while others indicated that such data were only available at a resolution that was insufficient for prioritization needs. Maryland WRR, for example, stated that obtaining land cover data at a resolution higher than the 30m resolution currently used by the model would improve the overall resolution of outputs for its eight prioritization tools (the effective resolution of GIS outputs is limited to the resolution of the lowest resolution data input).[21] Similarly, the WSDOE WCT models use 30m resolution raster datasets as inputs, which WSDOE is currently seeking to improve to 1m resolution.[104] TNC-ELI DPWAP described how updated land use/land cover datasets would significantly improve its Wildlife Tool, which uses land use/land cover data to parameterize its habitat models.[114] In addition, the MTNHP Landscape Integrity Model relies on the 2001 National Land Cover Dataset (NLCD), which is incomplete due to the fact that it was developed based on 1990s satellite imagery.[26] Some land cover data used in the IDFG Landscape Assessment for areas that have since experienced rapid urbanization have not been updated in more than ten years.[97] Representatives for the PLJV PLDSS noted that improved land cover data that included more accurately and consistently classified land cover features could be used to improve the output of the PLDSS Site-Scale Model.[120]

Habitat data: Of the six prioritization programs that described gaps for habitat data – NCEEP, VDCR, Caltrans RAMP, NOAA HPP MAHT, UMass Amherst CAPS, and WDNR –

four identified limitations in data for aquatic wildlife. In prioritizing streams for restoration and conservation, VDCR found that high quality fish and macroinvertebrate data were not consistently available for western Virginia.[101] However, because Virginia Commonwealth University actively maintains and updates these data as part of its Interactive Stream Assessment Resource (INSTAR) database, VDCR expects existing data gaps to be filled soon. For NCEEP, uncertainty surrounding the continued availability of Coastal Habitat Protection Plan data on fish habitat distributions (e.g., Submerged Aquatic Vegetation) due to recent funding cuts represents a potentially limiting factor.[106] Furthermore, the NOAA HPP MAHT requires updated and improved bay oyster and SAV data[15] while UMass Amherst CAPS would benefit from data on natural barriers to aquatic organism passage (e.g. waterfalls).[31]

To address more general gaps in habitat data, WDNR is actively seeking to fill gaps in wildlife species occurrence (i.e., "presence") data that form the basis of its Habitat Quality Index by coordinating data collection efforts by volunteers.[105] WDNR also expressed a desire to have species absence data, though these would be much more difficult to obtain than presence data. California RAMP cited a lack of comprehensive data on the location of rare and endangered plants and animal species and communities, which could be made available through improvements to the California Natural Diversity Database (CNDDB).[69] Likewise, the NOAA HPP MAHT described a need for threatened and endangered species data, including state species of concern and habitat change data.[15]

Parcel data: Three prioritization programs cited a need for parcel boundaries, ownership, or cost data. For MTRI's Wetland Mitigation Site Suitability Tool, parcel boundary data allowed MDOT to quickly obtain property ownership information for potential sites as it visualized the site suitability output map. However, these data were limited due to the fact that cities, which commonly produce this information, are generally cautious to release it.[98] Similarly, VIMS Wetland Mitigation Targeting tool indicated that property ownership and value data from local community databases would be useful. Unfortunately, these data are often not very GIS-friendly.[124] USACE SRWBP identified land cost data as a data gap.[30]

Population data: The prioritization abilities of two programs were limited by gaps in population data. For USACE SRWBMP, county-level population growth projection data were limited because counties often did not maintain them.[30] Where these data were available, they were often developed differently than they were for other counties, which prevented or complicated the process of combining datasets. As a result, significant assumptions were sometimes required to integrate population growth data into USACE's baseline assessment and SDSS processes.[30] NCEEP had difficulty obtaining accurate population data on a watershed basis due to the fact that U.S. Census data are organized by county. For NCEEP, reorganizing these county-level population data to a watershed scale requires a substantial time investment.[106]

5.4.2 Technical capacity

Six existing prioritization programs also cited technical capacity as a barrier to the development of their landscape prioritization tools (Table 16). The St. Paul Corps District, for instance, which developed the USACE SRWBP SDSS tool, lacked the technical GIS knowledge to develop the SDSS model in-house. However, the St. Paul Corps District is working toward building this capacity by sending a staff member to train at USACE's Environmental Research and Development Center for 4-5 weeks.[30] Similarly, insufficient technical capacity was cited as an obstacle to the initial development of EPA's Recovery Potential Screening Tool and NHDES's WRAM models.[16,28]

For other prioritization programs, the technical capacity necessary to develop their tools was initially available for tool development, but is no longer available for tool maintenance, updating, or implementation. For example, the GIS and remote sensing professionals that developed the DU Forested Wetland Restoration Suitability Model have since left DU's Southern Regional Office and were not replaced.[99] In the absence of the technical knowledge these staff members contributed, Ducks Unlimited currently lacks the ability update its Forested Wetland Restoration Suitability Model. MBNEP's capacity to re-run its NOAA HPP MAHT using new data has likewise been diminished now that support from TNC and NOAA, which initially provided the technical expertise to run the model, is no longer available.[121] Furthermore, a representative for the Kauffman-Axelrod and Steinberg (2010) tools described insufficient technical capacity as a barrier to the adoption and application of the tools in other Oregon tidal watersheds.[123]

Table 16. Prioritization programs evaluated in this study identified seven types of barriers to implementation of results.

	Technical capacity	Funding and staff time	Property rights concerns	Promoting use of the tool	Bureaucratic obstacles	Stakeholder collaboration	Maintaining updated data
AR MAWPT		X					
Caltrans RAMP		X	X				
CNHP		X	X				
Ducks Unlimited	X	X					
IDFG		X					X
Kramer et al. (2012)		X		X			X
LACPRA CMP		X	X		X		
MD WRR		X					
MTNHP		X					
MTRI		X			X		
NCEEP					X		X
NHDES WRAM	X	X	X				
NOAA HPP MAHT	X	X	X	X			
Kauffman-Axelrod and Steinberg (2010)	X	X					
PLJV PLDSS		X					
Strager et al. (2011)		X					
TNC Aquatic EA		X	X		X		
TNC-ELI DPWAP		X					
TNC WBSP			X				
TWRA CWCS					X		
UMass Amherst CAPS		X					
USACE SRWBMP	X	X				X	
USEPA RPS	X	X					
VDCR		X			X		
VIMS WetCAT		X					X
VIMS WMTT		X				X	
WADOE		X				X	
WDNR		X	X				
Weller et al. (2007)						X	

Needs of states lacking landscape prioritization tools: Three of the 11 states without landscape prioritization methods – Arizona, Kentucky, and New York – identified technical capacity as an obstacle to tool development. KDWR, for instance, stated that partnering with another organization with technical capacity would be essential for successful tool development.[59]

5.4.3 Funding and staff time

Of the twenty-four prioritization programs that described limited funding and/or staff as barriers to the development of their tools,[128] two identified limited staff or staff time to be the primary barrier. Caltrans RAMP noted that the fact that the California Department of Fish and Game (CDFG) is understaffed and has experienced substantial staff turnover has complicated CDFG's ability to dedicate adequate resources to mitigation planning efforts.[69] Similarly, the IDFG Landscape Assessment is limited by the fact that the staff members who work on the tool are seasonal and have limited time to contribute to developing it – for IDFG this represents an even more significant issue than budget constraints.[97] On occasions when IDFG has the funding necessary to hire more staff, it is unable to do so because the state of Idaho places a cap on the total number of staff members that state agencies are permitted to hire. In addition, WSDOE reported that although there is currently a large demand for it to complete development of the Watershed Characterization Tool, its capacity to do so quickly is limited by the fact that it only has 2-3 staff members available to work on the tool.[104] WSDOE's progress completing the individual watershed process models is limited only the number of personnel available to work on it. In developing its Coastal Master Plan, LACPRA cited available staff time as a more significant issue than money. LACPRA was constrained to completing the Master Plan in 18 months due to legislative deadline but additional time would have allowed it to do more.[102]

Needs of states lacking landscape prioritization tools: Of the 11 states without landscape prioritization tools, nine reported that a lack of adequate funding presented an obstacle to tool development, including Alaska, Arizona, Connecticut, New Jersey, New York, South Carolina, South Dakota, and Wyoming. These states cited a variety of investments they would need to make to develop landscape prioritization tools, including staff capacity for wetlands work (e.g., South Dakota[129]) and data (Kentucky[59] and New Mexico[34]).

The same set of nine states described a need for more staff time in order to facilitate development of a landscape prioritization tool. For example, Wyoming reported that it is not currently capable of developing a tool due to the fact that it would be able to commit few staff to such a project.[60] Wyoming estimated that in order to develop a prioritization tool, it would require at least one staff member working for two years to inventory and assign a priority ranking to wetlands throughout the state. Furthermore, developing the method underlying such a prioritization tool would require 3-5 staff members working for six months.[60] Because Wyoming would be unable to commit this amount of staff time, it has limited ability to produce a landscape prioritization tool. Additionally, Connecticut has already compiled a large amount of data (e.g., aerial photography, LiDAR, etc.) and now just needs to be able to commit staff time to developing an approach for applying the data using a landscape prioritization method.[111]

For other tools, barriers related to staff and funding were more directly rooted in the availability of funding. For instance, the primary barriers to wider development and implementation of EPA's Recovery Potential Screening Tool are budgetary decreases that many state and federal programs have experienced due to the economic downturn, which have limited staff and funding available to implement the approach. However, despite this barrier, EPA's Recovery Potential Screening Tool has remained successful because it applies an approach that relies on limited resources to systematically plan for better restoration investments.[16] On the other hand, representatives for the Kramer et al. (2012) models described how funding limitations have largely stemmed from the fact that goals for model outputs have yet to be clearly articulated.[100] Increased interest in the tool could lead to the development of new ideas for how to apply it, which in turn could lead to increased funding opportunities. For its Wetland Mitigation Site Suitability Tool, MTRI described how funding will be necessary to recode its tool, which currently runs as an ArcGIS 9.3.1 extension, to run in more recent versions of ArcGIS (i.e., ArcGIS 10.x).[98] MTRI also described funding to be the primary barrier limiting its ability to obtain parcel data from counties where they are not freely available.[98] Similarly, funding limitations have prevented WSDOE from obtaining expensive 1m-resolution C-CAP data, which could be used to improve the usefulness of outputs from its Watershed Characterization Tool.[104]

5.4.4 Property rights concerns

Eight prioritization programs – CNHP, TNC Aquatic EA, LACPRA CMP, Caltrans RAMP, NHDES WRAM, NOAA HPP MAHT, TNC WBSP, and WDNR – identified property rights concerns as a barrier to development or implementation of their tools. For most of these programs, property rights issues associated with identifying specific priority sites on a map were a concern. For example, TNC is cautious in applying results from its Aquatic Ecoregional Assessment because many landowners in Virginia are sensitive to TNC identifying specific locations on a map for restoration/conservation.[70] Property rights concerns were also raised during the development of the Caltrans RAMP prioritization process, which analyzes the availability of specific land parcels. Caltrans plans to address these concerns as part of its public outreach program.[69] In addition, given the sensitivity of property rights issues in New Hampshire, NHDES is careful not to identify specific properties using its WRAM models.[28] Likewise, developers of the NOAA HPP MAHT are cautious to communicate habitat priorities without singling out private parcels.[121]

Needs of states lacking landscape prioritization tools: Only one of the 11 states without a prioritization tool – Arizona – identified property rights concerns as a potential barrier to the development of a landscape prioritization tool.[110]

5.4.5 Promoting use of the tool

For two prioritization programs – NOAA HPP MAHT and Kramer et al. (2012) – a need to market prioritization results served as a barrier to continued tool development and implementation. Developers of the NOAA HPP MAHT are currently striving to ensure the tool’s availability, accessibility, and user-friendliness in order to maintain broad interest in the model outputs.[121] Conversely, developers of the Kramer et al. (2012) tools cited a need to better promote the tools in order to generate increased interest in them, which could in turn lead to the development of new ideas for how to apply the tools and subsequent funding.[100]

5.4.6 Bureaucratic obstacles

Six existing prioritization programs – LACPRA CMP, NCEEP, TNC Aquatic EA, VDCR, MTRI, and TWRA CWCS – have experienced bureaucratic obstacles related to data access, mitigation site selection, and available funding and staff time throughout the development and implementation of their tools. NCEEP and TNC Aquatic EA, for example, cited bureaucratic limitations on the availability of data produced by different government agencies. NCEEP, which has had difficulty obtaining data from other state agencies, described how the state has recently begun moving all state-specific data – including GIS data – to a single clearinghouse.[106] NCEEP hopes this move will make datasets created by other agencies more readily accessible. Similarly, bureaucratic obstacles exist for TNC due to the fact that many federal, state, and local agencies produce their own datasets but do not necessarily make them readily available.[70]

In addition, MTRI described bureaucratic obstacles to applying its Wetland Mitigation Site Suitability Tool to site selection for wetland compensatory mitigation. Further development of its tool has been limited by a lack of support from MDOT to expand use of the tool to an operational scale as part of MDOT's mitigation decision-making process. Because the MDOT Environmental Section (which collaborated in the development of the tool) represents only a small division within MDOT, it has a limited ability to obtain the funding necessary to make the MTRI WMSST operational.[98]

Lastly, two prioritization programs experienced bureaucratic barriers that limited available funding and staff time. The TWRA CWCS, for instance, predicted that application of CWCS prioritization results as part of the State Wildlife Grant program would decrease if federal funding for the program continued to be reduced. In addition, the data resolution of the tools used in the LACPRA Coastal Master Plan was not as high as it could have been due to legislative time constraints placed on the completion date of the plan.[102] Had LACPRA used high resolution data, the run time for the Eco-Hydrology and Wetland Morphology models would have exceeded the five-year deadline imposed by the state legislature. LACPRA plans to initiate development of the next iteration of the CMP immediately so that, with fewer projects to run and a larger amount of time available, it can obtain higher-resolution results.[102]

Needs of states lacking landscape prioritization tools: Only one of the 11 states without a prioritization tool – Arizona – cited bureaucratic obstacles as a limitation to efforts to develop prioritization tools.[110]

5.4.7 Stakeholder collaboration

Four of the prioritization programs reviewed encountered issues with stakeholder collaboration throughout the development phase of their prioritization process, including USACE SRWBMP, WSDOE, Weller et al. (2007), and VIMS WMTT. For example, USACE SRWBMP experienced difficulty achieving stakeholder buy-in across multiple levels of government during the development of its tool.[30] USACE SRWBP also expects that obtaining feedback from the variety of stakeholders necessary to update priorities in the future will require significant logistical coordination. Similarly, because WSDOE considered stakeholder involvement to be essential for producing an effective prioritization result, it received two years of extensive stakeholder feedback following the development of its Watershed Characterization Tool.[104] For the Weller et al. (2007) tool, which relied on HGM assessments as part of its process for deriving data inputs, a major barrier was the inability of field workers to access sample sites on privately-owned (stakeholder) lands.[130] In addition, the developer of the VIMS Wetland Mitigation Targeting Tool stated that goundtruthing of prioritization outputs would not be possible because many priority sites are located on private property – coordinating with a large number of private landowners would be prohibitively difficult.[124]

In contrast, two prioritization programs – USEPA RPS and WDNR – encountered stakeholder-related obstacles during the implementation phase of their prioritization process. For instance, in some cases, results from EPA's Recovery Potential Screening method have been obtained but not used due to a lack of consensus among stakeholders on multiple decision process alternatives.[16] In implementing its tools, WDNR has found that landowner cooperation varies throughout the state, with landowners in urban areas generally more interested in wetland restoration and protection than agricultural landowners, who tend to view conversion of land to wetlands as an unproductive use of the land.[105]

5.4.8 Maintaining updated input data

Four prioritization programs characterized the maintenance of updated input data to be a significant obstacle. Representatives for the Kramer et al. (2012) tools, for example, expected that the most significant data-related concern going forward would be its ability to continuously update the tool's inputs with new datasets so that outputs would remain as relevant as possible.[100] For NCEEP, because land use and aerial photography data are critical to its prioritization process, keeping these datasets up-to-date is always an issue.[106] Although NCEEP is capable of updating these data itself, it often cannot afford to do so and must use older data. Furthermore, to keep its WetCAT tool updated, VIMS expected that obtaining regular updates of land cover data will be the largest obstacle.[108] IDFG cited limited availability of resources/staff as a fundamental limitation to its ability to maintain updated data for its landscape assessment tool.[97]

6 Conclusion

6.1 Benefits of landscape prioritization methods for siting aquatic resource conservation

The programs examined for this handbook highlight the wide variety of ways in which landscape prioritization tools benefit wetland restoration and protection. Some particularly important benefits of landscape prioritization tools include:

- **Efficient identification of restoration and protection sites that address multiple conservation objectives:** Landscape prioritization tools can be designed to meet the objectives of multiple regulatory and non-regulatory programs that often have differing goals for the same or similar wetland or stream resources. Environmental managers can use landscape prioritization tools to visualize and identify projects or areas that are priorities for multiple programs or that achieve certain sets of functional benefits, allowing for more coordination of conservation and more cost-effective investments.

- **Advancement of regional conservation goals by prioritizing sites using a watershed approach:** Many of the landscape prioritization tools evaluated for this handbook are used to support the selection of mitigation sites using a watershed approach. For example, the TNC-ELI DPWAP promotes the functional replacement of wetland benefits on a watershed basis by identifying areas in which to target mitigation through an analysis of historic functional losses within HUC-12 watersheds.[14]
- **Streamlined permitting processes for transportation and natural resource agencies undertaking compensatory mitigation:** Landscape prioritization tools can support early collaboration and planning among agencies, which can reduce project delays, field visits, and time spent approving and monitoring compensation projects.
- **Reduced costs associated with field monitoring:** Long-term monitoring costs for programs that prioritize sites using landscape prioritization tools are low compared to costs for programs that prioritize sites based on field methods alone. While some landscape prioritization tools depend on field-based methods for some component processes (e.g., tool validation, Section 4.6.1), costs associated with these methods are likely to be relatively small. In contrast, programs that determine priorities using field-based methods alone incur much higher costs as they carry out field assessments on a much larger scale.
- **Increased transparency in the selection of conservation sites:** The processes applied by landscape prioritization programs are often well documented and highly transparent. This is especially true of those that draw heavily upon stakeholder input. For instance, stakeholder teams representing state and local government agencies, non-profits, and private businesses were responsible for developing metrics used to model priority habitat patches as part of the NOAA Habitat Priority Planner Mississippi-Alabama Habitats Tool.[131]
- **Offer considerable opportunities for cost-savings by enabling users to evaluate a large variety of potential conservation sites:** Since conservation costs vary throughout space and time based on component costs of conservation, such as land values and on-the-ground restoration work, prioritization can better target locations that will achieve high-quality environmental outcomes at lower costs. Consolidated projects, such as those performed by mitigation banks, conservation banks, and in-lieu fee programs, can achieve economies of scale in land acquisition and on-the-ground restoration costs, reducing the marginal cost of these projects.
- **Allow for effective cost-benefit analysis with respect to functional return on investment:** Practitioners can apply landscape prioritization tools to account for watershed-scale factors that inform assessment of functional return on investment when selecting aquatic resource restoration and protection sites. These include stressors, stream order, and proximity to existing conservation lands.
- **Reduce the time required to locate project sites:** Results of Level 1 prioritization analyses for a given watershed can have a long shelf life, assuming that the rate of land use change within the watershed is slow. As needs arise for aquatic resource restoration and protection (e.g., through compensatory mitigation), practitioners can readily reference prioritization results to guide selection of areas in which to pursue projects. This is especially true when prioritization results are disseminated widely to potential users – e.g., using interactive web-based maps (Section 4.8.5).

- **Development costs continue to decrease:** The costs required to obtain the hardware, software, and technical skills necessary to develop landscape prioritization tools are not insubstantial. However, as the programs evaluated in this handbook illustrate, once an agency or organization has incurred these fixed up-front costs, additional costs for data acquisition are often negligible as many datasets are freely available.

However, despite the significant advantages of landscape prioritization methods for the selection of high value aquatic resource restoration and protection sites, in some cases important disadvantages exist. For each wetland program considering the application of landscape prioritization tool, these disadvantages must be carefully weighed against the advantages discussed above.

A detailed discussion of the range of obstacles experienced by the landscape prioritization programs evaluated for this handbook was provided in Sections 6 above. These obstacles, which included both limitations to transferability (Section 5.3.5) and barriers to development and implementation (Section 5.4) are summarized in Table 17 below.

Table 17. Summary of disadvantages of landscape prioritization tools discussed in Section 6.

Disadvantage category	Description
Transferability (5.3.5)	The analysis is time-consuming to complete
	The analysis is data intensive
	Limited transferability to some geographic areas
	The tool is technically sophisticated
	The tool requires data inputs that are not widely available
	Documentation for how to apply the tool is lacking
Development and implementation (Section 5.4)	Data limitations
	Technical capacity
	Funding and staff time
	Property rights concerns
	Promoting use of the tool
	Bureaucratic obstacles
	Stakeholder collaboration
	Maintaining updated data

For programs that seek to apply landscape-scale tools to support planning for aquatic resource restoration and protection, factors such as large up-front costs and a lack of available data may be significant. However, for programs whose goal is to target aquatic resource restoration and protection activities in a way that ensures the long-term sustainability of aquatic resources on a regional scale while minimizing overall costs, the benefits of a landscape approach far outweigh the potential costs.

6.2 Applying this handbook to promote more successful conservation outcomes

As agencies and organizations charged with restoring and protecting the nation's aquatic resources confront a variety of constraints, ranging from funding limitations to a requirement to use a watershed approach to the selection of mitigation sites, demand for information to help guide the development of cost-effective prioritization methods will continue to grow. By analyzing the objectives and components of existing landscape prioritization tools and summarizing programmatic information for these tools, this handbook provides a useful resource for practitioners seeking to capitalize on the opportunities offered by landscape prioritization methods. In this way, the information presented in this handbook will support the development of state and local capacity for the successful prioritization of wetland and stream restoration and conservation projects.

For agencies and organizations interested in implementing wetland and stream conservation projects in locations that maximize overall landscape values, this handbook demonstrates the wide range of existing prioritization tools that may serve as models. The most appropriate model approach – of those detailed in Table 1 or others not covered in this handbook – depends on the specific needs of a prospective landscape prioritization program. Prospective programs with limited funding, for instance, may want to avoid approaches that are too labor and cost-intensive (Section 5.3.5) in favor of those that call for only readily available data (Section 5.3.2). To a large extent, selection of an appropriate model approach will depend on the specific objectives for which a prospective program wishes to prioritize (Section 4.4).

Furthermore, the information presented in this handbook on existing prioritization methods could also be used to inform the continued enhancement of other currently existing programs. For example, of the programs studied for this handbook, many cited a need for access to additional data resources (Section 5.4.1).

While states currently lacking landscape prioritization tools face much greater technical, staffing, and financial barriers compared to those with programs currently in place, they can benefit from the learning opportunities presented by the programs that have come before them. We hope that this handbook will promote these learning opportunities for all states, tribes, and local governments involved in the siting of wetland and stream restoration and protection projects. By improving the ability of wetland programs to site projects on a landscape basis, we hope that this handbook will contribute to an overall improvement in watershed and human health.

ENDNOTES

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[9] Programs with landscape prioritization tools for which we completed interviews but did not include in our final sample included the Missouri Department of Natural Resources Wetland Potential Screening Tool, which applied methods that overlapped substantially with other tools in our sample, as well as the Wisconsin Department of Natural Resources Ecological Priorities Tool and Washington State Tool for Selecting Mitigation Sites, which we discovered to be outside the scope of our analysis.
[10] Note that where two or more tools shared most of the same inputs, but had different outputs for different prioritization objectives, we considered both tools to comprise the same landscape prioritization tool. For example, UMass Amherst CAPS draws from a single pool of metrics to build 22 IEI models for aquatic community types. Because all IEI models shared most of the same inputs, the IEI was considered to be a single landscape prioritization tool.
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[24] Idaho Department of Fish and Game. 2010. Development of a landscape-scale wetland condition assessment tool for Idaho.
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[26] Vance LK. 2009. Assessing Wetland Condition with GIS: A Landscape Integrity Model for Montana. A Report to The Montana Department of Environmental Quality and The Environmental Protection Agency. Montana Natural Heritage Program, Helena, MT. 23 pp. plus appendices.
[27] Email correspondence received on 10/13/2011 from Jennifer Sheehan, Arkansas Multi-Agency Wetland Planning Team Coordination Office.
[28] Interview on 8/19/2011 with Collis Adams and Lori Sommer, NHDES Wetlands Bureau.
[29] Brooks C, Powell R, Shuchman R, Leonard G. Developing and applying a geospatial decision support tool for efficient identification of wetlands mitigation sites.
[30] Interview in 12/2011 with Tim Smith, Enforcement and Compliance Coordinator, U.S. Army Corps of Engineers, St. Paul District.
[31] Interview on 7/29/2011 with Scott Jackson, Program Director, UMass Extension's Natural Resources and Environmental Conservation Program, Department of Environmental Conservation, University of Massachusetts, Amherst.
[32] Smith T, Burks-Copes KA. 2010. Development of a GIS-Based Spatial Decision Support System to Target Potential Compensatory Mitigation Sites in Minnesota. National Wetlands Newsletter 32(6) 14-15.
[33] Interview on 1/10/12 with Robert Piel, New Jersey Department of Environmental Protection.
[34] Interview on 1/9/12 with Maryann McGraw, New Mexico Environmental Department.
[35] Interview on 2/22/12 with Tim Post, New York Department of Environmental Conservation.
[36] Berman MR, Rudnicky T, Berquist H, and Hershner C. 2002. Protocols for implementation of a GIS-based model for the selection of potential wetlands restoration sites in southeastern Virginia. Center for Coastal Resources Management, Virginia Institute of Marine Science, College of William and Mary. Gloucester Point, Virginia.
[37] Interview on 2/24/12 with Heather Preston, South Carolina Department of Health and Environmental Control.
[38] Vanesse Hangen Brustlin, Inc. 2009. Merrimack River Watershed Restoration Strategy. Prepared for New Hampshire Department of Environmental Services.
[39] Reed D. 2012. Storm surge/wave attenuation (potential for) technical report. Appendix D-23. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authority of Louisiana. Baton Rouge, LA.
[40] Fischback JR, Johnson DR, Ortiz DS, Bryant B, Hoover M, Ostwald J. 2012. Risk assessment (CLARA) model technical report. Appendix D-25. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authority of Louisiana. Baton Rouge, LA.
[41] Reed D. 2012. Freshwater availability (potential for) technical report. Appendix D-20. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authority of Louisiana. Baton Rouge, LA.
[42] Stanley S, Grigsby S, Hruby T, and Olson P. 2010. Chehalis Basin Watershed Assessment: Description of Methods, Models and Analysis for Water Flow Processes. Washington State Department of Ecology. Publication #10-06-006. Olympia, WA.
[43] Documentation provided on 8/4/2011by Ellen Bryson, USACE Baltimore District.
[44] Interview on 2/21/12 with Peter Schaefer, Texas Council on Environmental Quality.
[45] Nyman JA. 2012. American alligator habitat suitability index technical report. Appendix D-5. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authority of Louisiana. Baton Rouge, LA.
[46] Twedt DJ, Uihlein WB, Elliot AB. 2005. A spatially explicit decision support model for restoration of forest bird habitat. Conservation Biology 20(1) 100-110.
[47] PLJV PowerPoint presentation and notes for the PLDS.
[48] Tennessee Wildlife Resources Agency. 2005. Tennessee's Comprehensive Wildlife Conservation Strategy. TWRA: Nashville, Tennessee.
[49] Kline et al. (2006) further define the umbrella species concept as "based on the idea that conserving certain species will confer a protective 'umbrella' to co-occurring species due to shared habitat requirements (Launer & Murphy 1993, Lambeck, 1997). This assumes that if the resource requirements of an umbrella species are met, the requirements of many other species also will be satisfied (Fleishman et al., 2001)." satisfied (Fleishman et al., 2001)."
[50] The version of the WDNR Habitat Quality Index described by Kline et al. (2006) was later used as the basis for developing the TNC-ELI DPWAP Wildlife Tool. The primary difference between the Wildlife Tool and Habitat Quality Index is that the GIS model underlying the Wildlife Tool associates habitat types with "representative species" that reflect habitat, management, and restoration needs of each habitat rather than "umbrella species" that reflect the range of species that share similar habitat requirements.

[51] McGarigal K, Compton B, Jackson S, Plunkett E, Rolih K, Portante T, Ene E. 2012. Conservation Assessment and Prioritization System (CAPS) Statewide Massachusetts Assessment: November 2011.
[52] Areas selected as priorities by the Kramer et al. (2012) Connectivity to Existing Conservation Lands Tool supported habitat connectivity in addition to recreation, education, and scenic value.
[53] Strager MP, Anderson JT, Osbourne JD, and Fortney R. 2011. A three-tiered framework to selection, prioritize, and evaluate potential wetland and stream mitigation banking sites. Wetlands Ecology and Management 19:1-18.
[54] Reed D. 2012. Nature based tourism (potential for) technical report. Appendix D-21. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authority of Louisiana. Baton Rouge, LA.
[55] Multi-objective tools prioritizing suitability for preservation included: TNC-ELI DPWAP Function Variety Assessment, Kramer et al. (2012) Wetland Condition Index, Maryland WRR Wetland Preservation Tool, Maryland WRR Riparian Zone Preservation Tool, Maryland WRR Natural Stormwater Infrastructure Preservation Tool, NOAA HPP Riparian Buffers (Conservation) Tool, NOAA HPP Watersheds (River and Stream Conservation) Tool.
[56] Furthermore, because the WSDOE and the Duck-Pensaukee Pilot both combined outputs from their single-objective tools into a multi-objective output, these outputs – the WSDOE WCT Overall Watershed Characterization Tool and Duck-Pensaukee Pilot Function Variety Assessment – also prioritized for surface water supply.
[57] [Define human2 score here]
[58] Factors and data sources used by the USEPA RPS Social Context Tool are provided on EPA's website at: http://owpubauthor.epa.gov/lawsregs/lawsguidance/cwa/tmdl/recovery/indicatorssocial.cfm
[59] Interview on 2/21/12 with Barbara Scott, Kentucky Department of Water.
[60] Interview on 2/25/12 with David Waterstreet, Wyoming Department of Environmental Quality.
[61] Kline et al. (2006), pp. 46-59.
[62] Rivera-Monroy VH, Branoff B, Dortch M, McCorquodale A, Meselhe E, and Visser J. 2012. Nitrogen uptake model (potential for) technical report. Appendix D-22. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authority of Louisiana. Baton Rouge, LA.
[63] In addition, four programs that were currently developing tools described plans for validating their tools. The tools produced as part of the TNC-ELI DPWAP were not validated, though validation is a likely next step. TNC VARTF is currently considering developing methods for validating results of its ecoregional assessments based on monitoring data that it collects for ten years following the completion of mitigation sites in priority areas. If TNC could match field data identifying high- and low-quality sites with sites predicted by ecoregional assessments to have high and low viability, the results could provide valuable feedback that could be used to improve the assessment process. Although DU did not complete any groundtruthing originally for its Forest Breeding Bird Decision Support Model, it would like to validate the model within the next few years. However, the fact that the landscape has changed somewhat since the last model run could be problematic unless a revision to the model, which they are considering, is completed as well. The VDCR model is not validated using Level 2/3 data. This project and funding was focused on methodological development. A statewide expansion of the model will include groundtruthing.
[64] Bernthal T, Kline J, Burzynski M, Barrett K. 2007. Milwaukee River Basin Wetland Assessment Project: Phase Two: Groundtruthing the Potentially Restorable Wetlands Layer.
[65] Michigan Tech Research Institute. 2009. Validation Report: Wetland Mitigation Site Suitability Tool. Accessed from:
http://quickplace.mtri.org/QuickPlace/tarut/PageLibrary8525724B004F2A59.nsf/h_Toc/BA5057037CC37873852575B60045FF3C/?OpenDocument
[66] Feedback provided on 5/16/2012 by Joanna Lemly, Wetland Ecologist, Colorado Natural Heritage Program.
[67] In addition, three prioritization programs described future plans to refine results. The TNC-ELI DPWAP identified priorities using landscape prioritization tools as an initial step in the prioritization process and in the future will develop field-based methods for refining Level 1 priorities. For the Kramer et al. (2012) tools, validation using on-the-ground water quality analyses is desirable but has not yet been completed. The developers of the tools have been working to obtain funding to validate the tools using hydrologic modeling such as SWAT or LSTC. Furthermore, despite the strong predictive ability of the Level 1 models, Weller et al. (2007) stated that, because some uncertainty always exists, "Level 1 predictions alone should not be used to make management decisions." They emphasize that practitioners should always verify predictions with field observations and state that "field visits to prioritize wetlands for preservation could be focused on wetlands that the Level 1 models predict to be in good condition. Conversely, the Level 1 models could identify wetlands likely to be degraded, helping to target field visits aimed at selecting restoration sites." Although the model is calibrated using Level 2 data, sites identified for restoration or conservation action using it must be validated on-the-ground before such actions are taken.

[68] CRAM assessments are field-based evaluations of four attributes of wetland condition – landscape context, hydrology, physical structure, and biotic structure – that produce an overall score that can be used to prioritize mitigation sites. Level 2 CRAM data have been validated as effective using Level 3 approaches.

[69] Interview on 8/4/2011 with Jim Thorne, Andrea Williams, and Rebecca Loefller.

[70] Interview on 8/12/2011 with David Phemister, Director of Federal Government Relations for TNC in Virginia.

[71] For each CAP, TNC applies field data to data it compiles for target viability, threats, and stresses as part of its process for establishing priority projects. For the CAP, VARTF defined primary attributes that determine the biological health for each of its targets for the EDU. If these attributes are missing, the target degrades or is lost over time. For example, an attribute for a stream target may be some measure of water quality – if water quality becomes sufficiently degraded the stream may no longer be viable. For each target, VARTF defined the acceptable range of variation of target attributes by establishing a viability rating scale that rates the status of each attribute as "very good," "good," "fair," or "poor." VARTF then set goals for each target attribute in terms of these ratings. VARTF also ranked threats (defined as proximate stresses) to targets in terms of their contribution to target impairment and irreversibility. In addition, TNC ranked stresses (defined as impaired aspects of targets resulting from human activities) in terms of their scope and severity of impact to targets. For each of these threat/stress categories (impairment, irreversibility, scope, and severity), TNC collaborated with a team of experts to assign a rating of "very high," "high," "medium," or "low." This process allowed TNC to identify the most critical threats to targets within each EDU.

[72] Colorado Natural Heritage Program. 2010. Colorado Natural Heritage Program Wetland Program Plan: A Vision for Building Comprehensive Wetland Information for the State of Colorado. Planning Years 2011-2015.

[73] Interview on 5/22/2012 with Dan Bell, Willamette Valley Consevation Directory, The Nature Conservancy.

[74] Carpendo S and Kramer E. 2008. Modeling ecosystem functions to prioritize potential wetland mitigation sites in Georgia. Master's thesis. University of Georgia.

[75] Weber JT, Bulluck, JF. 2010. Methodology for developing a parcel-based wetland restoration, mitigation, and conservation catalog: A Virginia pilot. Natural Heritage Technical Report #10-22. Virginia Department of Conservation and Recreation, Division of Natural Heritage. Richmond, Virginia 34 pp.

[76] Environmental Law Institute. 2007. Mitigation of impacts to fish and wildlife habitat: Estimating costs and identifying opportunities. Accessible from: http://www.watershedinstitute.biz/index.html.

[77] National Research Council. 2001. Compensating for wetland losses under the Clean Water Act. Washington, DC: National Academies Press.

[78] In fact, this preference still exists in state law/policy; see e.g., California new wetlands policy that encourages on-site mitigation over off-site options.

[79] NRC (National Research Council on Wetland Mitigation). 2001. Compensating for Wetland Loss under the Clean Water Act. National Academy Press. Washington, D.C.; Kihslinger RL. 2008. Success of wetland mitigation projects. National Wetlands Newsletter. 30(2): 14-16.

[80] Alexander RB, Boyer EW, Smith RA, Schwarz GE, Moore RB. 2007. The role of headwater streams in downstream water quality. JAWRA Journal of the American Water Resources Association 43: 41-59.

[81] EPA recovery potential screening tool, detailed in later sections

[82] See e.g., MD WRR

[83] http://www.epa.gov/owow/NPS/Section319/319guide03.html

[84] This limitation on distribution of WRP funds would likely limit the program's usefulness for large-scale aquatic resource restoration or conservation efforts. For example, Duck Unlimited expressed concern regarding this limitation, stating that its prioritization results were used by WRP they would not necessarily lead to satisfying conservation outcomes (see Section 4.1.9).

[85] http://www.defenders.org/publications/conserving_habitat_through_the_federal_farm_bill.pdf

[86] http://www.tetratech-ffx.com/tfmeeting/spring2012_pub/downloads/Mills.pdf; http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/financial/eqip/?&cid=STELPRDB1047761

[87] Table adapted from Defenders of Wildlife Report on Conservation Programs in Farm Bill; see report for more details on funding, cost-share requirements/contributions, etc.

[88] http://wsfrprograms.fws.gov/Subpages/GrantPrograms/SWG/SWG.htm

[89] http://www.wildlifeactionplans.org/pdfs/eight_elements_handout.pdf

[90] Wilkinson, Jessica B., Robert Bendick, Bruce A. McKenney, James M. McElfish, Jr., and Rebecca Kihslinger. August 4, 2009. "The Next Generation of Mitigation: Linking Current and Future Mitigation Programs with State Wildlife Action Plans and Other State and Regional Plans." Washington, DC: Environmental Law Institute.

[91] http://www.fws.gov/birdhabitat/Grants/NAWCA/index.shtm; http://www.fws.gov/birdhabitat/Grants/NAWCA/Standard/index.shtm; http://www.fws.gov/birdhabitat/Grants/NAWCA/Small/index.shtm
[92] http://www.fws.gov/policy/640fw1.html
[93] http://www.fws.gov/policy/640fw1.html
[94] http://www.fws.gov/partners/aboutus.html; http://www.fws.gov/policy/640fw1.pdf
[95] http://www.fws.gov/policy/640fw1.pdf
[96] http://www.fws.gov/policy/640fw1.pdf
[97] Interview on 12/15/2011 with Chris Murphy, Wetland Ecologist, Idaho Department of Fish and Game.
[98] Interview on 1/17/2012 with Colin Brooks, Manager of the Environmental Science Laboratory at Michigan Tech Research Institute.
[99] Interview on 8/2/2011 with Dale James, Manager of Conservation Planning, Ducks Unlimited.
[100] Interview on 8/2/2011 with Elizabeth Kramer and Mark Risse, University of Georgia, and Elizabeth Booth and Jennifer Welte, Georgia Environmental Protection Division.
[101] Interview on 8/9/2011 with Jason Bulluck, Natural Heritage Information Manager, Virginia Department of Conservation and Recreation, Division of Natural Heritage.
[102] Interview on 4/9/2012 with Natalie Snider, Coastal Resources Scientist Senior, Planning Division, Coastal Protection and Restoration Authority of Louisiana.
[103] Interview on 7/28/2011 with Jennifer Sheehan, Arkansas Multi-Agency Wetland Planning Team Coordination Office.
[104] Interview on 8/3/2011 with Tom Hruby, Senior Ecologist, Washington State Department of Ecology.
[105] Interview on 8/18/2011 and 9/6/2011 with Thomas Bernthal, Wisconsin Department of Natural Resources.
[106] Interviews on 8/16/11 and 9/28/11 with Nancy Daly, Marc Recktenwald, and Rob Breeding, North Carolina Ecosystem Enhancement Program.
[107] Interview on 9/29/2011 with Donald Weller, Senior Scientist, Smithsonian Environmental Research Center.
[108] Interview on 7/29/2011 with Kirk Havens, Assistant Director, Center for Coastal Resources Management, Virginia Institute of Marine Science, College of William and Mary.
[109] Interview on 2/22/2012 with William Ashton, Alaska Department of Environmental Conservation.
[110] Interview on 12/13/2012 with Jason Jones and Debra Daniel, Arizona Department of Environmental Quality.
[111] Interview on 2/17/2012 with Robert Gilmore, Connecticut Department of Environmental Protection.
[112] Interview on 8/1/2011 with Daniel Twedt, Wildlife Biologist, United States Geological Survey.
[113] Interview on 12/9/2011 with Mark Thurman, Fisheries Program Manager, Tennessee Wildlife Resources Agency.
[114] Feedback received on 3/29/2012 from Nick Miller, Director of Science at The Nature Conservancy.
[115] Interview on 8/15/11 with Denise Culver, Colorado Natural Heritage Program.
[116] Interview on 1/12/2012 with Michael Strager, Assistant Professor, Division of Resource Management, West Virginia University.
[117] Feedback received on 5/18/2012 from Stephen Stanley, Wetland Specialist, Washington State Department of Ecology.
[118] Email received on 3/22/12 from Bobby Cochran, Executive Director, Willamette Partnership.
[119] Coastal Protection and Restoration Authority of Louisiana. 2012. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authority of Louisiana. Baton Rouge, LA.
[120] Interview on 1/3/2012 with Deb Baker, Kansas Water Office, and Ty Guthrie, Megan McLachlan, and Bob McCreedy, Playa Lakes Joint Venture.
[121] Interview on 8/1/2011 with Roberta Swann, Director of the Mobile Bay National Estuary Program.
[122] Feedback provided on 3/7/12 by Joanna Lemly, Wetland Ecologist, Colorado Natural Heritage Program.
[123] Interview on 12/19/2011 with Jennifer Axelrod, FLO Data and GIS.
[124] Interview on 8/17/2011 with Marcia Berman, Program Manager, Virginia Institute of Marine Science.
[125] Feedback received on 6/15/2012 from Jason Bulluck, Natural Heritage Information Manager, Virginia Department of Conservation and Recreation, Division of Natural Heritage.
[126] VDOT, for example, has offered to provide matching funds on a VDCR proposal to apply the model statewide. In addition, the Federal Highways Administration has embraced the VDCR Model for its ability to support long-term planning for compensatory mitigation for transportation impacts.[101]
[127] Idaho Department of Fish and Game. 2010. Development of a landscape-scale wetland condition assessment tool for Idaho.
[128] Prioritization programs citing limited funding or staff time as a limitation to their tool(s) included: Arkansas MAWPT, CNHP, Ducks Unlimited, TNC-ELI DPWAP, USEPA RPS, Kramer et al. (2012), LACPRA CMP,

USACE SRWBMP, Kauffman-Axelrod and Steinberg (2010), TNC Aquatic EA, VDCR, VIMS WetCAT, Caltrans RAMP, IDFG, UMass Amherst CAPS, Maryland WRR, MTRI, NHDES WRAM, NOAA HPP MAHT, PLJV PLDSS, Strager et al. (2011), VIMS WMTT, WSDOE WCT, WDNR, and MTNHP.

[129] Interview with Paul Lorenzen, South Dakota Department of Environmental and Natural Resources.

[130] Whigham DF, Jacobs AD, Weller DE, Jordan TE, and Kentula ME. 2007. Combining HGM and EMAP procedures to assess wetlands at the watershed scale – status of flats and non-tidal riverine wetlands in the Nanticoke River watershed, Delaware and Maryland (USA). Wetlands 27(3) 462-478.

[131] The Nature Conservancy, National Oceanic and Atmospheric Administration, and Mobile Bay National Estuary Program. 2009. Prioritization guide for coastal habitat protection and restoration in Mobile and Baldwin counties, Alabama. Accessed from: http://habitats.disl.org/HabitatMapperGuide.pdf.

Appendix A
Advancing State & Local Wetland Program Capacity to Identify Restoration and Conservation Priorities

Research Template

<u>Introduction:</u> ELI recently was awarded a grant from U.S. EPA HQ to identify and analyze the methods developed by state and local wetland programs to identify and prioritize wetlands with high restoration potential or conservation value. As part of this project, ELI will summarize the findings of the research in a final technical report that outlines existing model approaches, summarizes the types and sources of data used in these analyses, highlights tools or methods that are transferable or adaptable to other settings, and describes data gaps preventing implementation of these approaches in individual states. The results will be disseminated through web- and print-based distribution, a webinar, and presentations at professional conferences.

Note: our use of the word "tool" includes any regulatory or non-regulatory, GIS or non-GIS method of identifying aquatic resource restoration and/or conservation priorities. Some programs contain multiple "tools," each of which will be addressed in this research.

In addition, because we focus primarily on watershed approach-based aquatic resource prioritization, only tools that include level 1 (landscape-level) assessments fall within the scope of our study. Though many level 2 (rapid) and 3 (intensive) on-the-ground assessments of wetland condition exist, we consider level 2 or 3 assessments only if they inform (e.g., confirmed or verified) level 1 results. Furthermore, given our interest in prioritization tools that help state and local programs identify specific locations for aquatic resource restoration or conservation, we limited our scope to level 1 assessment tools that identify specific sites for prioritization. General assessments of watershed needs (e.g., "watershed profiling") are of interest only when they are used to support level 1 assessments that identify specific priority sites for aquatic resource restoration or conservation.

State:

Name of Program/Tool:

Name of interviewer:

Date interview completed (list all interviewees and the dates interviewed):

Name of all interviewees and contact information (name, title, address, phone, email):

Summary of Program (350 words):

Year the tool/method was originally developed:

Table of Contents:

Sections to be completed by assessment type(s)

I. General program information

1. Provide a brief general description of the prioritization program. If the program applies multiple prioritization tools, briefly describe each tool.

2. What is the status of your program/tool:
   - ☐ Being implemented
   - ☐ Under development
   - ☐ Currently unused, but may be used in future
   - ☐ Permanently out of use

   Details:

3. What is the **entire** geographic extent of the program?
   - ☐ Statewide
   - ☐ Watershed-wide
   - ☐ Ecoregion-wide
   - ☐ Other:

   Describe:

4. Are results made available publicly? (If yes, describe; if no, why not?)

5. What factors initiated investment in the development of each tool?
   - ☐ State requirements for monitoring
   - ☐ Performance standards for mitigation sites
   - ☐ Need for wildlife management
   - ☐ Improved decision-making (regulatory or non-regulatory)
   - ☐ Legal action (e.g., a lawsuit)
   - ☐ Other:

   Details (e.g., level 1, 2, or 3 data?):

6. What factors sustain investment in each tool?
   - ☐ State requirements for monitoring
   - ☐ Performance standards for mitigation sites
   - ☐ Need for wildlife management
   - ☐ Improved decision-making (regulatory or non-regulatory)
   - ☐ Legal action (e.g., a lawsuit)
   - ☐ Other:

   Details (e.g., level 1, 2, or 3 data?)

II. General purpose of the prioritization tool

If the program applies multiple tools, answer this section individually for each tool.

7. Which of the following assessment methods does your tool use to prioritize wetland or stream restoration or conservation (check all that apply)?
   - ☐ Level 1 (GIS-based/landscape-level analysis)

☐ Level 2 (rapid field-based assessment)
☐ Level 3 (intensive field-based assessments, e.g., measurement of plant species composition and cover)
☐ Best professional judgment
☐ None
☐ Other (explain):

8. Which of the following are central goal(s) of the tool (check all that apply)? Please note, but do not check, any that represent *possible applications* of the tool but that are not central goals.
   ☐ Identify priorities for wetland compensatory mitigation
   ☐ Identify priorities for stream compensatory mitigation
   ☐ Identify priorities for endangered species compensatory mitigation
   ☐ Identify priorities for water quality regulatory programs (e.g., TMDLs)
   ☐ Identify priorities for other regulatory programs
   ☐ Identify priorities for non-regulatory aquatic resource restoration
   ☐ Identify priorities for non-regulatory aquatic resource protection (i.e., land acquisition or the acquisition of conservation easements)
   Details (e.g., types of mitigation projects prioritized, inclusion of non-aquatic resources):

9. List all regulatory/non-regulatory programs to which the tool is intended to be applied. Describe how the tool is used to meet the needs of these programs.

10. To which of the following aquatic resource improvement/conservation types does the tool apply (check all that apply; can be for regulatory or non-regulatory programs)?
    ☐ Restoration (reestablishment)
    ☐ Restoration (rehabilitation)
    ☐ Creation
    ☐ Enhancement
    ☐ Preservation/Protection (e.g., conservation easements)
    ☐ Acquisition without preservation/protection (e.g., fee simple acquisition)
    ☐ Other:

11. What are the major components or aims of your tool (check all that apply)?
    ☐ Watershed needs and goals/watershed profiling (e.g. NWI Plus)
    ☐ Suitability of individual aquatic resource restoration or conservation sites (e.g., raster stacking approach)
    ☐ Other (explain):

III. Prioritization tool includes a level 1 component

If the program applies multiple level 1 tools, answer this section individually for each.

12. Ask first as open-ended question: If your tool assesses **watershed/landscape needs and goals**, what aquatic resource functions or values (e.g., habitat quality, flood attenuation, water quality improvement) or other factors (e.g., forecasted resource impacts) are evaluated?

☐ Aquatic resource types (e.g., HGM, Cowardin, or other)
☐ Habitat quality/configuration
☐ Wildlife
☐ Water quality
☐ Flood attenuation (e.g., precipitation estimates)
☐ Groundwater recharge
☐ Social values
☐ Forecasting aquatic resource impacts
☐ Reference sites/watersheds
  ☐ Historic functional losses
☐ Other:

For each factor selected, list all specific criteria and supporting data that are used to evaluate and discern watershed/landscape needs and goals. For example "Wildlife needs are assessed based on amphibian abundance data derived from the State Wildlife Action Plan." If known, please provide the geographic extent of datasets. Please indicate if these criteria are obtained through level 1, 2, or 3 assessments.

13. Ask first as open-ended question: If your tool assesses **site suitability**, what aquatic resource functions or values (e.g., habitat quality, flood attenuation, water quality improvement) or other factors (forecasted resource impacts) are evaluated? Please note that aquatic resource functions include the effect of adjacent/neighboring land uses on those functions.
☐ Aquatic resource types (e.g., HGM, Cowardin, or other)
☐ Habitat quality (e.g., field data, spatial configuration)
☐ Water quality
☐ Flood mitigation
☐ Groundwater recharge
☐ Wildlife
☐ Social values
☐ Land ownership (private vs. public) and easements
☐ Feasibility of restoration (key to distinguish whether level 2/3 assessments can do this)
  ☐ Potential functional uplift
  ☐ Time lag
  ☐ Risk
☐ Cost-effectiveness of project
☐ An ecological integrity metric (describe):

For each function/value selected, list all specific criteria and supporting datasets that form the basis of the site prioritization process (for example, "sites are prioritized for habitat quality based on proximity to other natural areas, data for which are derived from the 2006 National

Land Cover Dataset"). If known, please also provide the geographic extent of datasets and indicate whether ecological criteria are evaluated through level 1, 2, or 3 assessments.

14. For the criteria listed above for questions 12 and 13, indicate their relative weightings within the tool.

15. Were multiple partners/stakeholders involved in developing the weightings?
    ☐ Yes
    ☐ No
    If yes, please list partner/stakeholder categories (e.g., federal regulators, state regulators, local land use decision-makers, local land trusts, non-profit conservation organizations, mitigation bankers, federal or state agencies that conduct mitigations (e.g., DOT), etc…):

16. Does your level 1 site suitability analysis solely use a raster calculator model?
    ☐ Yes
    ☐ No, explain:

17. What software is used for the level 1 assessment?
    ☐ ArcGIS
    ☐ Other:

18. In what format are prioritization results presented (check all that apply)?
    ☐ Maps
    ☐ Static maps
    ☐ GIS data
    ☐ Online, interactive maps
    ☐ Web map service
    ☐ Online map viewer
    ☐ Data tables of site priorities
    ☐ Narrative description of site priorities
    ☐ Other:

19. At what scale is the tool applied within the program area?
    ☐ Watershed. Describe (e.g.., HUC-8, HUC-6):
    ☐ Ecoregion. Describe (e.g., Level III, Level IV):
    ☐ Political boundaries. Describe:
    ☐ Other:
    Why is this scale used?

20. Does any literature exist that describes the underlying mechanics of the tool?
    ☐ Yes
    ☐ Peer-reviewed
    ☐ Non-peer-reviewed
    ☐ No
    If yes, where can it be obtained?

21. If the level 1 analysis is integrated with level 2 and/or level 3 data, are these data used to calibrate or validate the level 1 analysis?
   - ☐ Calibrate
      - ☐ level 2
      - ☐ level 3
   - ☐ Validate
      - ☐ level 2
      - ☐ level 3
   - ☐ Level 2/3 data are used opportunistically
   - ☐ Level 1 analysis does not integrate with level 2/3 data

22. If your tool is based on level 1 assessment *only*, explain why your tool does not use level 2/3 assessments:
   - ☐ Using level 2/3 methods is too costly or level 1 tools cost less than level 2/3 methods
   - ☐ Level 1 tools are more accessible to stakeholders than level 2/3 methods
   - ☐ Level 1 tools are more objective than level 2/3 methods
   - ☐ Required expertise are not available to do level 2/3 assessments
   - ☐ Other (please explain):

23. Does the program monitor the ecological success of any aquatic resource restoration/conservation undertaken at priority sites to ensure that they are fulfilling the tool's objectives?
   - ☐ Yes
      - ☐ Level 1(GIS-based/landscape-level analysis)
      - ☐ Level 2 (rapid field-based assessment)
      - ☐ Level 3 (intensive field-based assessments, e.g., measurement of plant species composition and cover)
      - ☐ Other (explain)
   - ☐ No

   Details:

<u>IV. Level 1 approach includes level 2 Rapid Assessment Methods</u>

Complete this section only if the tool includes both level1 and 2 assessments.

24. What type of level 2 assessment do you perform? Describe the process used to develop and implement data collection plans for level 2 data.

25. Is your RAM documented?
   - ☐ Yes
   - ☐ No

   If yes, where can documentation be obtained:

26. Are level 2 Rapid Assessment Methods calibrated or validated using level 3 data?
   - ☐ Calibrated

☐ Verified
☐ Level 3 data are used opportunistically
☐ No
Explain:

27. How frequently are data collected for the RAM during the collection period?
☐ Quarterly
☐ Annually
☐ Less frequently than annually (explain):
☐ Other:

28. List all agencies/organizations that employ field personnel to collect level 2 data. Approximately how many FTEs are employed by each?

V. Level 1 approach includes level 3 intensive assessment methods

*Complete this section only if the tool includes a both level 1 and level 3 assessments***.**

29. What type of level 3 assessment do you perform? Describe the process used to develop and implement data collection plans for level 3 data.

30. Is your level 3 method documented?
☐ Yes
☐ No
If yes, where can documentation be obtained:

31. How frequently are data collected for the intensive assessment during the collection period?
☐ Quarterly
☐ Annually
☐ Less frequently than annually (explain):
☐ Other:

32. List all agencies/organizations that employ field personnel to collect level 3 data. Approximately how many FTEs are employed by each?

VI. Data gaps

If the program applies multiple tools, answer this section for each.

33. Are there any data gaps that limit the functionality of the tool?
☐ Yes
☐ No
If yes, please list each specific data gap and describe how it affects tool functionality.

34. Are you aware of any readily available data that could fill these data gaps?
☐ Yes
☐ No

If yes, please describe them:

35. Are you presently seeking to fill data gaps?
   ☐ Yes
   ☐ No
   Explain:

36. What measures did you take during the development of your tool, or do you take currently for the maintenance of your tool, to obtain spatial data?
   ☐ We produce our own base spatial datasets using staff resources
   ☐ We purchase access to existing spatial datasets
   ☐ We contract with outside companies/organizations to produce needed spatial datasets
   ☐ We use existing, freely-available, and readily accessible spatial datasets

37. What could other agencies/organizations do to support your data needs?

<u>VII. Present status and future development of the prioritization program</u>

If the program applies multiple tools, answer questions 39-40 for each.

38. Do you see your prioritization tool as a model for other states/regions?
   ☐ Yes
   ☐ No
   Explain why/why not:

39. Is your prioritization tool transferable to other states/regions?
   ☐ Yes
   ☐ No
   ☐ Part of the tool is transferable
   Explain why/why not:

40. Has the program been applied to inform actual aquatic resource restoration or conservation decisions?
   ☐ Yes
   ☐ No
   If yes, who used the prioritization products? For what purpose?
   If no, why not? What are the barriers?

41. Do any incentives promote use of priority restoration/conservation sites?
   ☐ Institutional
      ☐ Regulatory (e.g., credit ratio reduction in mitigation, expedited permitting)
      ☐ Non-regulatory (e.g., increased WRP points)
   ☐ Social
   ☐ Economic
   ☐ Other:
   ☐ None

For all incentives selected, provide an explanation:

42. Do you feel that there are opportunities to create additional incentives for using prioritization results?
   - ☐ Yes
   - ☐ No

   Explain:

43. Does your program collaborate with other state, federal, or local entities to determine restoration/conservation priorities (e.g., state water quality programs/TMDLs; SWAPs)
   - ☐ Yes
   - ☐ No

   If yes, list all collaborators and the purpose of the collaboration. If no, explain.

44. Aside from data gaps, has your program encountered any other obstacles/constraints to developing tool(s) for guiding selection of priority sites:
   - ☐ Technical capacity (trained people, staff turnover)
   - ☐ Functional capacity (hardware, software)
   - ☐ Political will
   - ☐ Bureaucratic obstacles (e.g., poor cooperation from federal permitting agencies, administration of program split between agencies):
   - ☐ Time
   - ☐ Money
   - ☐ Property rights concerns (issues with identifying specific sites on a map)
   - ☐ Time required to prioritize sites each iteration of the method
   - ☐ Other:

45. Where would you like to see your program/tool(s) in 5 years?

46. What obstacles do you expect to encounter in meeting this/these goal(s)?

47. What resources would help you meet this/these goals?
   - ☐ Training
   - ☐ Data
   - ☐ Time
   - ☐ Money
   - ☐ Staff
   - ☐ Other:

VIII. Prioritization program does not include a level 1 assessment method

48. Has your department considered developing a Level 1 aquatic resource prioritization tool?
    - ☐ Yes
    - ☐ No

    If yes, describe the status of this consideration and any potential tools that are being considered:

49. If your program decided to implement a Level I prioritization tool, what characteristics would be most desirable in this tool?
    - ☐ Ease of use
    - ☐ Uses readily available Level I data
    - ☐ Accuracy (e.g., validating or calibrating with Level II or III data)
    - ☐ Inclusion of restoration or conservation budgetary constraints
    - ☐ Ability to identify sites where sustainable wetland and stream resources will develop or persist
    - ☐ Ability to identify sites that address watershed water quality needs or objectives
    - ☐ Ability to identify sites that address watershed habitat needs or objectives
    - ☐ Ability to identify sites that address watershed flood control needs or objectives
    - ☐ Other: (please explain)

50. Are Level II RAMs or Level III intensive site evaluations used in your state to select aquatic resource restoration and conservation sites?
    - ☐ Yes
    - ☐ No

    If yes, explain and provide any relevant documentation:

51. What obstacles have you experienced to developing a Level I prioritization program?
    - ☐ Lack of data
      If so, please describe data needs:
    - ☐ Technical capacity (trained people)
    - ☐ Functional capacity (hardware, software)
    - ☐ Political will
    - ☐ Bureaucratic obstacles (e.g., administration of program split between agencies):
    - ☐ Time
    - ☐ Money
    - ☐ Property rights concerns (fear of identifying sites on a map)
    - ☐ Time required to prioritize sites each iteration of the method
    - ☐ Other:

52. What investments by federal, state, or local governmental agencies, or the private/nongovernmental community, would be particularly helpful in facilitating adoption of a Level I aquatic resource prioritization approach?

- ☐ Training
- ☐ New Data
  - ☐ Aerial photography
    - ☐ Land use/land cover
    - ☐ Vegetation
    - ☐ Other:
  - ☐ LiDAR data (Digital Elevation Models)
    - ☐ Floodplain boundaries
    - ☐ Topographic maps
    - ☐ Other:
  - ☐ RADAR data
    - ☐ Hydroperiod maps
    - ☐ Other
  - ☐ Digitize historic aquatic resource extent
    List:
  - ☐ Level II assessments
    List:
  - ☐ Level III assessments
    List:
  - ☐ Other data:
- ☐ Improvements to existing data
  - ☐ Higher-resolution data
    List:
  - ☐ Expand existing datasets
    List:
  - ☐ Data processing
    - ☐ Topographic Wetness Index maps
    - ☐ Other:
- ☐ Time
- ☐ Money
- ☐ Staff
- ☐ Other:

53. Could the state better incentivize/leverage private investment in prioritization efforts?

- ☐ Yes
- ☐ No

If yes, explain:

54. Who would benefit from the development of prioritization tool that includes level 1 capacity? Explain.

55. In what specific ways do you expect that development of level 1 capacity would benefit your program's effort to prioritize wetlands for restoration/conservation?

Information requested:

Date information received:

Citation:

Appendix B: Additional prioritization programs not included in this analysis

- Michael S. Weller, Missouri Department of Natural Resources: Wetland Potential Screening Tool
- Center for Watershed Protection: Wetlands-At-Risk Protection Tool
- USACE Los Angeles District and ERDC: SAMP aquatic resource integrity assessment
- Stephen Newbold, UC Davis (US EPA): Optimizing wildlife habitat and water quality improvements from wetland restoration in Central Valley CA
- Barrier removal prioritization in the Willamette basin
- Cuyahoga River watershed model (White and Fennessy 2004)
- East Credit subwatershed in Ontario, Canada: instream habitat prioritization
- Eco-Assessor: lower part of the Yazoo River basin, MS River Basin, Mississippi
- USACE Sacramento District: CA watershed approach pilot sponsored by the U.S. Army Corps of Engineers/U.S. Environmental Protection Agency
- Etowah River Watershed, Watershed Approach Pilot Project
- Stones River Watershed, Watershed Approach Pilot Project
- NatureServe: Watershed approach framework for Juneau Alaska
- Minnesota Wetland Restoration Stategy
- United States Geological Survey: Ecosystem Services and Wetland Condition Assessment in the Prairie Pothole Region
- Lower Columbia River Restoration Prioritization Framework
- Minnesota Board of Soil and Water Resources: Northeast Minnesota Potential Wetland Mitigation Finder
- Wetland Restoration Plan for the Woonasquatucket River Watershed, Rhode Island
- Argonne National Laboratory: Wetland mitigation suitabiliy tool
- Massachusetts Wetlands Restoration Program
- MD green infrastructure planning for highway (US 301) bypass around Waldorf, Maryland
- Narragansett Bay Estuary Program, U.S. Fish and Wildlife Service, University of Massachusetts Natural Resources Assessment Group, URI Environmental Data Center, Save The Bay: Salt Marsh Site Selection Tool
- The Nexus Project: Integrating Interagency Flood Hazard Solutions on Brush Creek
- U.S. Army Corps of Engineers Engineering Research and Development Center: Spatially explicit decision support system for prioritizing wetland restoration areas in Sharkey County, Mississippi
- Habitat restoration prioritization in the NY-NJ Harbor Estuary
- Wayne National Forest, Ohio: Riparian wetland restoration GIS model
- "Refinement and validation of a multi-level assessment method for Mid-Atlantic tidal wetlands (VIMS)"

- Southeastern Virginia Combined Benefits Mitigation Plan--Southern Watershed Area Management Plan
- 3 coastal Mississippi counties: Harrison, Hancock, and Jackson: prioritization for wetland restoration
- Wyoming Basins ecoregion planning to select mitigation sites (with TNC)
- Robert Brooks, Penn State University: Watershed Characterization and Prioritization Tool

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