2015 Project Abstract
For the Period Ending June 30, 2018

PROJECT TITLE: Conservation Easement Assessment and Valuation System Development
PROJECT MANAGER: Bonnie Keeler
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2015, Chp. 76, Sec. 2, Subd. 09k

APPROPRIATION AMOUNT: $250,000
AMOUNT SPENT: $247,000
AMOUNT REMAINING: $3,000

Overall Project Outcome and Results

Our research sought to address a problem that conservation practitioners and the LCCMR face; how do we know that a proposed easement acquisition is a good use of resources? What benefits does it provide, and is it the best parcel to provide those benefits? We set out to understand existing approaches, and create a tool to complement their strengths and improve conservation targeting.

After researching the methods state agencies and NGOs use to prioritize acquisitions in the state, we designed a tool to complement existing approaches in two ways. First, we observed that existing systems all use a rubric to score proposed acquisitions on a parcel-by-parcel basis. Detailed local knowledge gathered in site visits is important for decision-making, however, it is impossible to gather site-level data for the entire state. Valuable parcels will be missed without a statewide, landscape-level perspective. To complement existing rubrics, our approach scored over 300,000 privately held, undeveloped parcels to provide the context of how a proposed acquisition compares to all other parcels in the state.

Second, our approach created 11 environmental benefit metrics, designed to complement those used in existing prioritization systems. Our metrics combine spatial data to map not just where high quality natural resources are, but also where the public would benefit the most from conservation. For example, our bird watching metric considers where experts have identified as important bird habitat, and where the public actually goes to engage in bird watching. The resulting metric recognizes both important habitat, and where bird watchers go, but gives the highest scores to locations where both occur.

Our research provides conservation practitioners with the data and tools to quickly assess the environmental benefits of a parcel, and how those benefits compare to hundreds of thousands of other parcels in the state. By assessing all of the parcels in the state, practitioners will be able to identify the best parcel to meet their objectives and cost-effectively provide multiple benefits to all Minnesotans.

Project Results Use and Dissemination

Dissemination

We have been presented this research to conservation practitioners at organizations including:

- UMN Natural Resources Research Institute (they agree to include our metrics in their spatial data atlas)
- The Nature Conservancy Freshwater and Land teams
- Lessard-Sams Outdoor Heritage Council working group on impact assessment
- BWSR
- DNR Easement stewardship working group
- Authors of the MN Gulf nutrient reduction strategy
- Minnesota Land Trust

We will continue to communicate with these groups to ensure they are able to make the most of our research products.

In addition to traditional outreach through presentations, we also produced a professionally developed website (pebat.umn.edu), with a particular focus on explaining our methods in a simple, non-technical way. While the site has online been online for a month, it has had 100 visits and 25 downloads of the tool. We will continue to track visits and downloads. Furthermore, will also be publishing an article on the UMN Institute on the Environment site that publicizes the research products from this project. It will be produced in the same style as the post we used to publicize the manuscript that was produced in activity 1 of this project: http://environment.umn.edu/news/new-study-conservation-investments-working-harder-minnesotans/

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2015 Work Plan Final Report

Date of Report:	August 17, 2018
Date of Next Status Update Report:	Final Report
Date of Work Plan Approval:	June 11, 2015
Project Completion Date:	June 30, 2018

PROJECT TITLE: Conservation Easement Assessment and Valuation System Development

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Location: Statewide

Total ENRTF Project Budget:	**ENRTF Appropriation:**	$250,000
	Amount Spent:	$247,000
	Balance:	$3,000

Legal Citation: M.L. 2015, Chp. 76, Sec. 2, Subd. 09k

Appropriation Language:
$250,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to assess the effectiveness of existing conservation easements acquired through state expenditures at achieving their intended outcomes of public value and ecological benefits and to develop a standardized, objective conservation easement valuation system for guiding future state investments in conservation easements to ensure the proposed environmental benefits are being achieved in a cost-effective manner. This appropriation is available until June 30, 2018, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Conservation Easement Assessment and Valuation System Development

II. PROJECT STATEMENT:

An easement is a legal instrument that transfers one or more property rights to a third party, thereby imposing restrictions on the future uses of the property, typically in perpetuity. On rural lands, most permanent easements are conveyed for conservation purposes. Such easements commonly prohibit certain land-use practices (e.g., agricultural crop production, development), require the maintenance of specific vegetative cover conditions (e.g., grassland, wetland, forest), and/or restrict future land sale conditions (e.g., prohibit parcel subdivision).

The state of Minnesota has made a significant investment in using permanent conservation easements to further the public's interest in private land conservation. To date, state-funded conservation easements protect approximately 600,000 acres in Minnesota. Based on their size, location, and management, easements will vary in the ecological, social, and economic benefits they provide. Requests for easements often exceed the resources available to pay for them. More efficient and effective screening of easements depends on information about the magnitude of all public benefits and all costs associated with specific parcels protected by permanent conservation easements.

The goals of this project are to assess the benefits and costs of past investments in easements funded by the Natural Resources Trust Fund, and to develop a tool to score future proposed easements or acquisitions based on their potential to provide public benefits. Such estimates will provide information that should be helpful in prioritizing easements to pursue and, in some cases, might lead to no longer pursuing a potential easement that does not measure up as well. The focus of this study will be on permanent conservation easements funded by the Natural Resources Trust Fund. The tool has the potential to inform other types of easements and acquisitions including Reinvest in Minnesota (RIM) and working forest easements. The project will achieve this goal by carrying out the following tasks: 1) acquire data on existing easements from relevant state agencies, non-profit conservation easement program managers, and LCCMR staff, 2) determine the types of easements evaluated and the public benefits and costs to be estimated, 3) assess the benefits and costs associated with a subset of existing permanent conservation easements acquired with Environmental Trust Fund proceeds; and 4) develop a web-based tool that can be used to score specific parcels of land under consideration for permanent conservation easement based on their potential benefits and costs.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of *[January 2016]***:**

Dr. Keeler and co-PI's hired an Assistant Scientist to supported this project (Ryan Noe). Noe initiated the work by reviewing the data and methods used by different conservation organizations in Minnesota to make prioritization decisions on land acquisitions for conservation. The project team reached out organizations that acquire land for conservation purposes in Minnesota and used these responses to identify the metrics most frequently used to score easement investments. The project team has requested information on funded easements from LCCMR and is working to develop an approach to sample and analyze these documents.

Results from this assessment were shared with LCCMR staff in December and are being prepared for publication and dissemination. In addition to an analysis of metrics used by different agencies to make conservation easement decisions, the project has also assembled spatial data for Minnesota that may be useful in identifying high priority areas for future investments in easements. These data are being stored at the University of Minnesota's Institute on the Environment and are being considered for use in a spatial prioritization or dashboard tool as outlined in Activity 2.

Project Status as of *[July 2016]***:**
After a review of the current practices, the project team has produced a draft of a manuscript that describes ecosystem service principles both in current programs and the enabling legislation for those programs. This manuscript forms the basis for identifying opportunities for further integration of ecosystem services into the decision making process of conservation easement acquisition practitioners. With it we have observed that, while water quality is a priority for state funds such as the ENRTF, it is not always specified in the enabling legislation of programs, nor is it considered in the prioritization of easement acquisitions. Programs currently focused on a single environmental benefit, such as habitat for game species, could potentially produce more benefits per dollar of investment by actively targeting multiple benefits.

In response to this gap, we have begun formulating tool designs that would reduce the technical barriers to incorporating more ecosystem services into decisions. We have reached out to practitioners, both in the initial interviews and in a meeting with DNR staff at the end of July to learn more about their workflows and the challenges they face. These discussions will help inform the design a tool to streamline the assessment of multiple benefits.

We have also begun collecting statewide data and developing a list of candidate metrics that could be used to score or rank easements (past or future). Our next task is to narrow down this list of metrics and then "score" past easement projects to evaluate return on investment and the appropriateness of our candidate metrics.

Project Status as of *[January 2017]***:**
Consistent with the objective of Activity #1, we have completed our review of state agency programs that invest in conservation easements and acquisitions. In December we presented the draft of the manuscript derived from the first phase of this work to the LCCMR staff, and solicited feedback with regards to metrics selection, data availability, and research priorities. In response to this meeting, we are in the process of adding three additional programs to our review: 1) Minnesota Land Trust, 2) Ducks Unlimited, and 3) Dakota County. Over the next month we will integrate our review of these three additional programs into the final report.

We are devoting most of our effort to identifying the most relevant scoring metrics that capture the public benefits provided by easements and determining the data needed to calculate scores. Our aim is to score all past easements on a suite of metrics that describe their potential value in terms of multiple ecosystem services. The candidate metrics are designed to capture the environmental benefits that are derived specifically from easements, that is, benefits that are currently supplied but are in danger of disappearing without protection, and benefits that have public value even without access to the land (e.g. runoff prevention). We are also designing these metrics to fill a key gap identified in our review of methodologies currently used by state agencies and non-profits, that there are opportunities to use existing data to better link environmental changes from land protection to human wellbeing.

User interface software development and dissemination activities were on hold during this period as we focused on the development and iteration of candidate metrics for scoring easements. However, we continue to follow our colleagues' work on data visualization closely to identify any methods that could be adapted for this project.

Project Status as of *[July 2017]***:**
We submitted a manuscript describing the results of Activity #1 or peer-reviewed in the open-access journal Ecology and Society. The manuscript, complete with revisions called for by peer reviewers and the journal editor are attached to this report as a supplement. We have submitted the edited manuscript to the editor and anticipate it will be accepted for publication shortly. In addition to the peer-reviewed journal article, we are also preparing an appendix that will specifically review metrics and scoring systems used by the Minnesota Land Trust, Ducks Unlimited, and Dakota County. These scoring systems were not quantitative, and therefore did not fit within the scope of the submitted journal article. As requested by LCCMR, these programs will be reviewed in the final report submitted at the project end date.

We continue to refine and develop metrics for ecosystem services that can be used to score past or future easements statewide. Draft metrics for lake recreation and groundwater nitrate are complete and coded into a prototype tool. Work on a suite of 3-6 additional metrics is ongoing as data are downloaded, processed and reviewed by subject matter experts. We will be reaching out to LCCMR staff in the August to discuss the final list of metrics, as well as our plans to analyze and visualize them in a web interface.

Critical to the development of a tool, we have created a framework for scoring parcels on multiple service dimensions and combining them into a single prioritization. This framework improves on previous index-based approaches such as the Environmental Benefits Index by adding three elements; providing a reference for index values by scoring all parcels in the state, allowing the user to combine the indices by dynamically specifying importance weights, and visualizing a proposed acquisition relative to the cost and benefits of prior LCCMR funded acquisitions. These improvements are further explained in the Activity #2 section.

Finally, we have finalized plans for the development of a web tool as described in Activity #3. An amendment request to support a rebudget request in support of Activity #3 is described below. In short, we have decided to use funds for tool development in-house as opposed to paying an external contractor. We have a software developer on our team who has extensive experience in spatial modeling and web development, including developing user interfaces for another recent Natural Capital Project-branded decision support tool. More details on our plans for the tool development, including programming languages and specifications are detailed in the Activity #3.

Amendment Request (07/31/2017):
There will be substantial cost savings if we hire an internal software developer at the University of Minnesota as opposed to an outside contractor as originally budgeted. At the time of proposal submission, we did not have the capacity for software development in-house. That has since changed and we now believe the most efficient and cost-effective strategy to deliver the tool described in Activity #3 is to work with an internal developer. We have cleared other tasks off this individual's schedule such that he can begin work on the tool in September. To do this an amendment is required to reclassify the $50,000 in the budget allocated for software development contracts into personnel at the University of Minnesota. The money would remain a part of Activity #3 and there would be no changes to deliverables. In order to accommodate the software development schedule, we are also requesting a no-cost extension to the project until June 2018. The developer we would like to hire has to balance this project with other projects and therefore we can't get his full support until early 2018. To address any concerns with this extended timeline, we plan to give LCCMR staff frequent updates on the progress of the tool, beginning in September with a project proposal and prototype tool demonstration.
Amendment Approved by LCCMR 8/8/2017

Project Status as of *[January 2018]***:**
The manuscript documenting the work completed in Activity 1 was published in Ecology and Society - a peer-reviewed journal. The published copy is included as a supplement. We have shared the publication with LCCMR staff and partners that participated in the research. Based on feedback from partners and stakeholders, the paper has been well-received and generated interest from agency staff and local NGOs.

We made significant progress in the metric development aspect of our work. We have implemented the framework for scoring parcels in code, allowing us to rapidly make changes to our metrics and score parcels. This code is also capable of generating the figures and numbers that will make up the parcel report. With the analysis framework in place we returned to our prototype metrics to further refine them. The key changes from our previous approach are to de-emphasize the weighted combined score, breaking out some components of multiple scores to avoid double counting, providing more context on the values we calculate for each parcel, and aggregating some related metrics. The rationale for these changes is detailed under activity 2.

Concurrently with metric development, our web developer has completed functional interactive front-end interfaces for each of the interface elements we envisioned. See activity 3 for a discussion of the interface elements and the supplemental files for screen shots. While these interfaces are functional, we still need to deploy the back-end server before some of the more advanced scoring functions can be performed outside of our local machines. Project deliverables remain on track for completion by the project end date. We include an updated gantt chart as an attachment describing our timeline for all remaining project deliverables.

Overall Project Outcomes and Results:

Our research sought to address a problem that conservation practitioners and the LCCMR face; how do we know that a proposed easement acquisition is a good use of resources? What benefits does it provide, and is it the best parcel to provide those benefits? We set out to understand existing approaches, and create a tool to complement their strengths and improve conservation targeting.

After researching the methods state agencies and NGOs use to prioritize acquisitions in the state, we designed a tool to complement existing approaches in two ways. First, we observed that existing systems all use a rubric to score proposed acquisitions on a parcel-by-parcel basis. Detailed local knowledge gathered in site visits is important for decision making, however, it is impossible to gather site-level data for the entire state. Valuable parcels will be missed without a statewide, landscape-level perspective. To complement existing rubrics, our approach scored over 300,000 privately held, undeveloped parcels to provide the context of how a proposed acquisition compares to all other parcels in the state.

Second, our approach created 11 environmental benefit metrics, designed to complement those used in existing prioritization systems. Our metrics combine spatial data to map not just where high quality natural resources are, but also where the public would benefit the most from conservation. For example, our bird watching metric considers where experts have identified as important bird habitat, and also where the public actually goes to engage in bird watching. The resulting metric recognizes both important habitat, and where bird watchers go, but gives the highest scores to locations where both occur.

Our research provides conservation practitioners with the data and tools to quickly assess the environmental benefits of a parcel, and how those benefits compare to hundreds of thousands of other parcels in the state. By assessing all of the parcels in the state, practitioners will be able to identify the best parcel to meet their objectives and cost-effectively provide multiple benefits to all Minnesotans.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Identify easements, benefits and costs

Description: We will first review existing spatial targeting or scoring systems for restoration or conservation (e.g. Conservation Reserve Program Benefits Estimators, Ecological Benefits Index, Air and Water Economic Decisions Tool). This review of existing tools will ensure our work is leveraging the best available science and adding value above and beyond existing scoring systems. We will also review the literature and identify potential data sources documenting the types of ecosystem services (e.g., increased/improved wildlife habitat, reduced soil erosion, improved water quality) generated by land use and management in Minnesota, as well as studies that estimate the value of these ecosystem services. We will consult with relevant state agencies, non-profit conservation easement program managers, LCCMR staff, and other data providers to determine the types of easements to evaluate and the types of public benefits and costs to be estimated. For example, the project team will request parcel-specific easement data on easement terms, location, and aerial extent, parcel land cover and habitat conditions (on both the eased land and adjacent lands), and easement acquisition, maintenance, and monitoring costs. The project team will then identify the appropriate subset of easements to evaluate and the costs and benefits to include in the study.

Summary Budget Information for Activity 1: **ENRTF Budget: $ 40,400**

Amount Spent: $ 40,000
Balance: $ 400

Outcome	Completion Date
1. Project team will review existing scoring systems, data resources, and previous studies on the costs and benefits of easements.	September 2015
2. Project team will acquire data on a subset of existing easements, including costs, location, and other attributes of each parcel.	September 2015
3. Project team will identify the types of conservation easements that will be evaluated and the ecosystem service benefits and costs that will be included in the final scoring tool.	December 2015

Activity Status as of *[January 2016]***:**

Descriptions of prioritization methodologies were obtained for the following organizations or programs within an organization: DNR Wildlife Management Areas, DNR Scientific and Natural Areas, DNR, Prairie Bank, DNR Forests for the Future, DNR Forest Legacy Program, DNR Tullibee Watersheds Project, DNR Aquatic Management Areas, BWSR Wetland Easements, BSWR Grassland Easements, BSWR Riparian Buffer Easements for Wildlife, the Conservation Reserve Program, the Trust for Public Land, The Nature Conservancy, USFWS, Ducks Unlimited, the MN Land Trust, and the Conservation Fund. We collected data on these methods and aggregated metrics into categories such has habitat quality, spatial context, or water quality. The results of this analysis were shared with LCCMR and are being prepared for publication.

Spatial data and summary records of all acquisitions were obtained from the LCCMR. The project is currently selecting a subset of these easements to obtain a sample that covers a range of organizations and the dollars per acre. We will examining the easement language of this subset in greater detail to match easement language with potential public benefits provided by easements.

Activity Status as of *[July 2016]***:**

The manuscript produced from reviewing existing prioritization systems underwent several rounds of internal review by the project team. Comments and feedback on the methodological approach and the writing were incorporated by the lead author.

Activity Status as of *[January 2017]***:**

We have largely completed the specified outcomes in activity #1. We have completed our review of state agency programs that invest in conservation easements and acquisitions. We reviewed existing scoring systems, data resources, and previous studies on the costs and benefits of easements, with an emphasis on state agency programs active in Minnesota. In December we presented the draft of the manuscript derived from the first phase of this work to the LCCMR staff, and solicited feedback with regards to metrics selection, data availability, and research priorities. In response to this meeting, we are in the process of adding three additional programs to our review: 1) Minnesota Land Trust, 2) Ducks Unlimited, and 3) Dakota County. Over the next month we will integrate our review of these three additional programs into the final report. Project PI's have provided detailed comments on the manuscript that the lead author incorporated. We expect to submit the final manuscript for publication by Spring 2017.

The project team has acquired data from the LCCMR on a subset of existing easements, including costs, location, and other attributes of each parcel. We have migrated this information into a GIS and are actively exploring these data along with other spatial environmental data. Our team has clarified focus on conservation easements to be evaluated and have identified a set of candidate ecosystem service benefits and costs that will be included in the final scoring analysis.

A current draft of the manuscript, as well as supporting appendices is included as a supplement to this report.

Activity Status as of *[July 2017]***:**
We submitted the manuscript that is the outcome of activity #1 to the journal of Ecology and Society. The manuscript was peer-reviewed and only minor revisions were suggested. We have completed those revisions and re-submitted to the journal. The final version and associated appendices is included as a supplement to this report. All promised activities in Activity 1 have been completed. Only funds remaining are for travel ($400) that may be used to cover costs of presenting the metrics analysis at a regional conference later this year.

Activity Status as of *[January 2018]***:**
The manuscript completed for activity 1 was published as an open access, peer reviewed, article in Ecology and Society on October 11th, 2017. The article and supporting information can be accessed at this link: https://www.ecologyandsociety.org/vol22/iss4/art4/

The final published version of the manuscript and supporting information is also included as a supplement to this report.

Final Report Summary:
In activity 1 we interviewed practitioners at state agencies and NGOs that acquire land for conservation purposes. We reviewed the documents and methods they use when deciding whether or not to acquire a parcel. We synthesized our findings in an open access peer-reviewed publication available as a supplement to this report and at this URL: https://www.ecologyandsociety.org/vol22/iss4/art4/
Our peer-reviewed publication focused only on programs that have a quantitative scoring system so that we could analyze the weight place on different metric categories. At the request of the LCCMR, we also prepared an appendix describing the methods of programs that do not use a quantitative scoring system, which is included a supplement to this report.

The key finding from this report is that existing programs heavily weight habitat and biodiversity related metrics (Figure 1 of publication), and score parcels at the site level. This research was instrumental in the design of our tool in activity 3. We created human wellbeing metrics specifically to complement the habitat focused metrics already in use. To complement the detailed data acquired in site visits required by existing approaches, we developed data and a tool to quickly compare a parcel to all other parcels in the state.

By interviewing practitioners early in the project, we were able to both develop an approach in response the challenges they face in their current approach and developed a network of potential users.

ACTIVITY 2: Assess the benefits and costs of existing easements.
Description: Based on the types of conservation easements and public benefits and costs to be evaluated as identified in Activity 1, the project team will assess the public benefits and costs of existing conservation easements will using data, models, and tools available through the University of Minnesota-affiliated Natural Capital Project (*http://naturalcapitalproject.org*) and other sources. The models will be spatially explicit and incorporate easement cost data (i.e., easement acquisition, on-going maintenance, monitoring costs). We will apply the models to existing parcels from a subset of permanent conservation easements that were acquired with Environmental Trust Fund proceeds. Model refinements will be made, as necessary, based on the types of easements and benefits outlined in Activity 1.

Summary Budget Information for Activity 2:

ENRTF Budget: $ 121,700
Amount Spent: $ 120,000
Balance: $ 1,700

Outcome	Completion Date
1. *Identify existing models and data that can be used to score easements.*	January 2016

2. *Apply the models to the subset of existing easements to estimate benefits and costs.*	December 2016
3. *Expand modeling approach to develop a generalized model that can be applied to score future easements.*	June 2017

Activity Status as of *[January 2016]***:**
The project is beginning to compile relevant publically available biophysical data and spatial data on existing easements for the state of Minnesota. We will soon begin review of models used to evaluate multiple benefits of potential protection and restoration projects.

Activity Status as of *[July 2016]***:**
All of the spatial datasets available on the Minnesota Geospatial Data Commons were reviewed for their relevance to prioritizing conservation easement acquisition. Those that were deemed to have any relevance were downloaded and further reviewed to determine the spatial extent of the usable data and other potential limitations. Ways the data could be summarized (e.g. distance to feature, distance of adjacency, area in buffer of feature) were recorded based on the data type and the relevance to conservation easements. The review of these datasets will support the selection and aggregation of the datasets best suited for prioritizing conservation easements.

Activity Status as of *[January 2017]***:**
We have reviewed existing models and data sources that can be used to score easements. We are in the process of developing metrics based the insights from this review. The candidate metrics at this stage include lake recreation, ground water nitrate risk mitigation, habitat provisioning for hunting and wildlife viewing, scenic quality, greenhouse gas emissions, and pollinator habitat. We solicited input on these metrics from LCCMR staff in December, and will continue to iterate on their design so that they best capture public benefits derived from easements. These metrics are designed to go beyond more traditional metrics of proximity and land cover changes, to capture changes in attributes people value directly, such as lake recreation or safe drinking water.

We have begun to apply the metrics and models to the subset of existing easements to estimate benefits and costs. We have developed draft versions of lake recreation, ground water nitrate, and greenhouse gas emissions. *These are still in the draft stage, and their underlying assumptions may change*.

- *Lake recreation:*
    - In contrast to metrics that prioritize based on where there is the greatest potential per acre prevention of contaminants (e.g. phosphorus or sediment), our metric targets land that has the potential to prevent increased contaminants in lakes that are frequently used and valued for recreation. Furthermore, we incorporate an ecosystem services approach by considering the spatial distribution of both scarcity of recreation opportunities and the spatial demand of Minnesota residents.
    - To measure the quality of lake recreation, we use data on lake clarity, amenities (e.g. beaches, boat ramps, restrooms), and size. Dr. Keeler's previous research has used similar data to predict lake visitation in Minnesota.
    - To measure scarcity, we integrate high resolution spatial population data with the location of lakes and their recreation quality scores.
    - Areas with few high quality lakes and many people are prioritized over areas with more high quality lakes or lakes with fewer people nearby.
    - Last, we use the DNR's catchments layer to identify the land that is hydrologically connected to the priority lakes and use this to prioritize easement acquisition.
- *Groundwater Nitrate:*

- Our groundwater nitrate contamination metric is designed to identify areas where an easement would add protection to a drinking water supply area that serves vulnerable populations. This metric uses data from the Minnesota Department of Health to identify areas that contribute to drinking water, census data to identify vulnerable populations, and the cropland data layer to identify agricultural patterns. A high priority easement would be:
    - In the wellhead protection area of a public water supply
    - Underlying geology leaves aquifer highly susceptible to surface contamination
    - The wellhead protection area supplies water for a high number of people per hectare
    - A high proportion of the population served pays > 2% of their income for water
    - The wellhead protection area has extensive agricultural area
    - There is a high probability of further conversion to agriculture

- *Greenhouse Gas Emissions:*
    - Unlike lake recreation and groundwater nitrate, the spatial distribution of greenhouse gas emissions, and benefits from their reduction, is global. This means that prioritization can be based simply on the amount of greenhouse gasses that would be emitted under changes in land cover.

Metrics for wild life populations, pollinators, and scenic quality are under development; specific models and data have not yet been identified.

Activity Status as of *[July 2017]***:**
We have coded the lake recreation and groundwater nitrate metrics in python so they can be modified and re-run as we further refine the metrics. We have also completed code that allows us to change the weight place on model components and functions that make up the final easement scores. We have developed a list of candidate metrics for the final tool. This list will be presented to LCCMR staff in August or September. Currently, we are in the process of coding and testing models for the following services:

- Lake recreation
- Groundwater nitrate protection
- Waterfowl production/hunting
- Bird watching
- Trout angling
- Carbon storage
- Trail aesthetics
- Wild rice production
- Pollination

After researching the factors that contribute to deer population and hunting we determined that easements are not likely to influence the service of hunting in a measurable way. Deer population is strongly influenced by the severity of winter and hunting pressure. While some natural vegetation is important, deer thrive in agricultural and other disturbed environments and thus would not benefit from protection of small individual parcels of natural vegetation. If an easement allowed for public hunting access, there could be a measurable public benefit, however, this is unlikely given that it is common practice to lease hunting rights on private land. An easement that allowed public hunting access would effectively remove any incentive to retain ownership of the land.

Another milestone in scoring methodology development is the creation of a framework to meaningfully score parcels across metrics measured in different units. Past approaches have used unitless indices to score different services. We build and improve on this approach by adding three elements:

1) We will score all potential parcels in the state to create a frame of reference

   One of the biggest limitations of scoring using indices is the values lack a frame of reference to be able to differentiate between a parcel that is marginally better than alternatives and a parcel that is truly outstanding. We intend to address this by scoring all of the parcels in the state, thus giving the user a frame of reference for what are the best and worst parcels for all of the service we are scoring. While not every parcel is available, scoring all of them can both provide perspective on what is available and identify potential parcels that haven't been considered. Potential acquisitions do not need to be derived from the parcel map, it is only a starting point providing a realistic land management unit.

2) Our approach will allow the user to define importance weights dynamically

   Even when working with indices, combining multiple metrics requires some assumption about the value of one service relative to another. Past approaches often weight all services equally, or have the weights fixed in the final product. Our framework will allow the user to explore the changes in parcel prioritization given different service preferences.

3) Present potential acquisition results relative to past acquisitions

   In addition to exploring statewide maps of indices, our approach will include data on past acquisitions, and their cost to provide both a comparison of ES value, and a measure of cost effectiveness relative to past acquisitions.

In summary, we have almost completed the generalizable approach described in Activity #2 that can be applied to score any past or future easements for a range of ecosystem services.

Activity Status as of *[January 2018]***:**

Early in this reporting period we completed a set of draft metrics that acted as a proof-of-concept for developing the overall scoring framework. These metrics are detailed in the supplemental document "metrics_v1-2" (since the proof-of-concept stage we have developed a version 3 of our metrics which are detailed in the "metrics_v3" supplemental document). We used the version 1 and 2 metrics to construct a scoring framework in response to obstacles we identified when reviewing other scoring processes. Specifically, we designed the scoring framework and interface to address:

- The LCCMR would benefit from consistent quantitative scores on all applications for easement funding, but multiple agencies and non-profits seek funding, and organizations may not have capacity to take on additional modeling and reporting.
  - Our tool will allow organizations to quickly generate a report for a broad suite of services that can be included with funding requests.
  - We are pre-processing our analysis that makes uses large datasets such as EPA's 30m population map and DNR catchments layer so they can be included in comparisons without running the analysis for the entire state each time.
  - Our web interface will allow users to obtain a scores derived from dozens of data sources quickly. We are enabling any organization to leverage our extensive data preparation and analysis efforts with minimal expenditure on their part.

- Valuable parcels could be missed because traditional scoring systems are on a parcel by parcel basis and do not consider a full suite of benefits and a statewide extent. The magnitude and rarity of a parcels benefits are not clear when evaluating a single parcel.
    - Site-level evaluations are necessary for decision making, but should be complemented by statewide analysis available in our tool.
    - We prepare data for a broad suite of benefits and make it available so that organizations can easily explore co-benefits outside of their area of focus.
    - We generate scores for every parcel in the state so we can provide the context necessary to understand how exceptional a parcel is.
- Data and methods evolve, and tools need to be able to incorporate changes.
    - We are designing the tool to be able to incorporate any statewide raster that is on a 0-1 scale.
    - Changes to the metrics we develop can be performed quickly by changing the parameters of the code and re-running it.
    - The code is designed to take in and process standard datasets the government produces and updates regularly. Updates can be performed without replicating a complicated and time consuming workflow in a traditional GIS environment.

Since sharing outputs and the workflow of our scoring tool with LCCMR staff on November 3rd 2017, we have continued to iterate on both which metrics are used to score easements and how the metrics are constructed. In response to feedback we have opted to make several changes to the way we construct and present scores that are outlined below.

- Setting weights for approximately ten metrics proved to be a confusing task that obscured the values of individual metrics. We are de-emphasizing the use of weighted combination scores for the parcel level report and instead reporting the relevant values for individual metrics.
- Incorporating information on where a service is generated, the quality of the service, the local scarcity of the service, and the demand for the service into a single 0-1 metric obscured the value of each of the components, thus preventing their use in the decision-making process. Although we intend to continue to combine multiple datasets into scores using the processes we have described in previous reports, when we identify information that is best conveyed separately, we will provide those values separately from the score along with context on their meaning and interpretation.
- In an effort to make the components of scores more transparent and to avoid double counting, we are adding two metrics that are common to the majority of the metrics, but are not ecosystem services; population and risk of change.
    - An ecosystem services perspective considers the number of people that have access to a given service, so it would be redundant to include this in every service. Instead, we will report the number and proportion of the state's population that are within a day trip of the service endpoint. While people may travel further for a benefit, the day trip metric captures how many people the end point of a service is relatively accessible to.
    - Risk of change is particularly important for the decision context of easements, where it is important to protect resources before land use change occurs, and use resources efficiently by not protecting parcels that are not at risk. We are including preliminary results from work developed at the Institute on the Environment, however, we intend for this variable to be updated as projections are improved.
- We opted to aggregate our waterfowl and pheasant metrics into a single hunting access metric. Due to the lack of public access on easements, any hunting benefit would be derived only when habitat is

protected near a place with public hunting access. We used the existing network of Wildlife Management Areas to identify public access and scored WMAs higher if more game species were present or if there was evidence of more visitation than other WMAs.

After further refinement, we will use these metrics and scoring system to generate scores for all past LCCMR funded acquisitions. Metrics will be distributed as part of the web tool interface and in associated documentation available through the tool website. Work is in progress on evaluating how past easements perform relative to these ecosystem service metrics and summarizing findings in a report to LCCMR staff.

Final Report Summary:
Activity 2 required the development of a suite a metrics to evaluate past acquisitions against. We developed 11 metrics, 9 focused on ways humans benefit from conservation activities, and 2 metrics relevant to acquiring land for conservation; nearby population and risk of conversion. A user-friendly description of each metric is available at this URL: http://pebat.umn.edu/metrics.

These metrics prioritize all land in the state from highest to lowest priority for each of the metrics. We are making this data available to allow practitioners so they can build analyses on top of our work, allowing them to quickly assess benefits that might not have the time, resources, or expertise to assess in their normal operations.

We then used these metrics to score all past ENRTF funded conservation easements, as well as every other undeveloped parcel in the state. We compared ENRTF funded acquisition benefit scores to the scores you would expect if you acquired undeveloped parcels randomly. We found that past acquisitions on the whole performed better than random. Approximately half of past acquisitions had fewer than 5 parcels in the state that scored better than them on all metrics. Under 10% had over 100 parcel in the state that scored better on all metrics. These parcels were either acquired to support a benefit we did not have data for (e.g., duck production) or were not efficiently targeted. See the report for this activity 'past_acquisitions_report_August_2018.pdf' for an in-depth exploration of the benefit trends observed in past acquisitions.

In this activity we proposed analyzing the costs of an acquisition inclusive of maintenance and monitoring costs. After interviewing practitioners we elected not to incorporate maintenance and monitoring costs. Organizations responsible for stewardship of easements do not typically breakdown their expenses by parcel. The most consequential action in the process is acquiring the parcel with the most benefits. We did not monetize the benefits of an acquisition, because the uncertainty in valuation methodologies of produces a range of values that is too large to be useful for decision making. We were able to produce more precise data and better support conservation prioritization by opting for an index based approach. In our tool we include the price per acre of past acquisitions to provide a point of reference for what benefit scores were achieved for a given price in the past. For more information on the advantages of our approach, see the included past acquisitions report, or read about it on the tool website: http://pebat.umn.edu/howitworks

ACTIVITY 3: Develop a web-based easement benefits tool
Description: We will work with software developers and experts in user-interface design to develop a web-based tool that operationalizes the easement valuation model developed in Activity 2. Once developed, the tool will be demonstrated and made available to LCCMR staff and conservation easement program managers.

Summary Budget Information for Activity 3:

ENRTF Budget:	**$ 87,900**
Amount Spent:	**$ 87,000**
Balance:	**$ 900**

Outcome	Completion Date

1. *Public benefits models developed in Activity 2 will be converted into a user-facing web-based conservation easement screening tool.*	December 2017
2. *Tool demonstrated and made available to LCCMR and conservation easement program managers for testing and refinement.*	December 2017

Activity Status as of *[January 2016]***:**
A team member met with a web programmer who developed a web-based decision support tool for The Nature Conservancy that could serve as a model for our tool. If a web-based tool is determined to be the most appropriate way to achieve the goals of this project, he could potentially be a sub-contractor.

Activity Status as of *[July 2016]***:**
No development actions were taken while we work to determine the specific needs of practitioners. As part of a meeting with DNR staff in July 2016 to share preliminary findings from this research, we also solicited input on their workflows.

Activity Status as of *[January 2017]***:**
We did not take any action on user interface development during this period. However, we have continued to have scoping conversations with potential developers both within the University of Minnesota and through partners. We have identified a potential software engineer with experience in user interface design. When the scope and audience for the tool are clarified in Activity #2, we will proceed with hiring the staff on software development.

Activity Status as of *[July 2017]*
We identified an individual with skills well suited to both the web development aspect of this project, and the coding of some of the more advanced underlying analyses. Justin Johnson is a senior scientist at the Natural Capital Project with experience in software development, web development, and ecosystem service assessment. Dr. Johnson has recently completed user-interface design and implementation for two other Natural Capital Project tools – ROOT (Restoration Opportunity Optimization Tool) and MESH (Modeling Ecosystem Services and Human wellbeing). His experience in software development, web design and ecosystems services modeling make him the most efficient choice for software development tasks as part of Activity #3.

We have developed a prototype for what information will be displayed in the web tool, including potential visualizations of easement scores and benefits. We are using a combination of Python, Django, and D3.js as the languages to build the user interface and display. The back-end calculations will be performed in Python on data pre-generated and hosted on a remote server, with dynamic results calculated and returned to the user. We will be scheduling a meeting in early fall with LCCMR staff to demonstrate the prototype tool and receive feedback.

Activity Status as of *[January 2018]***:**
At our Nov. 3rd 2017 meeting with LCCMR staff, we shared a static mock-up of the tool interface we are developing that had four main elements; landscape level service explorer, parcel report generator, past acquisition viewer, and trade-off explorer.

The development of the web tool is comprised of two processes, the front-end interface, and the back-end calculations. The front-end interface is built with javascript and html and runs entirely in the browser. This enables the elements to be fast, but does not have the ability to query the large datasets that hold our metrics and pre-processed scores. In order to store and query these datasets we need to configure a back-end server to host our data, accept uploads, and perform basic queries. Updates on the specific elements are below.

- Landscape level service explorer (supplemental figure 1)

    - This interface allows users to see where in the state specific services are found. The user can specify weights for individual services so that they can visualize where multiple benefits occur. The user can zoom in to identify local trends.
    - The necessary data for this interface are stored entirely within the front-end HTML file, which enables the unique weighted combinations to be calculated in real time.
- Parcel report generator (supplemental figure 2)
    - This interface requires upload capabilities and server side calculations, so it is not yet available for distribution. However, a local development copy is already being used to generate figures that we are using to solicit feedback.
- Past acquisitions (supplemental figure 3)
    - This interface allows the user to find previous LCCMR funded acquisitions on a map and few the scores it received for each of the metrics we developed.
- Tradeoffs (supplemental figure 4)
    - This interface allows the user to view any two of the metric scores for potential acquisitions throughout the state in a scatter plot form. Organizations focused on a particular metric can use this interface to identify parcels that score highly for multiple metrics in addition to their metric of interest.
    - Users will be able to hover over a point to learn its location.

The front-end interface for the tool is in working prototype phase, and we are in the process of collecting feedback on its design. We are exploring hosting the webtool at the University or on a pay-per-service platform such as Amazon webservices.

Final Report Summary:
After several iterations in the development process, we developed two versions of our tool in order to eliminate any barriers to running it; a web version available here: http://pebat.umn.edu/ and a desktop version available here: http://pebat.umn.edu/desktop

We produced a desktop version of the tool that comes with all of the base data needed to run it. The user only needs to supply a shapefile of their parcel's boundaries to run the tool and generate a report. The report visualizes how the proposed acquisition compares to all viable parcels in the state, and how it compares to past acquisitions with the price is taken into account.

Although the tool is very simple to run, we wanted to further reduce the barriers associated with downloading large file and creating shapefiles. We pre-calculated the results for every parcel and put the results in a web application. The user only needs to know the address or latitude and longitude of a parcel to get the score to generate a report for the nearest 40 acre parcel.

We designed these tools after interviews with practitioners indicated they did not always have capacity to run complicated models. Our tools were designed to produce a report for 11 benefits within seconds without adding any addition technical capacity. Advanced users can access the underlying data and perform new analyses.

V. DISSEMINATION:
Description:
After co-development and iteration on the tool design and user interface with LCCMR members and staff, the conservation easement valuation tool will be made publicly available online to LCCMR, its staff, conservation easement program managers, and others as requested.

Status as of *[January 2016]***:**
Not yet started.

Status as of *[July 2016]***:**
Visit to DNR in July 2016 to discuss the project and share preliminary findings.

Status as of *[January 2017]***:**
Beyond our presentation to LCCMR staff, we did not take any dissemination actions during this period.

Status as of *[July 2017]***:**
We did not engage in dissemination of our metrics or tool as they are still under development. However, as described above, our manuscript reviewing current prioritization practice in Minnesota was peer reviewed at the journal Ecology and Society. Pending minor revisions, we hope it will be accepted and published within a few months.

Status as of *[January 2018]***:**
In an effort to make the findings from our manuscript more accessible to the public, we wrote a brief, non-technical, blog post covering the key findings of our work. The post is available here:
http://environment.umn.edu/news/new-study-conservation-investments-working-harder-minnesotans/

We have sent copies of the manuscript to all of our contacts at state agencies and NGOs that contributed in any way to the paper, and continue to disseminate the manuscript and/or blog post to new contacts as an entry point to our research and tool development.

We also have given presentations that include both the manuscript and prototypes of our easement prioritization tool to staff at the DNR, the Minnesota Land Trust, and the McKnight Foundation.

Final Report Summary:
We have been actively disseminating this work to practitioners for several months. Key groups that we have presented to include:

- UMN Natural Resources Research Institute (they agree to include our metrics in their spatial data atlas)
- The Nature Conservancy Freshwater and Land teams
- Lessard-Sams Outdoor Heritage Council working group on impact assessment.
- BWSR
- DNR Easement stewardship working group
- Authors of the MN Gulf nutrient reduction strategy
- Minnesota Land Trust

Individual at many of these organizations have expressed interest in following up and analyzing the data further.

Our dissemination efforts also include a professionally developed website (pebat.umn.edu), with a particular focus on explaining our methods in a simple, non-technical way. We also produced extensive technical documentation to accommodate users that need to fully understand our assumptions before using our tool.

VI. PROJECT BUDGET SUMMARY:
A. ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation

Personnel:	$ 247,000	1 scientist at 12% FTE per year for 2.5 years; 2 scientists at 4% FTE per year (each) for 2.5 years; 1 scientist at 2% FTE per year for 2.5 years; 2 assistant scientists at .4 FTE per year (each) for 2.5 years; 1 scientist at .5 FTE for 1 year
Printing:~~Professional/Technical/Service Contracts:~~	$500~~$50,000~~	Printing of reports and project materials~~1 contract for software development / programming (TBD) through competitive bid~~
Travel Expenses in MN:~~Printing:~~	$2,500~~$500~~	Mileage, lodging, meals~~Printing of reports and project materials~~
TOTAL ENRTF BUDGET:~~Travel Expenses in MN:~~	**$250,000**~~$2,500~~	~~Mileage, lodging, meals~~
~~**TOTAL ENRTF BUDGET:**~~	~~**$250,000**~~	

Explanation of Use of Classified Staff: NA

Explanation of Capital Expenditures Greater Than $5,000: NA

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: ~~2.95 FTEs~~ 3.95 FTEs

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: NA

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
	$	$	
State			
	$	$	
TOTAL OTHER FUNDS:	**$**	**$**	

VII. PROJECT STRATEGY:

A. Project Partners: (not receiving funds)

- MN DNR
- MN Board of Water and Soil Resources
- US Fish and Wildlife Service
- MN Land Trust
- Ducks Unlimited
- Local government representatives
- Other land trusts and conservation organizations that acquire permanent conservation easements

B. Project Impact and Long-term Strategy:

The project will result in the development of a tool that can be used by land management and conservation organizations to prospectively estimate the public benefits and costs associated with acquiring a permanent conservation easement on specific parcels in Minnesota. The tool will help these organizations better identify and prioritize resources permanent conservation easement opportunities that will produce the greatest net public benefits.

C. Funding History:

Funding Source and Use of Funds	Funding Timeframe	$ Amount
LCCMR pending project 33-B "Informed Water Management: Mapping Scarcity, Threats, and Values"	Pending legislative approval, starting July 1 2015, ending June 30 2018.	$234,000
Sub-award to co-investigator Steve Polasky as part of LCCMR 2010 project 04i "Reconnecting Fragmented Prairie Landscapes" led by the Nature Conservancy. Funds to Polasky were used to estimate the goods and services provided by grasslands in western MN.	Project began in July 2010 and was completed in June 2014	$380,000
		$

VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS: NA

IX. VISUAL COMPONENT or MAP(S):

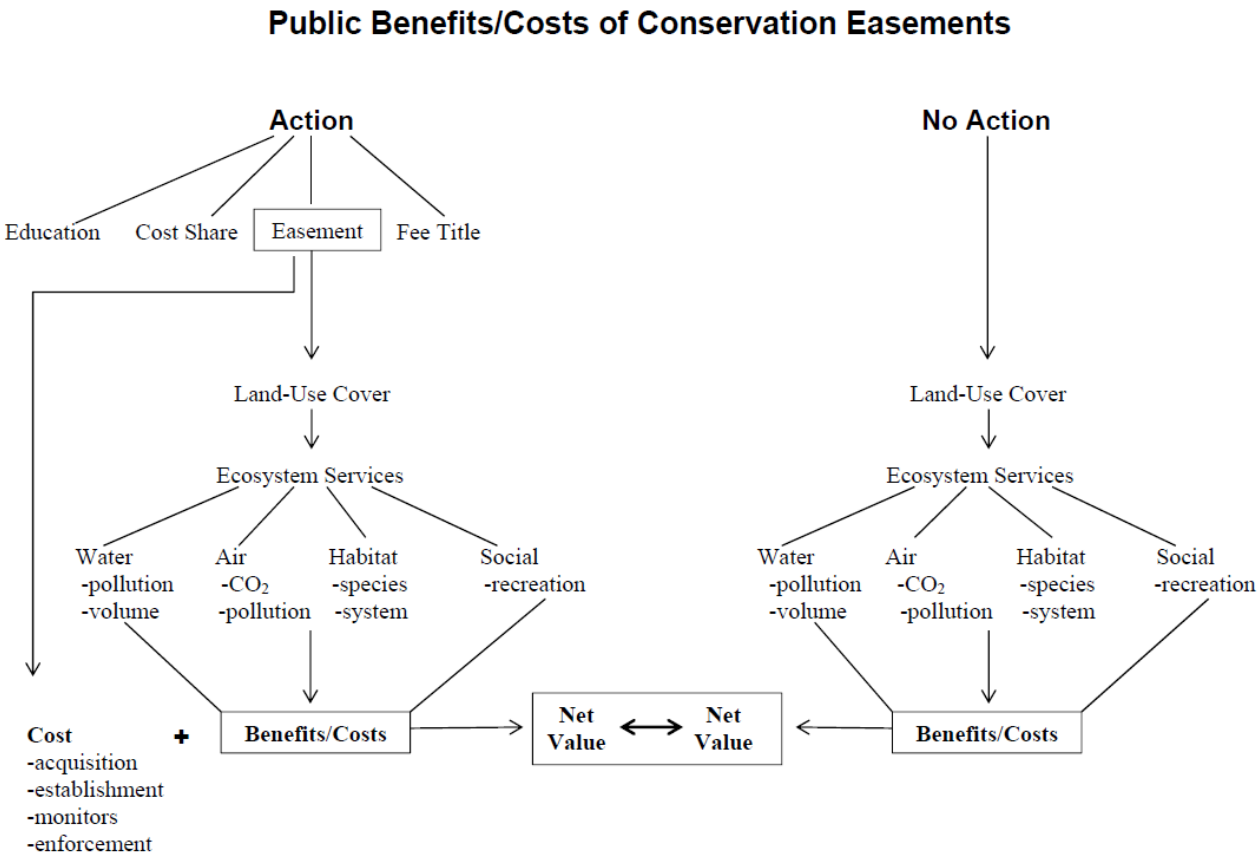

Figure Caption: There are multiple actions or interventions that can be taken that affect land-use cover including easements, education, cost share, and fee title. This project will focus on easements as the action under investigation. For each easement we will assemble data on the costs (acquisition, establishment, monitoring, enforcement) and the ecosystem service benefits (water, air, habitat, recreation). This will facilitate a comparison of benefits and costs under scenarios of action (easements) vs. non-action (baseline or business-as-usual).

X. RESEARCH ADDENDUM: NA

XI. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than *January 2016*, July 2016, January 2017, July 2017, and December 2017. A final report and associated products will be submitted between June 30 and August 15, 2018.

Environment and Natural Resources Trust Fund
M.L. 2015 Project Budget

Project Title: *Conservation Easement Assessment and Valuation System Development*
Legal Citation: M.L. 2015, Chp. 76, Sec. 2, Subd. 09k **00053432** **Through 1/17/18**
Project Manager: Bonnie Keeler
Organization: *Natural Capital Project, IonE, University of Minnesota*
M.L. 2015 ENRTF Appropriation: $ *250,000*
Project Length and Completion Date: 2.5 *Years, December 31, 2017*
Date of Report: *January 31st 2018*

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance
BUDGET ITEM	***Identify easements, benefits, and costs***			***Assess the benefits and costs of existing easements***			***Deploy and test a web-based easement benefits tool***		
Personnel (Wages and Benefits)	$40,000	$40,000	$0	$120,000	$120,000	$0	$87,000	$87,000	$0
Bonnie Keeler, Project Manager and Scientist, $30,000 (67% salary, 33% benefits) 12% FTE per year for 2.5 years.		$7,867			$30,386			$2,660	
Mike Kilgore, Scientist, $19,000 (67% salary, 33% benefits) 4% FTE each year for 2.5 years		$0			$7,774			$10,366	
Steve Taff, Scientist, $19,000 (67% salary, 33% fringe) 4% FTE each year for 2.5 years.		$9,897			$6,738				
Steve Polasky, Scientist, $19,000 (67% salary, 33% fringe) 2% FTE each year for 2.5 years.		$10,117			$10,000			$16,163	
2 Assistant Scientists, $110,000 (74% salary, 26% fringe) 40% FTE per year (each) for 2.5 years.		$12,119			$65,102			$57,811	
Professional/Technical/Service Contracts							$0		$0
Software professional services (development and programming), $50,000.									
Printing									
Report and project material printing.	$75	$0	$75	$225	$0	$225	$200	$0	$200
Travel expenses in Minnesota									
In-state travel to meet with project partners and field visits.Mileage: $1,700; lodging: $500; meals: $300	$325	$0	$325	$1,475	$0	$1,475	$700	$0	$700
COLUMN TOTAL	**$40,400**	**$40,000**	**$400**	**$121,700**	**$120,000**	**$1,700**	**$87,900**	**$87,000**	**$900**

Assessing the benefits of ENRTF funded conservation easements

October 2018, version 1.2

Ryan Noe*
Bonnie Keeler
Justin Johnson
Michael Kilgore
Steven Taff
Stephen Polasky

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Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

INSTITUTE ON THE ENVIRONMENT
UNIVERSITY OF MINNESOTA
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Table of Contents

Our Approach

Overview

After researching the methods used to prioritize acquisitions in the state[1], we designed a tool to complement existing approaches in two ways. First, we observed that existing systems all use a rubric to score proposed acquisitions on a parcel-by-parcel basis. Detailed local knowledge gathered in site visits is important for decision making, however, it is impossible to gather site-level data for the entire state. Valuable parcels will be missed without a statewide, landscape-level perspective. To complement existing rubrics, our approach scored over 426,000 privately held, undeveloped, and unprotected parcels (hereafter referred to as 'viable parcels') to provide the context of how a proposed acquisition compares to all other parcels in the state that could be considered for a conservation easement.

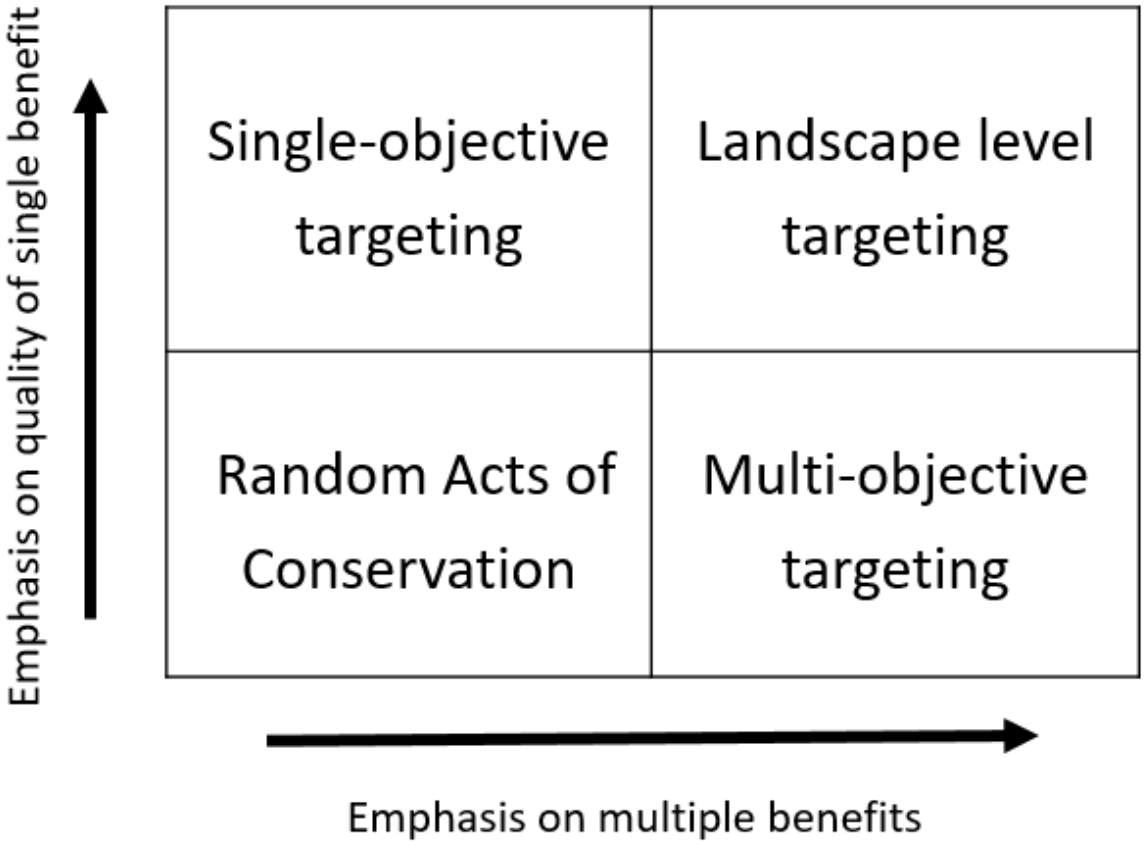
Second, our approach created 11 environmental benefit metrics, designed to complement those used in existing prioritization systems. Our metrics combine spatial data to map not just where high quality natural resources are, but also where the public would benefit the most from conservation. For example, our bird watching metric considers where experts have identified as important bird habitat, and also where the public goes to engage in bird watching. The resulting metric recognizes both important habitat, and where bird watchers go, but gives the highest scores to locations where both occur.

The information used in our approach is designed to be used in conjunction with local expertise; disagreement between the tool's scores and local expertise is an opportunity to better understand how benefits are perceived, measured, and valued.

Maximizing benefits by avoiding random acts of conservation

Our analysis compares past LCCMR funded easement acquisitions to all other viable parcels in the state. This provides insight into what services are being prioritized and which are being randomly targeted. Parcels that receive scores lower than or similar to the average scores of all other viable parcels for all of the metrics may be a sign of 'random acts of conservation'. While all conservation activities have value, the limited resources available necessitate targeting activities with strong public benefits.

[1] Noe, R. R., B. L. Keeler, M. A. Kilgore, S. J. Taff, and S. Polasky. 2017. Mainstreaming ecosystem services in state-level conservation planning: progress and future needs. *Ecology and Society* 22(4):4. https://doi.org/10.5751/ES-09581-220404



More targeted conservation strategies can take multiple forms, ranging from emphasis on the quality of a single benefit to emphasis on the number of benefits an acquisition provides. Both approaches are useful for producing targeting acquisitions with strong public benefits. When a landscape level approach is used, it is possible to combine elements from both single and multi-objective targeting to identify all parcels that score highly on a single objective, and further target among them those with the most other benefits. Our approach and tool help practitioners identify whether or not other parcels exist that meet their objectives and also provide other previously unconsidered benefits.

Factors to consider when interpreting results

Environmental benefits are diverse and numerous

Our metrics are designed to complement those used in existing prioritization systems. Our research indicated that habitat and biodiversity related metrics are already emphasized by existing prioritization systems, therefore we opted to focus on metrics in terms of human wellbeing. Other benefits derived from the environment, such as spiritual and cultural, are not well suited to a quantitative prioritization framework, but

can be immensely valuable. A parcel may have value that we were not able to consider in our landscape level approach because statewide data are not available. For example, high quality duck habitat supports the environmental benefit of duck hunting, however outputs from the most appropriate duck habitat model are not available statewide, and could not be included as a landscape level metric.

A statewide tool is best used to gain perspective and identify potentially valuable, previously unconsidered parcels; not to reject parcels for not obtaining an arbitrary score threshold. These metrics provide a valuable tool for quickly quantifying, visualizing, and considering multiple benefits, but consider what benefits are not captured by this approach before rejecting a parcel.

Combining multiple benefits is a values question

Any acquisition has tradeoffs between benefits. We can illuminate benefits, provide a framework to think about tradeoffs, and visualize portfolios of benefits. However, considering which benefits to prioritize requires that policymakers decide which values best represent the interests of the public. We encourage agencies and policymakers to use this tool and metrics as a framework for communicating priorities, and to continue to consider the interests of the public.

Comparison parcel definitions are approximate

To define parcels we used the statewide map of 40 acre public land survey parcels. These boundaries conform well to the shape of major features, and offer a good approximation of the scale at which land management and ownership operates. We defined ‘viable’ parcels as >50% privately held, >50% undeveloped, and <75% water. These 426,000 parcels are not necessary an exact representation of land management or ownership, and they do not indicate the land owner is willing to sell, but they do represent a realistic set of parcels for comparison and targeting purposes. Note that a parcel can be any shape and does not need to conform to the public land survey parcels in order to be considered with this approach.

Consider factors that influence cost

Land prices vary drastically around the state and expensive land does not mean that it doesn’t provide valuable benefits. High prices can indicate that land is likely to be developed without protection or that there is a large population of beneficiaries nearby. The ROI in our reports is a benchmark to visualize where parcels excel when their cost is considered. An expensive parcel may still be more valuable than a parcel with a

higher ROI if it provides great benefits and it is very likely to be developed. For example, shoreline property on Lake Superior would likely have a lower ROI compared to past acquisitions because its price is much higher than land in the rest of the state. This does not indicate it is a worse investment, but rather that it has value that isn't captured in our metrics. These are factors which must be considered on a case by case basis, but in many cases can be informed by reviewing past acquisition scores and prices.

Compare parcels, not metrics

Due to differences in the distribution of benefits, scores of different metrics are not comparable, and should not be combined. For example, high scores for the groundwater nitrate metric are much rarer than high scores for the wild rice metric. Because of these differences, it is best to only make comparisons between different sets of parcels within individual metrics (e.g., groundwater nitrate score for a proposed acquisition vs. average groundwater nitrate score of all viable parcels in the state).

Environmental benefit metrics

We created 11 statewide metric maps that depict where individual environmental benefits are produced, and how their quality compares to the rest of the state. For example, to contribute to lake recreation, an acquisition must be in the catchment of a publicly accessible lake. Among these, land that contributes to lakes with higher visitation and that are more sensitive to increased runoff pollution have higher scores. The metrics focus on ways in which human wellbeing is influenced by the environment, such as providing recreation opportunities or protecting drinking water. We also include two non-environmental metrics, nearby population and risk of conversion, to help users consider the impact and efficiency of a proposed acquisition.

We designed the metrics for prioritizing protection of undeveloped land without public access, such as with a conservation easement. Benefits must be provided to the public without access to the parcel, such as by controlling runoff into a public lake or by sequestering carbon from the atmosphere. The metrics all range from zero to one, where zero indicates the benefit is not produced there, and one indicates it is the best place for that benefit in the state. However, due to differences in the distribution of benefits, scores of different metrics are not comparable, and should not be combined. See the expanded documentation (z.umn.edu/pebat-documentation) for more information on how the metrics were constructed.

Past Acquisitions Analysis

Single-objective performance

One approach to targeted conservation is to acquire a portfolio of parcels that each excel at different benefits. With this approach, each acquisition only needs to be strong in one area, so you would expect to have a relatively small proportion of past acquisitions two standard deviations above the average of viable parcels, and many below average. Having a high proportion of acquisitions below average for a metric can also be explained by the limited endpoints that contribute to certain services. For example, acquisitions outside of the catchments of trout streams receive a trout angling score of 0. Since it is impossible for a single acquisition to be in all of the endpoints at once, it is normal for these metrics to have many 0 scores.

Figure 1-a. In figures 1 a-k, the green bars represent the average scores, and the average scores plus one and two standard deviations (SD) of all viable parcels in the state. The orange bar represents the average of past LCCMR funded easement acquisitions and the blue dots represent the scores of individual acquisitions. Metrics with all acquisitions (blue dots) near the average of all viable parcels (evenly dashed dark green line) indicate that metric is being randomly targeted. However, even a relatively small proportion of high scoring acquisitions can indicate successful targeting of a portfolio approach.

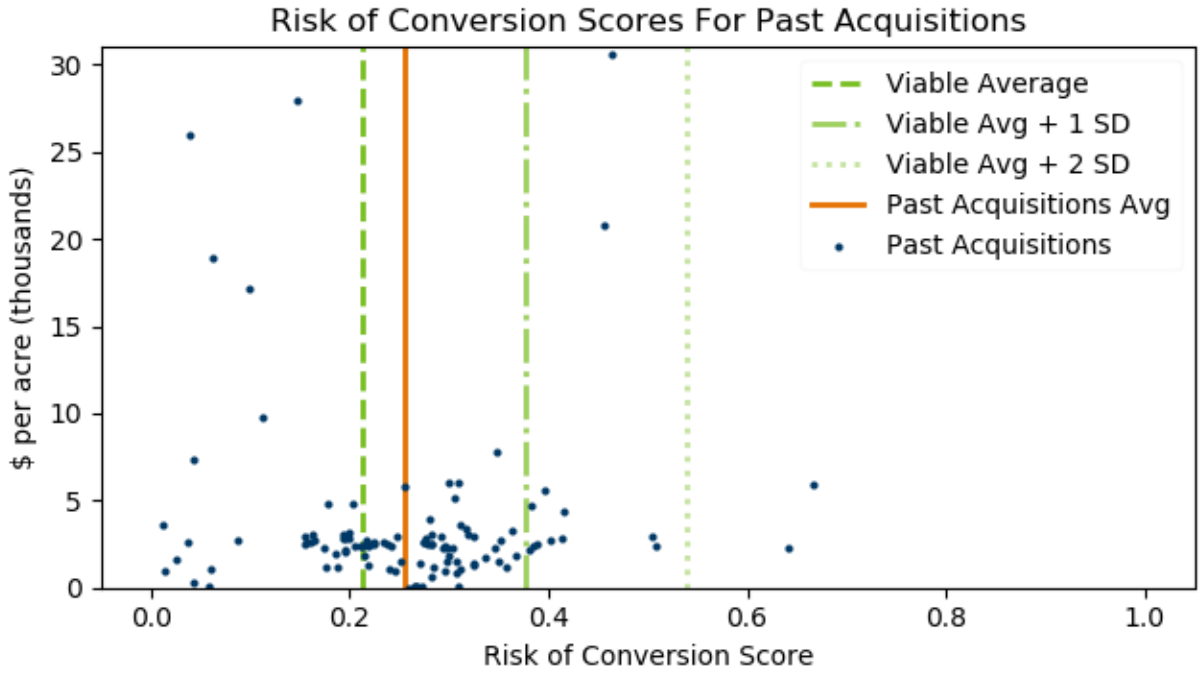


Figure 1-b.

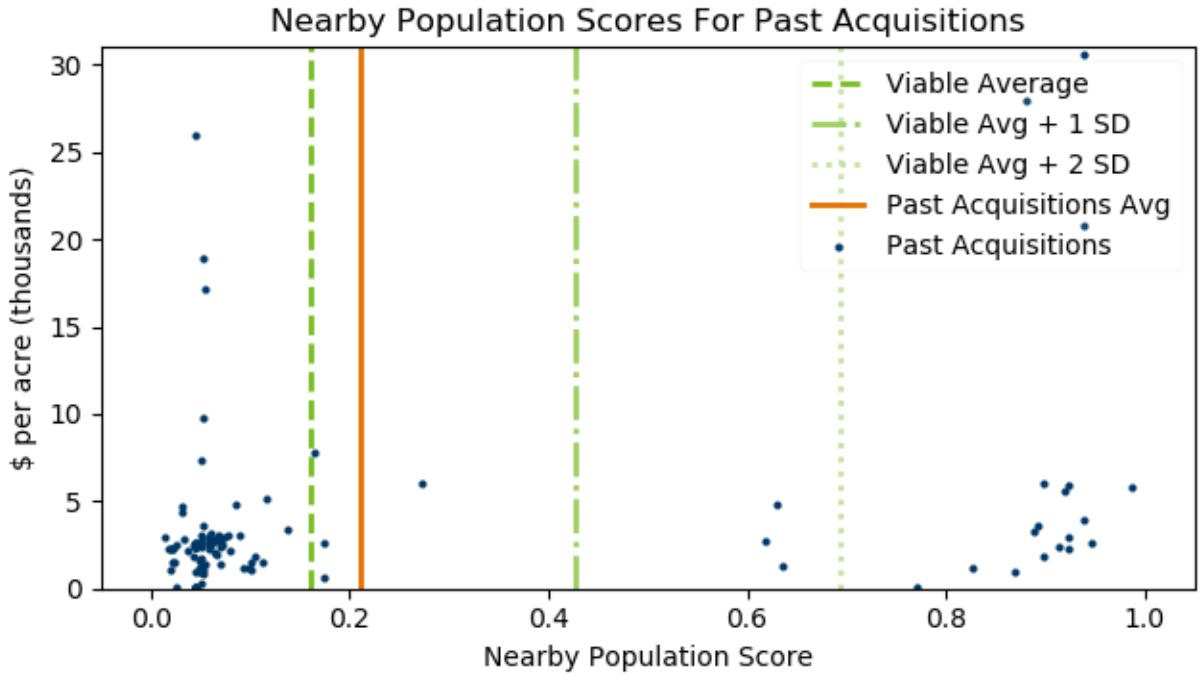


Figure 1-c.

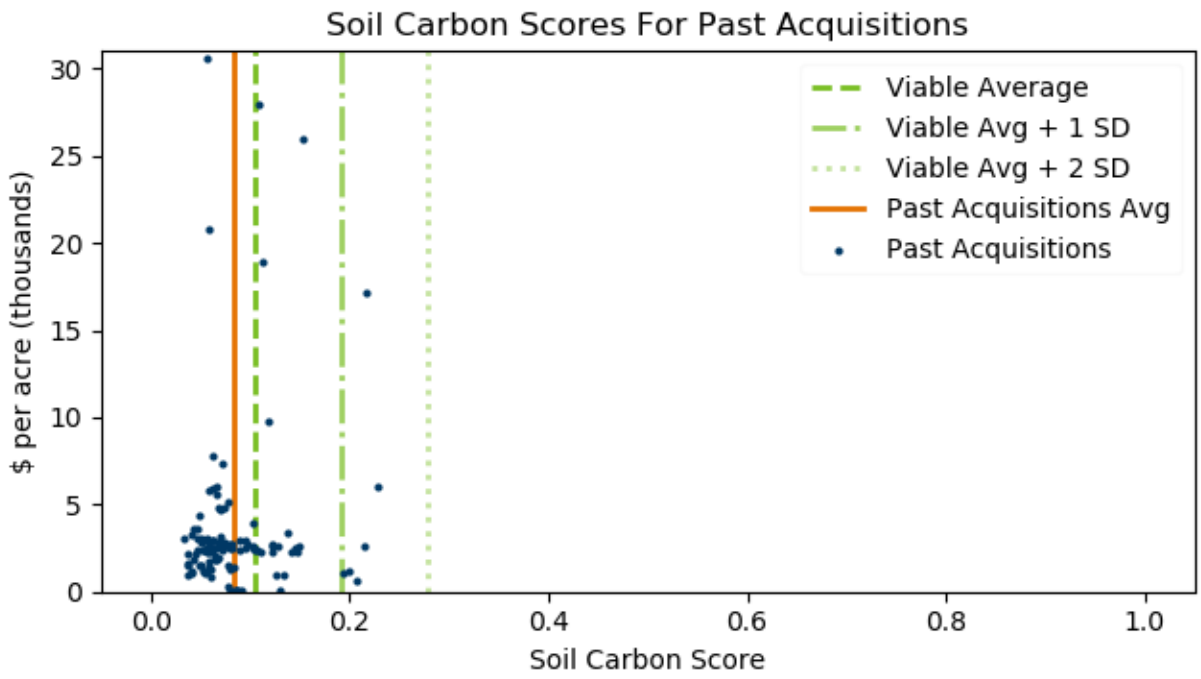


Figure 1-d.

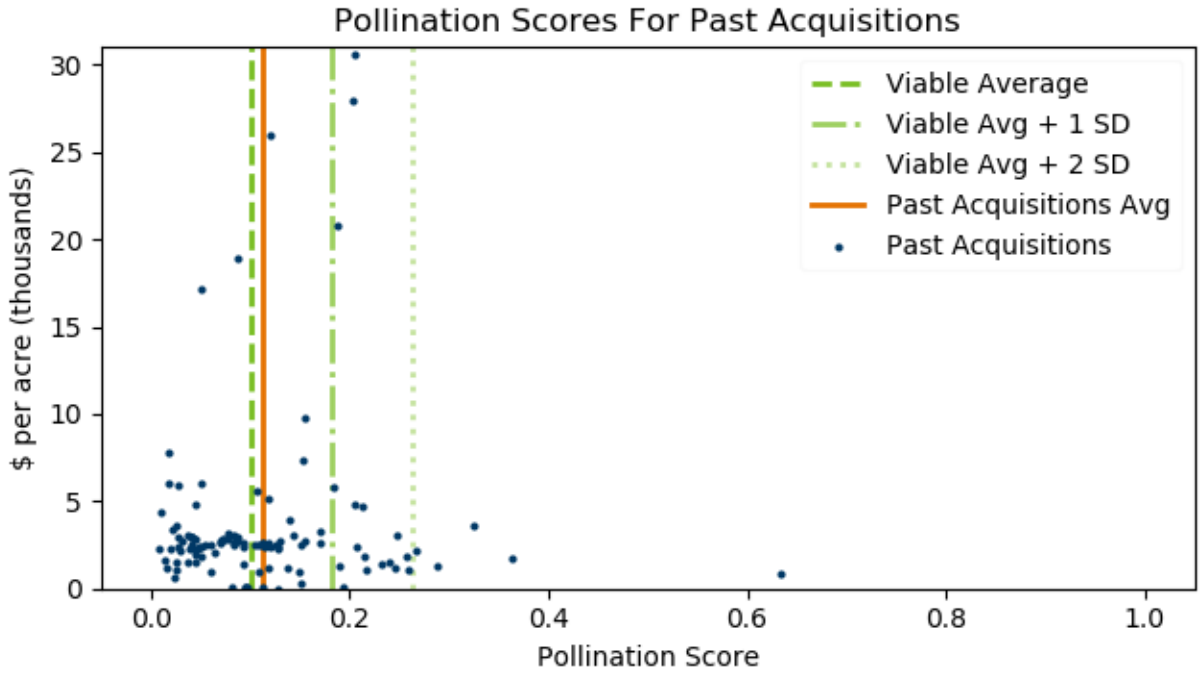


Figure 1-e.

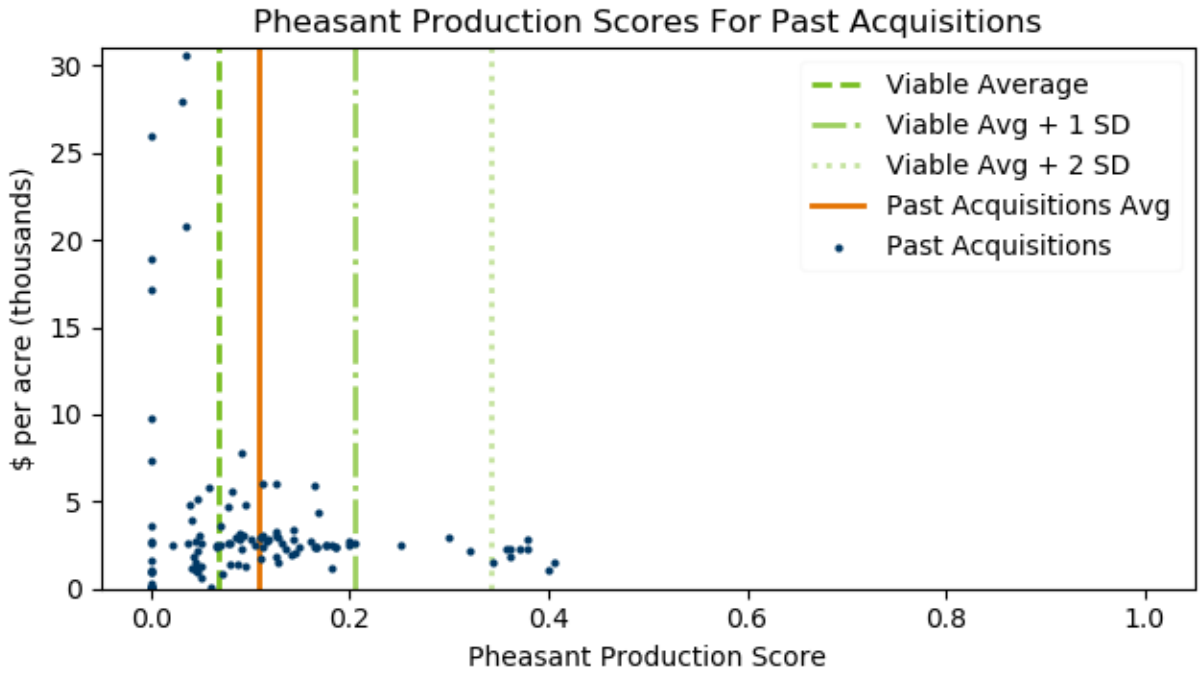


Figure 1-f.

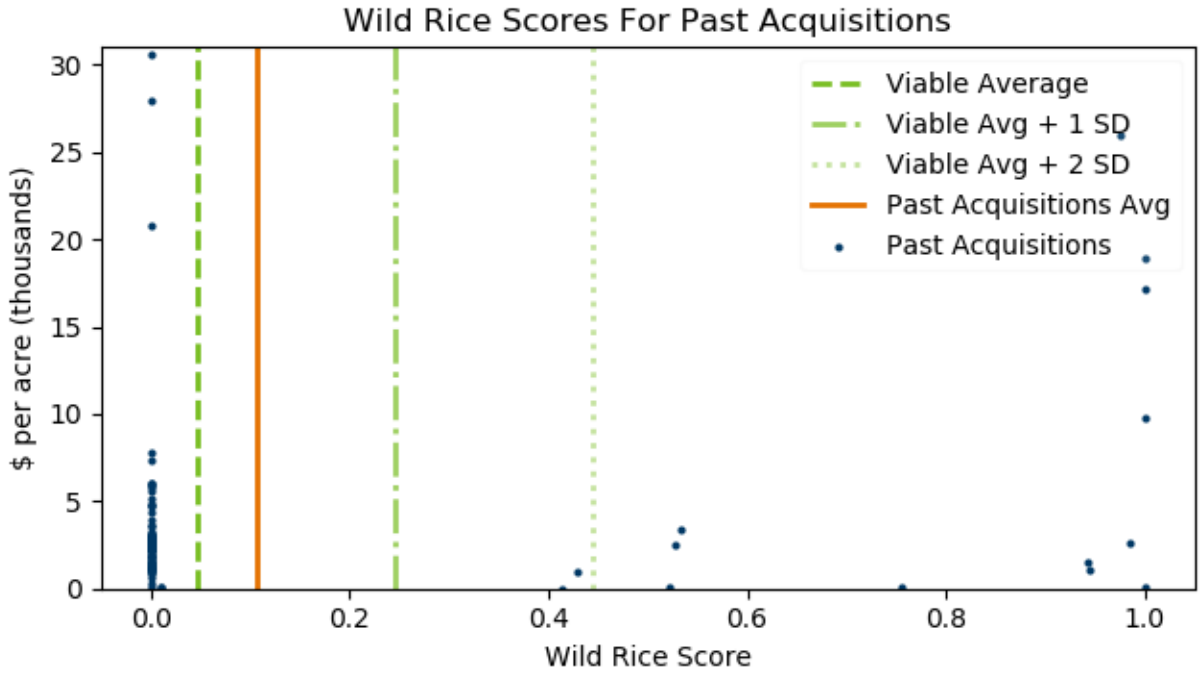


Figure 1-g.

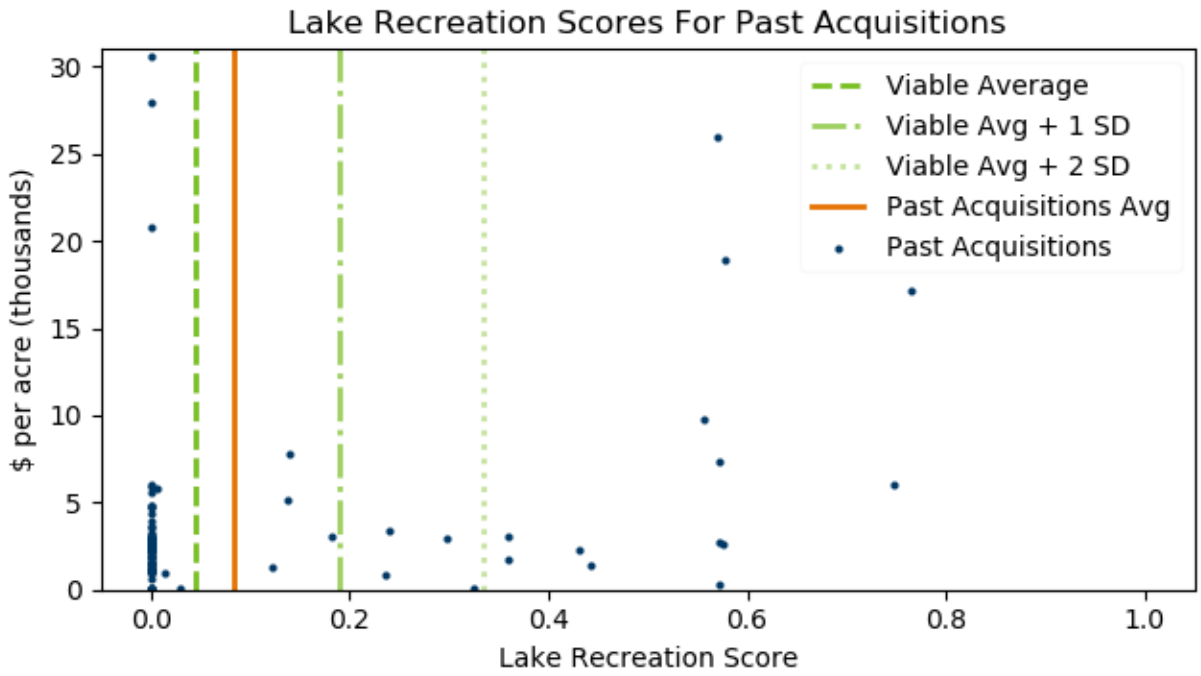


Figure 1-h.

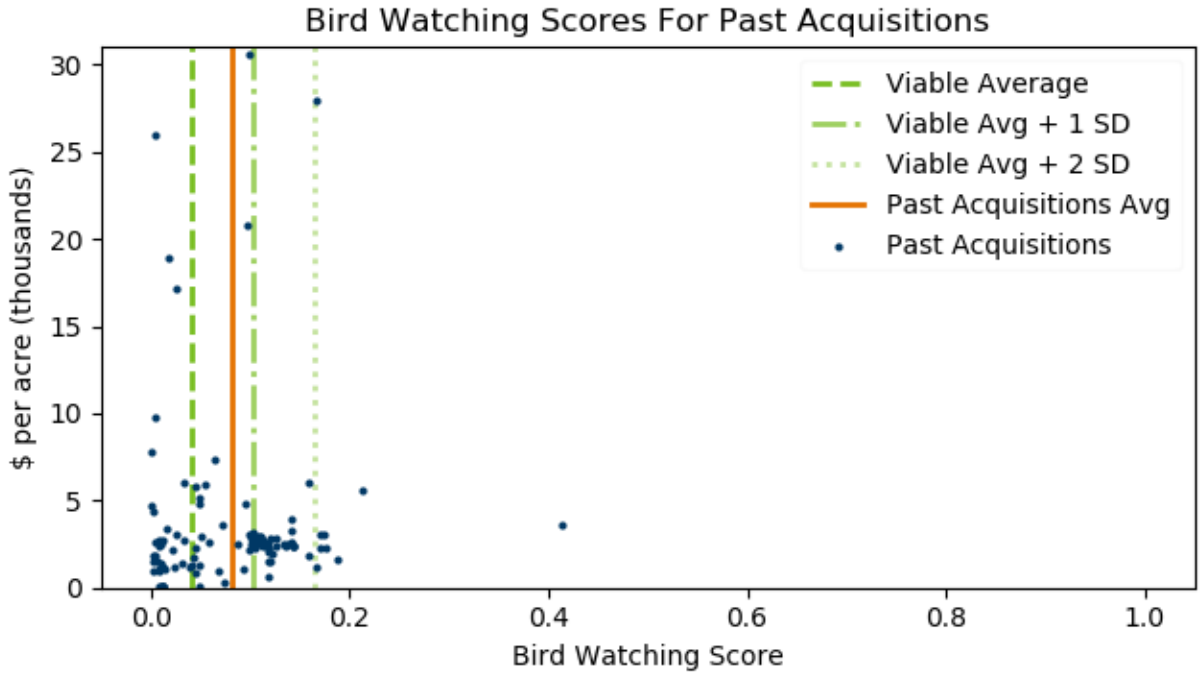


Figure 1-i.

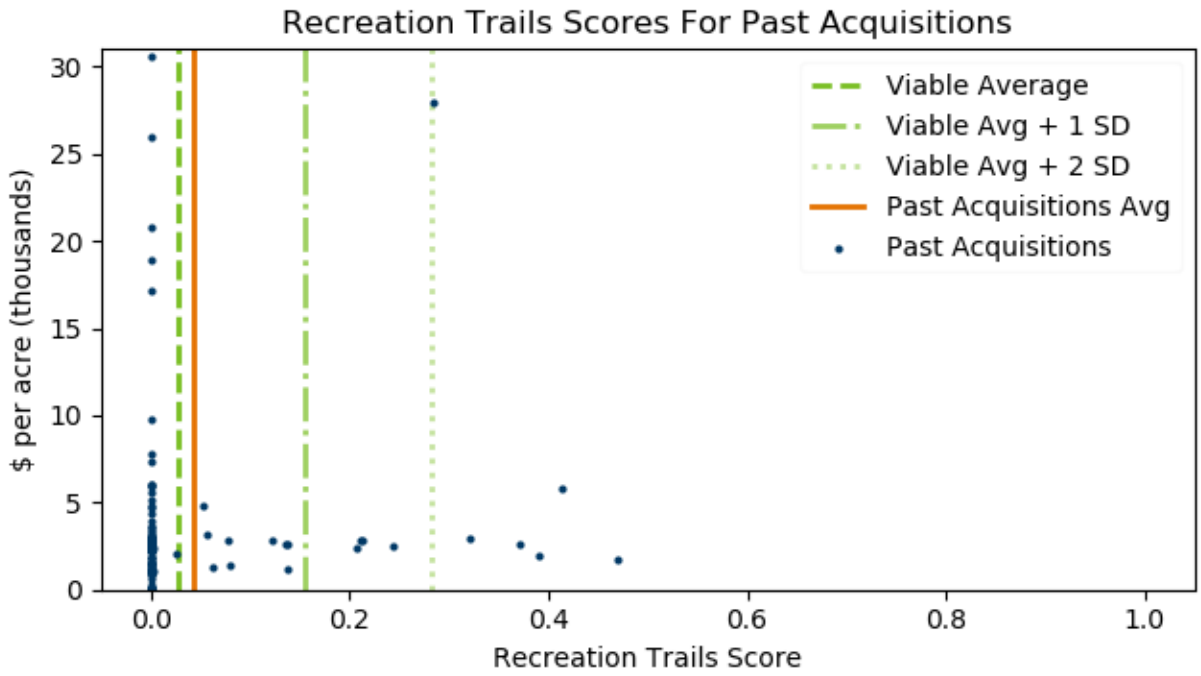


Figure 1-j.

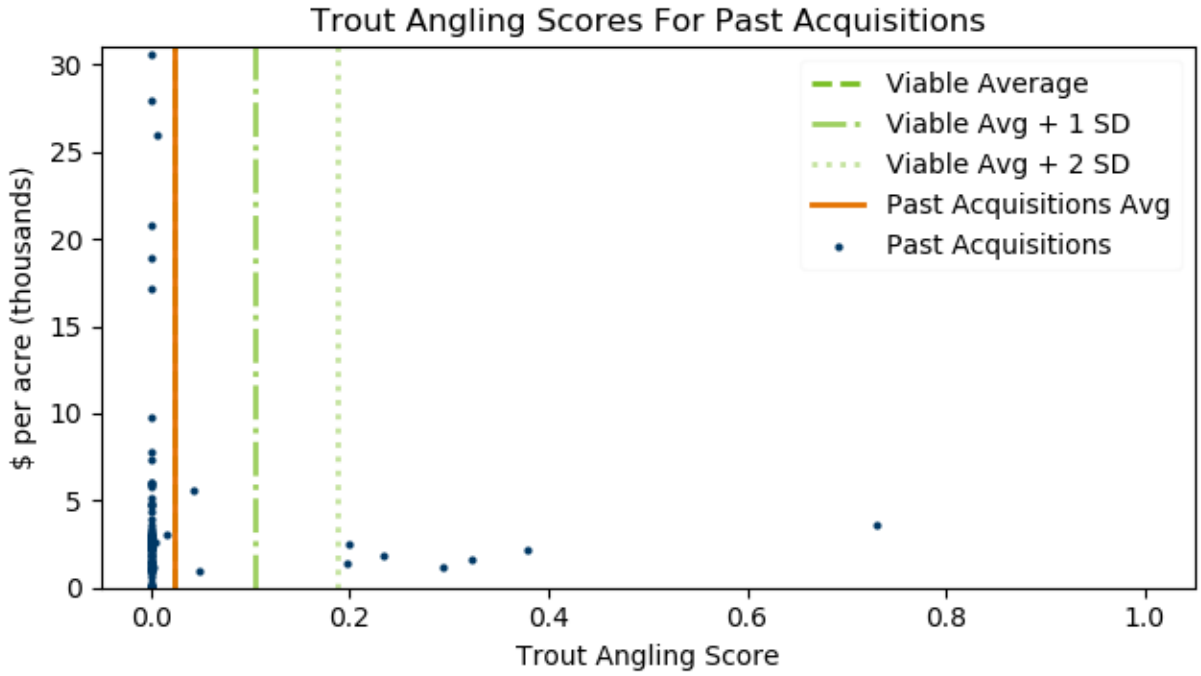


Figure 1-k.

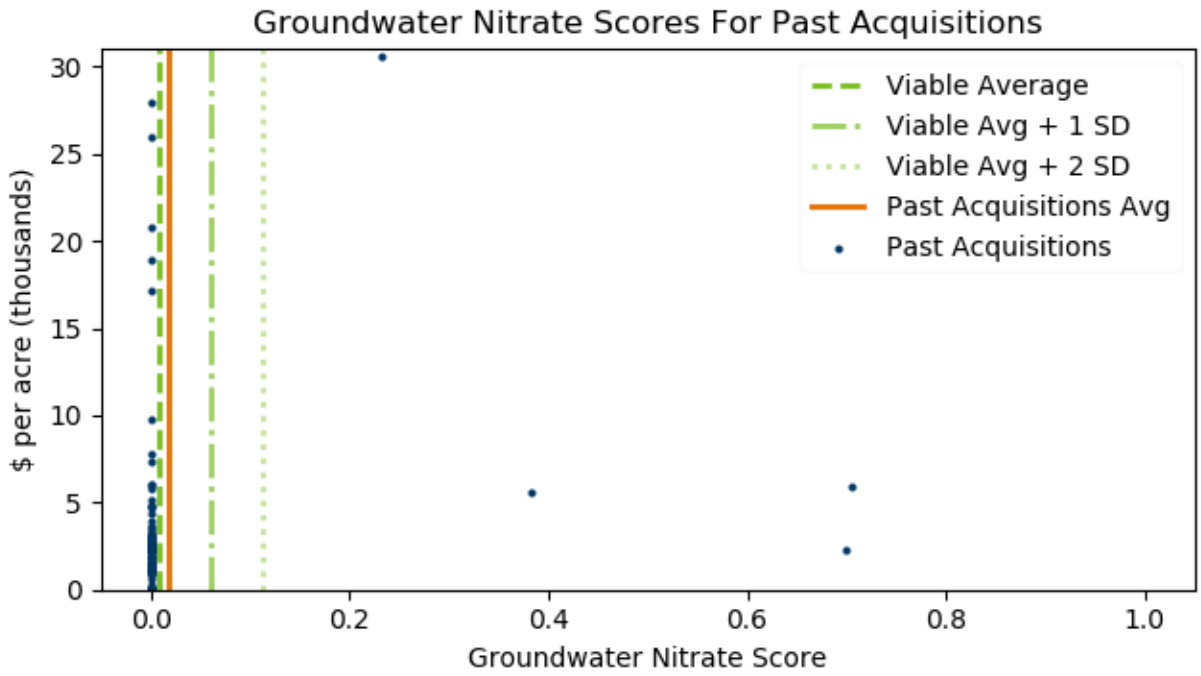


Table 1. Break down of proportion of past acquisitions that had scores above the average of all viable parcels in the state. The proportion of past acquisitions is also broken down by number of standard deviations (SD) above average.

	Groundwater Nitrate	Trout Angling	Trails	Bird Watching	Lake Recreation	Wild Rice	Pheasant Production	Pollination	Soil Carbon	Nearby Population	Risk of Conversion
Above Average	4%	9%	18%	67%	19%	13%	59%	47%	23%	22%	66%
Below Average	96%	91%	82%	33%	81%	87%	41%	53%	77%	78%	34%
Average to < 1 SD Above Average	0%	3%	8%	23%	4%	0%	49%	27%	18%	4%	54%
1 SD to < 2 SD Above Average	0%	0%	4%	36%	4%	2%	3%	15%	5%	3%	11%
> 2 SD Above Average	4%	6%	6%	8%	12%	12%	8%	4%	0%	16%	2%

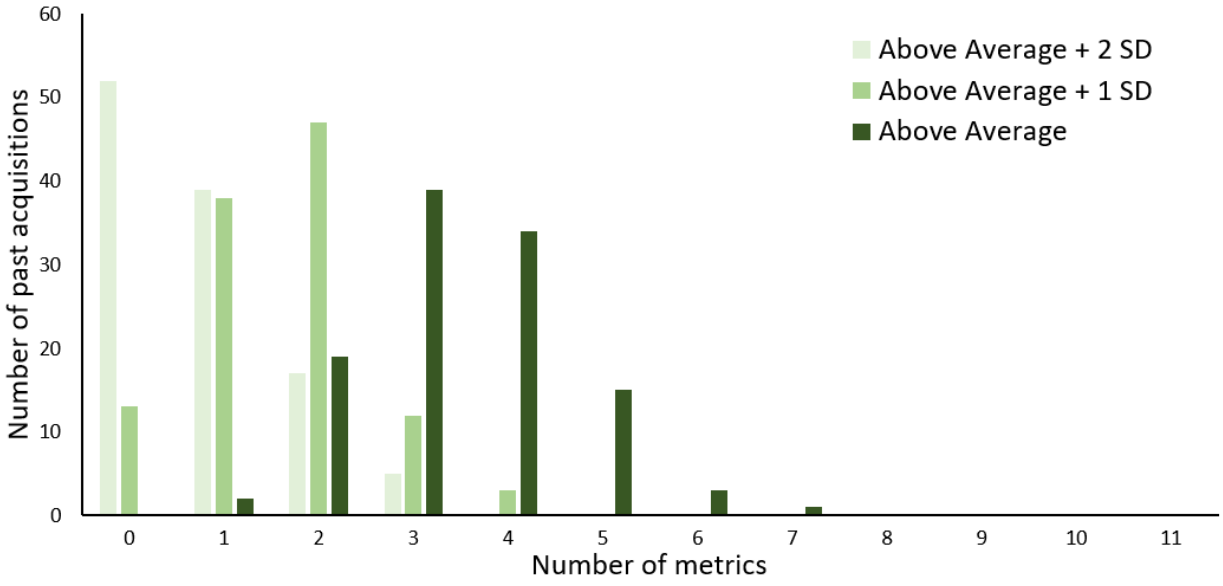
Table 2. Highest performing easement acquisition per metric. Metric scores are created such that the highest scoring viable parcel in the state receives a 1. The closer to 1, the closer a given acquisition is the highest scoring in the state for that metric. All dollar values are adjusted for inflation and presented in 2016 dollars.

Metric	Metric score	LCCMR ID	Original Purchaser	Acres	Year	Total $/Acre	ENRTF $/Acre
Risk of Conversion	0.666	11-037-009	Dakota County	193.2	2011	5,918	2,817
Nearby Population	0.987	11-053-001	Minnesota Land Trust	44.7	2011	5,801	4,119
Soil Carbon	0.228	14-093-001	Ducks Unlimited	33.6	2012	5,996	4,923
Pollination	0.634	06-041-001	MN DNR	555.6	2006	864	104
Pheasant Production	0.405	11-011-004	MN DNR	178.8	2010	1,466	537
Wild Rice	1.000	14-005-005	Minnesota Land Trust	37.4	2013	32	32
Lake Recreation	0.765	08-035-002	MN DNR	61.3	2007	17,197	1,273
Bird Watching	0.414	11-075-001	MN DNR	2.8	2008	3,620	3,620
Trails	0.750	11-075-004	Minnesota Land Trust	11.5	2011	61,869	22,273
Trout Angling	0.729	11-075-001	MN DNR	2.8	2008	3,620	3,620
Groundwater Nitrate	0.706	11-037-009	Dakota County	193.2	2011	5,918	2,817

Multi-objective performance

Another approach to maximizing returns of public benefits from an acquisition is to target acquisitions that are positioned to provide multiple benefits. In figure 2, past acquisitions are broken down by the number of metrics where they scored above the average of all viable parcels in the state. The break down is repeated in the lighter green bars for the number of metrics where they were above the average plus one and two standard deviations. This figure demonstrates one of the trade-offs commonly associated with a multi-objective approach. Parcels that perform better on individual metrics (i.e., more standard deviations above average), often do not perform as well on multiple objectives.

Figure 2. Number of past acquisitions that scored better than average of all viable parcels on a given number of metrics.



While trade-offs exist, the figure also shows acquisitions that were both far above average and contributing to multiple objectives (Table 3). These parcels excel at both single and multiple objectives, but this does not imply that other acquisitions are not valuable. There may not be alternatives to a parcel that performs well on a single objective that also has co-benefits. Furthermore, simply counting the number of above average metrics does not indicate you are maximizing public benefits. If the public views one metric as a much higher priority than the others, having good performance on several lower priority metrics could be equivalent to good performance on a single metric. Policy makers and practitioners must weigh public needs and priorities when determining what portfolio of benefits to prioritize and protect.

Table 3. Past acquisitions that had above average or greater performance on the most metrics. Counting the number of above average metrics does not account for variation in preferences in the public. This analysis provides a framework to identify what benefits a parcel provides, and how the benefit's quality compares to the rest of the state. Policy makers and practitioners should consider the values and priorities of the public when deciding which benefits to emphasize. All dollar values are adjusted for inflation and presented in 2016 dollars. For detailed information on all past acquisitions see the parcel score appendix.

LCCMR ID	Original Purchaser	Acres	Year	Total $ / Acre	ENRTF $ / Acre	Above Average Count
10-037-001	Dakota County	42.3	2008	5,548	1,054	7
15-037-003	Dakota County	27.4	2015	2,279	1,071	6
09-041-004	Ducks Unlimited	180	2009	1,328	181	6
09-041-005	Ducks Unlimited	23	2009	1,717	498	6
						Above Average + 1 SD Count
15-037-002	Dakota County	103.1	2012	30,633	1,532	4
10-037-001	Dakota County	42.3	2008	5,548	1,054	4
08-163-005	MN DNR	42.5	2006	27,951	4,808	4
						Above Average + 2 SD Count
11-037-009	Dakota County	193.2	2011	5,918	2,817	3
15-037-003	Dakota County	27.4	2015	2,279	1,071	3
10-037-001	Dakota County	42.3	2008	5,548	1,054	3
08-163-005	MN DNR	42.5	2006	27,951	4,808	3
09-041-005	Ducks Unlimited	23	2009	1,717	498	3

Targeting with a landscape level approach

Our framework is designed to leverage the benefits of both single and multi-objective approaches by using a landscape level approach. For any parcel we can assess how many, if any, viable parcels exist that perform better than it on every metric. This does not guarantee that those land owners are interested in selling development rights, but it does provide leads on potentially more desirable acquisitions. The number of parcels that score better than a given parcel on all metrics is an indicator of how well a parcel performs at both single and multi-objective targeting. Parcels that score very highly on a single attribute or those that have strong performance on several will have few parcels that can match either their single objective strength or unique combination of benefits across multiple objectives, respectively.

The high proportion (40%) of acquisitions with fewer than 10 parcels that scored better on all metrics indicates that past acquisitions have successfully targeted parcels with high quality benefits and/or co-benefits. Despite these successes, some parcels had hundreds of alternatives that were better on all metrics assessed here. These acquisitions still may have been well targeted if they were acquired to support a benefit not included in our metrics. Identifying parcels that scored better on all metrics is a high standard. Relaxing this requirement would reveal many parcels that scored better than past acquisitions most, but not all metrics. Practitioners could identify promising parcels by querying our dataset for parcels that perform well on their metric of interest and also have strong co-benefits.

Table 4. Count of viable parcels that had higher scores on all metrics than a given past acquisition. Parcels with a high number of parcels better on all metrics could have benefited from a landscape level approach. Note that a parcel may excel at a benefit we did not produce a metric for. For example, there was not sufficient data to construct a statewide duck production metric.

LCCMR ID	Original Purchaser	Acres	Year	Total $ / Acre	ENRTF $ / Acre	Better On All Metrics Count
11-075-004	Minnesota Land Trust	11.5	2011	22,273	61,869	0
13-073-001	BWSR	45.1	2011	2,329	2,329	0
11-039-001	BWSR	39.7	2011	2,656	2,656	0
11-173-004	BWSR	67.9	2011	2,442	2,442	0
14-111-001	Minnesota Land Trust	48.6	2012	114	1,444	0
13-073-003	BWSR	30	2011	2,229	2,229	0
06-041-001	MN DNR	555.6	2006	104	864	0
09-041-005	Ducks Unlimited	23	2009	498	1,717	0

11-055-002	BWSR	190.1	2008	148	2,466	0
11-037-009	Dakota County	193.2	2011	2,817	5,918	0
09-041-004	Ducks Unlimited	180	2009	181	1,328	0
08-157-001	The Nature Conservancy	33	2007	3,083	3,083	0
11-173-010	BWSR	43.6	2011	2,432	2,432	0
10-037-001	Dakota County	42.3	2008	1,054	5,548	0
13-023-002	BWSR	35.1	2012	2,592	2,592	0
11-053-001	Minnesota Land Trust	44.7	2011	4,119	5,801	0
14-093-001	Ducks Unlimited	33.6	2012	4,923	5,996	0
15-037-003	Dakota County	27.4	2015	1,071	2,279	0
11-127-004	BWSR	46.4	2010	2,621	2,621	1
08-035-002	MN DNR	61.3	2007	1,273	17,197	1
09-041-003	Ducks Unlimited	78	2008	184	3,072	1
14-021-006	Cass County	38.6	2011	399	2,610	1
08-047-002	Ducks Unlimited	39	2007	2,933	3,372	2
11-127-007	BWSR	53.9	2011	2,855	2,855	2
12-003-001	Minnesota Land Trust	80	2012	1,125	2,616	2
11-157-003	MN DNR	284.6	2010	1,188	1,212	2
08-129-002	BWSR	70.6	2008	2,820	2,820	2
14-005-004	Minnesota Land Trust	198.9	2013	953	953	3
08-127-001	BWSR	46.6	2008	2,329	2,329	3
14-021-002	Cass County	5.8	2012	1,427	25,950	3
08-129-001	BWSR	15.9	2008	2,701	2,701	4
11-037-010	Dakota County	39.3	2011	1,086	3,621	4
11-127-009	BWSR	13	2011	2,007	2,007	5
08-127-002	BWSR	79.3	2008	2,920	2,920	5
11-127-003	BWSR	50	2010	2,054	2,054	5
16-155-001	MN DNR	150.8	2014	1,792	2,891	5
11-127-008	BWSR	20	2011	2,564	2,564	5
14-005-005	Minnesota Land Trust	37.4	2013	32	32	6
11-157-004	MN DNR	30	2010	1,719	1,848	6
14-151-001	MN DNR	19.34	2013	1,007	2,798	6
11-129-001	BWSR	15.8	2010	3,178	3,178	7
08-163-005	MN DNR	42.5	2006	4,808	27,951	7
13-073-002	BWSR	28	2011	2,314	2,314	7
11-127-001	BWSR	21.6	2010	2,546	2,546	8
11-127-006	BWSR	79.9	2011	2,539	2,539	8
11-045-002	MN DNR	40.5	2010	2,164	2,172	10
11-157-005	MN DNR	1220.3	2010	1,116	1,139	10
14-021-007	Cass County	21.7	2011	480	9,791	11
11-129-007	BWSR	30.7	2011	2,874	2,874	12
15-037-001	Dakota County	34.3	2015	1,133	2,361	12

16-037-004	Dakota County	20.6	2016	2,932	6,008	12
15-037-004	Dakota County	26.1	2015	925	1,814	12
15-037-002	Dakota County	103.1	2012	1,532	30,633	13
14-067-001	Minnesota Land Trust	30.7	2011	97	5,105	15
11-173-002	BWSR	26.3	2010	2,523	2,523	15
11-173-009	BWSR	18.5	2011	2,506	2,506	16
15-025-001	Minnesota Land Trust	79	2014	30	30	17
11-129-009	BWSR	27.6	2011	2,882	2,882	17
11-173-001	BWSR	43	2010	2,503	2,503	20
14-021-009	Minnesota Land Trust	31	2013	313	313	23
12-127-001	MN DNR	19.6	2012	2,861	2,895	23
15-059-001	Minnesota Land Trust	158.5	2014	1,057	1,140	23
11-173-006	BWSR	44.5	2011	2,449	2,449	25
11-011-004	MN DNR	178.8	2010	537	1,466	25
11-129-005	BWSR	16.6	2010	2,976	2,976	26
09-025-002	Minnesota Land Trust	140	2007	446	4,852	27
11-173-003	BWSR	40.4	2010	2,518	2,518	27
11-049-002	MN DNR	33.4	2010	3,301	3,317	27
14-021-005	Cass County	4.5	2011	2,344	54,892	27
11-173-007	BWSR	35.4	2011	2,434	2,434	28
12-173-001	BWSR	61	2011	2,438	2,438	28
11-173-005	BWSR	13.5	2011	2,442	2,442	29
11-173-008	BWSR	40.9	2011	2,433	2,433	30
16-011-001	MN DNR	125.5	2015	1,139	2,316	32
11-145-003	Ducks Unlimited	75.7	2011	1,459	1,520	35
14-021-008	Cass County	6.8	2013	1,693	7,398	39
11-037-011	Dakota County	16.8	2011	8,258	20,802	40
14-021-003	Cass County	9.4	2010	520	18,925	40
11-075-001	MN DNR	2.8	2008	3,620	3,620	47
10-003-001	Minnesota Land Trust	45	2010	3,985	3,985	53
11-117-001	MN DNR	160.2	2009	810	1,060	57
11-145-005	Minnesota Land Trust	56.5	2011	586	681	64
14-021-001	Cass County	2.7	2012	1,989	2,673	67
14-121-001	MN DNR	65.7	2014	1,435	1,435	70
11-157-001	MN DNR	262.4	2009	1,011	1,032	74
16-167-001	MN DNR	53.4	2014	1,478	1,795	82
11-011-003	MN DNR	63.2	2010	1,482	1,527	84
14-015-001	MN DNR	26.99	2014	4,759	4,856	87
14-005-002	Minnesota Land Trust	108.7	2013	14	14	88
16-037-003	Dakota County	17.2	2016	1,480	2,953	94
11-129-004	BWSR	3.7	2010	3,044	3,044	96
14-041-002	BWSR	39.5	2013	1,062	2,722	98
11-149-004	BWSR	122.8	2010	1,509	4,717	105

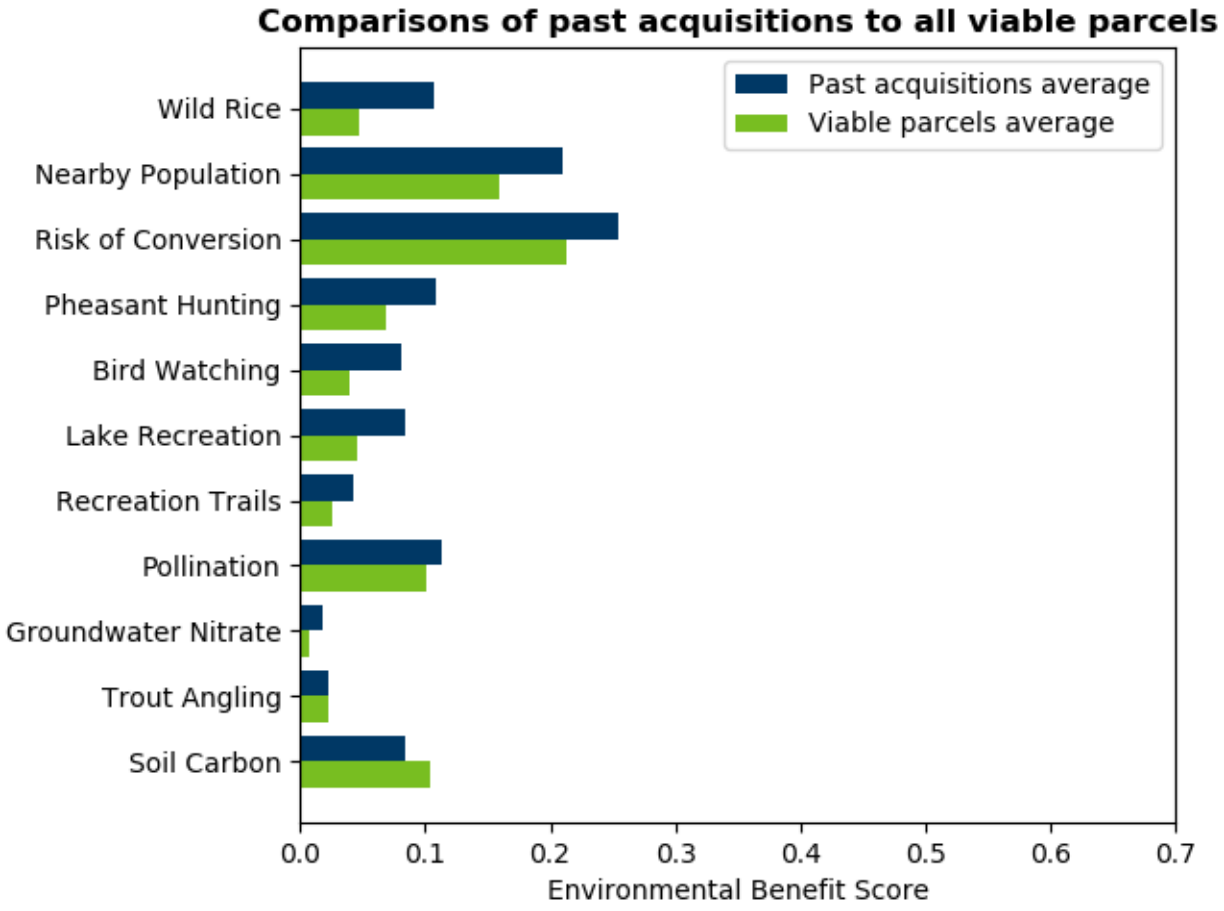
15-143-001	Minnesota Land Trust	79.6	2014	752	1,331	105
12-163-001	Minnesota Land Trust	294	2012	10	988	110
11-127-002	BWSR	136.8	2010	3,080	3,080	115
14-005-006	Minnesota Land Trust	58	2013	25	25	152
11-025-001	Minnesota Land Trust	39.7	2010	416	2,771	167
11-035-002	Ducks Unlimited	150	2011	1,049	1,093	168
14-041-001	BWSR	343.9	2012	891	2,345	184
14-007-001	Minnesota Land Trust	145.5	2014	30	30	190
14-005-003	Minnesota Land Trust	71	2013	75	75	236
13-111-002	Minnesota Land Trust	71	2013	38	38	236
14-041-003	BWSR	192.2	2014	1,139	2,530	247
11-145-004	Minnesota Land Trust	43.9	2011	2,331	2,649	354
09-051-003	Ducks Unlimited	28.62	2008	428	2,139	409
14-041-005	BWSR	55.1	2014	1,200	2,728	411
09-161-001	Ducks Unlimited	12.42	2008	6,481	7,809	503
11-075-005	Minnesota Land Trust	88	2010	188	1,631	707
08-041-001	Ducks Unlimited	111	2007	987	1,131	754
11-157-002	MN DNR	114.4	2009	1,429	1,489	1034
11-149-003	BWSR	155.8	2010	398	4,417	5288
12-035-001	Minnesota Land Trust	88	2011	259	926	9804

Portfolio Statistics

Targeting a suite of benefits with a portfolio of acquisitions is a necessary tool because all of the benefits of interest cannot be found in a single area. When protecting a portfolio of parcels practitioners must decide how to prioritize benefits relative to one another. Our tool is useful for identifying strengths and weaknesses within a portfolio. In figure 3, the average scores of past acquisitions is compared to the average scores of all viable parcels, sorted from the metric where past acquisitions are most above the other viable parcels to the metric where they are the most below. Randomly acquiring parcels would produce benefit scores near the average of all viable parcels in the state. Being near or below the average of viable parcels indicates that that benefit is under represented in your portfolio.

However, other factors are also relevant in portfolio allocation. For example, the highest soil carbon concentrations in the state are in areas with some of the lowest risk of conversion. It would not be efficient to acquire land unlikely to be convert solely to increase the soil carbon benefits in the ENRTF portfolio. Acquisition decisions require weighing trade-offs and priorities across both benefits and geographies. Our tool provides data and a framework for organizing information to improve conservation targeting.

Figure 3. Analysis of ENRTF portfolio in comparison to all viable parcels in the state. The further the blue bar is past its adjacent green bar, the more that metric is represented in past acquisitions relative to all privately held undeveloped parcels.



Recommendations

Target acquisitions for a portfolio of benefits

The ENRTF has a broad constitutional mandate to protect Minnesota's “air, water, land, fish, wildlife, and other natural resources.” Addressing these environmental benefits equitably for all Minnesotans will require a portfolio of diverse benefits from acquisitions throughout the state. Having a clear picture of the strengths and weaknesses of a portfolio will allow for better targeting of specific benefits. Our analysis and tools are a useful framework for assessing a portfolio conservation activities, however, continued work with conservation practitioners and the public are vital for identifying benefits not included in this analysis, and prioritizing among those benefits.

Survey the public to better understand conservation values and priorities

The ENRTF plays a vital role in foundational data collection; many of the metrics in our tool were built on data not available in other states. However, a recurring question in acquisition decisions is how to prioritize among multiple metrics. Funding foundational social data acquisition (e.g., surveys) would provide more information on what the public's priorities and preferences for environmental benefits are, and would ensure that all Minnesotans are equitably represented. This information would help policymakers and practitioners make decisions that maximize returns of the wellbeing of Minnesotans.

Use a landscape level approach to target multiple benefits

Acquiring parcels that excel at a single benefit is a useful strategy when acquiring a portfolio of benefits. However, once promising parcels have been identified, test to see if there are other parcels that perform as well or better on all metrics. Conversations with practitioners indicated that often a parcel isn't considered until after the land owner comes forward. By querying our data, practitioners can identify parcels that meet their objectives and also have co-benefits. Broadening land owner outreach efforts to these parcels would help protect valuable parcels that might have been missed without a landscape level approach.

Improve risk of conversion estimates

Many past acquisitions scored highly on our risk of conversion metric, indicating that practitioners are efficiently using resources to protect the benefits most in danger of being lost. However, our metric, and those used by practitioners, could be refined to provide more reliable, higher resolution, and specific predictions of conversion. For example, our metric is ill-suited for identifying small-scale recreation-oriented development, such as lakeshore cabins. Land use change models and data are advancing rapidly, and improving estimates of risk of conversion would maximize the efficacy of any organization acquiring land for the public benefit.

Appendix I - Parcel Score Appendix

See included file "parcel_score_appendix.xlsx".

Also available at https://z.umn.edu/pebat-report-appendix

Appendix II - Past Acquisitions Analysis: Comparison to publicly held land

Overview

Our primary analysis focused on how past and proposed acquisitions compare to all privately held, undeveloped, and unprotected parcels in the state because this is the most relevant set of alternatives when targeting conservation easements. Another useful comparison set for assessing how outstanding a parcel's benefits are is all publicly held, undeveloped, and often protected parcels. This appendix presents the same analysis as in the main section of the report, but uses publicly held undeveloped land as the comparison set. The definition for public land used in this analysis differs slightly from the main analysis in that it uses a single, slightly older data set to define public land, the 2008 GAP stewardship layer. Note that the order of the metrics in the figures and tables of this analysis differs from the main analysis because metrics are typically sorted by the mean score of the comparison set.

Single-objective performance: public land comparison

Figure 1-a. In figures 1 a-k, the green bars represent the average scores, and the average scores plus one and two standard deviations (SD) of all *publicly held undeveloped* parcels. The orange bar represents the average of past LCCMR funded easement acquisitions and the blue dots represent the scores of individual acquisitions.

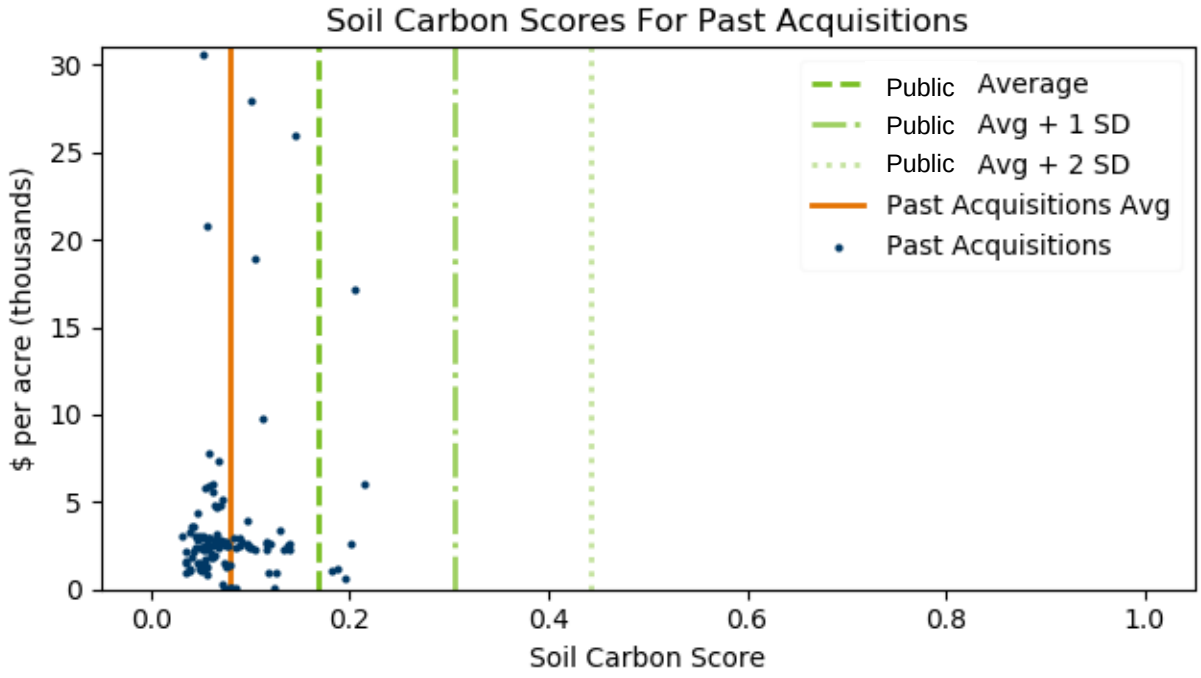


Figure 1-b.

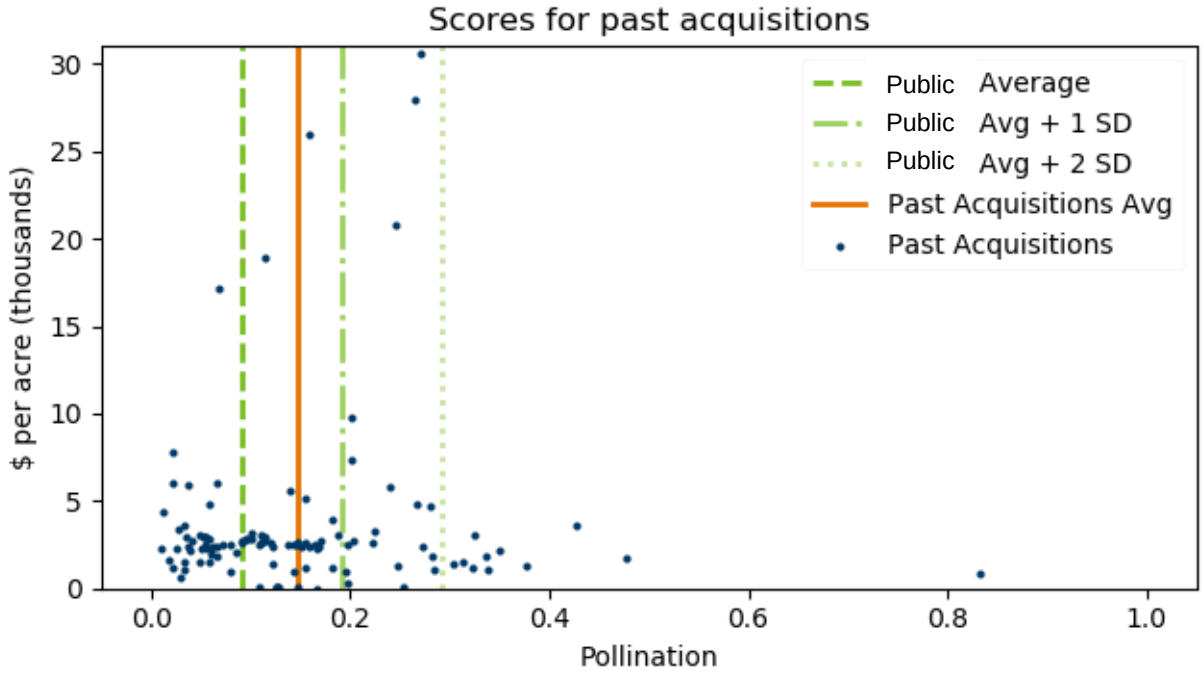


Figure 1-c.

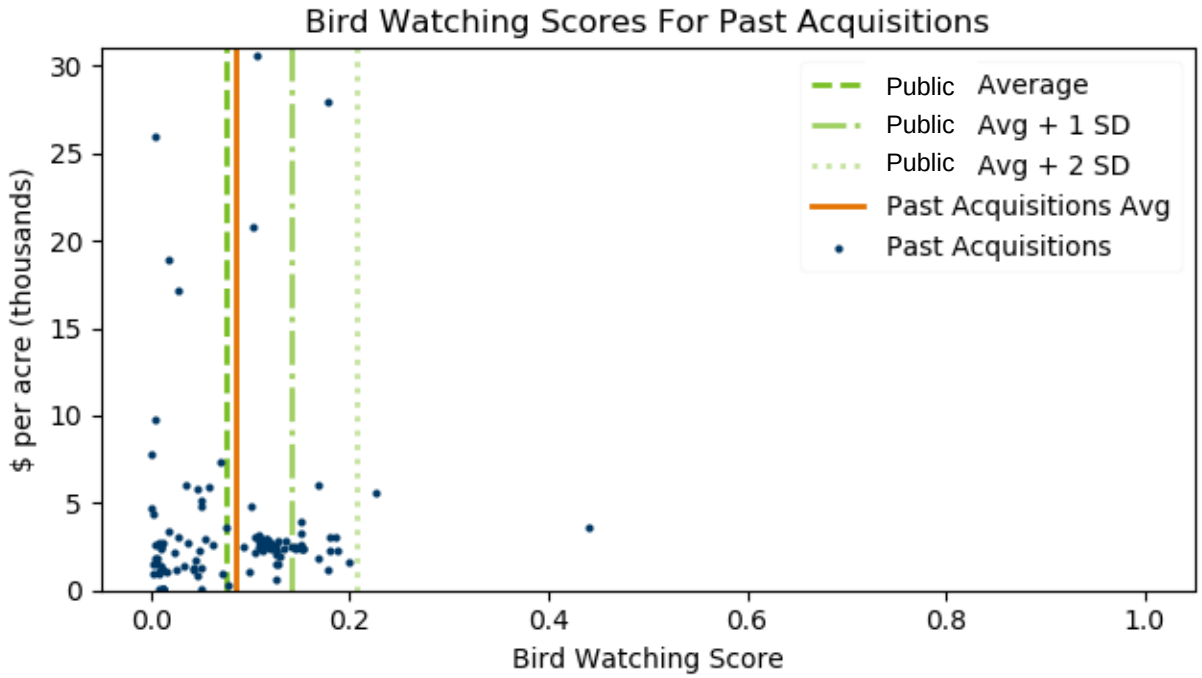


Figure 1-d.

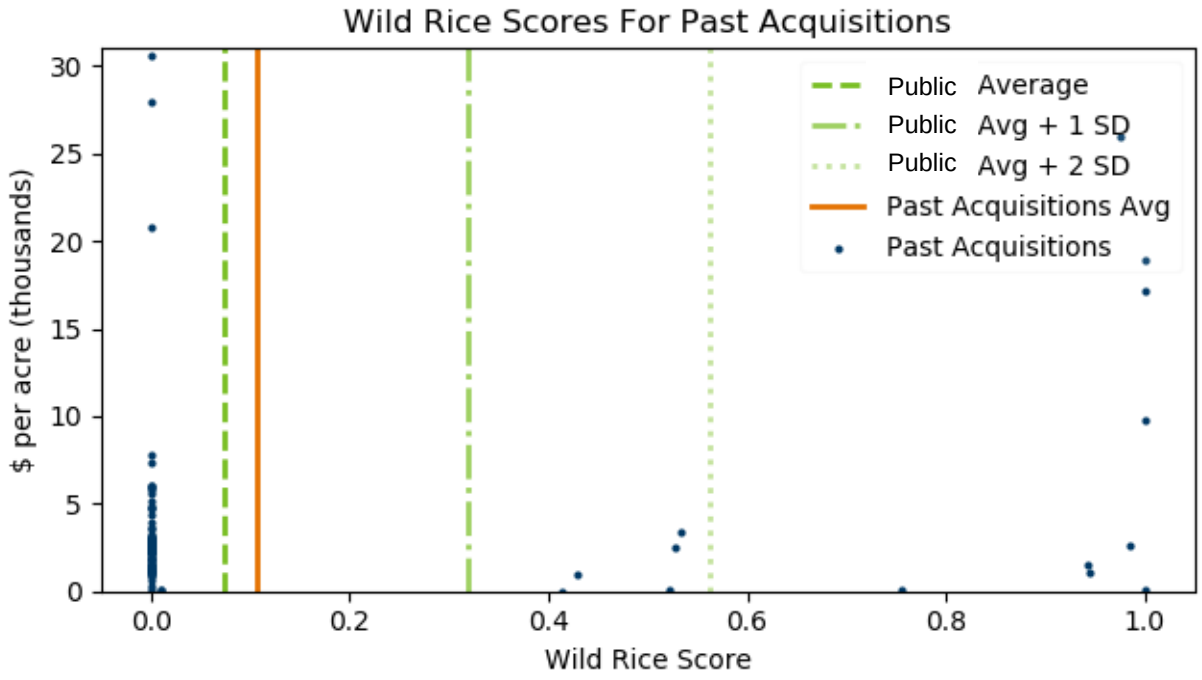


Figure 1-e.

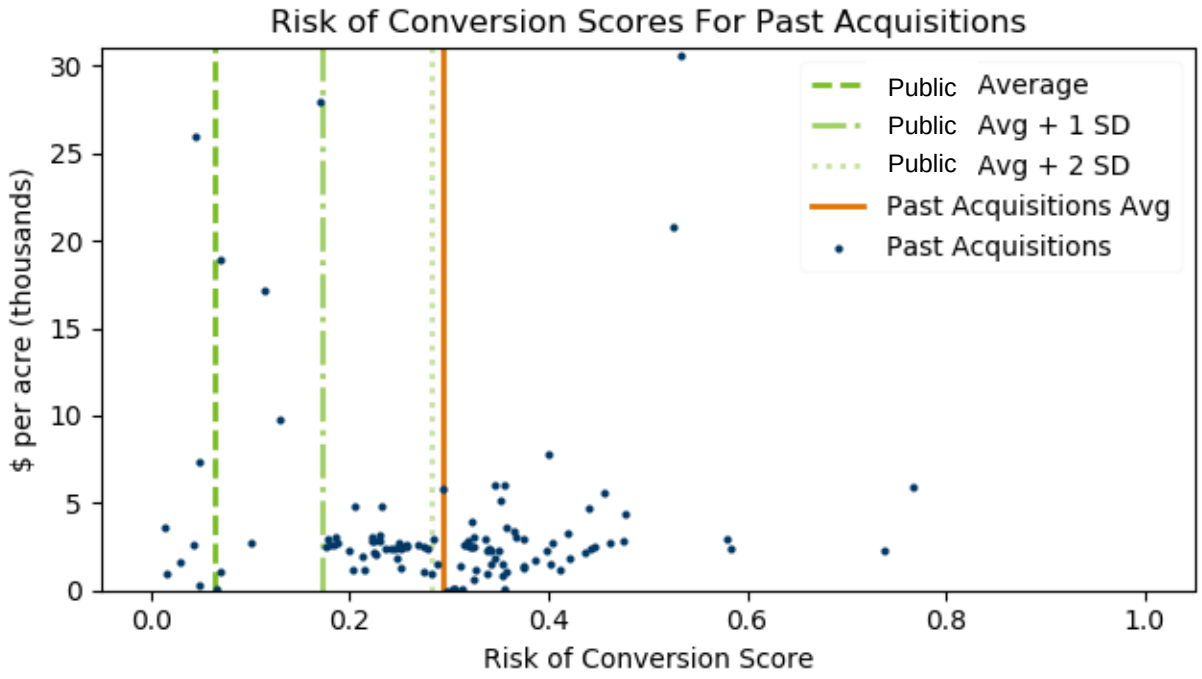


Figure 1-f.

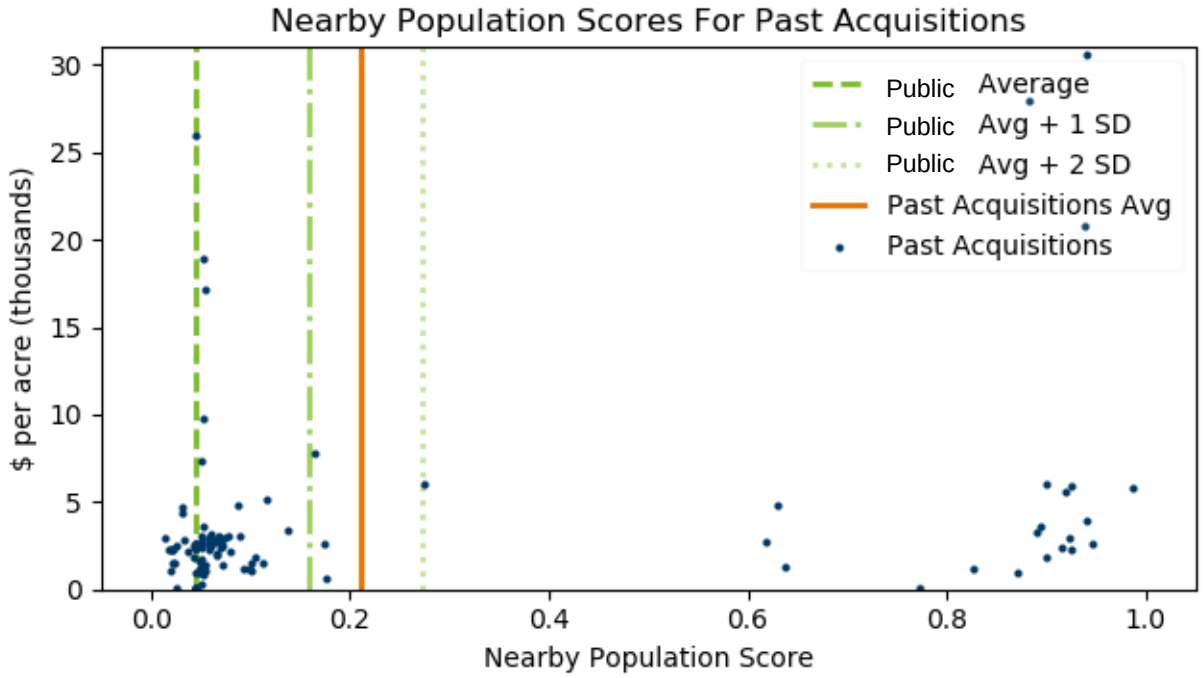


Figure 1-g.

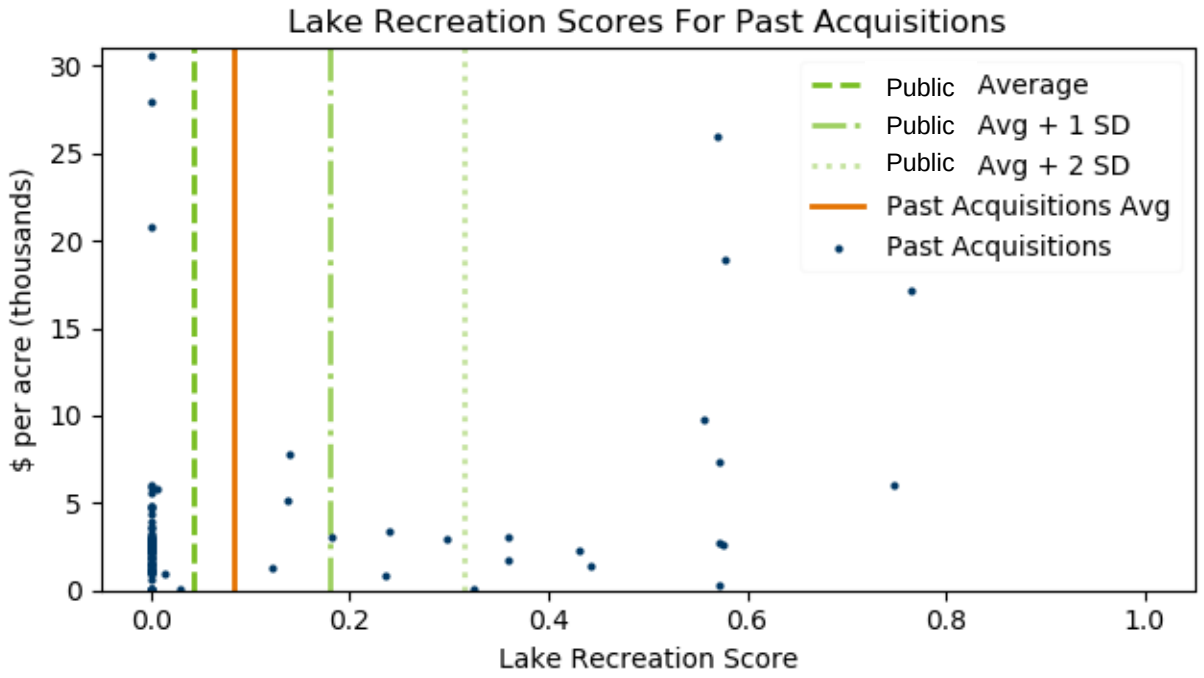


Figure 1-h.

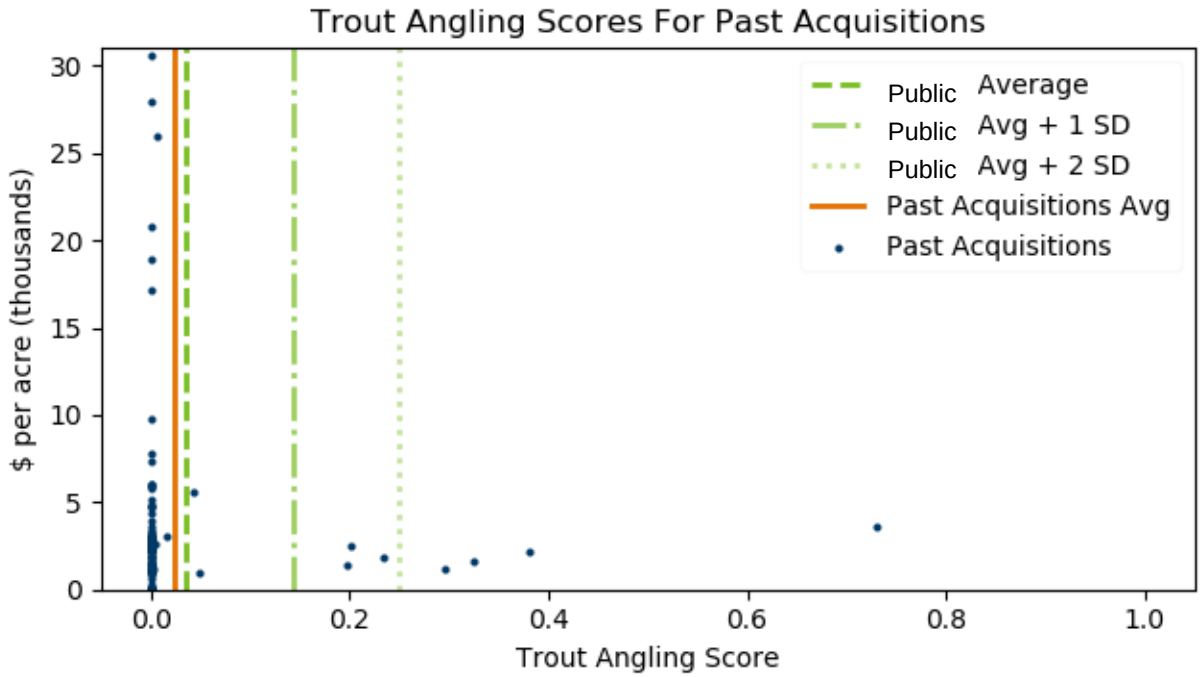


Figure 1-i.

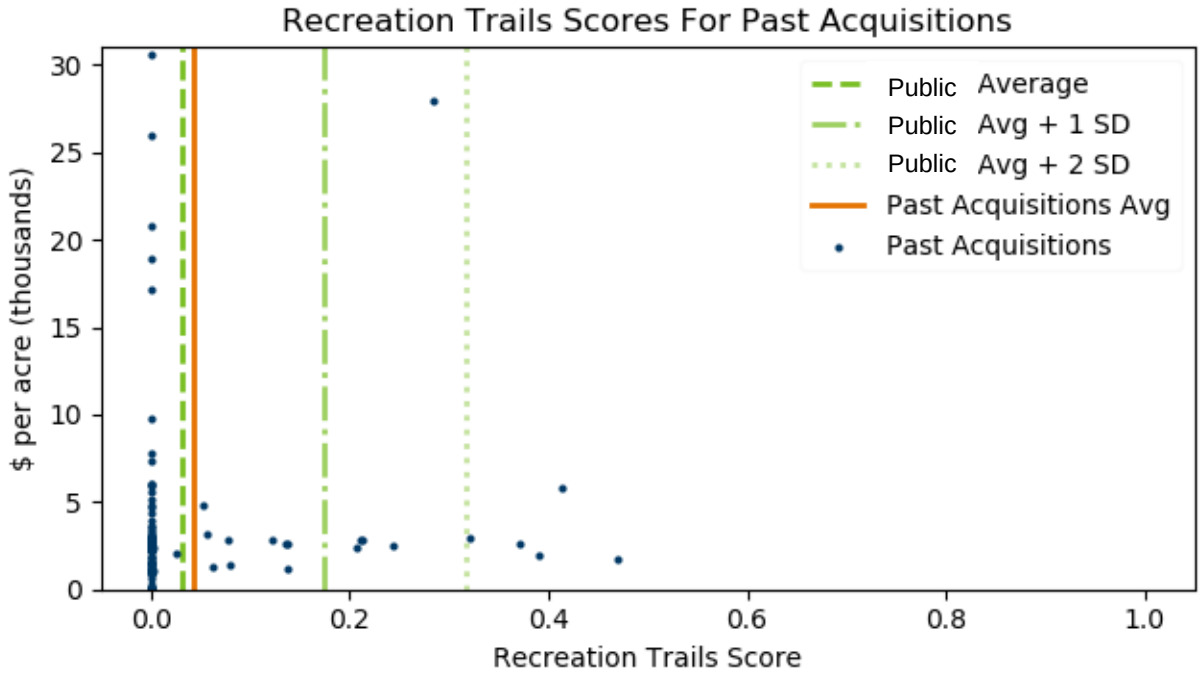


Figure 1-j.

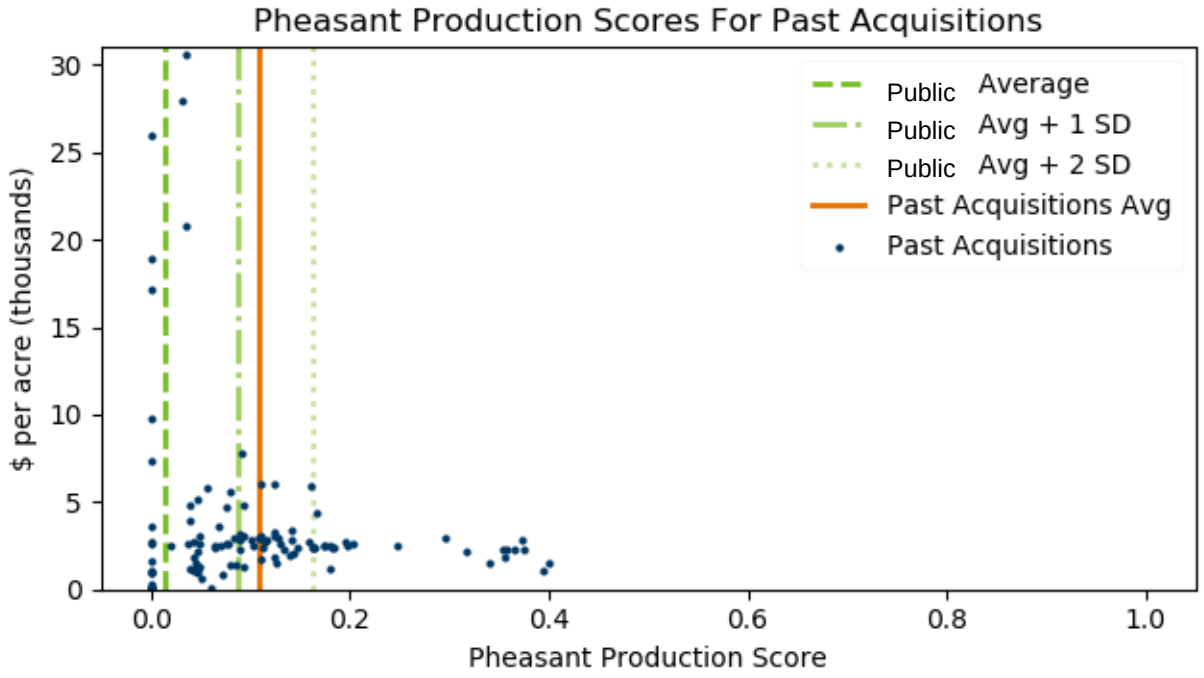


Figure 1-k.

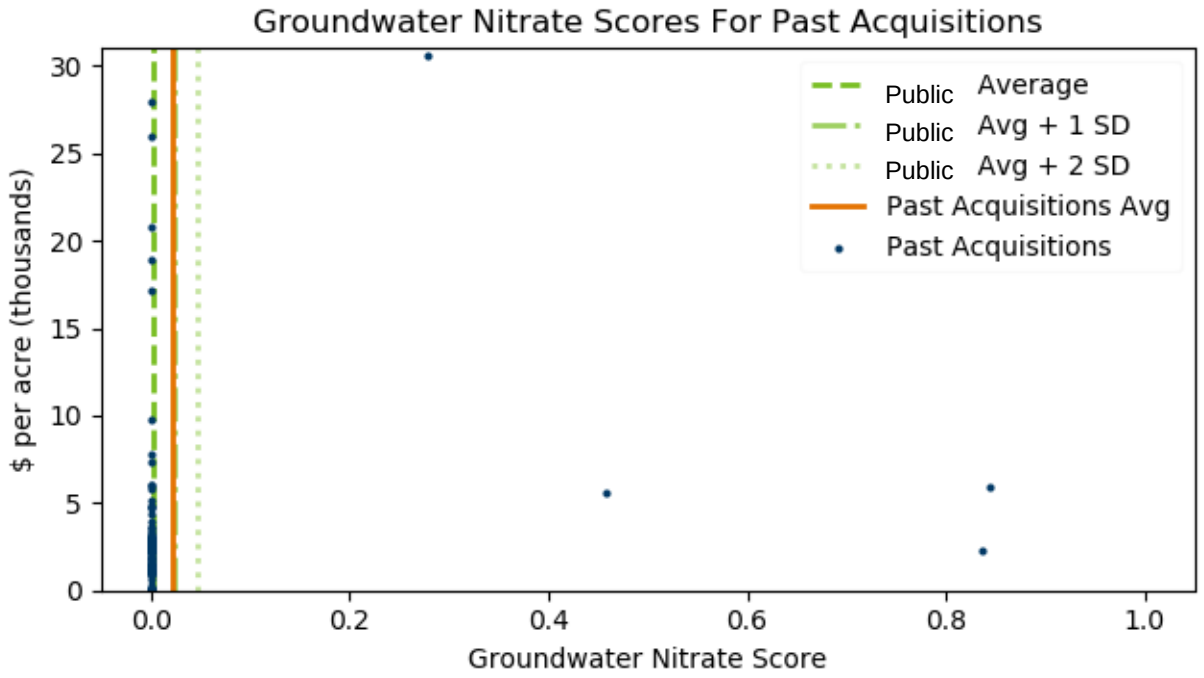


Table 1. Break down of proportion of past acquisitions that had scores above the average of all *publicly held undeveloped* parcels in the state. The proportion of past acquisitions is also broken down by number of standard deviations (SD) above average.

	Groundwater Nitrate	Pheasant Production	Trails	Trout Angling	Lake Recreation	Nearby Population	Risk of Conversion	Wild Rice	Bird Watching	Pollination	Soil Carbon
Above Average	4%	81%	18%	9%	19%	75%	94%	13%	55%	64%	5%
Below Average	96%	19%	82%	91%	81%	25%	6%	87%	45%	36%	95%
Average to < 1 SD Above Average	0%	31%	8%	3%	3%	53%	8%	0%	36%	37%	5%
1 SD to < 2 SD Above Average	0%	28%	4%	3%	4%	3%	30%	4%	17%	17%	0%
> 2 SD Above Average	4%	22%	5%	4%	13%	19%	56%	9%	2%	10%	0%

Table 2. Highest performing easement acquisition per metric relative to all *publicly held undeveloped* land. Metric scores are created such that the highest scoring viable parcel in the state receives a 1. The closer to 1, the closer a given acquisition is the highest scoring in the state for that metric. All dollar values are adjusted for inflation and presented in 2016 dollars.

Metric	Metric score	LCCMR ID	Original Purchaser	Acres	Year	Total $/Acre	ENRTF $/Acre
Soil Carbon	0.215	14-093-001	Ducks Unlimited	33.6	2012	5,996	4,923
Pollination	0.832	06-041-001	MN DNR	555.6	2006	864	104
Bird Watching	0.441	11-075-001	MN DNR	2.8	2008	3,620	3,620
Wild Rice	1.000	14-005-005	Minnesota Land Trust	37.4	2013	32	32
Risk of Conversion	0.766	11-037-009	Dakota County	193.2	2011	5,918	2,817
Nearby Population	0.988	11-053-001	Minnesota Land Trust	44.7	2011	5,801	4,119
Lake Recreation	0.765	08-035-002	MN DNR	61.3	2007	17,197	1,273
Trout Angling	0.731	11-075-001	MN DNR	2.8	2008	3,620	3,620
Trails	0.750	11-075-004	Minnesota Land Trust	11.5	2011	61,869	22,273
Pheasant Production	0.400	11-011-004	MN DNR	178.8	2010	1,466	537
Groundwater Nitrate	0.844	11-037-009	Dakota County	193.2	2011	5,918	2,817

Multi-objective performance: public land comparison

Figure 2. Number of past acquisitions that scored better than average of all *publicly held undeveloped* parcels on a given number of metrics.

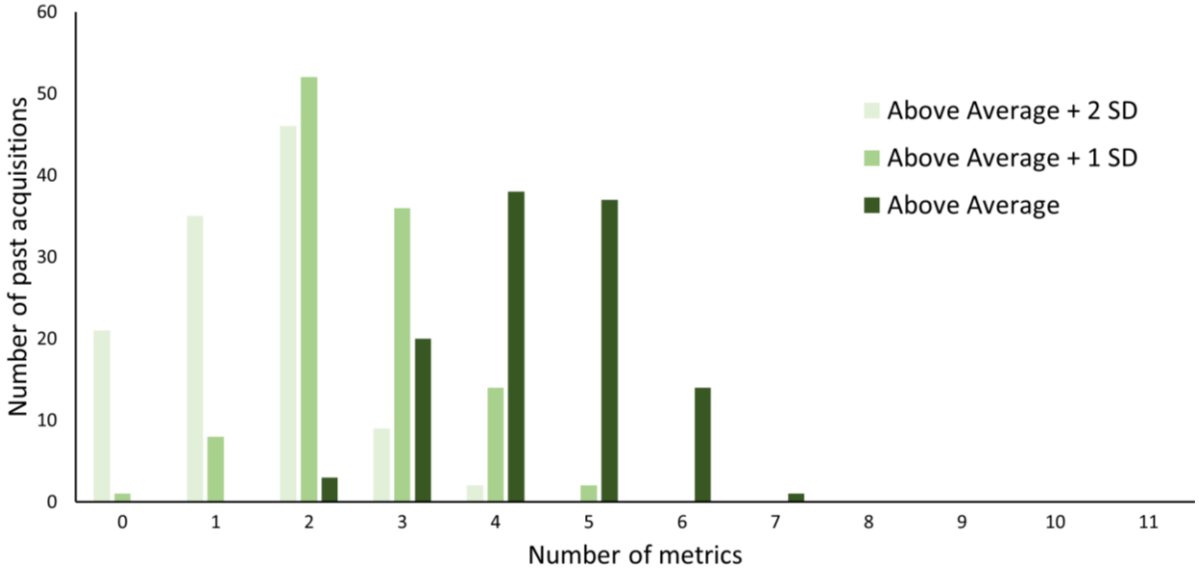


Table 3. Past acquisitions that had above average or greater performance relative to *publicly held undeveloped* land on the most metrics. Counting the number of above average metrics does not account for variation in preferences in the public. This analysis provides a framework to identify what benefits a parcel provides, and how the benefit's quality compares to the rest of the state. Policy makers and practitioners should consider the values and priorities of the public when deciding which benefits to emphasize. All dollar values are adjusted for inflation and presented in 2016 dollars.

LCCMR ID	Original Purchaser	Acres	Year	Total $ / Acre	ENRTF $ / Acre	Above Average Count
10-037-001	Dakota County	42.3	2008	5,548	1,054	7
11-127-004	BWSR	46.4	2010	2,620	2,620	6
11-045-002	MN DNR	40.5	2010	2,172	2,163	6
14-111-001	Minnesota Land Trust	48.6	2012	1,444	114	6
11-127-007	BWSR	53.9	2011	2,855	2,855	6
09-041-005	Ducks Unlimited	23	2009	1,716	497	6
11-055-002	BWSR	190.1	2008	2,465	147	6
09-041-004	Ducks Unlimited	180	2009	1,328	180	6
15-037-002	Dakota County	103.1	2012	30,632	1,531	6
11-157-003	MN DNR	284.6	2010	1,211	1,187	6
08-157-001	The Nature Conservancy	33	2007	3,083	3,083	6
11-129-001	BWSR	15.8	2010	3,178	3,178	6
08-163-005	MN DNR	42.5	2006	27,950	4,807	6

11-129-009	BWSR	27.6	2011	2,882	2,882	6
08-129-002	BWSR	70.6	2008	2,819	2,819	6
						Above Average + 1 SD Count
09-041-005	Ducks Unlimited	23	2009	1,716	497	5
11-049-002	MN DNR	33.4	2010	3,317	3,300	5
						Above Average + 2 SD Count
10-037-001	Dakota County	42.3	2008	5,548	1,054	4
09-041-005	Ducks Unlimited	23	2009	1,716	497	4

Targeting with a landscape level approach: public land comparison

Table 4. Count of *publicly held undeveloped* parcels that had higher scores on all metrics than a given past acquisition. Parcels with a high number of parcels better on all metrics could have benefited from a landscape level approach. Note that a parcel may excel at a benefit we did not produce a metric for. For example, there was not sufficient data to construct a statewide duck production metric.

LCCMR ID	Original Purchaser	Acres	Year	Total $ / Acre	ENRTF $ / Acre	Better On All Metrics Count
11-127-009	BWSR	13	2011	2,007	2,007	**0**
11-075-004	Minnesota Land Trust	11.5	2011	61,869	22,273	**0**
08-047-002	Ducks Unlimited	39	2007	3,372	2,933	**0**
13-073-001	BWSR	45.1	2011	2,329	2,329	**0**
11-039-001	BWSR	39.7	2011	2,656	2,656	**0**
11-173-004	BWSR	67.9	2011	2,442	2,442	**0**
13-073-003	BWSR	30	2011	2,229	2,229	**0**
06-041-001	MN DNR	555.6	2006	864	104	**0**
11-127-007	BWSR	53.9	2011	2,855	2,855	**0**
11-055-002	BWSR	190.1	2008	2,466	148	**0**
11-037-009	Dakota County	193.2	2011	5,918	2,817	**0**
12-003-001	Minnesota Land Trust	80	2012	2,616	1,125	**0**
16-037-003	Dakota County	17.2	2016	2,953	1,480	**0**
11-157-003	MN DNR	284.6	2010	1,212	1,188	**0**
08-157-001	The Nature Conservancy	33	2007	3,083	3,083	**0**
10-037-001	Dakota County	42.3	2008	5,548	1,054	**0**
08-035-002	MN DNR	61.3	2007	17,197	1,273	**0**
08-129-001	BWSR	15.9	2008	2,701	2,701	**0**
08-163-005	MN DNR	42.5	2006	27,951	4,808	**0**

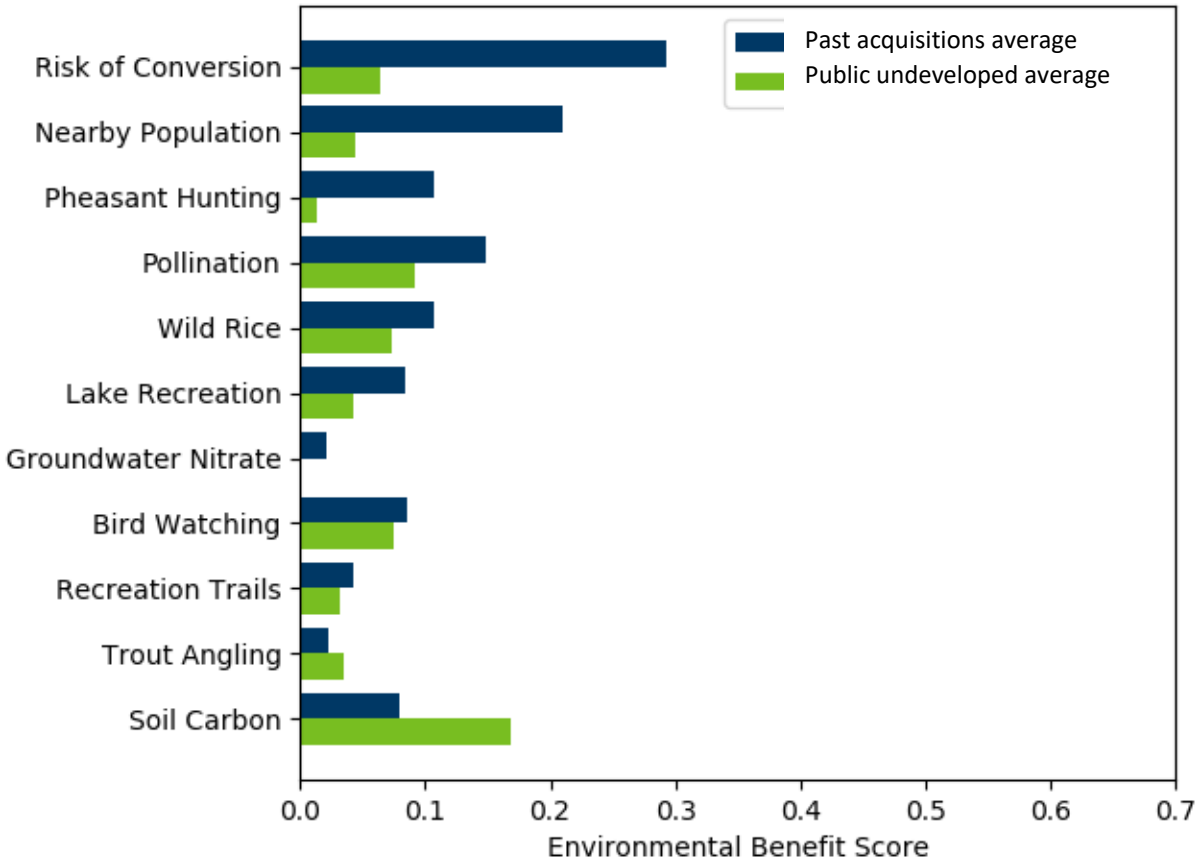
13-023-002	BWSR	35.1	2012	2,592	2,592	**0**
11-049-002	MN DNR	33.4	2010	3,317	3,301	**0**
11-127-003	BWSR	50	2010	2,054	2,054	**0**
11-053-001	Minnesota Land Trust	44.7	2011	5,801	4,119	**0**
16-037-004	Dakota County	20.6	2016	6,008	2,932	**0**
13-073-002	BWSR	28	2011	2,314	2,314	**0**
14-093-001	Ducks Unlimited	33.6	2012	5,996	4,923	**0**
15-037-003	Dakota County	27.4	2015	2,279	1,071	**0**
11-037-010	Dakota County	39.3	2011	3,621	1,086	**0**
08-127-001	BWSR	46.6	2008	2,329	2,329	**0**
08-129-002	BWSR	70.6	2008	2,820	2,820	**0**
15-037-004	Dakota County	26.1	2015	1,814	925	**0**
14-021-007	Cass County	21.7	2011	9,791	480	**0**
14-021-006	Cass County	38.6	2011	2,610	399	**0**
11-127-004	BWSR	46.4	2010	2,621	2,621	**1**
11-157-004	MN DNR	30	2010	1,848	1,719	**1**
11-129-007	BWSR	30.7	2011	2,874	2,874	**1**
11-127-006	BWSR	79.9	2011	2,539	2,539	**1**
14-151-001	MN DNR	19.34	2013	2,798	1,007	**1**
15-037-001	Dakota County	34.3	2015	2,361	1,133	**1**
14-021-002	Cass County	5.8	2012	25,950	1,427	**1**
14-111-001	Minnesota Land Trust	48.6	2012	1,444	114	**2**
09-041-004	Ducks Unlimited	180	2009	1,328	181	**2**
11-157-005	MN DNR	1220.3	2010	1,139	1,116	**2**
11-173-010	BWSR	43.6	2011	2,432	2,432	**2**
11-129-001	BWSR	15.8	2010	3,178	3,178	**2**
11-127-008	BWSR	20	2011	2,564	2,564	**2**
14-021-003	Cass County	9.4	2010	18,925	520	**2**
14-005-005	Minnesota Land Trust	37.4	2013	32	32	**3**
11-127-001	BWSR	21.6	2010	2,546	2,546	**3**
11-145-003	Ducks Unlimited	75.7	2011	1,520	1,459	**3**
14-021-005	Cass County	4.5	2011	54,892	2,344	**3**
09-041-005	Ducks Unlimited	23	2009	1,717	498	**4**
08-127-002	BWSR	79.3	2008	2,920	2,920	**4**
11-129-004	BWSR	3.7	2010	3,044	3,044	**4**
14-005-004	Minnesota Land Trust	198.9	2013	953	953	**4**
12-163-001	Minnesota Land Trust	294	2012	988	10	**5**
11-145-005	Minnesota Land Trust	56.5	2011	681	586	**5**
11-045-002	MN DNR	40.5	2010	2,172	2,164	**5**
11-173-008	BWSR	40.9	2011	2,433	2,433	**5**
11-173-005	BWSR	13.5	2011	2,442	2,442	**5**
15-025-001	Minnesota Land Trust	79	2014	30	30	**5**
12-173-001	BWSR	61	2011	2,438	2,438	**5**

15-059-001	Minnesota Land Trust	158.5	2014	1,140	1,057	**5**
11-173-003	BWSR	40.4	2010	2,518	2,518	**6**
11-173-002	BWSR	26.3	2010	2,523	2,523	**6**
11-129-009	BWSR	27.6	2011	2,882	2,882	**6**
11-173-009	BWSR	18.5	2011	2,506	2,506	**7**
09-025-002	Minnesota Land Trust	140	2007	4,852	446	**8**
14-021-009	Minnesota Land Trust	31	2013	313	313	**8**
14-067-001	Minnesota Land Trust	30.7	2011	5,105	97	**8**
11-173-006	BWSR	44.5	2011	2,449	2,449	**8**
14-121-001	MN DNR	65.7	2014	1,435	1,435	**9**
11-173-001	BWSR	43	2010	2,503	2,503	**10**
11-075-001	MN DNR	2.8	2008	3,620	3,620	**10**
15-037-002	Dakota County	103.1	2012	30,633	1,532	**10**
16-155-001	MN DNR	150.8	2014	2,891	1,792	**10**
11-173-007	BWSR	35.4	2011	2,434	2,434	**11**
09-041-003	Ducks Unlimited	78	2008	3,072	184	**12**
11-157-001	MN DNR	262.4	2009	1,032	1,011	**14**
14-021-008	Cass County	6.8	2013	7,398	1,693	**14**
11-011-004	MN DNR	178.8	2010	1,466	537	**15**
11-127-002	BWSR	136.8	2010	3,080	3,080	**17**
16-011-001	MN DNR	125.5	2015	2,316	1,139	**18**
15-143-001	Minnesota Land Trust	79.6	2014	1,331	752	**22**
11-129-005	BWSR	16.6	2010	2,976	2,976	**23**
14-005-002	Minnesota Land Trust	108.7	2013	14	14	**28**
10-003-001	Minnesota Land Trust	45	2010	3,985	3,985	**28**
14-021-001	Cass County	2.7	2012	2,673	1,989	**28**
11-117-001	MN DNR	160.2	2009	1,060	810	**29**
16-167-001	MN DNR	53.4	2014	1,795	1,478	**31**
11-037-011	Dakota County	16.8	2011	20,802	8,258	**33**
11-011-003	MN DNR	63.2	2010	1,527	1,482	**34**
09-161-001	Ducks Unlimited	12.42	2008	7,809	6,481	**42**
11-149-004	BWSR	122.8	2010	4,717	1,509	**43**
12-127-001	MN DNR	19.6	2012	2,895	2,861	**44**
14-041-002	BWSR	39.5	2013	2,722	1,062	**45**
14-005-006	Minnesota Land Trust	58	2013	25	25	**50**
14-041-001	BWSR	343.9	2012	2,345	891	**51**
14-041-005	BWSR	55.1	2014	2,728	1,200	**51**
14-041-003	BWSR	192.2	2014	2,530	1,139	**53**
14-015-001	MN DNR	26.99	2014	4,856	4,759	**66**
11-025-001	Minnesota Land Trust	39.7	2010	2,771	416	**67**
14-005-003	Minnesota Land Trust	71	2013	75	75	**72**
13-111-002	Minnesota Land Trust	71	2013	38	38	**72**
11-145-004	Minnesota Land Trust	43.9	2011	2,649	2,331	**85**

08-041-001	Ducks Unlimited	111	2007	1,131	987	**88**
14-007-001	Minnesota Land Trust	145.5	2014	30	30	**110**
11-157-002	MN DNR	114.4	2009	1,489	1,429	**113**
11-035-002	Ducks Unlimited	150	2011	1,093	1,049	**120**
09-051-003	Ducks Unlimited	28.62	2008	2,139	428	**121**
11-075-005	Minnesota Land Trust	88	2010	1,631	188	**182**
11-149-003	BWSR	155.8	2010	4,417	398	**696**
12-035-001	Minnesota Land Trust	88	2011	926	259	**2120**

Portfolio Statistics: public land comparison

Figure 3. Analysis of ENRTF portfolio in comparison to all publicly held parcels in the state. The further the blue bar is past its adjacent green bar, the more that metric is represented in past acquisitions relative to all *publicly held undeveloped* parcels.



Parcel Environmental Benefit Assessment Tool

Expanded Documentation

October 2018, version 1.2

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Table of Contents

Key Scoring Concepts

Indices

Our environmental benefit metrics are presented in the form of indices. An index is useful for conveying prioritization within a defined area (i.e., the state of Minnesota), because the highest value can be mapped to 1 and the lowest to 0 while still maintaining the relative distributions of priority within (e.g., 0.8 is much higher priority than 0.2).

Indices were also important when we wanted to use multiple datasets to inform prioritization. For example, in our lake recreation metric we indexed the sub-scores for phosphorus sensitivity, amenities, and social media based visitation. This allowed us to perform a weighted sum of components that were originally in different units. We calculated indices by subtracting the lowest observed value from every value in the dataset and then dividing each value by the range observed in the dataset. As an example, imagine our soil carbon data were composed of 5 observations:

Original data (Mg/ha)	Indexed value
23	0
176	1
40	0.11
105	0.54
92	0.45

Endpoints

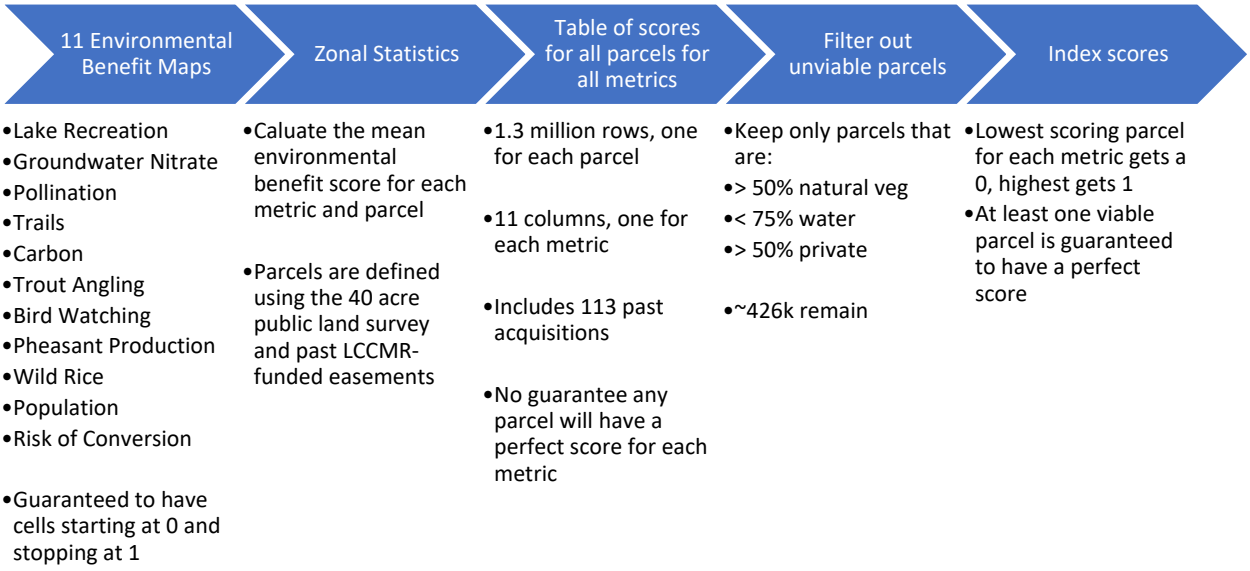
Endpoints are a geographic area where an environmental benefit is produced. Some services, such a soil carbon, are produced almost everywhere, and do not have specific endpoints. Others, such as drinking water protection from nitrate contamination, are only produced only in the recharge area for a wellhead. Our environmental benefit metrics are statewide maps, but if the service is specific to an endpoint, the scores outside of the endpoint are zero. The definition of the endpoint is provided in the metric documentation below.

Base Scores

Many of our metrics provide prioritization between and within endpoints. To represent the scarcity of endpoint based metrics relative to those that are produced broadly, we assign a base score to any land that is with the endpoint of metrics for wild rice, lake recreation, trout angling, trails, and groundwater nitrate. Endpoint base scores were

also used to refine prioritization in the pollination metrics. We did not perform further prioritization on endpoints in the wild rice or trails metrics, therefore their base scores are 1. For the remaining metrics, we selected a base score of 0.2 to ensure land in an endpoint stood out against land that does not contribute to that service, but also reserved enough of the total possible score to prioritize between and within endpoints.

Flow chart



Parcel Data Preparation

Parcel Data

We used 40 acre public land survey parcels as an approximation for the scale that land management decisions are made. They are intended as an approximation of management boundaries; they do not capture sub-division and other changes over time. Specifically, we used plsown_fortypy3.shp, which is the version modified to better match the MNDNR Land Records. We further modified it by removing three polygons that represented large lakes (GM_CH = '4000000000099', '11000000000099', and '48000000000099'). We then split apart (with an operation commonly known as also known as 'explode') multi-part polygons and assigned all parcels a new unique identifier.

Viable Parcel Criteria

Due to sub-division and management changes, our parcel data may not align with all management or ownership boundaries. We used thresholds to determine if they should be included in the 'viable' comparison set. We included parcels that were > 50% natural vegetation, < 75% water, > 50% privately held.

To calculate the proportion of each land cover in each parcel, we performed zonal statistics using the University of Minnesota's Minnesota Land Cover Classification and Impervious Surface Area by Landsat and Lidar: 2013 update - Version 2. We grouped the continuous measurement of imperviousness into three categories to facilitate analysis as categorical data. Although newer land cover maps are available from the Cropland Data Layer, these are optimized for crop detection, rather than non-agricultural land covers. The U of M data is also higher resolution and uses modern object-based classification techniques. It was the preferred land cover map in this analysis unless crop specific information was required.

To create a comparison set of viable parcels we excluded publicly held land. We also excluded land that was privately held but was already protected with a conservation easement, or by a private conservation NGO. We performed zonal statics on a raster containing several merged layers of ownership data to get the proportion each parcel that is privately held. The datasets and assumptions we used to define public land are described below, and implemented in the script define_viable_parcels.py.

Data layer: Natural Resources Conservation Service Easements

URL: available from the Geospatial Data Gateway

Additional processing: We only included the subset of permanent easements.

Data layer: State Surface Interests Administered by MNDNR or by Counties

URL: https://gisdata.mn.gov/dataset/plan-stateland-dnrcounty

Additional processing: This layer does not contain the exact boundaries of parcels, but rather records what proportion of a PLS 40 acre parcel is held by the state. Some records were missing data for the proportion of the parcel that is held by the state, but did have the absolute area. We calculated the proportion for all parcels using the value for absolute area of the state and the GIS calculated area of the parcel. Our analysis is conducted at the PLS 40 acre level, so we defined publicly held as those with greater than 50% held by the state. We excluded any interests that were not matched at the forty/glot level because they could not be mapped precisely enough for this analysis and there were very few interests not matched at this level. We applied this processing to two layers in the state surface interests layer; land held in fee-title and permanent conservation easements.

Data layer: GAP Stewardship 2008

URL: ftp://gdrs.dnr.state.mn.us/gdrs/data/pub/us_mn_state_dnr/plan_gap_stewardship_2008.zip

Additional processing: We used a subset which included parcels where the 'OWNER_DESC' attribute was equal to: county, federal, other public, or private conservancy.

Data layer: Protected Areas Database of the United States (PAD-US) version 1.4

URL: https://gapanalysis.usgs.gov/padus/data/download/

Additional processing: We used a subset which included only land that had a protection status of 1 or 2, which corresponds to land managed for biodiversity. We also excluded the category as 'Designation' because it can include private unprotected land.

Data layer: State Funded Conservation Easements (RIM Reserve)

URL: https://gisdata.mn.gov/dataset/bdry-bwsr-rim-cons-easements

Additional processing: We used a subset which included only permanent easements. We also excluded the category ‘ACUB’ (Army Compatible Use Buffer) because these easements prevent development, but not agriculture.

Due to uncertainty in land cover and ownership maps, we do not exclude any land from the underlying environmental benefits that are used to score a proposed acquisition. It is the responsibility of the user to propose parcels that are undeveloped and not already protected.

Past Acquisitions Data Preparation

Identifying Data Inconsistencies

Spatial and cost data were provided by the LCCMR, with recent entries acquisitions manually updated with information available on the LCCMR website. While recent LCCMR acquisitions have relatively consistent data, acquisitions prior to 2010 sometimes had inconsistencies that needed to be addressed before inclusion in the past acquisitions comparison data. We cannot include any acquisition that does not have spatial data of the boundaries available, which was not typical prior to 2007. Inconsistencies fell into two main categories; spatial data, and contributions to the total project costs. The source data and code used to identify inconsistencies and apply other corrections is available in the script past_acquisitions_prep.py in the expanded base data.

We identified inconsistencies in spatial data by calculating the area of each of the provided parcel boundaries and comparing it to the reported size of the acquisition. Differences typically occurred when multiple parcels were lumped together in one data source but not the other, or when a point was converted to a small polygon instead of the complete boundaries of a parcel. When the reported and calculated sizes were notably different, the acquisition was excluded.

To identify manual corrections in cost data, we compared ‘enrtfdollars’/’totalfundsdollars’ to ‘enrtfpercent’. ‘enrtfdollars’ is the expenditures from the Environment and Natural Resources Trust Fund (ENRTF), ’totalfundsdollars’ is the total cost of the project which includes funding from all sources, and ‘enrtfpercent’ is the proportion of the total costs paid by the ENRTF. If the breakdown of organization contributions and the total cost were consistently reported, these values should be the same. If the difference was less than +/- 2 it was assumed to be due to rounding and was ignored. For larger differences, the larger of either ‘totalfundsdollars’ or the sum of all funding sources (i.e., ‘enrtfdollars’, ‘othersfdollars’, ‘fedfundsdollars’, ‘reglocaldollars’, ‘npfundsdollars’, bargaindollars, otherfundsdollars, and related professional costs), was used as the total project cost which was in turn used to calculate a new ‘enrtfpercent’. To be consistent in our calculations and maximize use of the most reliable data (i.e., the expenditures of the ENRTF) we divided the ‘enrtfdollars’ by ‘enrtfpercent’ to give the total project costs. Other errors such as recording percentages as a fraction of 1 or not calculating the percentage were also corrected.

Adjusting for Inflation

We adjusted the costs of past acquisitions to 2016 dollars using the Consumer Price Index from the Bureau of Labor Statistics.

Excluded Parcels

To be consistent with our metrics designed for conservation easement prioritization, we excluded fee-title acquisitions from the past acquisitions comparison set. We also excluded agricultural easements from Rural Advantage and short term "3rd crop" easements, as they have already been converted to agriculture.

After filtering out inconsistencies, adjusting for inflation, and excluding inappropriate comparisons, 97 conservation easement acquisitions remained. Their scores and price per acre can be viewed in the scatter plots in the metric descriptions below. Note that for display purposes two acquisitions with costs above $31,000 an acre are not shown, however, those values are included in the mean ROI comparison metrics.

Risk of Conversion

Overview

We calculated risk of conversion by modeling the probability that a location will convert from natural land to developed land. This is a preliminary metric based on new, ongoing research at the University of Minnesota (see Hyejin et al., 2018[1] for more details). To determine which grid-cells have the highest risk of conversion, the metric combines coarse-scale projections of land-use change from the Intergovernmental Policy Platform on Biodiversity and Ecosystem Services and the Land-Use Harmonization project (LUH) with fine-scale data on conversion probability based on physical suitability, adjacency to existing land-use types and conversion constraints for each grid-cell.

High priority parcel description

Endpoint: Statewide

A high priority parcel:

- has a high probability of converting to agriculture or human development
- is near existing agriculture or development
- is in a 30 km^2 gridcell projected to have high expansion of cropland or human development
- has high suitability for agricultural expansion (in terms of potential yield) or human development (physically suitable location)

Data sources

Land-use, land-cover data from the European Space Agency's Climate Change Initiative

https://www.esa-landcover-cci.org/

Coarse land-use, land-cover projections based on Shared Socioeconomic Pathways

Defined by the Intergovernmental Science/Policy Platform on Biodiversity and Ecosystem Services, provided by the Land-Use Harmonization project (available at

[1] Kim, HyeJin, et al. "A protocol for an intercomparison of biodiversity and ecosystem services models using harmonized land-use and climate scenarios." *bioRxiv* (2018): 300632.

http://luh.umd.edu/data.shtml, based on the RCP7.0, SSP3 states.nc file http://gsweb1vh2.umd.edu/LUH2/LUH2_v2f/AIM/multiple-states_input4MIPs_landState_ScenarioMIP_UofMD-AIM-ssp370-2-1-f_gn_2015-2100.nc

Climate data from Worldclim version 2.0

http://worldclim.org/version2

Soil data from ISRIC

https://soilgrids.org/#!/?layer=TAXNWRB_250m&vector=1

Digital elevation map from Hydrosheds
https://hydrosheds.cr.usgs.gov/datadownload.php?reqdata=3dirb

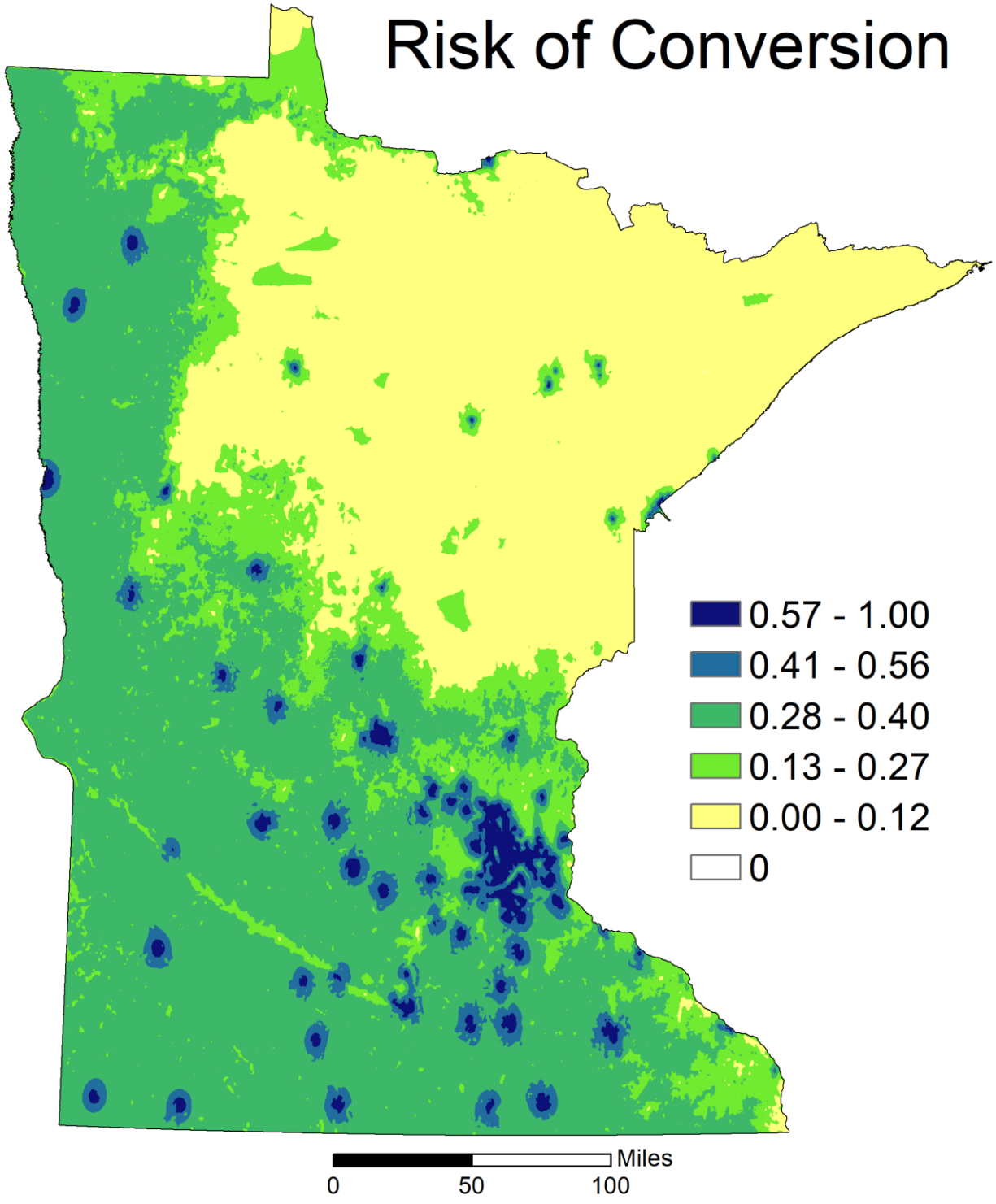
Crop suitability from the Food and Agriculture Organization of the United Nations Global Agro-Ecological Zones project

http://www.fao.org/nr/gaez/en/

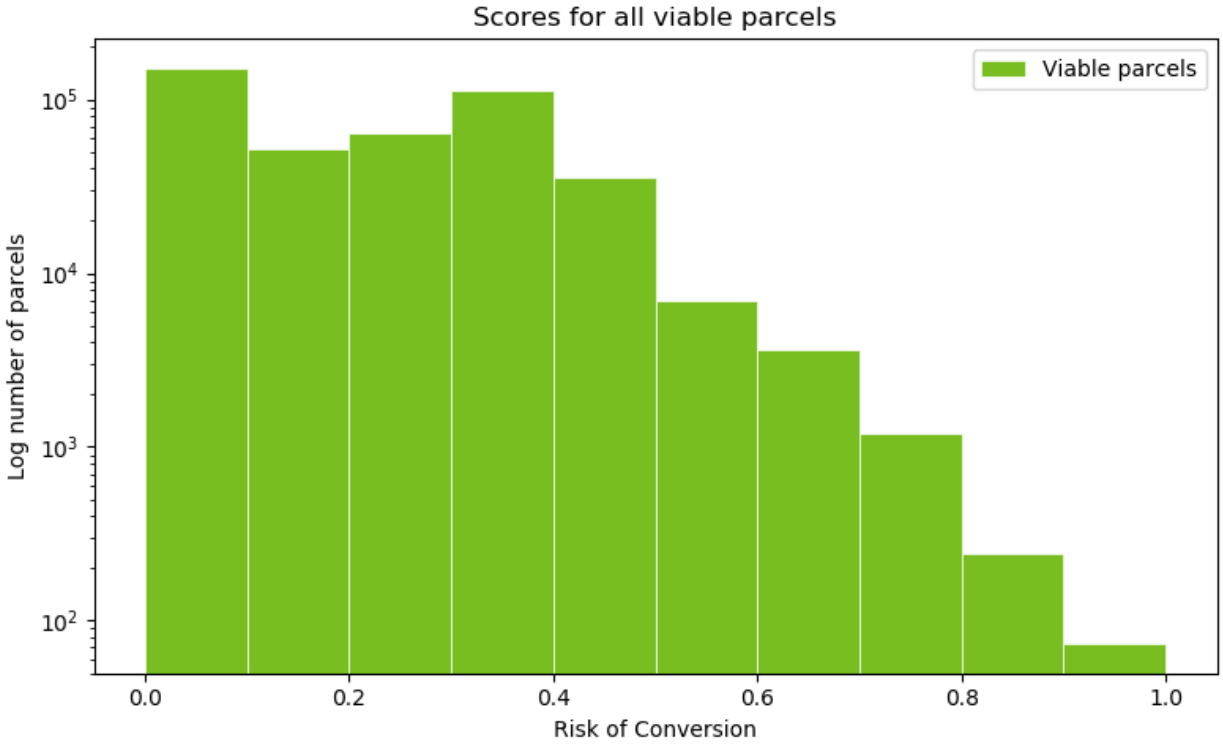
Data preparation

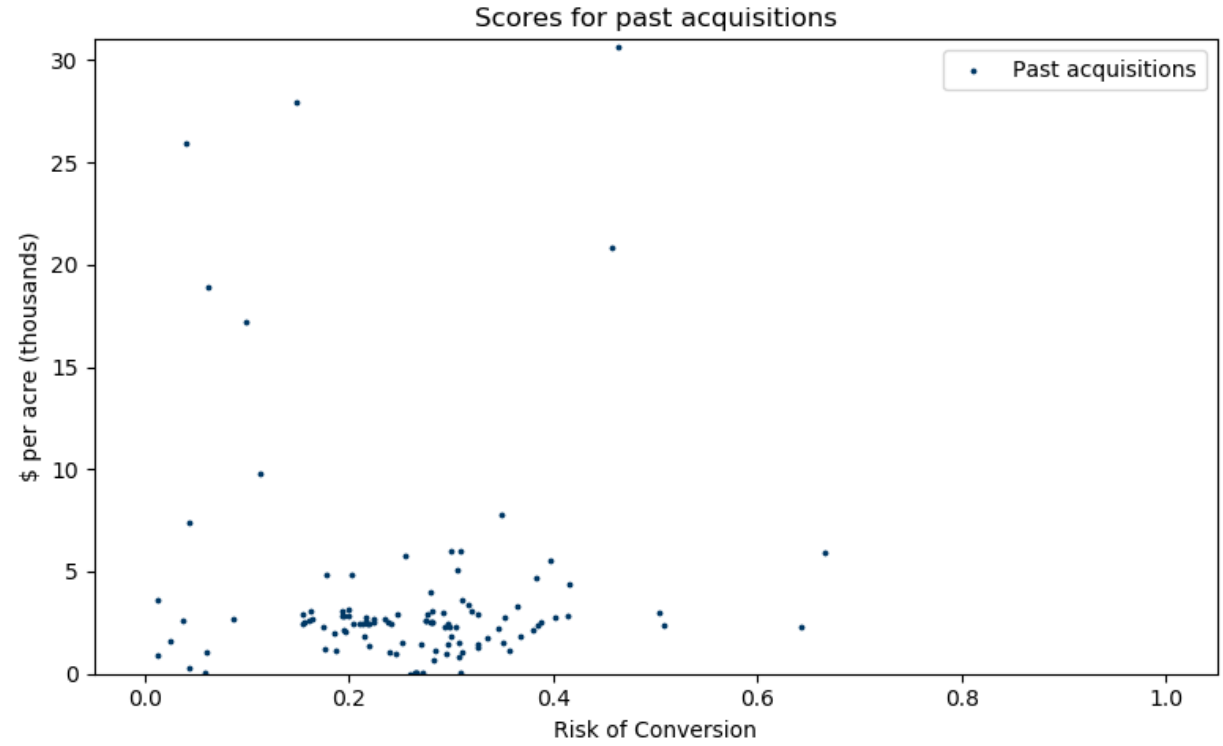
Soil data for organic carbon content, digital elevation data and land-use, land-cover were combined via log-normalized, equal weighted sum-product to produce a proxy of land-suitability. The DEM data were processed further to calculate topographic roughness indicator and topographic ruggedness indicator for physical suitability. Crop suitability was from GAEZ and was also log-normalized and included via equal-weighted sum-product for the cropland-specific risk of expansion. Adjacency suitability was calculated for agriculture and urban expansion separately for each other LULC class in the ESACCI data based on expert calibration to best match observed predictions in the prior time-series of ESACCI LULC data. The physical suitability was log-normal multiplied by adjacency suitability to get overall suitability, which was then multiplied by the projected changes in the LUH data to get weighted adjacency suitability, which was then log-normalized. The risk of conversion metric is the weighted sum of the risk of conversion to agriculture and risk of conversion to urban, where the weight is determined by the proportion that each of those land covers expanded in MN according to coarse global projections from the Land-Use Harmonization project.

Map


Risk of Conversion
0.57 - 1.00
0.41 - 0.56
0.28 - 0.40
0.13 - 0.27
0.00 - 0.12
0
Miles
0
50
100

Score distributions





Nearby Population

Overview

The nearby population metric represents the proportion of the state's population that can easily access the benefits of a proposed acquisition. We assumed nearby population to be the people residing within a radius of 50 miles from each parcel. This distance is based on the US National Tourism Resources Review Commission's definition of a "day trip". The population within 50 miles was calculated using the EPA's 30 meter population map. Higher scoring parcels are those with higher nearby population.

High priority parcel description

Endpoint: Statewide

A high priority parcel:

- has a high proportion of the state's population within 50 miles

Data sources

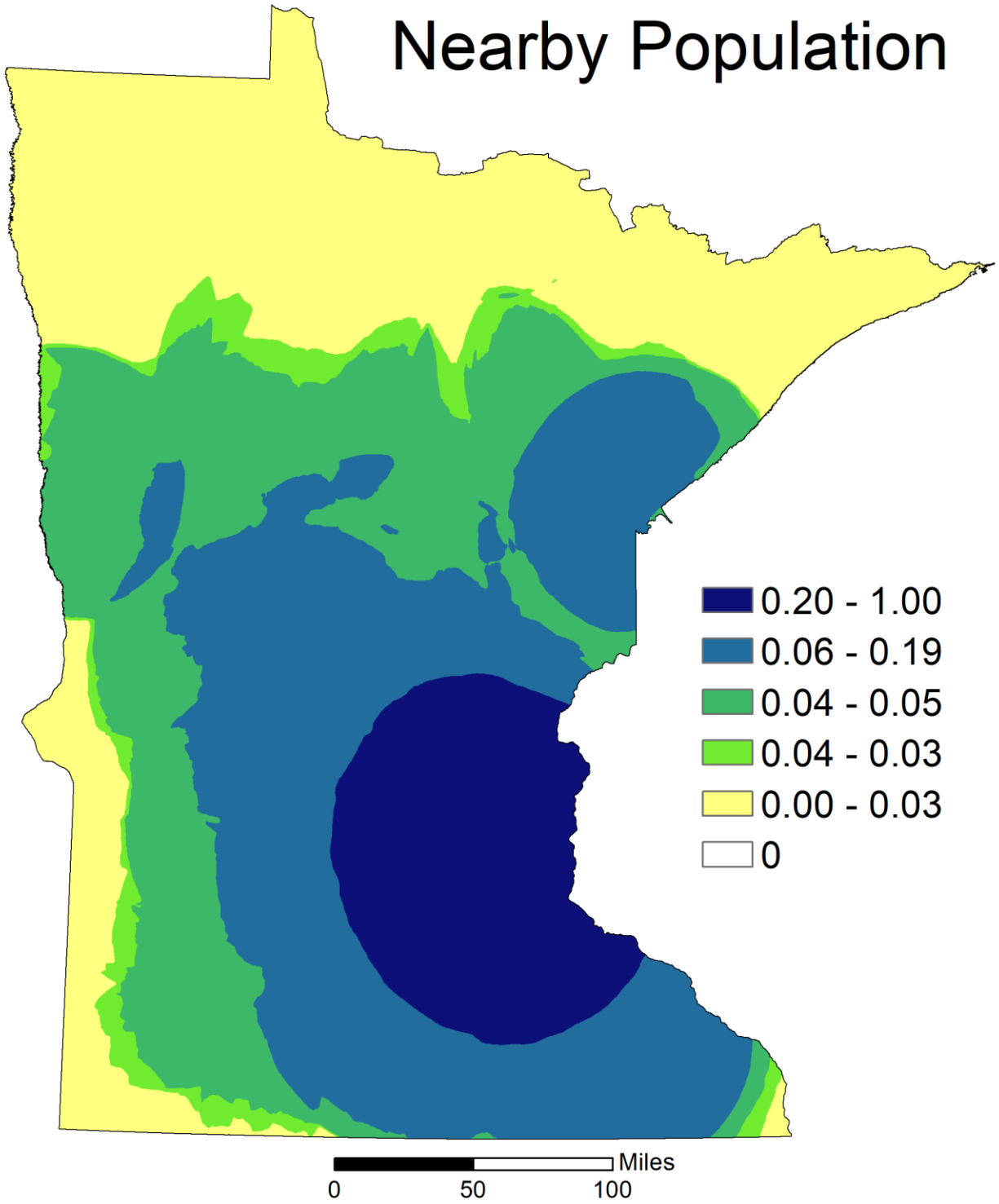
Dasymetric Allocation of Population Raster

ftp://newftp.epa.gov/epadatacommons/ORD/EnviroAtlas/dasymetric_us_20160208.zip

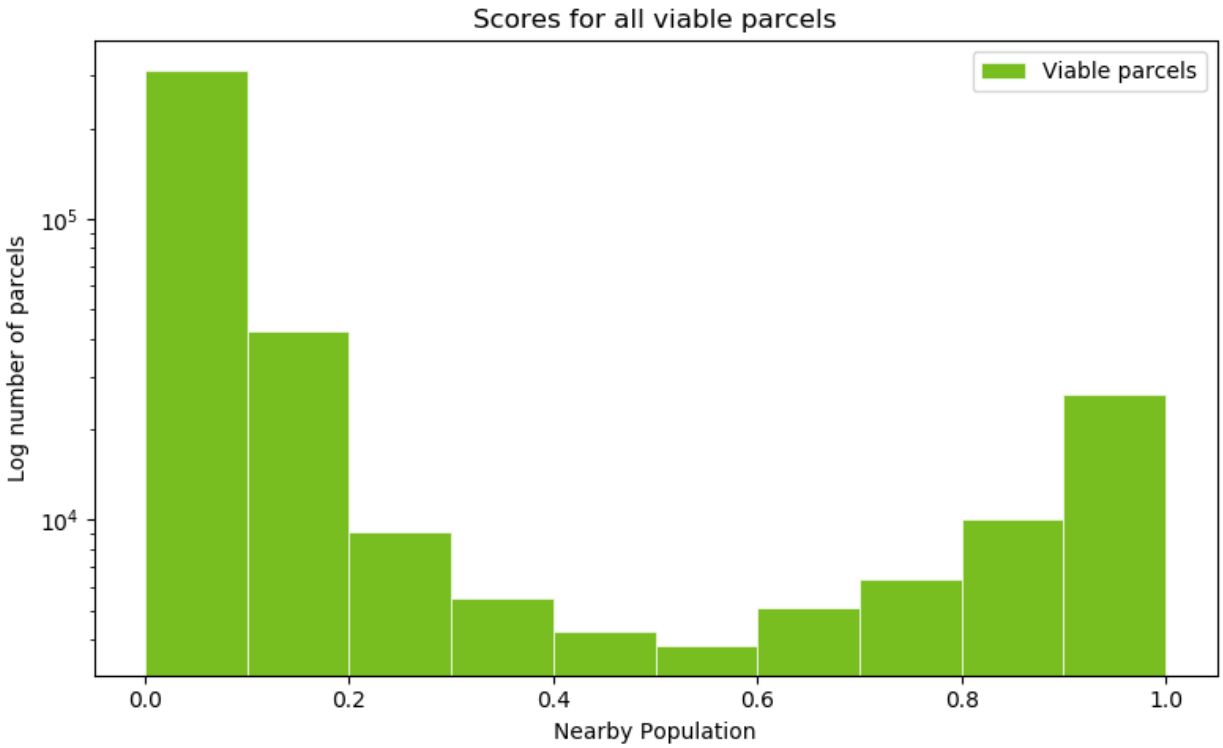
Data preparation

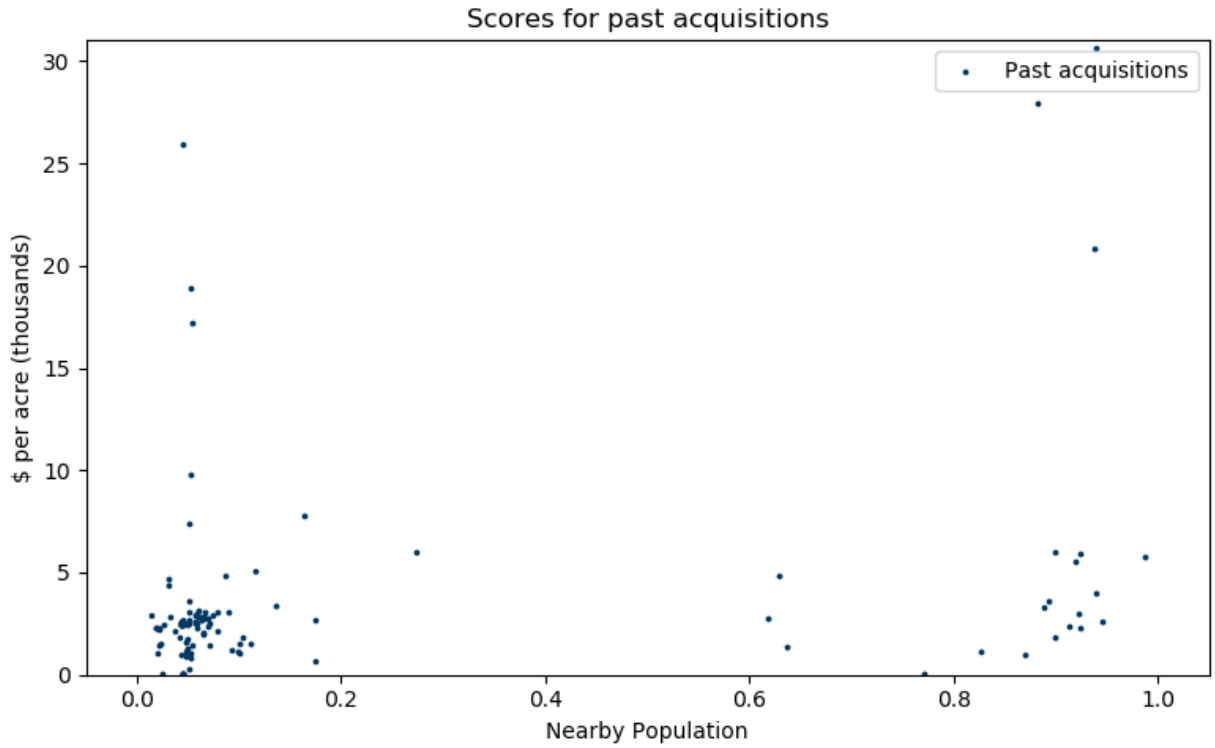
We clipped the EPA's national dasymetric allocation map to the extent of Minnesota and then used ArcGIS focal statistics to calculate the sum of all of the cells within 50 miles of each cell. We selected 50 miles based on the US National Tourism Resources Review Commission's definition of a "day trip" (National Tourism Resources Review Commission, 1973). We divided the population within 50 miles of a cell by the total population of the state (i.e. the sum of all cells in the population map) to produce a map of the proportion of the population of the state within 50 miles of each cell and indexed the result to a zero to one scale.

Map


Nearby Population
0.20 - 1.00
0.06 - 0.19
0.04 - 0.05
0.04 - 0.03
0.00 - 0.03
0
Miles
0
50
100

Score distributions





Soil Carbon

Overview

Carbon stored in the soil can be emitted to the atmosphere when land is developed. We created the soil carbon metric by multiplying the bulk density and percent carbon maps published in Ramcharan (2017). Soil carbon storage benefits are provided throughout the state, but some regions have much higher concentrations of soil carbon than others. For example, north central Minnesota has some of the highest concentrations of soil carbon in the state, often more than 15 times greater than soil in southern Minnesota. High scoring parcels are in carbon-rich areas.

High priority parcel description

Endpoint: Statewide

A high priority parcel is:

- has a high average soil organic carbon content

Data sources

Soil Properties and Class 100m Grids United States (Ramcharan et al., 2017a)

https://doi.org/10.18113/S1KW2H

bd_M_sl6_100m.tif, bd_M_sl5_100m.tif, bd_M_sl4_100m.tif, bd_M_sl3_100m.tif, bd_M_sl2_100m.tif, bd_M_sl1_100m.tif, soc_M_sl6_100m.tif, soc_M_sl5_100m.tif, soc_M_sl4_100m.tif, soc_M_sl3_100m.tif, soc_M_sl2_100m.tif, soc_M_sl1_100m.tif

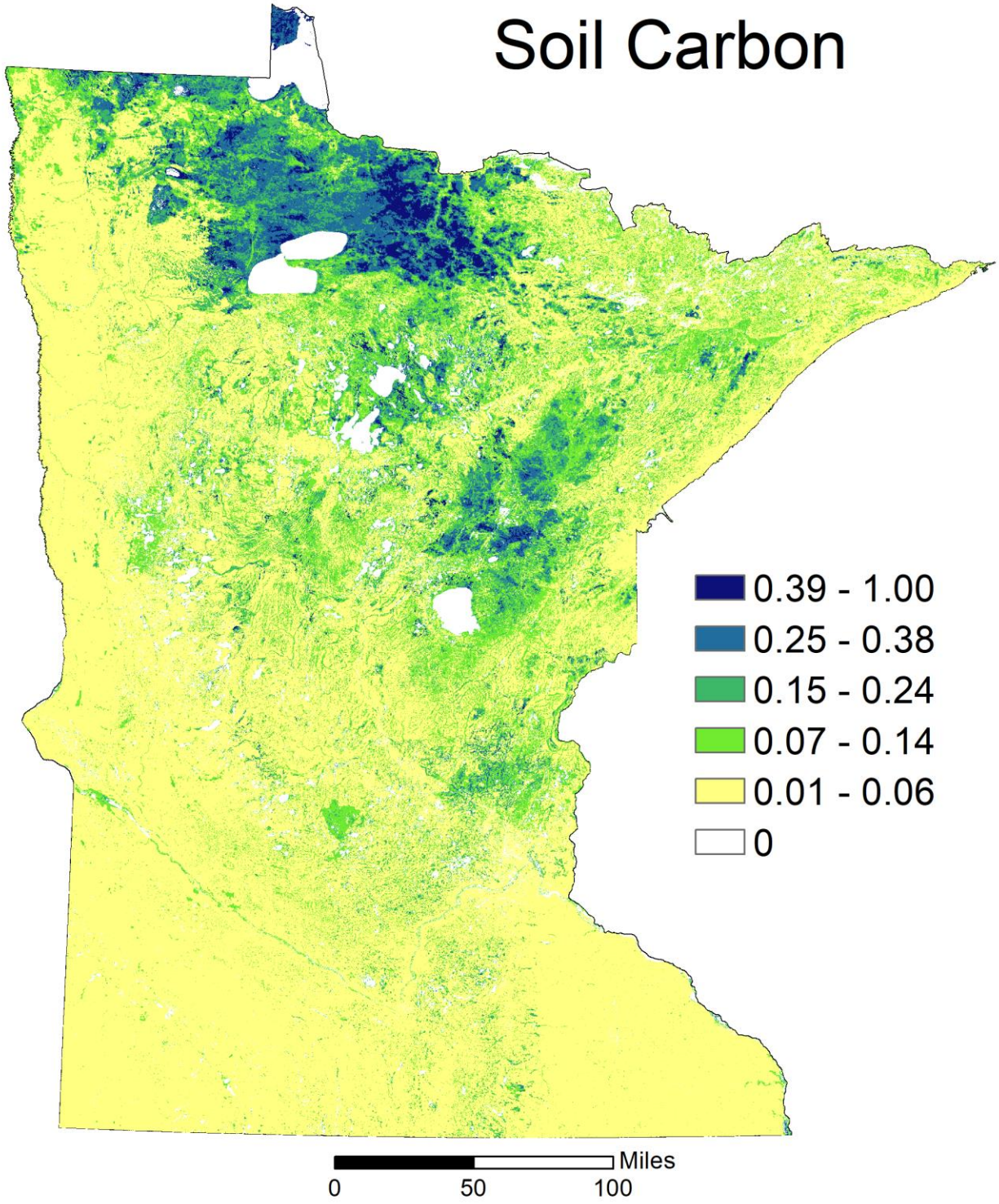
Data preparation

We used maps depicting estimates of bulk density and soil organic carbon percentage at six depths to calculate the metric tons of carbon stored per hectare throughout the state to a depth of one meter (Ramcharan et al., 2017b). The source maps provided estimates at depths of 0, 5, 15, 30, 60, and 100 cm. We created the script carbon.py to combine the source layers and produce our carbon metric.

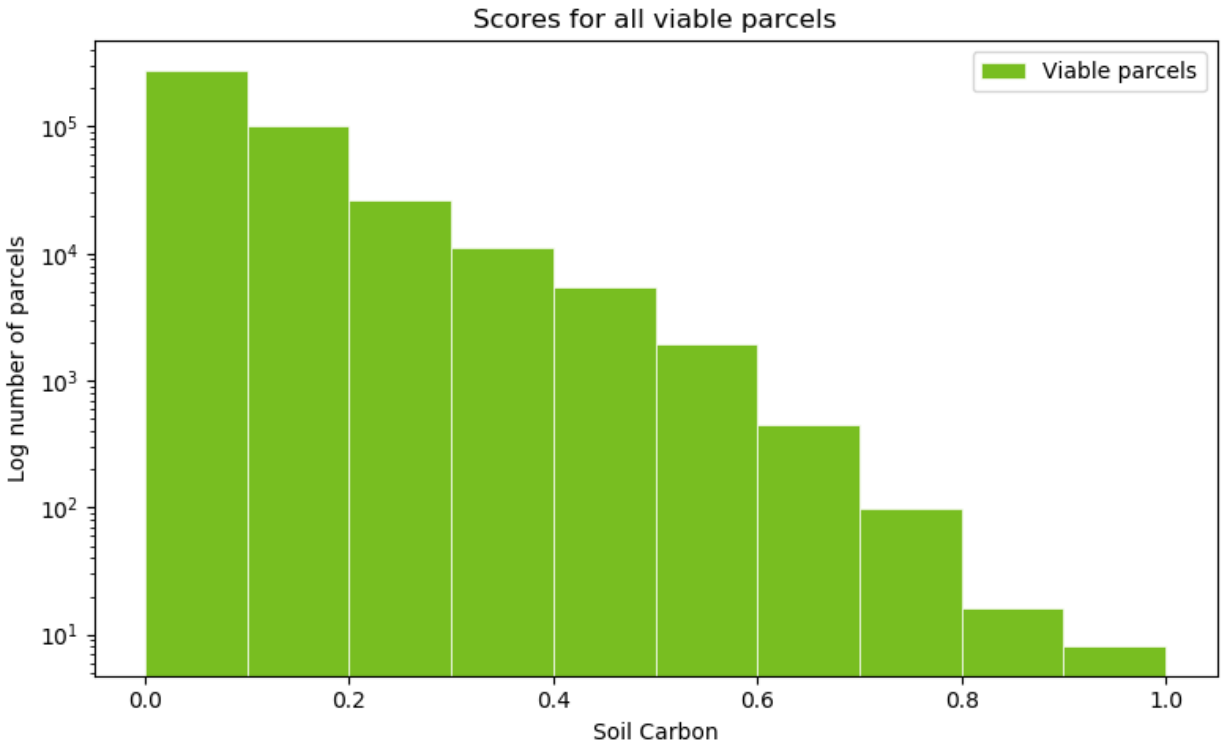
First, the 12 original national maps are aligned, clipped, and projected. Their no data value is set to 0, and they are multiplied by 0.001 because the values in the source data are multiplied by 1000 to facilitate distribution as integer files rather than much larger

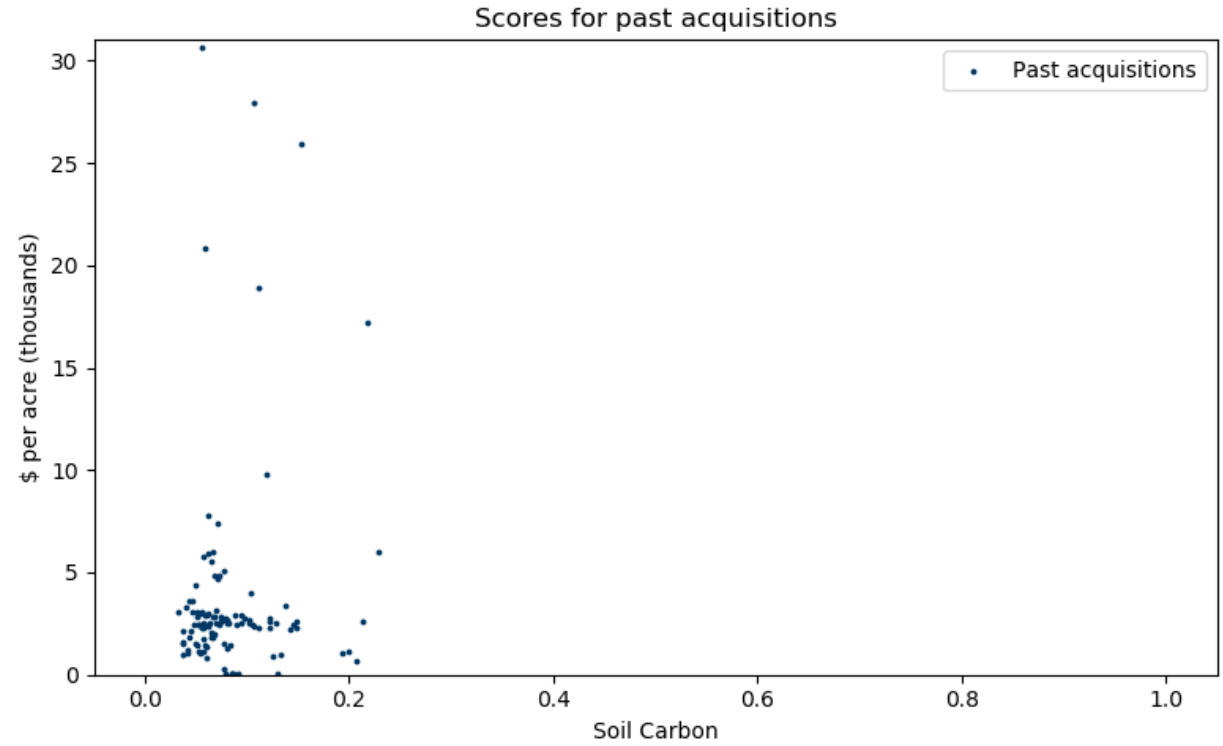
float files. For both bulk density and soil organic carbon maps we took the average of adjacent depth ranges to estimate the value of soil between them (i.e., averaging sl2 and sl3, or sl3 and sl4). Each bulk density layer is multiplied by its corresponding soil organic carbon percentage layer to estimate the amount of carbon in the soil. Each layer is multiplied by the portion of the depth profile it represents (e.g., 30-40cm, is multiplied by 0.1) and summed to estimate the total carbon in one meter of soil.

Map


Soil Carbon
0.39 - 1.00
0.25 - 0.38
0.15 - 0.24
0.07 - 0.14
0.01 - 0.06
0
Miles
0
50
100

Score distributions





Pollination

Overview

Pollinated crops benefit from having an abundant supply of pollinators nearby. This metric uses the output from the InVEST pollination model along with the cropland data layer. The InVEST pollination model uses data on land cover and the foraging habits of bees to produce a bee abundance index. The model output used in this metric is described in Koh (2016). We used the cropland data layers from 2014 to 2017 to identify where pollinated crops such as sunflowers and apples are produced, and buffered these fields by the foraging distance of bees. Consistent with the base score used in other metrics, we assigned a value of 0.2 to land in proximity to pollinated crops. The metric is the sum of the pollinator abundance index and the presence/absence of pollinated crops. High scoring parcels are those that have high relative pollinator abundance and are in close proximity to pollinator-dependent crops.

High priority parcel description

Endpoint: Supplied statewide, with demand concentrated in close proximity to pollinator-dependent crops.

A high priority parcel:

- has land cover and a neighborhood land cover configuration that supports high relative pollinator abundance
- has crops that benefit from insect based pollination within the travel distance of a typical pollinator

Data sources

USDA NASS Cropland Data Layer (CDL) 2014, 2015, 2016, and 2017

https://gisdata.mn.gov/dataset/agri-cropland-data-layer-2014

https://gisdata.mn.gov/dataset/agri-cropland-data-layer-2015

https://gisdata.mn.gov/dataset/agri-cropland-data-layer-2016

https://gisdata.mn.gov/dataset/agri-cropland-data-layer-2017

Invest Pollination Model

http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/croppollination.html

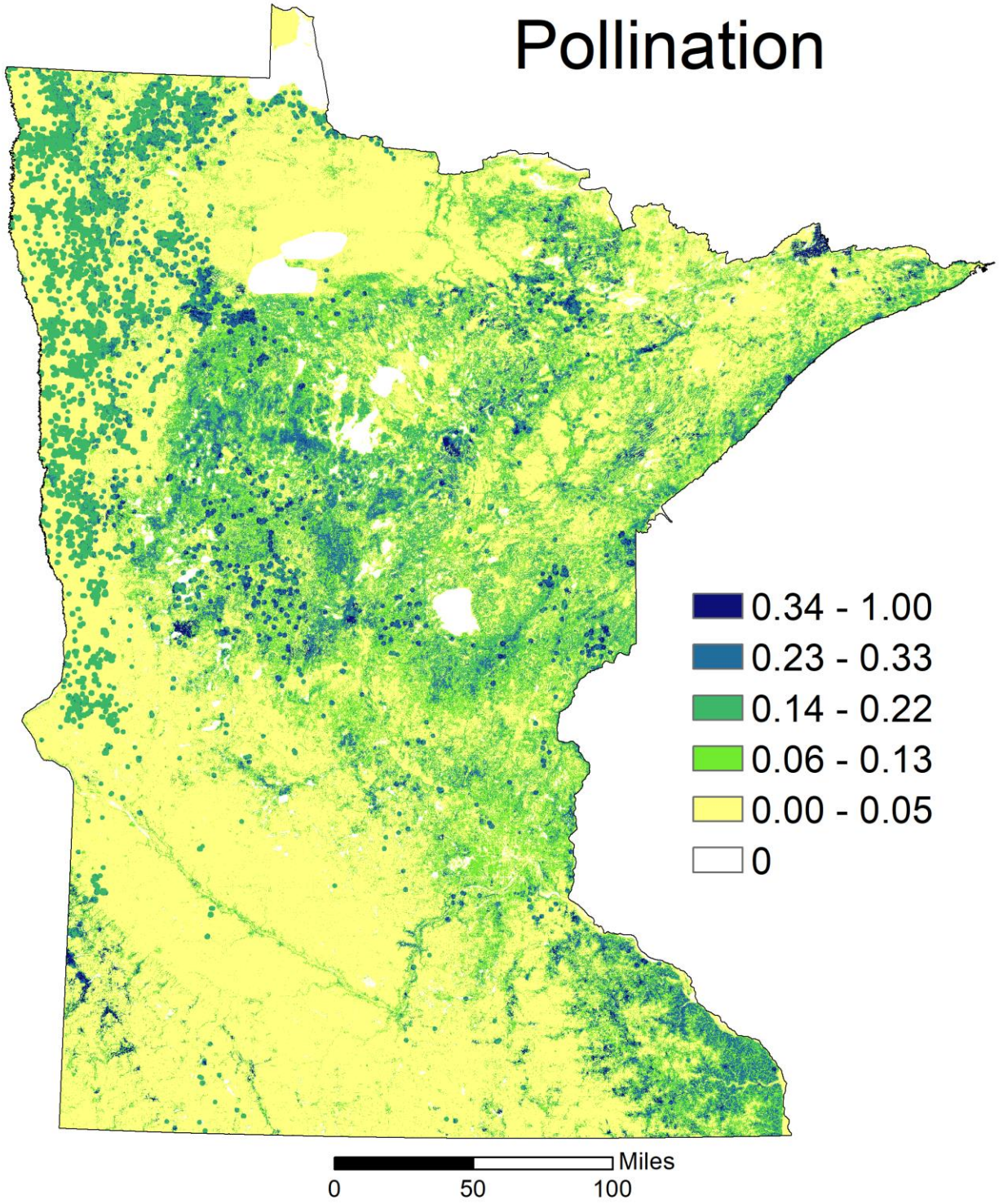
Availability note: the model output used for this metric was originally published in (Koh et al., 2016), (see Figure 1 A), and is available in the expanded base data.

Data preparation

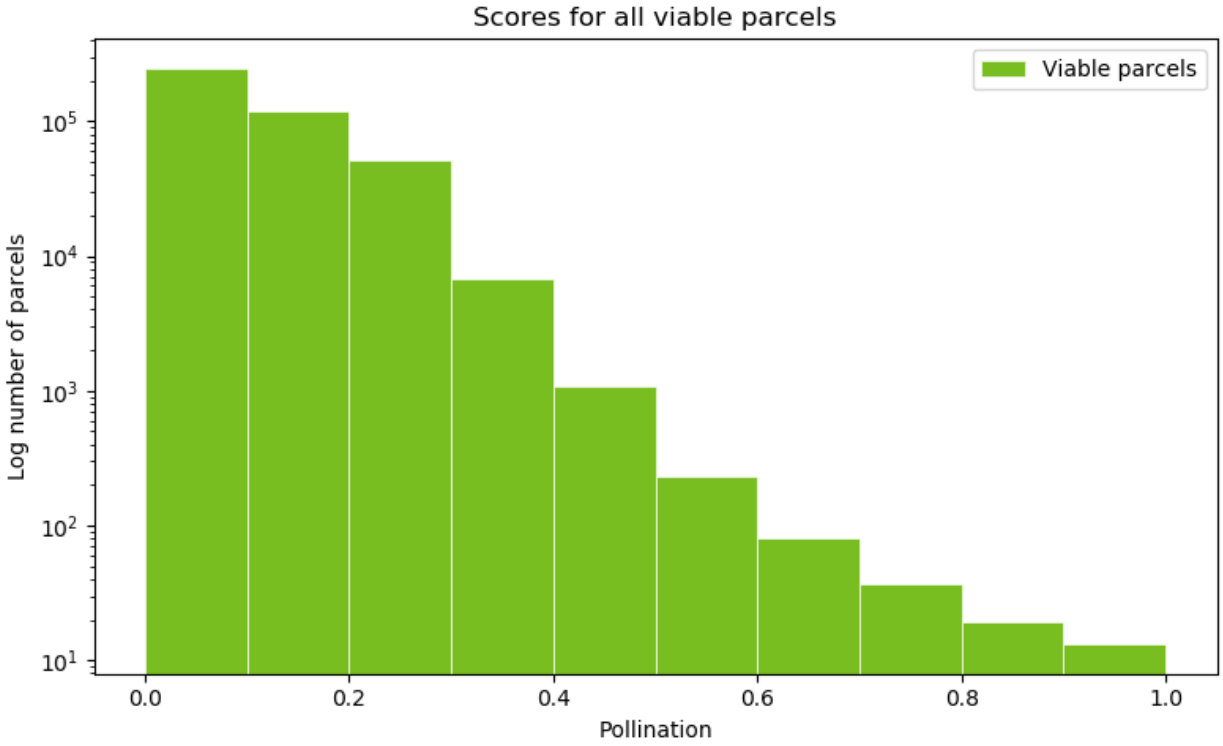
We reclassified the CDL to one for pollinated crops and zero for all other values. The vast majority of pollinated crops in Minnesota are sunflower, but the complete list of CDL codes for pollinated crops we used is in pollination.py. We created a binary map of pollinated crops for each year 2014 through 2017 to capture fields that in are in rotation with crops that are not pollinator-dependent. We used ArcGIS to perform a focal statistics 5x5 majority operation to remove likely erroneous cells that were not a part of a larger field. After filtering, we merged the four years into a single raster and buffered the fields by 1340m to represent the foraging distance of honey bees. Similar to the base score used in other metrics, we assigned all land within the buffer of pollinated crops (i.e., the pollination demand endpoint) a value of 0.2.

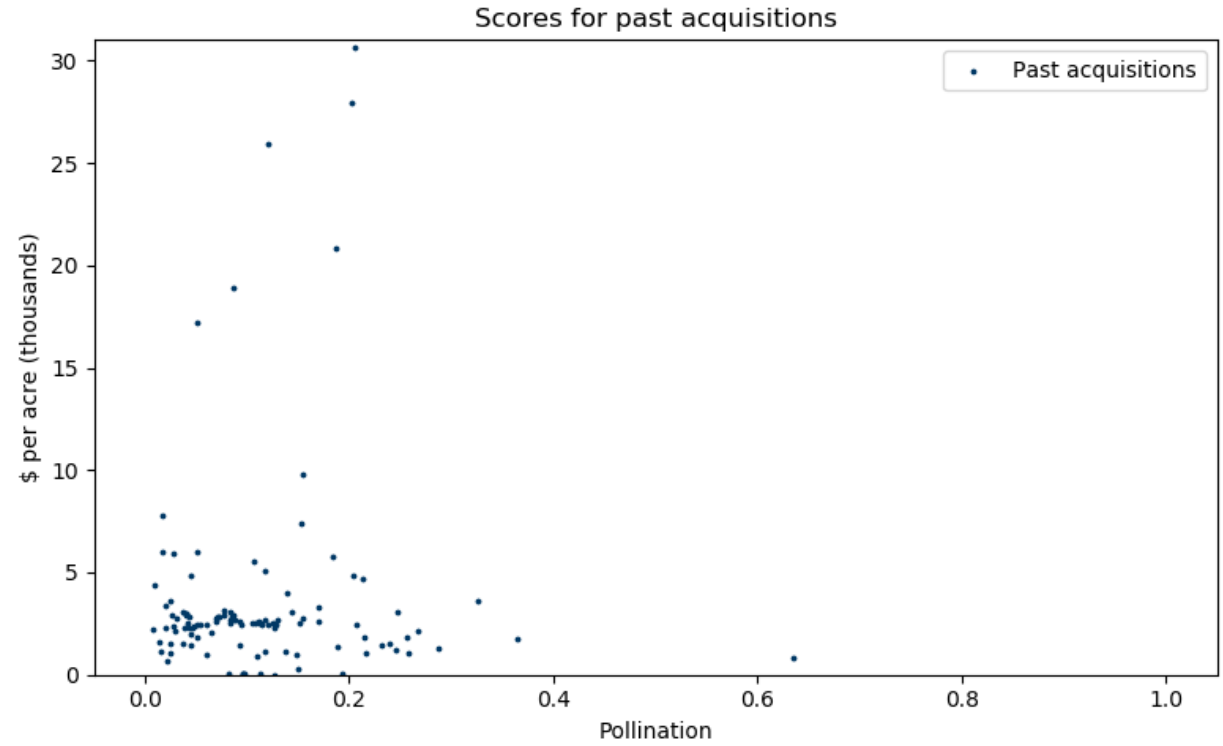
Because the pollination model output is in relative abundance, no further processing was applied except for re-indexing the data to zero to one. The resulting metric is the sum of the pollinator abundance index and the presence/absence of pollinated crops.

Map


Pollination
0.34 - 1.00
0.23 - 0.33
0.14 - 0.22
0.06 - 0.13
0.00 - 0.05
0
Miles
0
50
100

Score distributions





Pheasant Production

Overview

Abundant pheasant populations support pheasant hunters and related industries. Our metric is based on pheasant production models first published in Jorgensen (2014) and then refined in Wszola (2017). In brief, the metric uses relationships between the amount of grass, agriculture, small grains, trees and wetlands in one or five kilometer buffers around a proposed parcel to estimate relative pheasant abundance. Higher scores are given to parcels with greater potential pheasant abundance.

High priority parcel description

Endpoint: Pheasant range in Minnesota (southern half of the state)

A high priority parcel:

- has a high proportion of grassland within a 1km radius
- has a low proportion of trees within a 5 km radius
- has a low proportion of woody wetlands within a 1km radius
- has a moderate amount of agriculture within a 5 km radius
- has a moderate amount of small grains within a 5km radius

Data sources

USDA NASS Cropland Data Layer (CDL) 2017

https://gisdata.mn.gov/dataset/agri-cropland-data-layer-2017

Minnesota Pheasant Range

https://gisdata.mn.gov/dataset/env-pheasant-range-minnesota

Data preparation

Our metric is based on pheasant production models first published in (Jorgensen et al., 2014) and then refined in (Wszola et al., 2017). The model predicts pheasant abundance based on local and regional scale land cover composition. We adapted the

model to use data available for Minnesota. First, we aggregated land covers categories in the 2017 cropland data layer to five categories used in the Wszola (2017) model; grassland, woodland, wetland, agriculture excluding small grains, and small grains. The reclassification tables and maps are available in the expanded base data.

The original model also found that Conservation Reserve Program (CRP) land within one kilometer was a strong predictor of pheasant abundance, however, spatial CRP data is not publicly available. Because we were unable to include this predictor, pheasant abundance may be underestimated by our metric in areas with a high proportion of CRP land.

After masking the inputs to the pheasant range in Minnesota, the final score is calculated as:

index of (exp(3.0666 +

(((-0.54781 * trees_5k) - (-0.54781 * 0.06301747)) / 0.053441) + (((0.131763 * ($trees\_5k^2$)) - (0.131763 * 0.00682374)) / 0.00918277) +

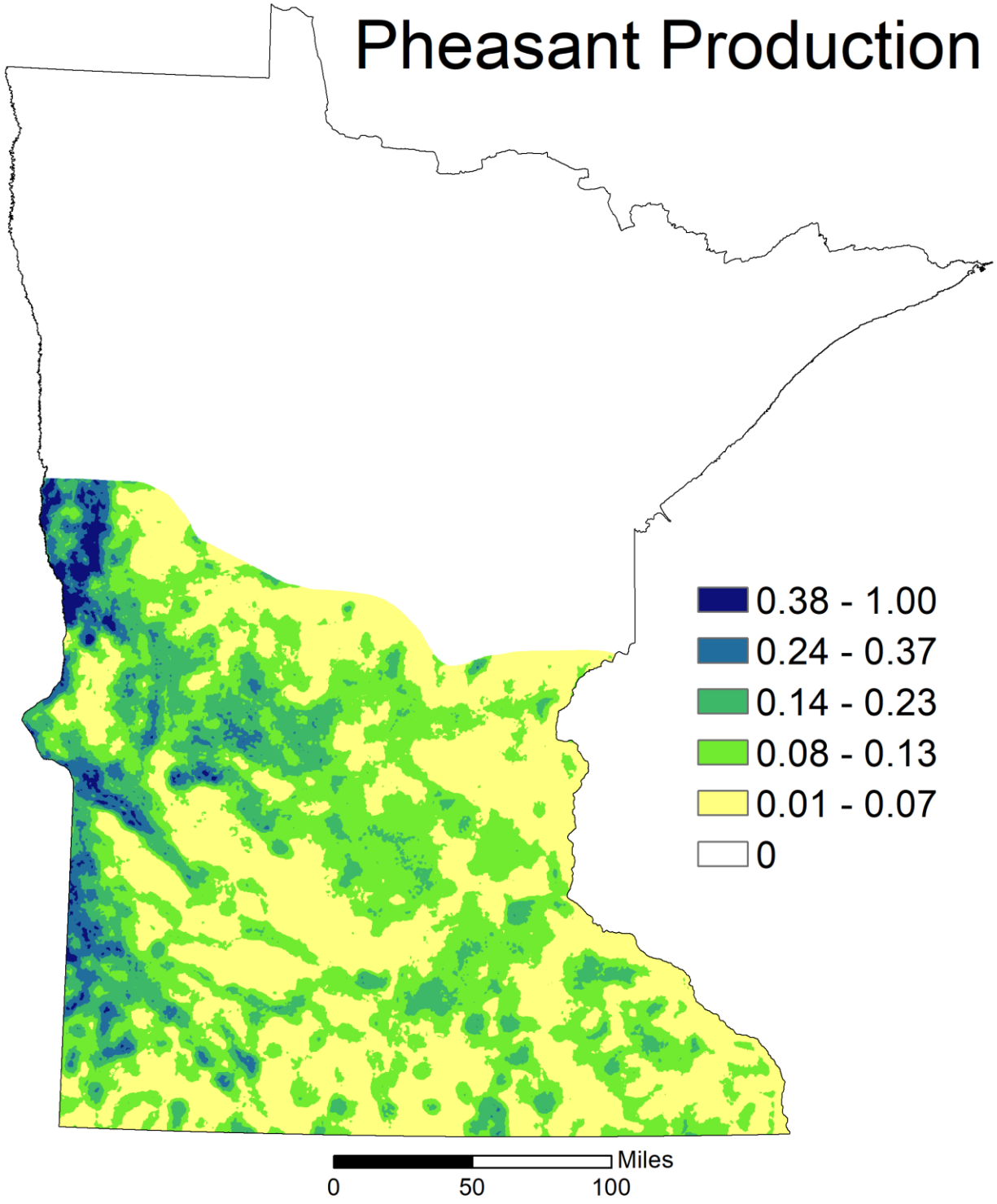
(((0.511138 * ag_5k) - (0.511138 * 0.25670848)) / 0.20208898) + (((-0.05282 * ag_5k^2) - (-0.05282 * 0.10669046)) / 0.16528966) + (-4.6611202 * ag_5k^3) +

(((0.133586 * grass_1k) - (0.133586 * 0.47500357)) / 0.21036192) +

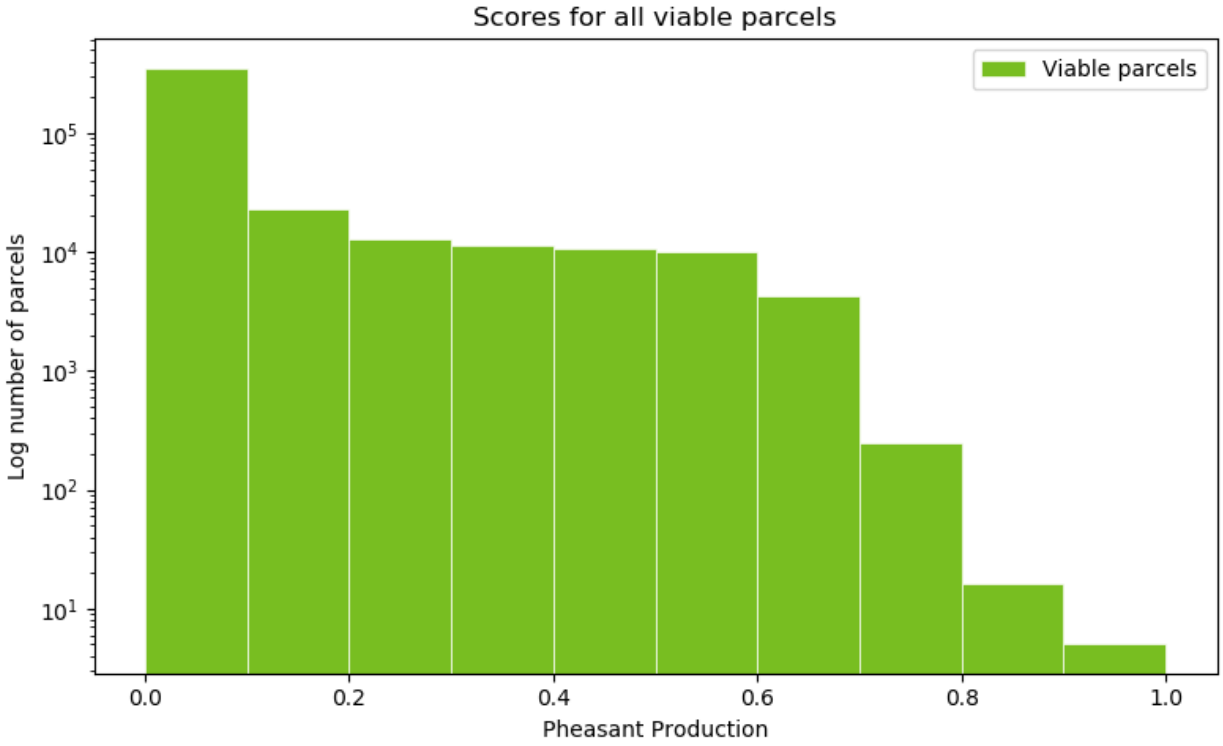
(((0.451256 * sg_5k) - (0.451256 * 0.07708618)) / 0.06580207) + (((-0.04344 * sg_5k^2) - (-0.04344 * 0.01026702)) / 0.016885) + (-6.849455 * sg_5k^3) +

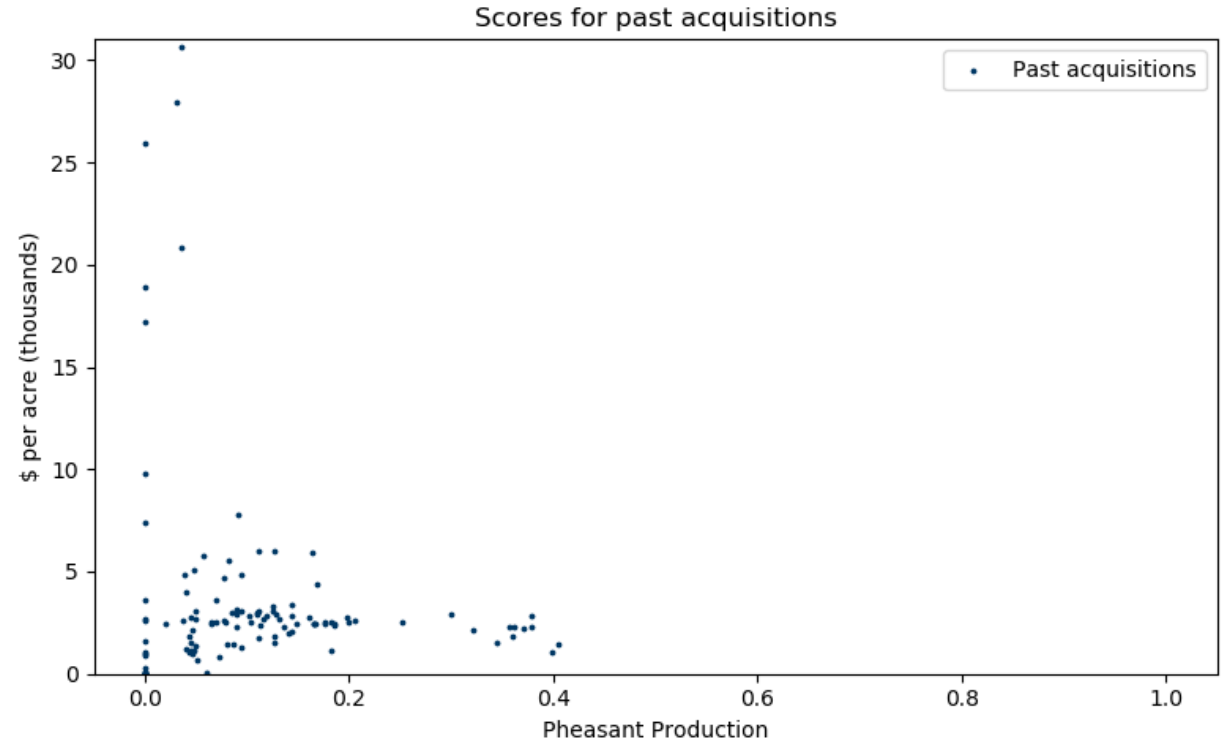
(((-0.10249 * wetland_1k) - (-0.10249 * 0.02997624)) / 0.07880755) - 0.15981))

Map


Pheasant Production
0.38 - 1.00
0.24 - 0.37
0.14 - 0.23
0.08 - 0.13
0.01 - 0.07
0
Miles
0
50
100

Score distributions





Wild Rice

Overview

For this metric, we assume that acquisitions within the catchment of a wild rice site identified by the DNR have the potential to provide wild rice benefits, while parcel outside wild rice catchments do not. If a parcel is partially within a catchment, its score is equivalent to the proportion of the parcel's total area that is within the catchment. We do not differentiate among wild rice sites, nor does the metric account for the impact of management on wild rice habitat or water quality.

High priority parcel description

Endpoint: Catchment of wild rice sites

A high priority parcel:

- is entirely within the catchment of a wild rice site

Data sources

Wild rice sites

Availability note: The exact point location of wild rice sites is not posted publicly. Our metric identifies the catchments with wild rice within them, but we do not include the point data used to identify them.

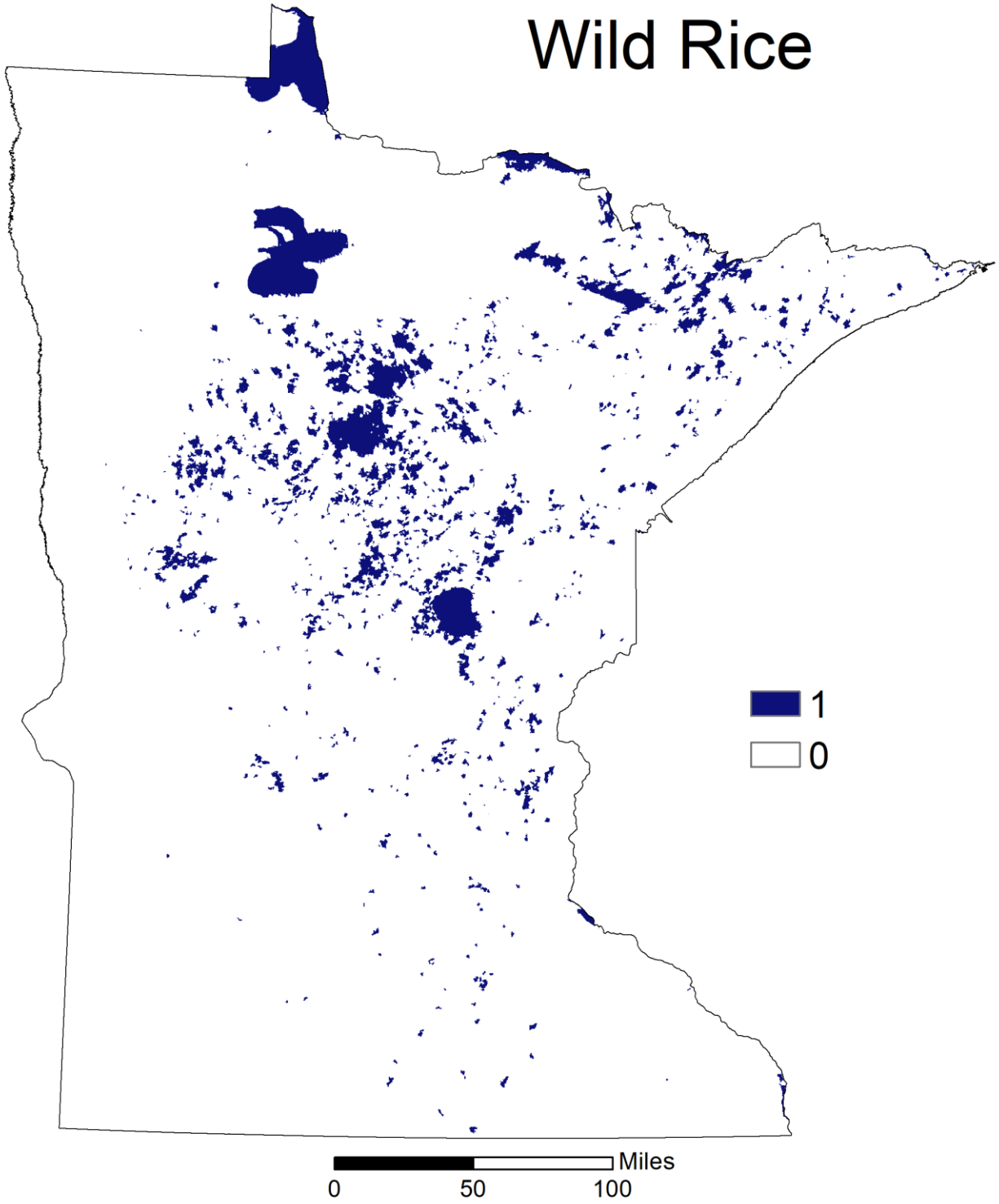
MNDNR Level 09 - DNR AutoCatchments

https://gisdata.mn.gov/dataset/geos-dnr-watersheds

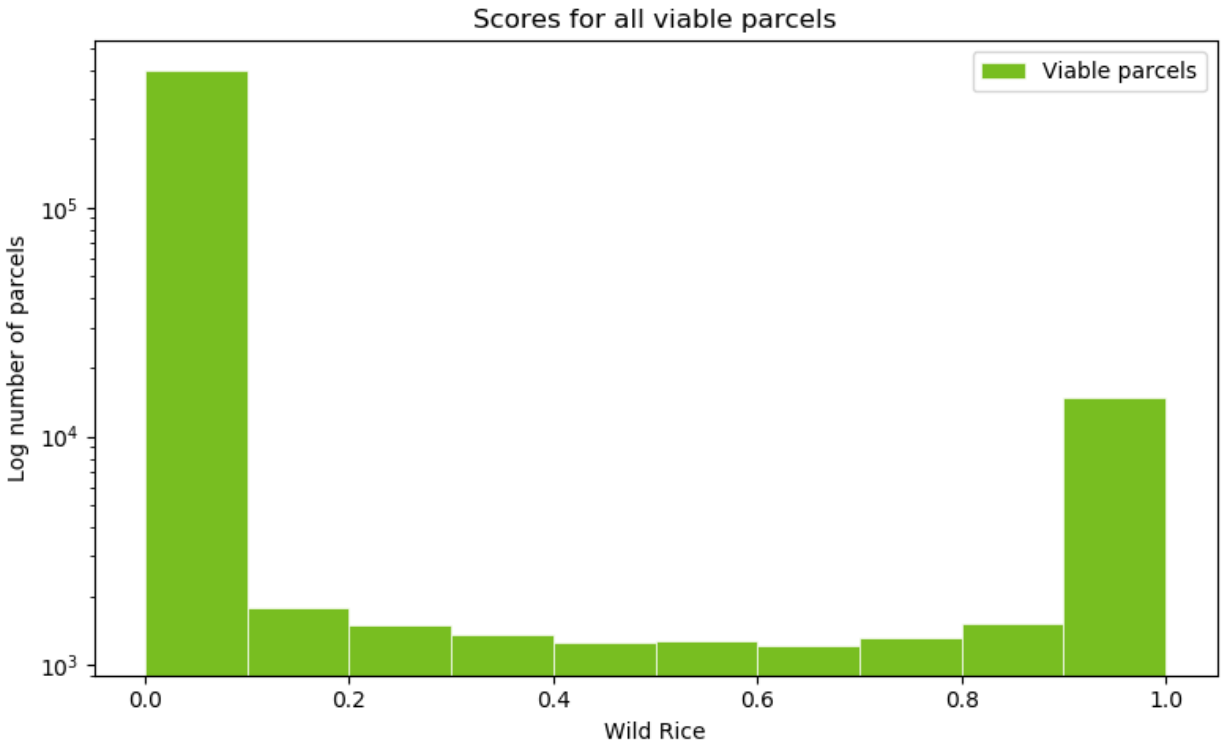
Data preparation

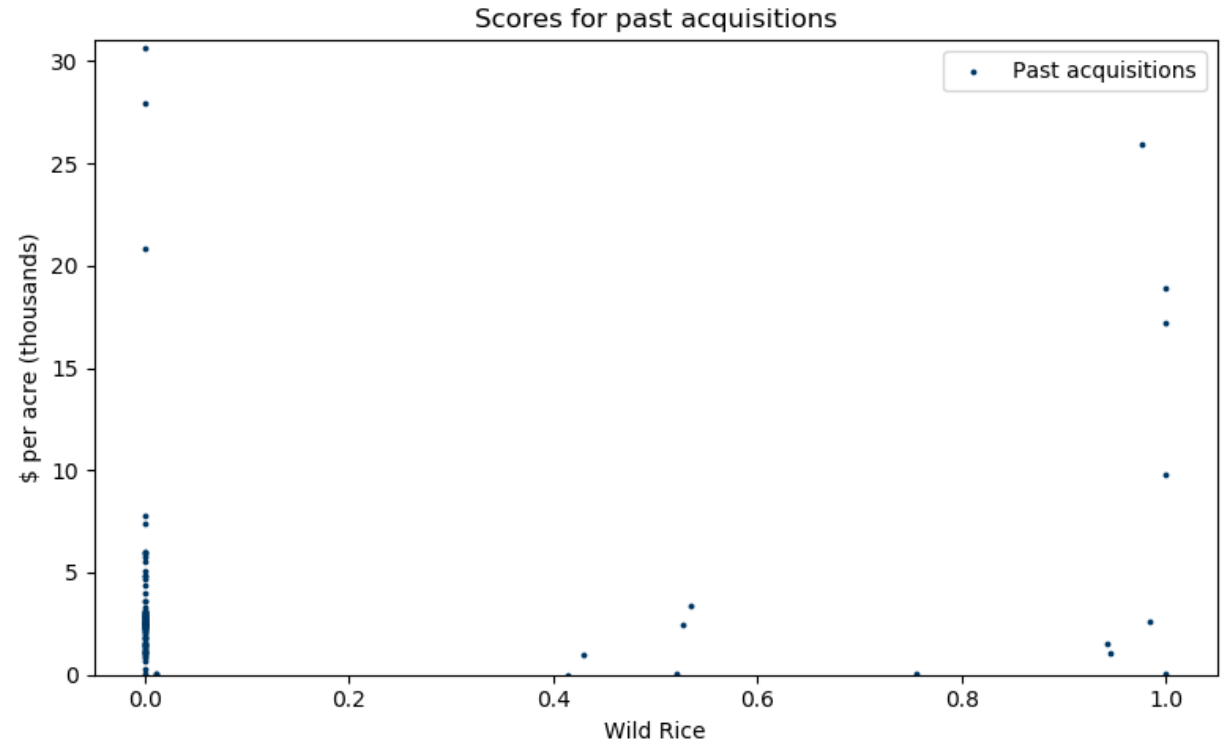
This metric is intended to quickly assess if a parcel has the potential to protect wild rice production, and does not prioritize between sites or assess the magnitude of the impact. We used a spatial join operation to select all catchments with a wild rice site within them and assigned them a value of one, everywhere else received a value of zero. If a parcel is partially within a catchment, its score is equivalent to the proportion of the parcel's total area that is within the catchment.

Map



Score distributions





Lake Recreation

Overview

The lake recreation metric prioritizes protection of land that influences the water quality of lakes important for public recreation. It applies to the catchments of lakes with a publicly accessible water access site. Parcels outside of these catchments receive a score of zero for lake recreation. Among lakes with public access, prioritization is based on three attributes; the sensitivity of the lake's clarity to additional phosphorus runoff, the public amenities (i.e., restrooms, boat launches, docks) of the lake, and lake visitation. Catchments with publicly accessible lakes receive a minimum score of 0.2. The rest of the score is equally divided between a physical measure of the lake's sensitivity to phosphorus, and measures of the social benefit of the lake as measured by proxies for visitation. High scoring parcels are those that are within a catchment of a publicly-accessible lake highly sensitive to additional phosphorus, which has public amenities and high scores for lake visitation.

High priority parcel description

Endpoint: Land that is in the catchment of lakes that have public, no cost water access sites as identified in the DNR water access sites database.

A high priority parcel is in the catchment of a publicly accessible lake that:

- is in danger of becoming impaired with more phosphorus loading
- has high visitation
- has amenities (i.e., restrooms, boat launches, docks) that enable and improve recreation experiences

Data sources

Lakes of Phosphorus Sensitivity Significance

https://gisdata.mn.gov/dataset/env-lakes-phosphorus-sensitivity

Availability note: the metric is based on LPSS scores which are presented only in aggregated classes in the public version of this dataset.

Natural Capital Project Recreation Model

http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/recreation.html

The output from the model is available in the expanded base data.

Public Water Access Sites in Minnesota

https://gisdata.mn.gov/dataset/loc-water-access-sites

MNDNR Watershed Suite - Level 09 autocatchments and autolakes

https://gisdata.mn.gov/dataset/geos-dnr-watersheds

MNDNR Hydrography - Lakes and Open Water

https://gisdata.mn.gov/dataset/water-dnr-hydrography

Data preparation

Identifying public lakes:

The lake recreation metric applies to the catchments of publicly accessible lakes. While the surface of a lake is public if any public land (e.g., roads, parks) touches its riparian area, the location of these lakes is not readily available to the public, and the physical access may be very difficult. We defined public lakes as those with free, open to the public, water access sites in the DNR's Parks and Trails authoritative database. We used two sources to define lakes; DNR Watershed Suite level 09 autolakes and DNR Hydrography database lakes and open water. We primarily used the level 09 autolakes layer because it aligned best with the autocatchments layer, however it does not include reservoirs or gravel pits, both of which are used for recreation. To include those water bodies we extracted them from the DNR Hydrography database and merged them with the autolakes layer.

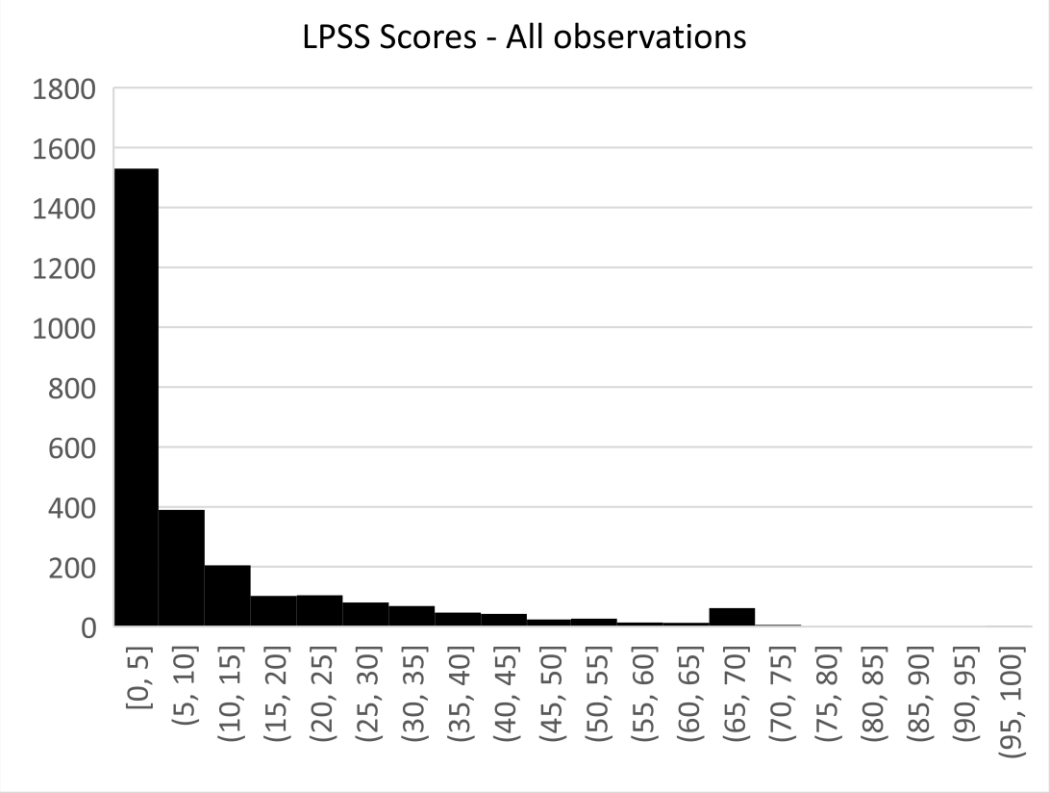
Due to inconsistencies between data sources, joining the water access points to lakes and catchments required several manual corrections. We identified a set of manual corrections by comparing the results of an attribute join between the water access points layer and our merged lakes layer on 'dowlknum'. For access points with a 'dowlknum' but no match we use aerial imagery and the lakes and open water layer to identify a match or removed it if applicable. We also used a spatial join between the lakes and open water layer and the access points layer to identify points that had the

incorrect ‘dowlknum’ assigned. Manual changes are identified and performed in the script lake_rec_prep.py.

Lakes of Phosphorus Sensitivity Significance:

Because the Lakes of Phosphorus Sensitivity Significance (LPSS) layer is already an index, no further processing was applied except for re-indexing the data to zero to one. The formulation of this index is described in documentation linked to on the Minnesota Geospatial Commons dataset page.

We joined the phosphors sensitivity significance scores to our public lakes layer by ‘dowlknum’. The Lakes of Phosphorus Sensitivity Significance layer is regularly updated as new observations are added, but it is not complete for all lakes with public access sites. Of the 1964 lakes with public access sites, 372 did not have a corresponding phosphorus sensitivity significance score. To include this data source, we used the median value of the data set for the missing observations. Values in the dataset ranged from 0 to 100, with a median of 3.5 and a mean of 10.7. Over 71% of the values where in the range 0-10.



Social media-based visitation data:

We used our public lakes layer as the input to the InVEST Recreation model. We used the index of the log of all photo-user-days between 2005 and 2014 to score lakes by visitation, and applied the score to any catchments a lake intersects (typically one).

Lake amenities:

While the presence of geotagged photos on lakes is a good indicator of higher levels of visitation, many lake recreationist do not publicly share geotagged photos, and thus many lakes have 0 photo-user-days. To supplement social media-based visitation data, we used amenities at the lake recorded in the Public Water Access Sites database. Previous research has indicated that these amenities are correlated with higher visitation (Keeler et al., 2015).

Specifically we consider whether or not a lake has a dock, trailer launch site, and toilets. In previous surveys of Minnesota lake recreationists (e.g. MNDNR 2002), sufficient parking is also an important consideration. While we have data on the amount of parking at most access sites, we do not have data on whether or not it is typically enough and therefore do not include this information in our metric. The amenity component is the weighted sum of three amenities, where a lake receives 1 * the amenity value weight if that amenity is present at a lake, regardless of the quantity. If it is absent the lake receives 0 * the amenity value weight.

When selecting weights for individual amenities, we reviewed five DNR surveys of lake recreationists from different regions throughout the state (MNDNR, 2011, 2009, 2007, 2006, 2002). Unfortunately, the ways in which questions were asked about amenities cannot be directly mapped to preference weights. The weights used are primarily based on a question that was asked in two surveys (MNDNR, 2011, 2009); “How important to public access users are the following items at public accesses?” Responses to this question rated docks and toilets similarly in both surveys. However this question did not ask about trailer launches. In other surveys (MNDNR, 2007), when trailer launch sites were limited, it was generally rated highly on the question “Which of the following improvements do you feel are needed at this launch sites?” Note that a lake is still considered publicly accessible if it does not have a trailer launch site, but does have a carry-in access site. Given that survey questions did not show clear differences in preference for the three amenities we considered, we opted to weight them equally. For example, a lake with a dock, and trailer launch would receive and amenity component score of 0.67.

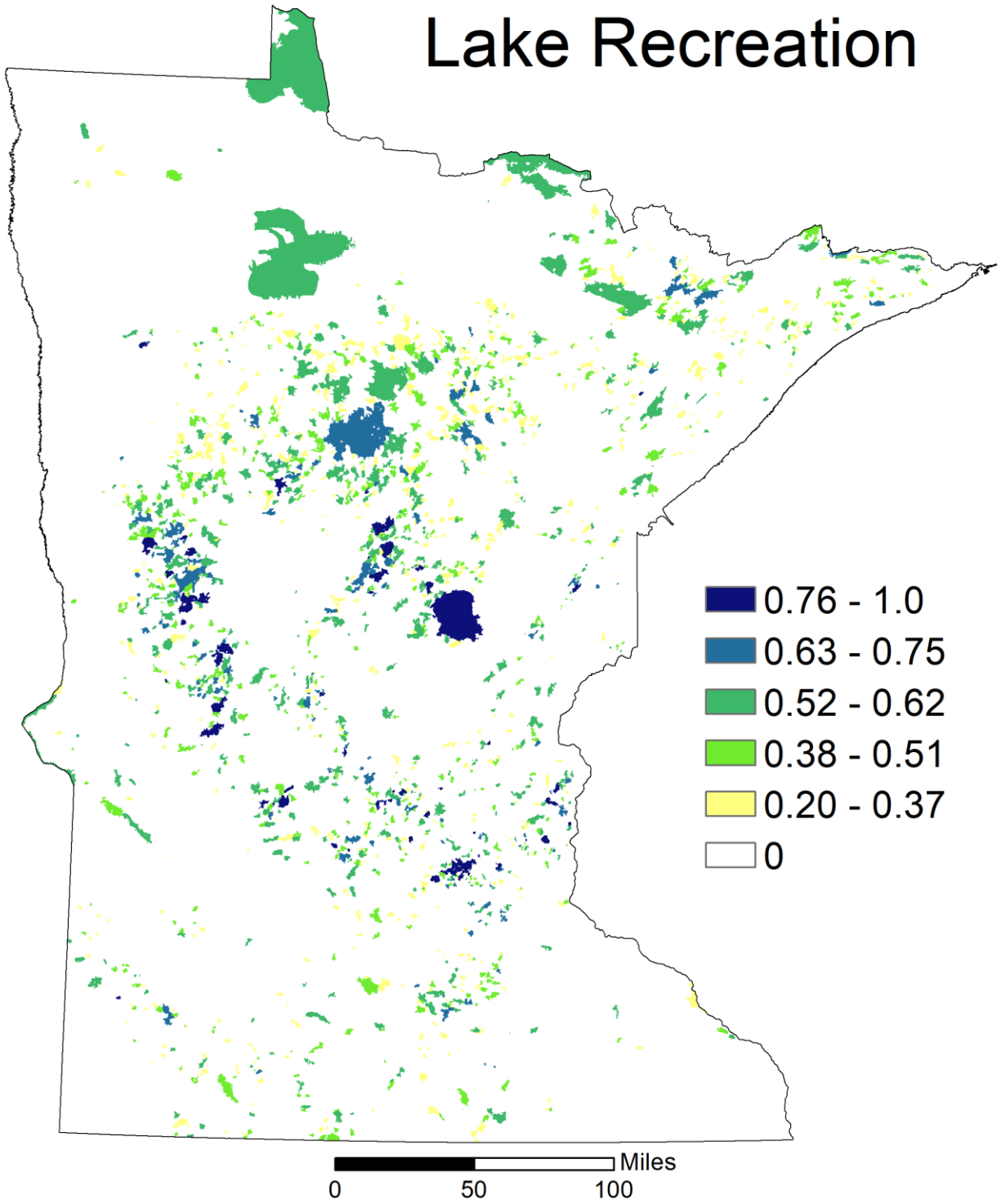
Metric formulation:

When formulating the lake recreation metric, all land in the catchment of a publicly accessible lake received a minimum score of 0.2. The remainder of the score was split between the biophysical measure of the phosphors sensitivity score (0.5), and the social demand represented by social media based visitation and investment in amenities. Given the more comprehensive data on amenities, we weighted it at 0.4 and the social media based visitation at 0.1.

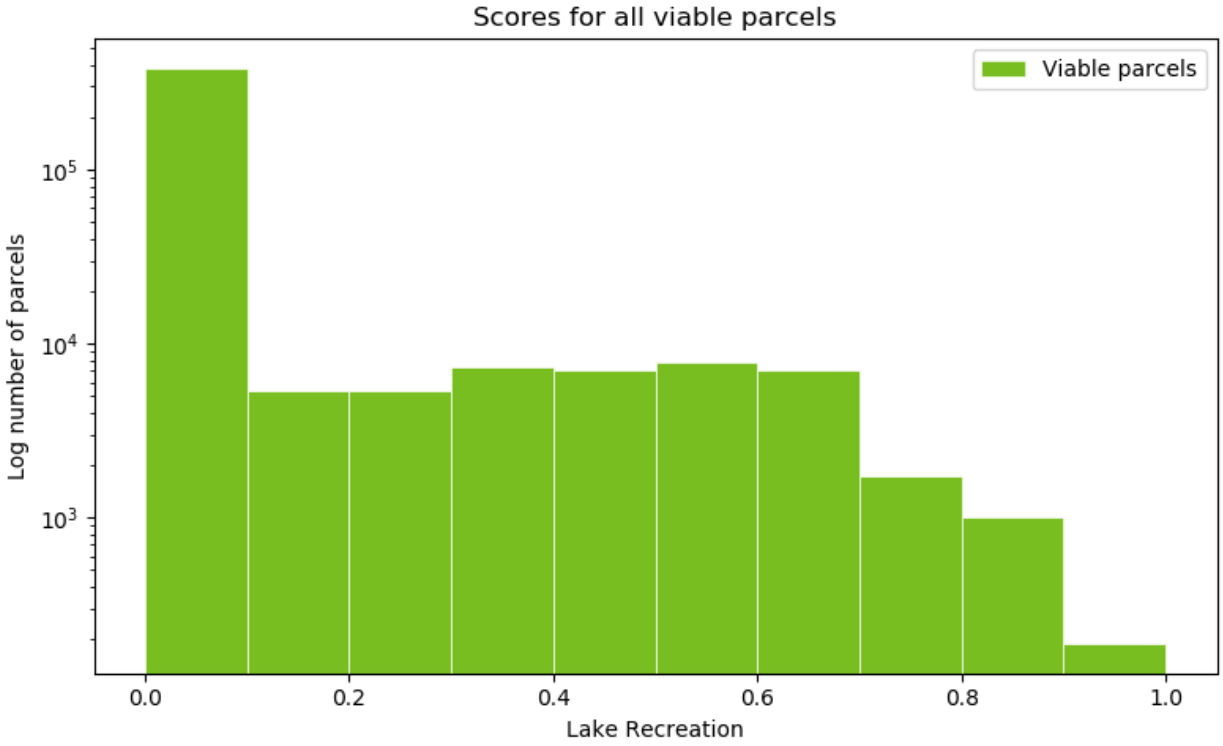
Final score:

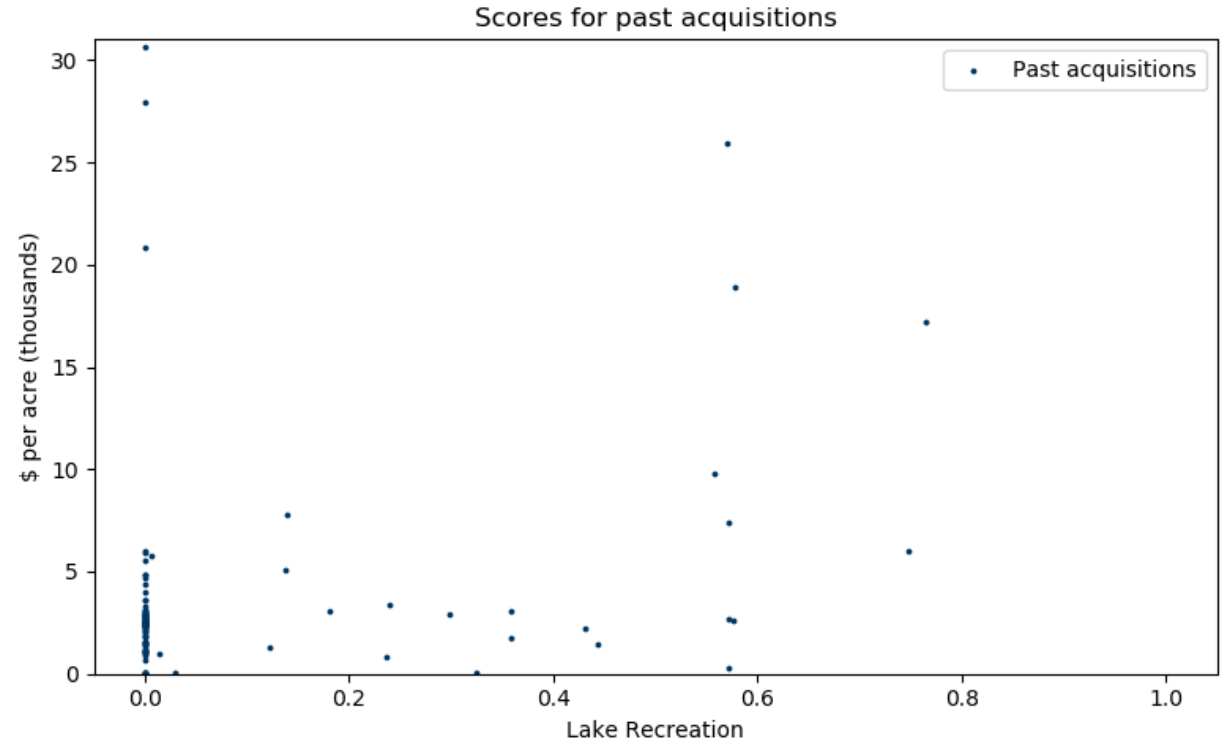
0.2 + 0.8 * (index of (0.5 * index of phosphorus sensitivity +
0.4 * index of amenity level +
0.1 * index of social media based visitation))

Map


Lake Recreation
0.76 - 1.0
0.63 - 0.75
0.52 - 0.62
0.38 - 0.51
0.20 - 0.37
0
Miles
0
50
100

Score distributions





Bird Watching

Overview

Our metric combines data on the location of important bird habitat with data on the behaviors of bird watchers. To define important bird habitat we relied on the Audubon Society's Important Bird Areas layer. To estimate the intensity and location of bird watching, we used the Cornell Lab of Ornithology's citizen science initiative, eBird. The eBird database allows bird watchers to report when and where they engaged in bird watching. We interpolated the data to create a statewide layer with high scores for bird watching hot spots and declining scores with low reported visits. To combine the habitat layer and the visitation layer we set the value for 'presence' in the Important Bird Areas data such that the average of all of the values in the map was equal to the average of all of the values in the eBird map, and then summed the two maps. High scores for bird watching are found on parcels that have both high reported visitation and are located in important bird habitat.

High priority parcel description

Endpoint: Statewide

A high priority parcel:

- is within an Audubon Society Important Bird Area
- is near a large number of unique observer entries in the eBird database

Data sources

Audubon Society Important Bird Areas

http://datazone.birdlife.org/site/requestgis

Availability note: GIS data are available by request only. See here to view the data in a web interface or pdf maps:

http://mn.audubon.org/conservation/minnesota-important-bird-areas

eBird database

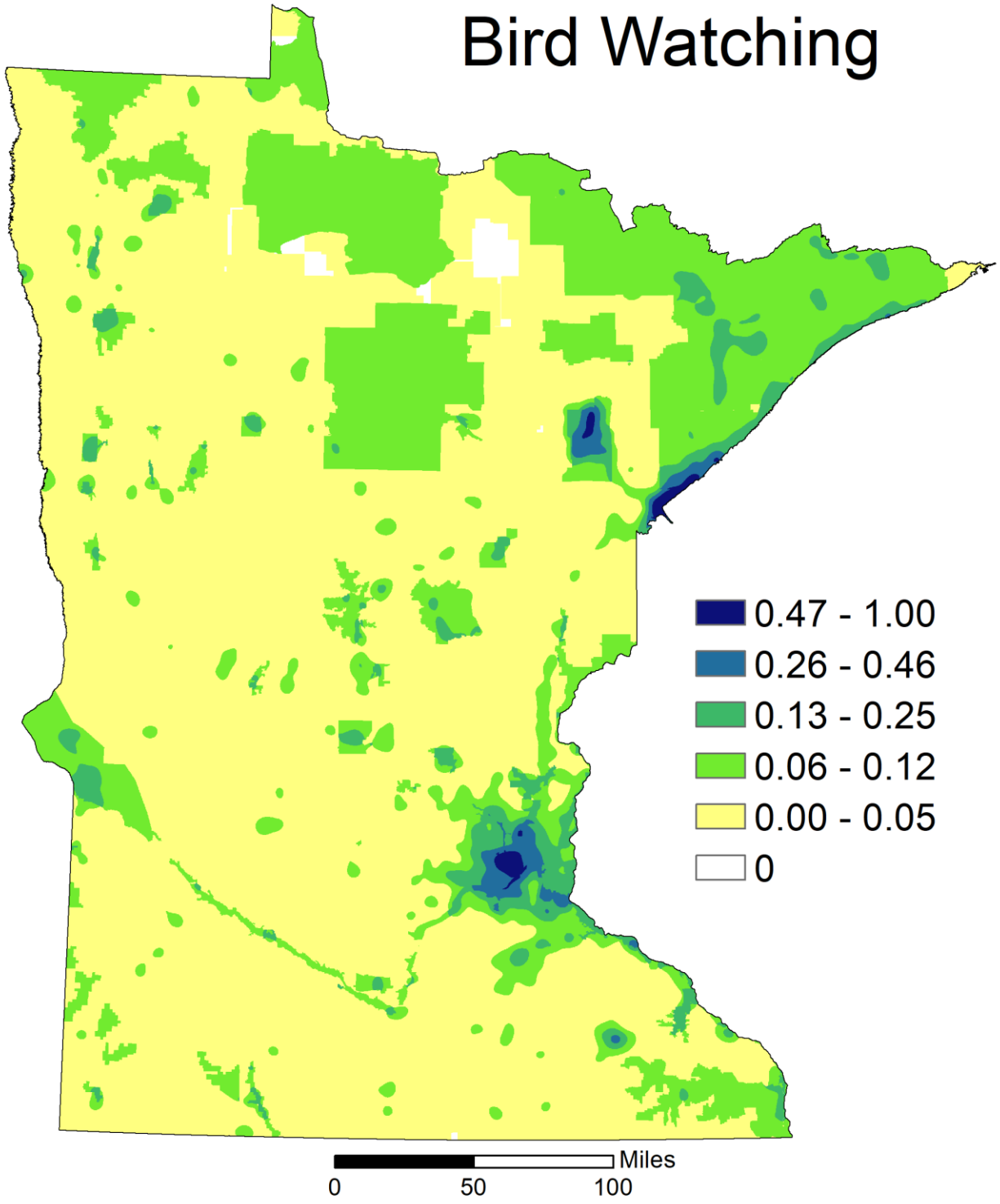
Availability note: data are available by request only:
https://ebird.org/ebird/data/download

Data preparation

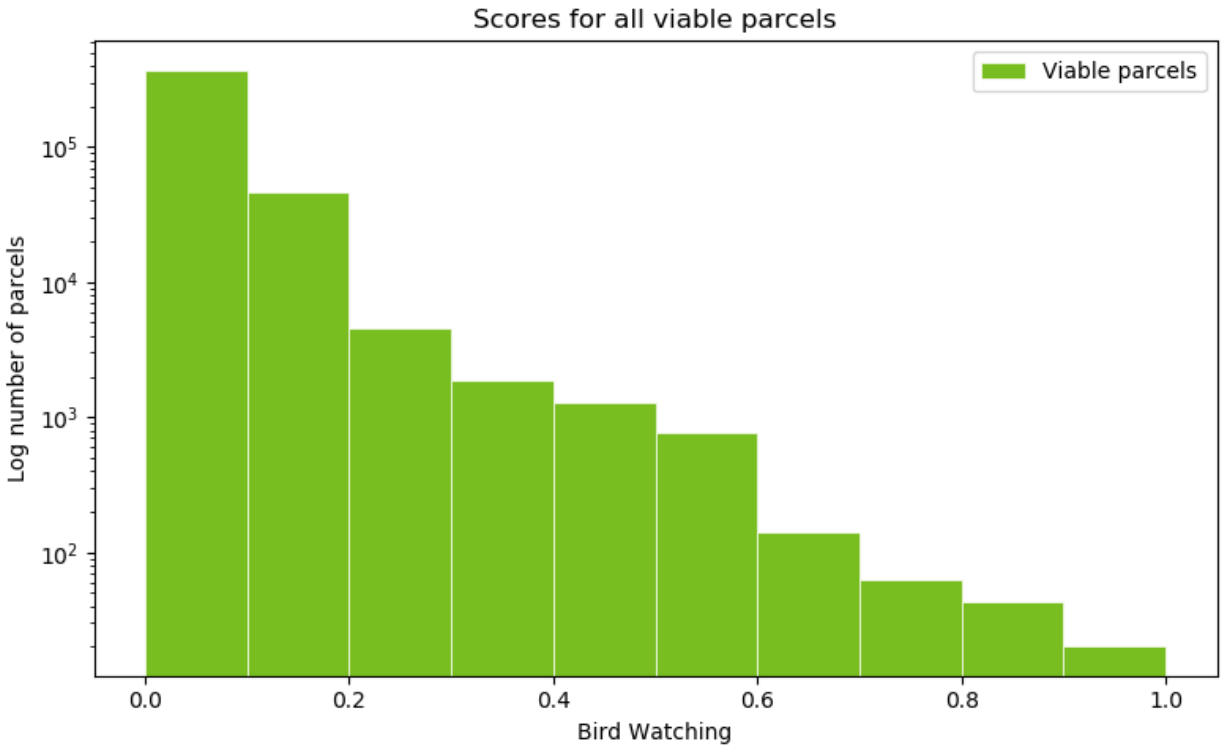
We prepared the eBird data by grouping all entries by locality ID and assigning it the log of the sum of the number of unique observer-days between 2006 and 2016. This produced a map of point locations scored on their bird watching activity. We investigated several interpolation methods to extend this score to the habitat surrounding the points. Interpolation methods that extrapolate the values between points were rejected because the score at one location can have a disproportionate influence if there are no nearby points. Instead we opted for a gaussian blur that takes the value of a focal cell and assigns it to its neighbors following a gaussian distribution. When considering the distance of the effect we reviewed the home range of many bird species, and found that many occupy areas on the order of tens to hundreds of acres, but there was a very large range of values (Bowman, 2003; Schoener, 1968). We selected our raster resolution and gaussian parameters to concentrate most of the effect of a locality score in an area of a few hundred acres.

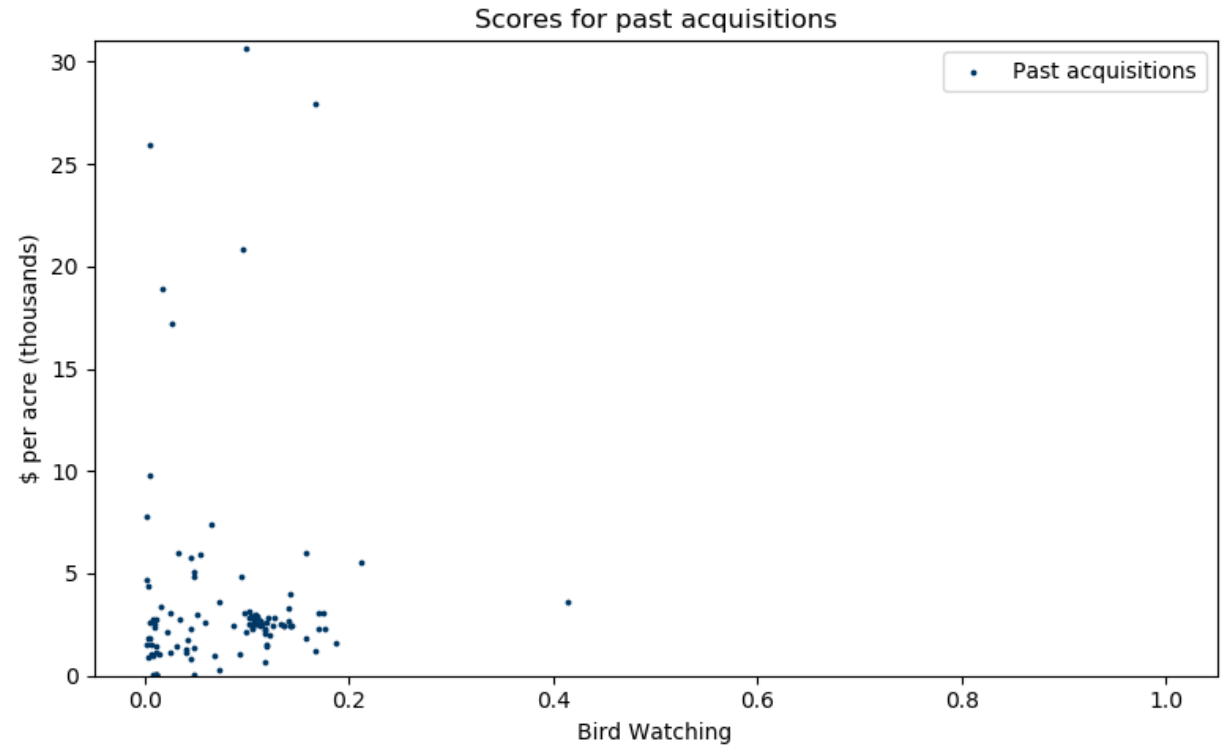
When combining the supply of habitat as defined by Important Bird Areas with the demand for bird watching as defined by the eBird data, we wanted to weight the two inputs similarly. However, this is challenging because one is continuous (with few values equal to one) and the other was binary (with many values equal to one). We set the value for ‘presence’ in the Important Bird Areas layers such that the average of all of the values in the map was equal to the average of all of the values in the eBird map, and then summed the two maps.

Map


Bird Watching
0.47 - 1.00
0.26 - 0.46
0.13 - 0.25
0.06 - 0.12
0.00 - 0.05
0
Miles
0
50
100

Score distributions





Recreation Trails

Overview

Trails in the state provide a wide range of recreation activities, such as hiking and biking on non-motorized trails, ATV and snowmobile used on motorized trails, and boating on water trails. Conservation of parcels via easements or acquisitions can protect the aesthetic experience around trails by providing scenic beauty and noise attenuation for trail users. Our metric scores parcels based on their proximity to existing recreational trails, as designated by the Minnesota DNR. A parcel's score is equivalent to the proportion of the parcel's total area that is within a 500 foot buffer of a trail, where higher scores are given to parcels with a greater proportion of their area in proximity to trails.

High priority parcel description

Endpoint: 500 foot buffer of recreation trails

A high priority parcel:

- has a high proportion its area within 500 feet of state recreation trails

Data sources

Metro Region Trails

https://gisdata.mn.gov/dataset/us-mn-state-metc-trans-regional-trails-exst-plan

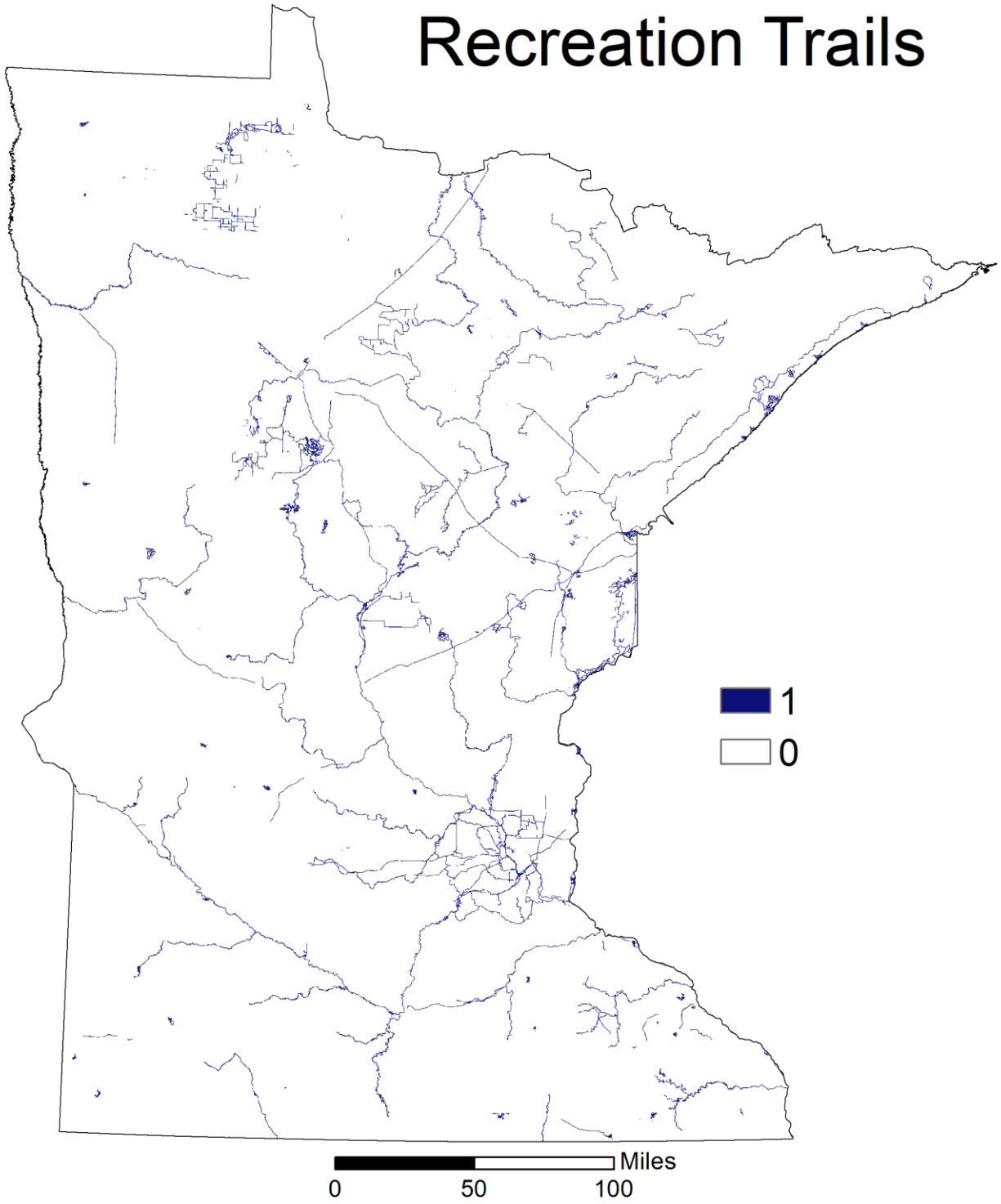
State Trails of Minnesota

https://gisdata.mn.gov/dataset/trans-state-trails-minnesota

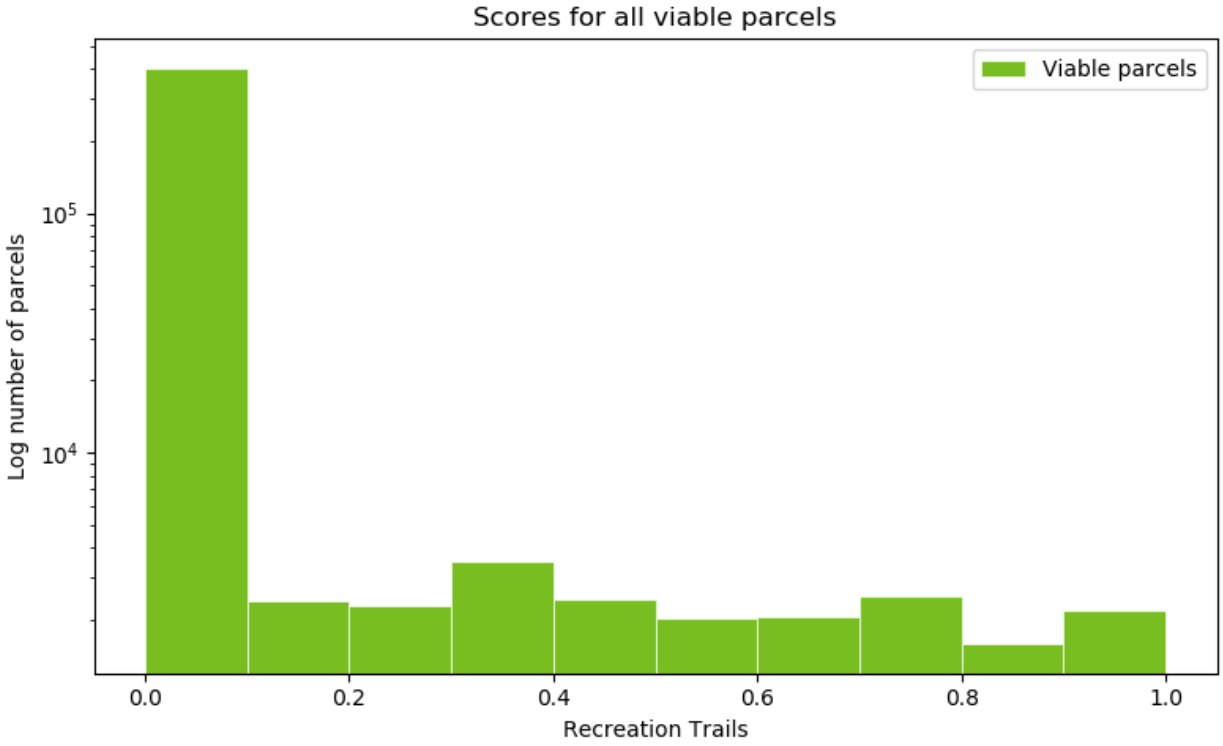
Data preparation

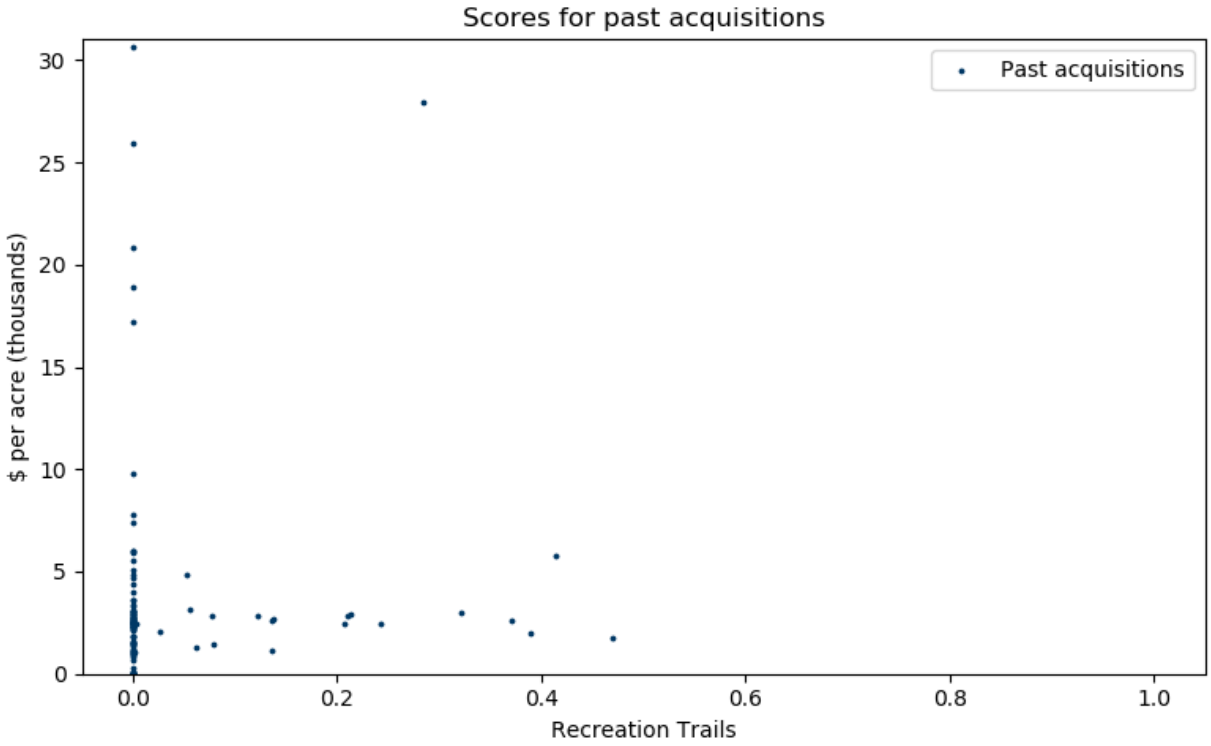
We merged the state and metro trail maps. We included all trails (i.e., motorized, non-motorized, and water), from the state trails database and proposed trails from the metro regional trails database. We selected a 500 foot buffer because beyond that noise attenuation benefits are not generated (Bentrup, 2008).

Map



Score distributions





Trout Angling

Overview

The trout angling metric applies to the catchments of legally designated trout streams, and prioritizes among them using social media based visitation data. If an acquisition is within 66 feet (the buffer size often used in Aquatic Management Area acquisitions), it receives a higher score. Catchments with a legally designated trout stream receive a minimum score of 0.2. The remainder of the score is the weighted sum of the proportion of the parcel within the buffer, and visitation, weighted at 0.6 and 0.4, respectively. High scoring parcels have a large proportion of their area in close proximity to a trout stream that has high scores for visitation.

High priority parcel description

Endpoint: Catchments of legally designated trout streams.

A high priority parcel:

- has a high proportion its area adjacent to a trout stream
- contributes to a trout stream with high visitation

Data sources

State Designated Trout Streams

https://gisdata.mn.gov/dataset/env-trout-stream-designations

Natural Capital Project Recreation Model

http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/recreation.html

The output from the model is available in the expanded base data.

MNDNR Level 09 - DNR AutoCatchments

https://gisdata.mn.gov/dataset/geos-dnr-watersheds

Data preparation

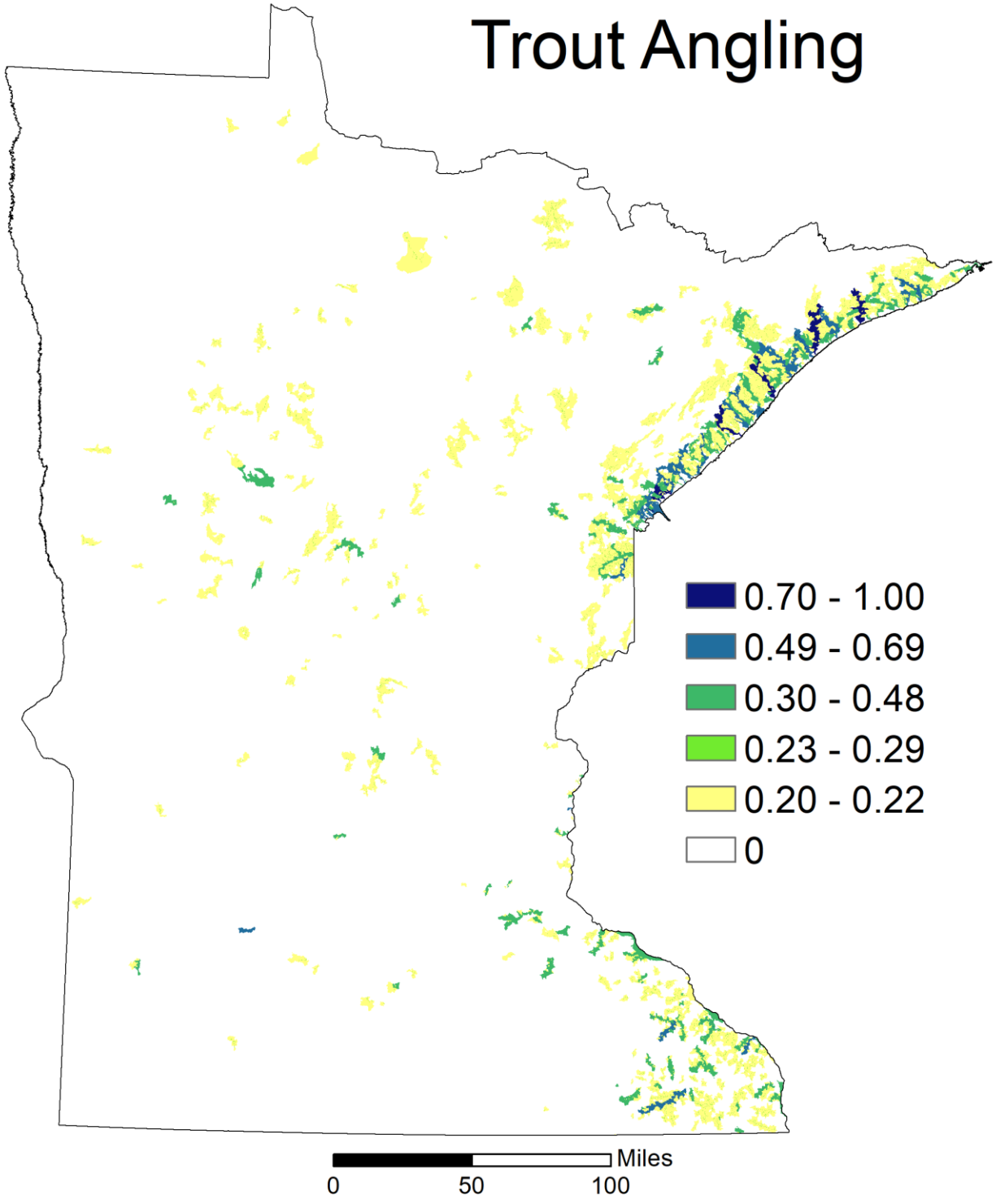
We first selected all MN DNR level 09 catchments that intersect a legally designated trout stream and assigned them a base score of 0.2. We then buffered the trout stream layer by 66 feet, which is the size frequently used in Aquatic Management Area acquisitions, and used it as the input to the InVEST Recreation model. We used the log of all photo-user-days between 2005 and 2014 to score trout streams by visitation, and applied the score of the stream to the catchment that it intersects. If more than one trout stream intersected a catchment, the higher score was assigned.

When constructing the metric, land in the catchment of a trout stream received a minimum score of 0.2. The remainder of the score was divided between being within the stream buffer, and the amount of visitation. We emphasized proximity to the stream by weighting it 0.6, and the visitation index 0.4.

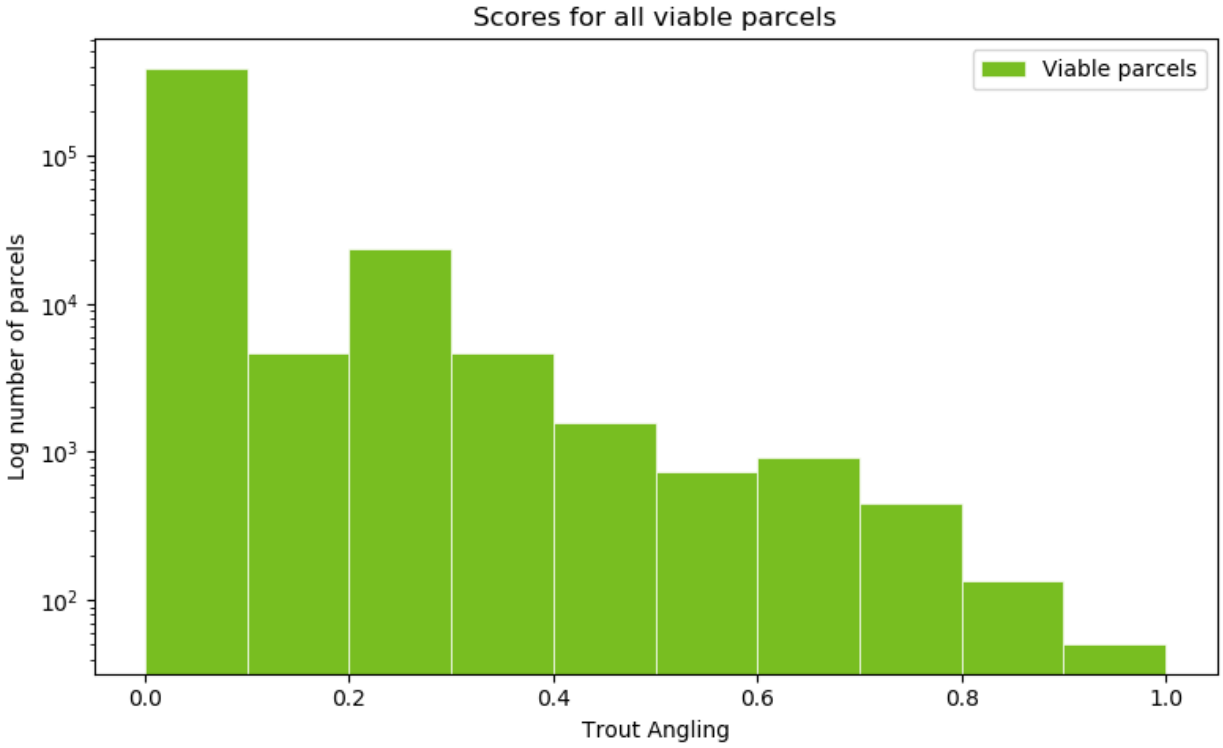
Final score:

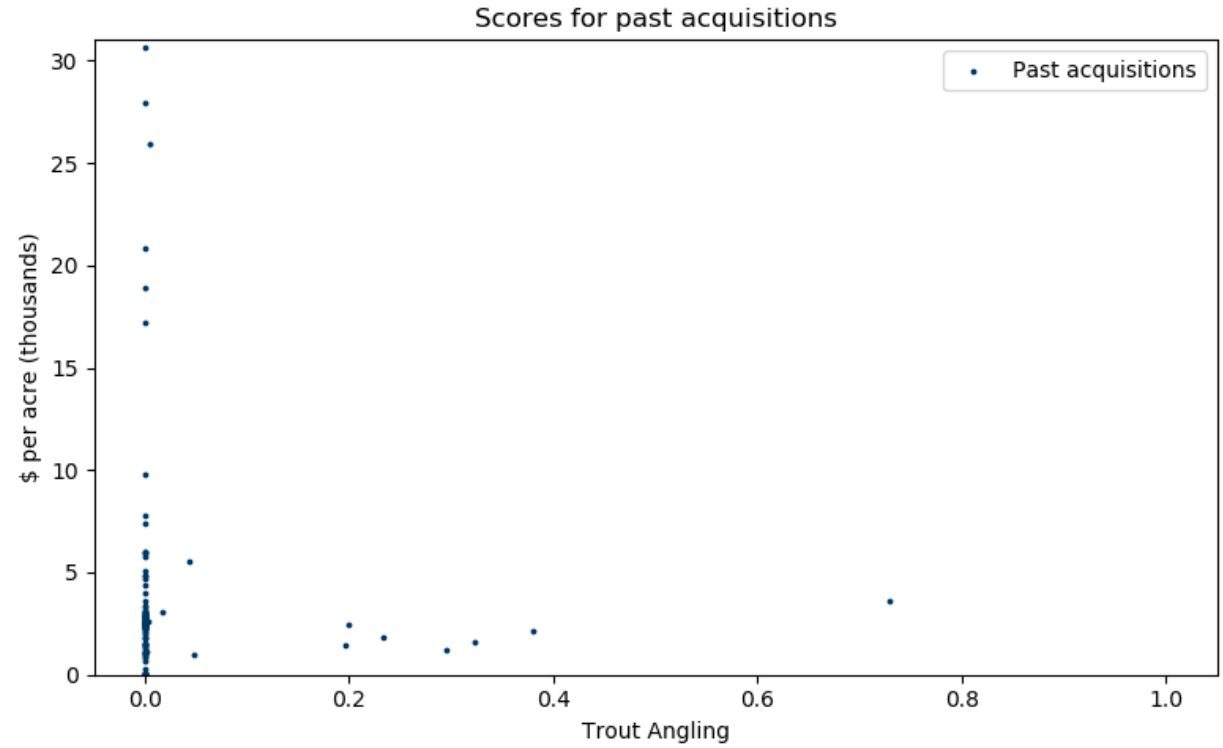
0.2 + 0.8 * index of ((0.6 * within stream buffer) + (0.4 * index of log photo user days))

Map


Trout Angling
0.70 - 1.00
0.49 - 0.69
0.30 - 0.48
0.23 - 0.29
0.20 - 0.22
0
Miles
0
50
100

Score distributions





Groundwater Nitrate

Overview

Nitrate in groundwater poses a threat to human health and increases water treatment costs, especially for rural communities. Our metric assumes that parcels located within identified Drinking Water Supply Management Areas (DWSMA) as mapped by the Minnesota Department of Health are more likely to contribute to drinking water protection than parcels outside DWSMAs. Parcels within DWSMAs receive a minimum score of 0.2, the remainder of the score is based on the amount of agriculture within the DWSMA (a proxy for threats to groundwater), and sensitivity of the geology to surface contamination. High priority parcels are within the boundary of a DWSMAs, have a high proportion of agricultural land cover, and are located in regions with soil and geologic characteristics that make groundwater more vulnerable to contamination.

High priority parcel description

Endpoint: Drinking Water Supply Management Areas (DWSMA)

A high priority parcel is within a DWSMA and:

- The DWSMA has a high proportion of its area in agriculture
- The DWSMA has a high proportion of its area on land with soil and geologic characteristics that make groundwater more vulnerable to contamination
- The agriculture is on land with soil and geologic characteristics that make groundwater more vulnerable to contamination
- The parcel is on land with soil and geologic characteristics that make groundwater more vulnerable to contamination

Data sources

Minnesota Land Cover Classification and Impervious Surface Area by Landsat and Lidar: 2013 update - Version 2

https://gisdata.mn.gov/dataset/base-landcover-minnesota

Drinking Water Supply Management Areas - Vulnerability

http://www.health.state.mn.us/divs/eh/water/swp/maps/index.htm

Data preparation

We used the Minnesota Department of Health's (MDH) Drinking Water Supply Management Areas (DWSMA) layer as the endpoint for the metric. All land in a DWSMA received a minimum score of 0.2, with higher scores assigned where groundwater was more at risk based on indices for overall nitrate loading, and groundwater vulnerability described below.

Nitrate Loading Index:

Drinking water supply management areas are sub-divided into five vulnerability classes by the MDH based on the geological characteristics that leave ground water vulnerable to surface contamination. For each of these units we calculated the proportion of it that has agriculture as a land cover and the proportion of the total area DWSMA it represents. We then calculated a weighted sum of the proportion of agriculture in each vulnerability class. Thus, if the weight for each class were 1, the end result would be the proportion of the DWSMA in agriculture. We weighted units with lower vulnerability classes lower because they have a less direct influence on groundwater. We created an index of the weighted sum of proportion of agriculture in every DWSMA to identify the DWMAs that have a high risk combination of nitrate loading on land with vulnerable geologic characteristics. The end result is an index prioritizing DWMAs based on the total nitrate load on their ground water. Because water from throughout the DWMA is aggregated at the well, this score applies evenly to the entire DWSMA.

Groundwater Vulnerability Index:

We further prioritized acquisitions within DWSMAs based on the vulnerability class of the land they were located on. Thus, parcels with a vulnerability class 'Very Low' in a DWSMA with a high nitrate loading index score may be lower priority than a parcel in a DWSMA with a lower nitrate loading index score if the parcel's groundwater vulnerability score is 'Very High'.

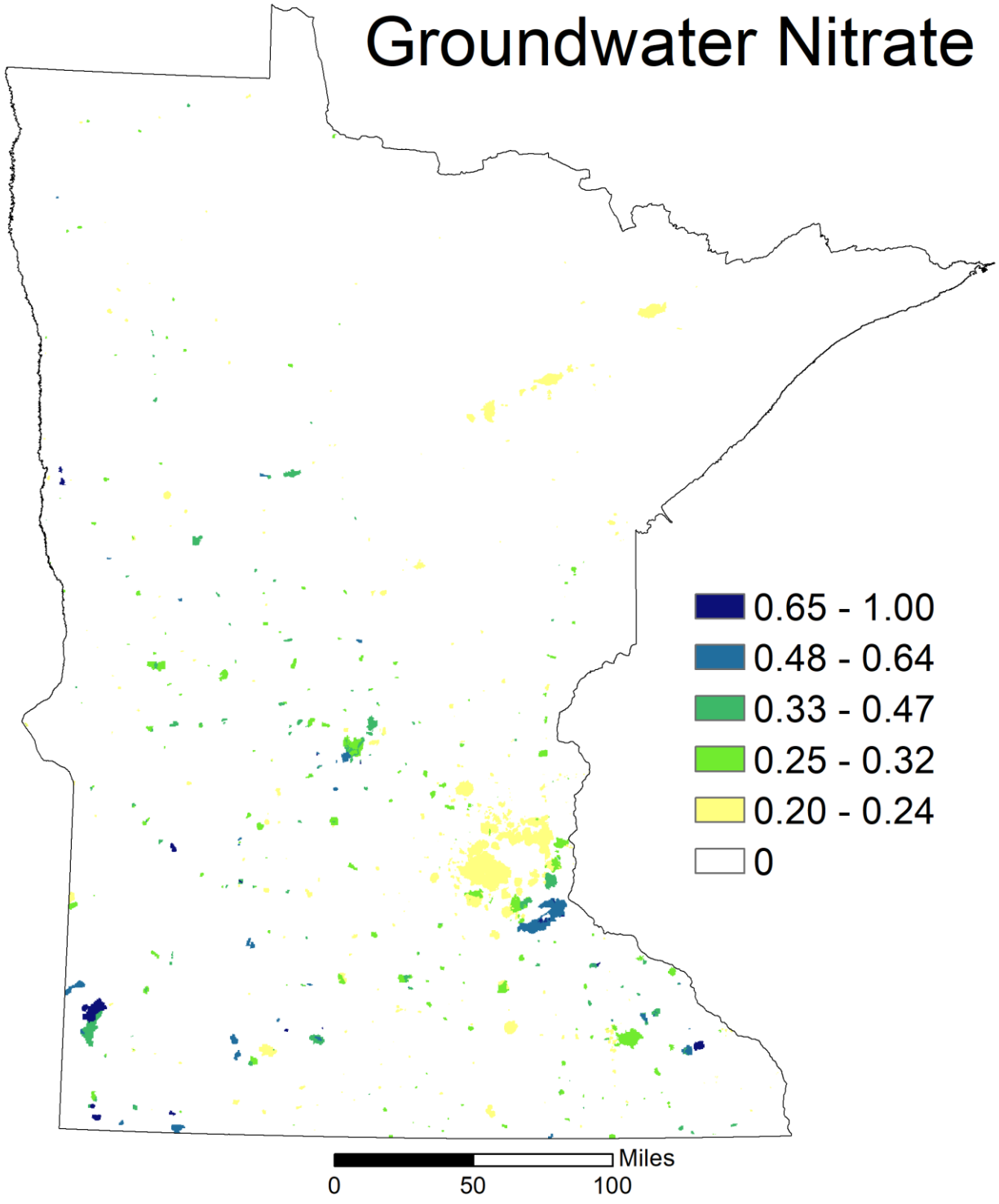
Nitrate Loading Index variables	**Weight**
% of DWSMA in agriculture and on very high vulnerability land (%_vh_ag)	1

% of DWSMA in agriculture and on high vulnerability land (%_h_ag)	0.8
% of DWSMA in agriculture and on moderate vulnerability land (%_m_ag)	0.6
% of DWSMA in agriculture and on low vulnerability land (%_l_ag)	0.4
% of DWSMA in agriculture and on very low vulnerability land (%_vl_ag)	0.2
Groundwater Vulnerability Index variables	
Groundwater vulnerability of land of parcel is very high	1
Groundwater vulnerability of land of parcel is high	0.8
Groundwater vulnerability of land of parcel is moderate	0.6
Groundwater vulnerability of land of parcel is low	0.4
Groundwater vulnerability of land of parcel is very low	0.2
Base Score	0.2

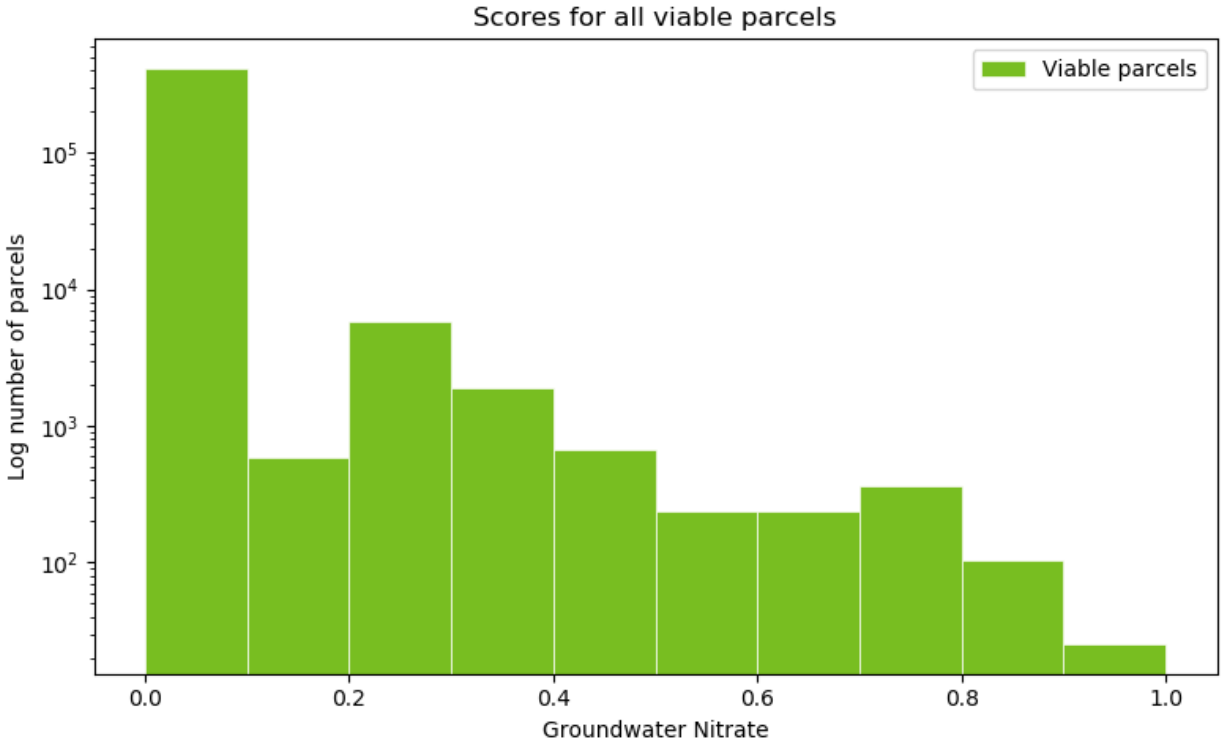
Final score:

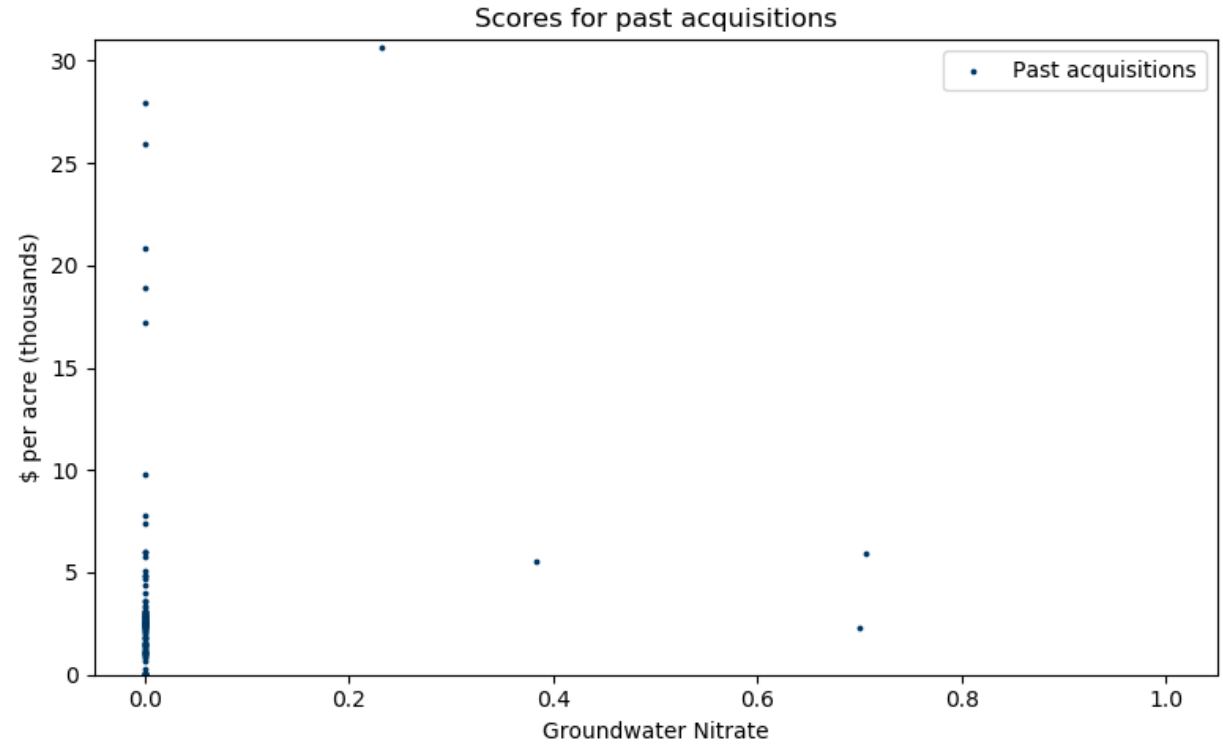
0.2 + 0.8 * (Index of (weighted %_vh_ag' + weighted %_h_ag + weighted %_m_ag' + weighted %_l_ag' + weighted %_vl_ag) * groundwater vulnerability)

Map


Groundwater Nitrate
0.65 - 1.00
0.48 - 0.64
0.33 - 0.47
0.25 - 0.32
0.20 - 0.24
0
Miles
0
50
100

Score distributions





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Parcel Environmental Benefit Assessment Tool

User Guide

October 2018, version 1.2

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Bonnie Keeler
Justin Johnson
Michael Kilgore
Steven Taff
Stephen Polasky

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ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

INSTITUTE ON THE ENVIRONMENT
UNIVERSITY OF MINNESOTA
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natural capital PROJECT

Table of Contents

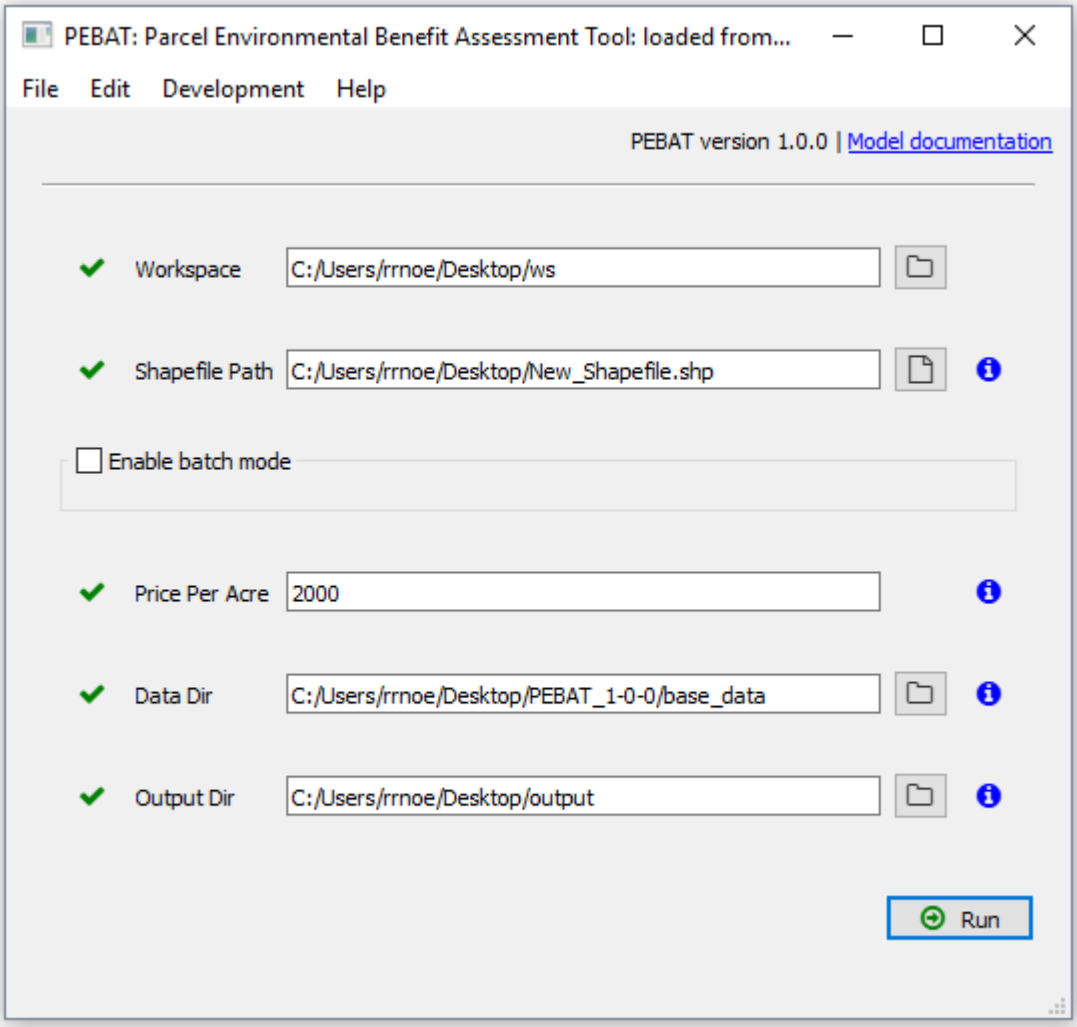
How to download and open

1. Download the current version of the tool and base data from: https://z.umn.edu/pebat-download
   Note: because the tool includes all of the base data required to run it, the file is approximately 2.2 gb when compressed.
2. Extract the contents .zip file using windows explorer or a utility such as 7-zip. The uncompressed file requires approximately 12 gb of free space. Due to the complexity of the files, it may require more than 10 minutes to extract the file.
3. In the extracted folder, double click the file called ‘Run’. The tool does not require installation.

The tool uses a portable version of python that contains all of the packages necessary to run the tool. It will not modify your computer or existing python environments. It is compatible with Microsoft Windows XP/7/8/10.

How to run

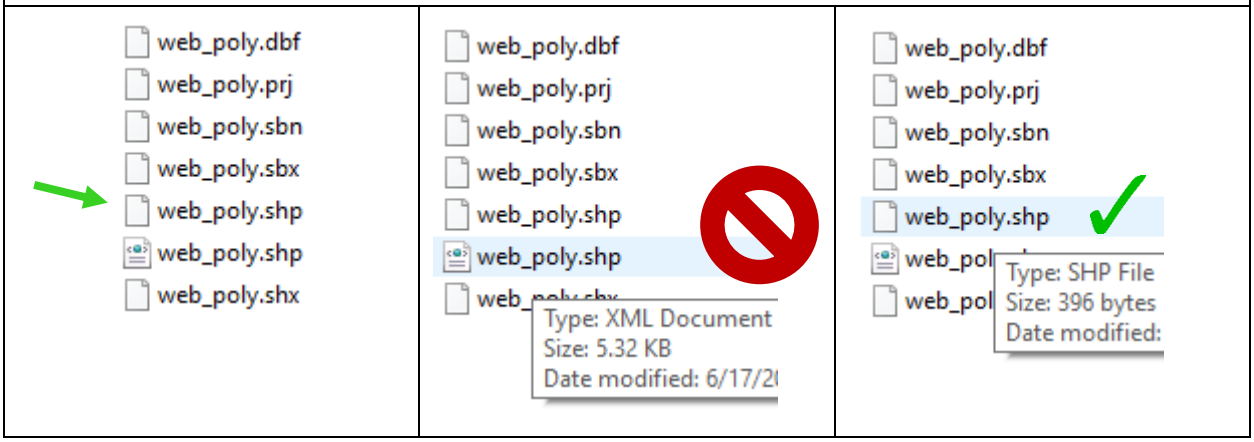
After clicking run, two windows should appear; a command window with a black background, and the user interface for the tool. The command window can be minimized and ignored, but not closed. The user interface for the tool looks like this:



Workspace: Where temporary files the tool generates as it runs are stored. It can be any folder on your computer and can be deleted when complete. This can be left as the default value.

Shapefile Path: The path to the shapefile of your proposed parcel. Click the button to the right of this field to navigate to the file ending in .shp.

Note: if you see two files with the same name that both end in .shp, you likely have Window configured to not show file extensions. The correct one will say Type: SHP file when you hover over it with your mouse. The icon resembles a plain white page.



The shapefile coordinate system must be either UTM 15N or WGS 1984. The tool will calculate the average score of all of the features in the shapefile*, so ensure that only the feature(s) of the proposed acquisition are included*.

If you do not have a shapefile of the boundaries of your proposed parcel, see the 'Creating a shapefile' section for resources on the topic.

Enable Batch Mode: Check this box if you want to generate reports for multiple parcels. To use this mode, put all of the shapefiles–one proposed acquisition per file–into one folder and select that folder. *Shapefile Path* is ignored when batch mode is enabled. See the 'How to use batch mode' section for more information on scoring multiple parcels.

Price per acre: Divide estimated total cost of project (including closing costs) by the size of the acquisition in acres. This is compared to the total project cost per acre (including contributions by other organizations) of past LCCMR-funded easements.

Data Dir: The folder of base data that comes with the tool. This can be left as the default value unless you move the base data, or it is not found. In that case, navigate to the location of the base data and select the 'base_data' folder.

Output Dir: The folder where the reports will be saved. Select any folder you wish.

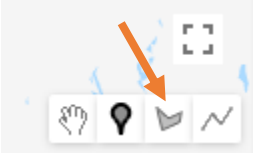
Creating a shapefile

Users familiar with GIS can use their preferred software to create a shapefile of the boundaries of a proposed acquisition. If the proposed acquisition is in a shapefile with other features, the feature(s) that represent the proposed acquisition should be selected and exported to their own shapefile. The preferred projection is UTM 15N, though WGS 1984 is accepted as well.

Users who do not wish to use GIS software can use the web service below to draw the boundaries of a proposed acquisition based on aerial imagery. This service is run by a third party and we cannot guarantee its availability.

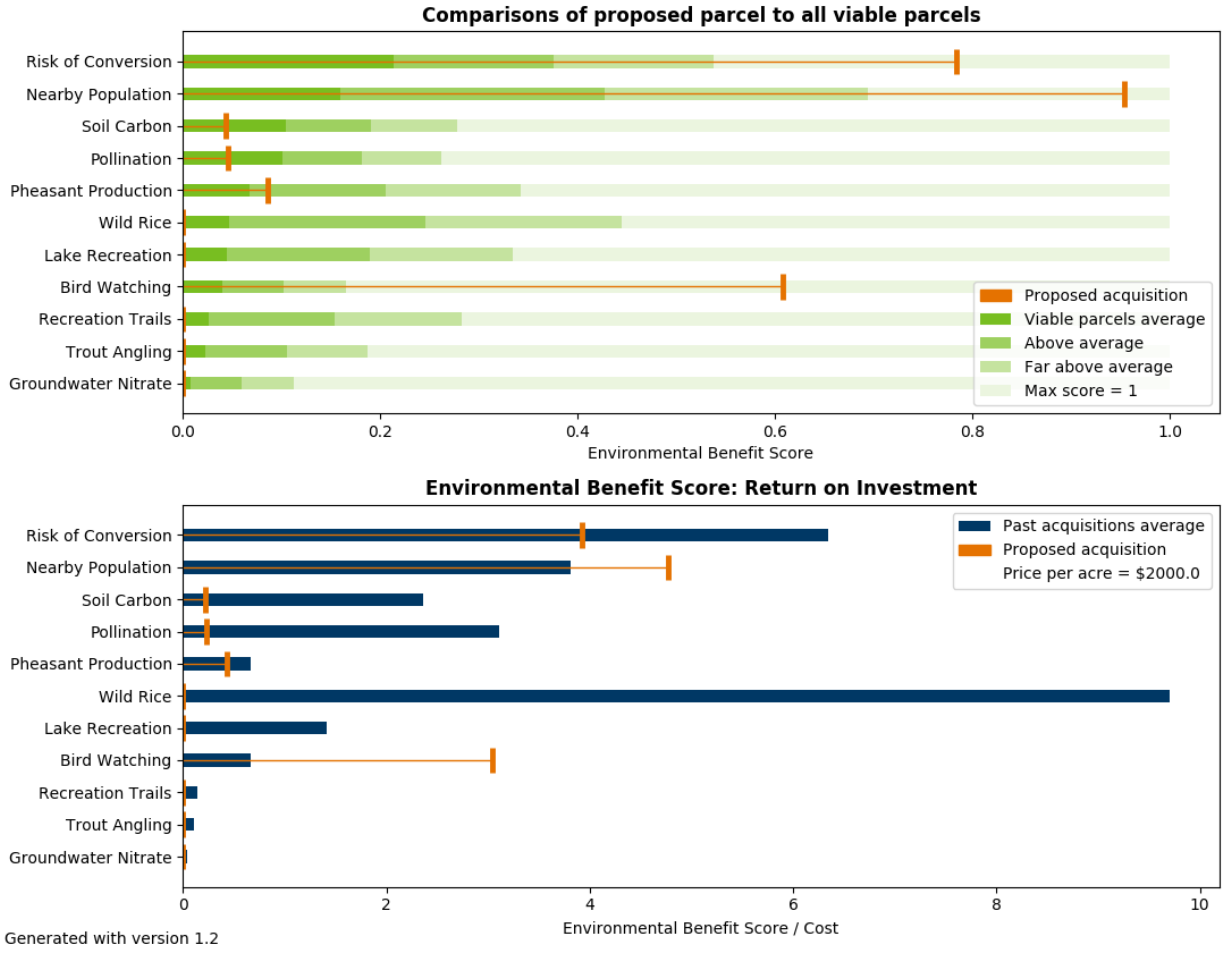
Click2shp

- Click the polygon icon in the upper right corner:



- Turn on satellite imagery with the button in the upper right corner.
- Navigate to the location of the parcel and add points around the outline until your polygon is complete by clicking the first point.
    - If you make a mistake, refreshing the page and starting over is the only way to correct it.
- Enter a filename in the field at the bottom of the page and click ‘Generate Shapefile(s)’
- Extract resulting file

Interpreting the report



The top graph compares the benefits score for your parcel (orange bars) to the average benefits scores for other statewide parcels (green bars). The green bars show the statewide average and distribution of scores for each metric on a scale from 0 to 1, where 1 represents the highest scoring parcel in the state and 0 represents the lowest scoring parcel in the state (color variations represent the average plus one and two standard deviations).

Compare the difference between the score for your parcel of interest (orange bar) and the statewide average (green bars). For example, high scores for wild rice are more common than they are for groundwater nitrate. A score of 0.05 is very good for groundwater nitrate, but is below average for wild rice. Compare the length of the green and orange bars for each metric, rather than comparing one metric's score to another. See the documentation to learn more about how metrics were created and how their distributions vary.

The bottom graph compares your parcel of interest to parcels acquired through past LCCMR-funded easements. Here, scores are presented relative to their cost of acquisition (in price per acre). Use this figure to visualize the relative value of your parcel compared to past parcels (benefit per cost). The blue bars are fixed and represent the average return on investment (adjusted for inflation) of past LCCMR-funded easements. Compare your parcel (orange bar) to the blue bars to see how your parcel scores relative to past easements based on its potential return on investment. Note that higher values reflect a better value (more benefit per cost).

As above, compare the orange bar to the blue bar under it, rather than comparing the metrics to each other. Differences in the blue bars does *not* mean that the past acquisitions have been better for some metrics than others. The natural distribution of benefits throughout the state and the methods used to score them mean that scores for one metric are not comparable to another metric.

If a proposed parcel's return on investment is below average on all of the metrics, its asking price may be too high for the benefits it provides. This report is designed to give an overview of a broad suite of benefits for any parcel in the state and it should be considered in conjunction with local knowledge of a parcel's benefits. An easement should not be rejected solely because this tool scored it poorly, rather that should be a starting point for better understanding the perceived values of a parcel.

How to use batch mode

Users who wish to generate reports for many parcels may wish to use batch mode. Batch mode generates a report for every shapefile in a folder, and puts all of the parcel's scores into a .csv file. However, it is not possible to specify a different price per acre for each parcel. When batch mode is enabled, the 'Shapefile Path' field is ignored.

To prepare your data, ensure that each shapefile contains only one proposed acquisition. The proposed acquisition can have more than one feature in it (e.g. two parcels), but only if those features are being considered as part of the same acquisition. The report scores will represent the average environmental benefit scores of all of the land defined by a single shapefile. If you have a single shapefile with many features in it that you would like to score separately using batch mode, it is recommended you use a tool such as the ArcGIS 'Split by Attributes' tool to generate individual files for each feature.

Batch mode is primarily intended for users considering dozens or more acquisitions relative to one another. The .csv file can be used to quickly compare many parcels; however, it does not include comparisons to all viable parcels or past acquisitions that can be found in the .pdf report. As with other reports generated by the tool, scores from different metrics should not be combined or compared.