Measuring Ecosystem Service Benefits: The Use of Landscape Analysis to Evaluate Environmental Trades and Compensation

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Abstract

Ecosystem compensation and exchange programs require benefit analysis in order to guarantee that compensation or trades preserve the social benefits lost when ecosystems are destroyed or degraded. This study derives, applies, and critiques a set of ecosystem benefit indicators (EBIs). Organized around the concept of ecosystem services and basic valuation principles we show how GIS mappings of the physical and social landscape can improve understanding of the ecosystem benefits arising from specific ecosystems. The indicator system focuses on landscape factors that limit or enhance an ecosystem's ability to provide services and that limit or enhance the expected value of those services. The analysis yields an organized, descriptive, and numerical depiction of sites involved in specific mitigation projects. Indicator-based evaluations are applied to existing wetland mitigation projects in Florida and Maryland in order to practically illustrate the virtues and limitations of the approach.

Key Words: Ecosystem Valuation, Wetlands, Spatial Analysis, Landscape Analysis
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Introduction

Ecosystems support more than species and biological functions: they also support the provision of services that are socially valuable. Ecosystems can purify water, reduce flood risks, support recreation, improve nearby agricultural output – the list goes on. When ecosystems are changed or damaged the social value of the services provided by those ecosystems changes. This creates a substantial challenge for decision-makers.[1] How are ecosystem service benefits to be measured? The issue arises when damages require compensation. If an oil spill damages shoreline, how is compensation for that damage to the shore's ecosystem services determined? It also arises when landuse planners are choosing future patterns of development or when agriculture support programs target lands for conservation. Which lands are most in need of preservation or changes in management practices? Finally, ecosystem benefit measurement must be a central part of any regulatory program that involves the trade of ecosystems. Without benefit measures it is impossible to judge whether the restoration or creation of one ecosystem is an adequate trade for the loss of another.

These issues are of importance to government agencies as diverse as the Department of Agriculture, the National Oceanic and Atmospheric Administration, the Environmental Protection Agency, and the Corps of Engineers.[2] Ecosystem benefit estimation can also play a beneficial role in state and local governments' land use, conservation, and tax planning. For instance, there is a growing interest in incentives to motivate or compel conservation by private landowners and

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[1] See James Salzman, Barton Thompson, and Gretchen Daily, Protecting Ecosystem Services: Science, Economics, and Law, Stanford Environmental Law Journal, 309-332, 2001.

[2] The desirability of having agencies use more ecosystem benefit valuation is discussed in Section 3.

property developers.[3] These incentives include tax code changes designed to motivate land or easement donations to private charitable organizations and tradable development rights, where aggregate development is restricted over some geographic area and developers bid amongst themselves to secure the scarce "right to build." In addition, many governments are actively pursuing conservation through outright purchase of properties or easements.[4] All of these policies beg the same questions: if trading or banking is to occur, what types of compensating habitat conservation are enough to offset habitat losses elsewhere? If conservation is to be induced via cash payments or tax-breaks, which ecosystems should be the highest-priority targets for conservation?

1.1 The Role of Benefit Assessment in Ecosystem Compensation and Trade Programs

Environmental damage assessment requires measures of ecosystem benefits in order to determine the level of damage to be compensated. This is the challenge for natural resource damage assessment, for example, under the Oil Pollution Act and CERCLA. Whenever environmental laws create liability for damages to ecosystems and their services, there is a need for techniques to measure lost ecological benefits.[5] The development of these techniques is continuing and has been controversial.[6]

Ecosystem benefit estimation is also important whenever ecological assets are traded. Environmental trading schemes are no longer a mere gleam in the economist's eye. The celebrated success of air emission permit markets has advanced the trading-scheme cause considerably, and policymakers, scientists, and many environmentalists now appreciate that well-managed

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[3] See, for example, Keystone Center, Final Report: The Keystone Dialogue on Incentives for Private Landowners to Protect Endangered Species, The Keystone Center, Keystone, Colorado, 1995. And for a good overview of alternatives see Keith Wiebe, Abebayehu Tegene, and Betsey Kuhn, Partial Interests in Land: Policy Tools for Resource Use and Conservation, US Department of Agriculture, AER-744, 1996.

[4] James Boyd, Kathryn Caballero, and R. David Simpson, "The Law and Economics of Habitat Conservation: Lessons From an Analysis of Easement Acquisitions," 19 Stanford Environmental Law Journal, 2000.

[5] Natural resource damage estimation is discussed in more detail Section 2.4.

[6] Northeast-Midwest Institute and National Oceanic and Atmospheric Administration, Revealing the Economic Value of the Great Lakes, 2001, ("The development of natural resource damage assessment regulations was controversial because stakeholders disagreed over what damages would be assessed, how damages would be calculated, and how damages to environmental goods and services not valued in traditional markets would be calculated"), at 22.

environmental trading can result in more, not less, environmental protection.[7] A variety of ecological assets are now considered fair game for trade. Notably, trade in entire ecosystems is taking place in the context of land use regulation. The exchange of complex environmental assets creates significant challenges for implementation, however. In particular, ecosystem exchanges, such as tradable development rights or wetland mitigation trades, require more than good ecological analysis. They require the conscientious application of economic analysis in order to guarantee that trades preserve what is socially valuable about ecosystems.[8] In most cases, regulators are not adequately equipped, financially or technically, to judge the relative value of environmental assets to be exchanged in such markets. Until these challenges are met, badly regulated ecosystem trades may undermine, rather than advance, the achievement of environmental and social welfare objectives.[9]

In emphasizing the success of the United States' air emission trading programs, ecosystem-trading advocates often overlook the practical challenges of transferring successes in air programs to the realm of ecosystem trades. Air emission trading differs significantly from trades involving more complex, heterogeneous, environmental assets such as habitat, water quality, and biodiversity. Unlike air emission trading, trading ecosystem assets requires complex biophysical comparisons and

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[7] The EPA has implemented trading markets for acid rain, 42 U.S.C. §§ 7401-7671(q) (1994 & Supp. IV 1998); chlorofluorocarbons, 40 C.F.R. §§ 82.5, 82.12 (2000); auto fuel efficiency standards, 15 U.S.C. §§ 2002, 2003 (1994) (repealed); and other pollutants. Most emissions trading under the Clean Air Act has been in the form of netting, offsets, and bubbles. See, e.g., Robert W. Hahn & Gordon L. Hester, "Marketable Permits: Lessons for Theory and Practice," 16 Ecology L.Q. 361, 368-76 (1989). The Clean Air Act and its 1990 amendments provided further authority for the EPA and states to control air pollution through tradable allowances. 42 U.S.C. §§ 7401-7671(q). California has created trading programs for nitrogen oxides, sulfur oxides, and VOCs. See Matthew Polesetsky, "Will a Market in Air Pollution Clean the Nation's Dirtiest Air? A Study of the South Coast Air Quality Management District's Regional Clean Air Incentives Market," 22 Ecology L.Q. 359, 1995. Trading in sulfur emissions under both Title IV of 1990 Clean Air Act Amendments and California's Regional Clean Air Incentives Market has achieved its environmental objectives and reduced compliance costs. For a particularly subtle analysis of the financial benefits of trade under Title IV, see Curtis Carlson et al., "Sulfur Dioxide Control by Electric Utilities: What are the Gains from Trade?," 108 J. Political Econ. 1292, 2000.

[8] See generally James Salzman & J.B. Ruhl, "Currencies and the Commodification of Environmental Law," 53 Stan. L. Rev, 2001.

[9] See E. Donald Elliott & Gail Charnley, "Toward Bigger Bubbles," Forum for Applied Research & Pub. Policy, Winter 1998, at 48; Carol Rose, "From Local to Global Commons: Private Property, Common Property and Hybrid Property Regimes: Expanding the Choices for the Global Commons: Comparing Newfangled Tradable Allowance Schemes to Old-fashioned Common Property Regimes," 10 Duke Envtl. L. & Pol'y Forum 45, 1999.

trade-specific environmental valuation.[10] This difference has significant legal, economic, and practical implications for environmental trading. The social costs of air pollution from different sources are relatively easy to compare since the pollutant itself and the environmental damages it causes are relatively uniform. By contrast, environmental damages to land, a watershed, or a species are highly idiosyncratic and hence difficult to compare or rank, in large part because the social value of a habitat or a species depends crucially on location in the landscape, relationship to human activities, and changes over time. Valuation methods allow for the comparison of these idiosyncratic impacts. Without these environmental asset valuation methods, confidence in ecosystem exchange is impossible. In short, a ton of sulfur dioxide (SO_2) may be a ton of SO_2 anywhere, but an acre here may not be worth an acre elsewhere.[11]

There are a growing number of complex environmental trades taking place based on only vague trading criteria. When programs fail to assess the relative benefits of ecosystem trades a central purpose of such trading-schemes is undermined: namely, the maximization of net social benefits. If regulators do not adequately assess the value of environmental assets, differences in asset costs alone will tend to determine the pattern of trades. For example, if habitat compensation rules are based solely on lost acreage, habitat restoration will occur on the cheapest lands. All else being equal, this is efficient. But usually, all else is not equal. The migration of preserved and restored habitats to remote, cost-effective locations is unlikely to be ecologically or economically desirable.

To prevent trades based solely on differences in costs, there is a need for tools to evaluate the social benefit of ecosystem trades and compensation.[12] Most current state and federal programs where these issues are pertinent rely on purely biophysical, and often very rudimentary, descriptions

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[10] Because pollutants in an airshed "mix" and disperse widely, the specific location of pollutant reductions is less environmentally important than in other contexts. Accordingly, the environmental consequences of many air emission trades are relatively homogenous and little attention must be paid to the environmental consequences of particular trades. In some cases, however, locational differences in pollution damages can be important in air pollution markets. See Tom Tietenberg, Emissions Trading: An Exercise In Reforming Pollution Policy, Resources For The Future, 60-92, 1985; Jennifer Yelin-Kefer, "Warming up to an International Greenhouse Market: Lessons from the U.S. Acid Rain Experience," 20 Stan. Envtl. L.J. 221-245, 2001.

[11] Early analyses of environmental trading were quick to point out site-specific effects at a conceptual level. See, e.g., J.H. Dales, Pollution, Property and Prices, 1968 ("[I]t is immediately pointed out that a ton of any particular kind of waste will do much more damage in some places than in others . . . ."), at 79. When damages vary by location (as they do with ecosystem degradation) trading ratios must be imposed that account for these differences. See Albert McGartland & Wallace Oates, "Marketable Permits for the Prevention of Environmental Deterioration," 12 J. Envtl. Econ. & Mgmt. 207, 207-28, 1995.

[12] There is an extensive academic literature on the subject of ecosystem valuation methods. See, e.g., A. Myrick Freeman III, The Measurement of Environmental and Resource Values: Theory and Methods, Resources for the Future, 1993. Economic ecosystem valuation tools are described in more detail in Section 3.

of ecosystems to make judgments regarding compensation and appropriate trades. While the best of these systems have strong ecological content, they usually lack economic content.[13] This is a significant oversight. Economic tools help preserve the social value of ecosystems by highlighting the connection between ecosystems' underlying bio-physical properties and ecosystem benefits that matter to people (such as recreational opportunities and aesthetic benefits). They allow us to justify or criticize proposed trades or trading rules in ways that matter to stakeholders and voters. A practical corollary to this prescription, of course, is that the evaluation of ecosystem assets and the "scoring" of ecosystem trades require the integration of economic principles and ecological science.

Biophysical or "functional" assessment, while challenging in its own right, is more a form of characterization than it is a form of valuation. Consider the distinction between ecosystem functions and ecosystem services: ecosystem services are the beneficial outcomes of ecosystem functions. For example, the ability to absorb floodwater is a biophysical function. A service is created if the absorbed floodwater yields less damage to buildings, roads, and agriculture. Even if an ecosystem rates highly in terms of a functional characteristic, that function may not provide a socially valuable service.[14] While anthropocentric, the notion of service value is the best practical means of differentiating between ecosystems when making difficult tradeoffs.

1.2 The Goals of the Study

On one hand, current regulatory landuse programs under-analyze the social value of ecosystems being traded or ecosystem losses requiring compensating mitigation. For example, a common practice in wetland mitigation decisions is simply to require an "acre for an acre" of bio-physically similar wetland when another is destroyed.[15] These acre-based ratios fail to account for

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[13] For more discussion of this point, see section 2. Also see J.B. Ruhl and Juge Gregg, "Integrating Ecosystem Services into Environmental Law: A Case Study of Wetlands Mitigation Banking," Stanford Environmental Law Journal, 365-392, 2001 ("...notwithstanding the available framework and historical context of wetlands mitigation banking, attention to ecosystem service values only rarely occurs"), at 367.

[14] Perhaps a more direct way to make the point is to consider functionally identical ecosystems. Functional equivalence does not imply equivalent social value. Wetlands with an equivalent ability to purify groundwater or absorb floodwater pulses will nevertheless differ in their social value. This follows since the number of people whose drinking water is purified and the number of homes protected from flooding will not be identical.

[15] Whether or not even this is being achieved is open to question. See National Research Council, Compensating for Wetland Losses Under the Clean Water Act, 2001 ("The goal of no net loss of wetlands is not being met for wetland functions by the mitigation program, despite progress in the last 20 years"), at 2.

many of the things that determine the social value of a particular ecosystem, such as a site's location in the greater landscape, the importance of local substitutes for and complements to the site, and future risks to the site's ability to provide services.

On the other hand, state of the art economic methods that employ these basic elements of valuation are difficult and costly to apply. The conventional economic solution involves monetization of the value provided by an ecosystem's services using hedonic, travel cost, contingent valuation, and other econometrically sophisticated methods. However, while monetization is desirable in theory, it is often impractical. In practice, it is rare to see agency decision-makers, or private conservation organizations, making land use decisions based on comprehensive monetization exercises.[16]

One resolution to this conflict is a methodological middle ground: evaluation tools that identify, based on sound economic principles, likely differences in ecosystems' social value but that are easily implemented by non-economists using existing data sources. The overarching hypothesis of this study is that simple "indicators" of ecosystem service benefits would be a welcome addition to the tool-kit of many environmental regulators and landuse planners. While economic precision is sacrificed by a system of simple indicators, so too is the cost, narrowness, and complexity of sophisticated ecosystem valuation methods. Clearly, there is a tradeoff between simplicity and economic precision that has be confronted. In defense of tradeoffs made in the name of simplicity, it should be noted that in many cases even crude application of valuation tools is an improvement over current regulatory practice.

The more specific goal of the study is the design, implementation, and evaluation of a relatively simple indicator-based approach to benefit estimation. Because of the emphasis on implementability we focus on the use of currently available Geographic Information System (GIS) and census data that can be used to draw distinctions, and relative comparisons, between ecosystems.[17] The goal is a system of indicators that is transparent, replicable, and easy-to-use by

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[16] Bio-physical assessments can be difficult for regulatory staff to apply, even without an economic valuation layer. See Betty McQuaid and Lee Norfleet, Assessment of Two Carolina Watersheds Using Land and Stream Habitat Quality Indices, Journal of Soil and Water Conservation, 54:4, 657-665, 1999 ("Currently, many indexing tools are too complex for NRCS field use…").

[17] Others have emphasized the desirability of GIS analysis for the bio-physical (as opposed to benefits) assessment of ecosystems. See Paul Cedfeldt, Mary Watzin, and Bruce Richardson, "Using GIS to Identify Functionally Significant Wetlands in the Northeastern United States," Environmental Management, 26:1, 13-24, 2000. (Describing conventional assessment methods: "these methods all rely on time-consuming site visits to evaluate each wetland of concern. This requirement has restricted their use. A more efficient approach to functional assessment could be performed with the aid of a Geographic Information System," at 13.)

field office and other regulatory staff. In addition, the project seeks to inform benefit assessment methods with a better understanding of ecological science. The spatial aspect of ecological relationships, in particular, is often not adequately appreciated by economists. Can ecosystem service valuation be made simple? We remain agnostic on that point. To be sure, benefit *evaluation* – as opposed to service *valuation* – can be made simpler. But this project also highlights the complexity of any effort to unites ecological science and economic valuation in a framework that is clear, simple, uncontroversial, and methodologically sound.

What is clear is that GIS and census data can be easily used to evaluate the scarcity of ecosystem services in the landscape, the accessibility of sites for recreation and aesthetic enjoyment, future risks to the ecosystem, and the ecosystem's marginal impact on a larger area's provision of ecosystem services. In other words, basic economic valuation principles can be combined with existing data sources to improve our understanding of the relative benefits of different pieces of the landscape. For example, readily available data can be used to judge whether a wetland is in a hydrological position to reduce flood pulses. It can also be used to identify the number and value of structures that might be protected by such a wetland. This does not allow us to place a dollar value on the wetland's flood protection services. Indicators, by their nature, are not designed to assess subtle tradeoffs. But indicators do allow us to identify hydrologically connected versus hydrologically isolated wetlands. This kind of distinction in turn suggests that flood control services associated with the former site are likely to yield greater benefits than at the latter site. Landscape indicators also allow us to index the relative value of flood control based on the number and value of structures, roads, and home that would be protected. Again, it should be emphasized that many existing decision tools fail to explore this kind of basic issue when evaluating sites or the adequacy of ecosystem compensation and trades.

A final goal of the project is greater integration of ecological thinking into economic evaluation procedures. The ecosystem services perspective provides the necessary linkage for this task. Ecosystem functions, as described and evaluated by ecological science, are the basic inputs to the ecological services valued by society. An understanding of those inputs is essential to any valuation exercise.

2. Ecosystem Evaluation in Practice

An ecosystem's features, such as size, vegetation, boundaries, and its functional aspects, such as ability absorb floodwater or remove contaminants from surface water are biophysical indicators of its value. Equally important to understand, however, are factors such as the ecosystem's setting in terms of local landuse configurations, related human activities, and demography. Comprehensive evaluation, in particular evaluation of service benefits, requires the analysis of both biophysical and socioeconomic considerations. In practice, agency ecosystem assessment methods under-employ service valuation, in favor of bio-physical analysis. Federal wetland and agricultural reserve programs exhibit some appreciation for ecosystem service valuation.[18] In practice, however, biophysical assessment, rather than service valuation, dominates regulatory evaluation of sites. Ecosystem service valuation is not broadly applied largely because there are few ecosystem service compensation requirements under United States law. Only the natural resource damage (NRD) provisions of the Oil Pollution Act (OPA)[19] and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)[20] explicitly mandate ecosystem valuation as a response to ecosystem service losses. NRD assessment is an exception worthy of note.

Despite the limited use of ecosystem services as a basis for evaluation, service benefit evaluation is not inconsistent with statutory requirements for wetland mitigation, the targeting of agriculture assistance programs, and the management of federal lands. This section provides a brief overview of the current (and possible) role of service benefit estimation in agency decision-making.

2.1 Wetland Mitigation

Section 404 of the Clean Water Act, which governs wetland impacts above a certain size, requires mitigation for wetland losses cause by development and other activities.[21] Wetland mitigation projects – particularly off-site mitigation projects – either implicitly or explicitly involve the exchange of one wetland for another. Development permits may be issued contingent on a restoration activity, conservation easement, or payment of a fee to be applied later to some wetland-enhancing action. In some cases, wetlands are explicitly traded via so-called wetland mitigation

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[18] See sections 2.2 and 2.3.

[19] 33 U.S.C. §§ 2701-2761 (1994 & Supp. IV 1998).

[20] 42 U.S.C. §§ 9601-9675 (1994 & Supp. IV 1998).

[21] 33 U.S.C. § 1344 (1994).

banks.[22] These requirements mean that regulators must determine how much restoration or compensating preservation is enough to offset permitted wetland losses.

Historically, regulations guiding wetland mitigation maintained a clear preference for "on-site, in-kind" mitigation.[23] Mitigation was required at or near the site of wetland loss. With lost and replaced wetlands arising at the same location, location-specific services are not gained or lost. provided that wetland functions were themselves replaced, similar services and benefits were likely to arise on-site. In this context, bio-physical indicators are acceptable proxies for service valuation. With in-lieu fee and mitigation banking programs, however, mitigation takes place off-site. With of-site mitigation, even if functional losses are met with equal functional gains, the functions will have different social benefits depending on their location in the human and natural landscape.

Accordingly, ecosystem service valuation is directly relevant to the goals of wetland mitigation policy, but is not explicitly required by regulation. Among other things, mitigation includes "[c]ompensat[ion] for the impact by replacing or providing substitute resources or environments."[24] But replacement of lost social value is not a regulatory requirement. In addition, the program's goal is one of "no net loss" in wetlands. This standard is vague, however. First, the no net loss goal is just that: a goal rather than a regulatory requirement.[25] Second, no net loss does not refer to "no net loss in social value." Instead, the "no net loss" goal is in practice taken to mean "no net loss in area" or at best "no net loss in 'functional capacity'."[26] In short, wetland trades and mitigation could easily feature a "preservation of service value" test, but in practice do not do so.[27]

Program guidance documents for the use of wetland mitigation banks highlight the emphasis on functional characterization, rather than service valuation, as the relevant metric for wetland comparisons. According to federal guidelines, "[t]he objective of a mitigation bank is to provide for

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[22] For a good description of wetland mitigation banking practices see Paul Scodari & Leonard Shabman, National Wetland Mitigation Banking Study, Commercial Wetland Mitigation Credit Markets: Theory and Practice, U.S. Army Corps of Engineers, Institute for Water Resources, IWR Rep. 95-WMB-7, 1995.

[23] See James Salzman & J.B. Ruhl, supra note 8.

[24] 40 C.F.R. § 1508.20(e) (2000).

[25] Final Notice of Issuance and Modification of Nationwide Permits, 65 Fed. Reg. 12,818, 12,830 (March 9, 2000) ("[C]ompensatory mitigation is required to ensure that the authorized activities result in minimal adverse effects on the aquatic environment, individually or cumulatively, not to achieve 'no net loss' of wetland acreage. [Nationwide permits] compensatory mitigation requirements are not driven by the 'no net loss' goal, but will help support that goal.").

[26] 23 C.F.R. § 777.2 (2000) (defining net gain).

[27] See Ruhl and Gregg, supra note 8, noting the emphasis on functional assessment, not service valuation ("At best...the current legal framework of wetlands mitigation banking establishes the implicit authority, but no explicit requirement, for the consideration of ecosystem services"), at 378.

the *replacement of the chemical, physical, and biological functions* of wetlands and other aquatic resources which are lost as a result of authorized impacts" (emphasis added).[28] Surveys of wetland mitigation banking practice confirm the reliance of bank program administrators on relatively vague, function-based compensation ratios.[29] A 1992 study found that while a variety of evaluation methods were in use at that time, all of them were based on functional assessment, habitat evaluation, or simple acreage-based conversion rules.[30] Case studies of forty-six banks, published that same year, showed twenty banks using functional assessment, and twenty-six using rough acreage-based ratios.[31] Current practices are much the same.[32] Recent criticism of Corps' evaluation procedures has been based on the Corps' failure to address lost functions.[33] Lost services derived from lost functions is rarely mentioned.

Generalizations regarding the Corps' decision criteria must be made with some care, since most wetland mitigation decisions rely heavily on case-by-case judgments by district engineers and other administrators. It is likely that these judgments, made by administrators familiar with the wetlands in question, are based on information or opinions relating to ecosystem service benefits, as well as biophysical site characterization. Reliance on best professional judgment is problematic, however, due to the inherently subjective and idiosyncratic nature of personal judgments, no matter how ecologically or economically sophisticated.

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[28] Federal Guidance for the Establishment, Use and Operation of Mitigation Banks, 60 Fed. Reg. 58,605, 58,607 (November 28, 1995). Functional assessment itself is not a strict requirement. See id. at 58,612.

[29] See John Brady, "Mitigation of Damage to Wetlands in Regulatory Programs and Water Resource Projects," 41 Mercer L. Rev. 893, 941-46, 1990.

[30] Environmental Law Institute & The Institute for Water Resources, National Wetland Mitigation Banking Study, Wetland Mitigation Banking, U.S. Army Corps of Engineers, Institute for Water Resources, IWR Rep. 94-WMB-2, 1994.

[31] Robert Brumbaugh & Richard Reppert, National Wetland Mitigation Banking Study: First Phase Report, U.S. Army Corps of Engineers, Institute for Water Resources, IWR Rep. 94-WMB-4, 1994.

[32] J.B. Ruhl & R. Juge Gregg, "Integrating Ecosystem Services into Environmental Law: A Case Study of Wetlands Mitigation Banking," 20 Stan. Envtl. L.J. 365, 2001. See also Leonard Shabman, Kurt Stephenson, and Paul Scodari, "Wetlands Credit Sales as a Strategy for Achieving No Net Loss: The Limitations of Regulatory Conditions," *Wetlands*, 18:3, 1998.

[33] According to one Congressman critical of Corps' procedures, "compensating for both [lost acreage and lost functions] is essential." See Susan Bruninga, Bill to Codify Mitigation Banking Guidance Has Support of Bush Administration Officials, Environment Reporter, September 28, 2001, 1876-7.

2.2 Agriculture Support Programs

A variety of programs administered but the U.S. Department of agriculture involve planning or government expenditures for conservation.[34] There is also a growing consensus that it is desirable to measure and act on the public environmental benefits of private lands.[35]

As an example, ecosystem ranking occurs under the Wetland and Conservation Reserve Programs.[36] While the ranking process is unique to each State, most scoring criteria relate to factors such as habitat type, hydrology, species support, operations and maintenance costs, and the likelihood of limiting factors, such as invasive species.[37] These factors are largely biophysical in nature, with very little ecosystem service-related data.

The Conservation Reserve Program places a similar emphasis on functional evaluation. Here, though, some value-based indicators are evident. Sites are given an "Environmental Benefits Index" ranking. The biophysical components of this ranking include measures of soil erodibility and leachability. Service indicators include the number of well-water users in proximity to the land. This approach does not simply index a land's functional characteristics; it also indexes the social value of the land's water purification function. The value of including additional service value indicators in the USDA's targeting of CRP lands has been explored by the agency, though a service-intensive index is not currently in use.[38]

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[34] For an overview of these programs, see National Governors Association, Private Lands, Public Benefits: Principles for Advancing Working Lands Conservation, 2001, Appendix A, 46-49.

[35] Id. ("Goverment-supported working lands conservation programs should demonstrate that they produce valuable and measurable 'environmental goods' or 'conservation commodities.'"), at 6.

[36] See generally Heimlich et al., Wetlands and Agriculture: Private Interests and Public Benefits, U.S. Dept. of Agric., Agric. Econ. Rep. No. 765, 1998. The Fish and Wildlife Service also targets wetland creation and restoration through Private Lands Partnerships and Wildlife Extension Agreements. For overviews of these programs see Partners for Fish & Wildlife, U.S. Fish & Wildlife Service, Partners Program, at http://midwest.fws.gov/alpena/prvprogr.htm (last visited March 29, 2001) and Partners for Fish & Wildlife, U.S. Fish & Wildlife Service, U.S. Fish & Wildlife Service Programs, *at* http://www.r6.fws.gov/pfw/r6pfw8c.htm#WEA (last visited March 29, 2001).

[37] See, e.g., Natural Resources Conservation Service, U.S. Dep't Agric., Wetland Reserve Program (WRP) Ranking Forms, Oregon Bulletin No. OR300-2001-1, Attachment 3, 2000, at http://www.or.nrcs.usda.gov/admin/ orbulletin.html (last updated, April 4, 2001).

[38] See Peter Feather et al., Economic Valuation of Environmental Benefits and the Targeting of Conservation Programs: the Case of the CRP, U.S. Dep't Of Agric., Agric. Econ. Rep. No. 778, 1999 (discussing non-market benefits and valuation, and describing three valuation models).

2.3 The Forest Service and Bureau of Land Management

The Forest Service's planning guidelines point toward a future role for ecosystem service analysis in the management of National Forest System lands and resources.[39] New management rules, finalized in 2000 but then subsequently withdrawn, require "the development of information on the range and estimated long-term value of market and non-market goods, uses, services, and amenities that can be provided by National Forest System lands consistent with the requirements of ecological sustainability."[40] This aspiration is a fairly explicit statement of the need for ecosystem service benefits estimation in Forest Service planning.

In addition, the Federal Land Management Policy Act (FLPMA) authorizes the USFS and BLM to exchange federal land for non-federal land, subject to certain conditions being met.[41] These conditions are that both the market value and public benefit of the lands being aquired are comparable or exceed the market value and public benefits of the lands being lost. Also, an environmental analysis must be completed for certain exchanges, as required by the National Environmental Policy Act.[42] The Forest Service and BLM have recently been criticized for their poor evaluation of both market value and public benefits. A GAO review team found a "lack of documentation to support certain public interest determinations" and that the agencies failed to show the preservation of public benefits.[43] Accordingly, analysis of public benefits is a current priority for both agencies. Hundreds of these exchanges are conducted by each agency every year.

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[39] This is not a new idea, at least in academic circles. See Michael Boews and John Krutilla, Multiple-Use Management: The Economics of Public Forestlands, Resources for the Future, 1989.

[40] 65 Federal Register 67514, 67551, November 9, 2000 ("The Department believes this language in the final rule requires the inclusion of commodity and non-commodity resource benefits in economic analyses, with values assigned to those benefits"). The rule is currently suspended. Federal Register 27551, May 17, 2001.

[41] P.L. 94-579, Oct. 21, 1976. The public interest determination requires the agency to "...give full consideration to better Federal land management and the needs of the State and local people, including needs for lands for the economy, community expansion, recreation areas, food, fiber, minerals, and fish and wildlife..." 43 U.S.C. 1716(a).

[42] P.L. 91-190, Jan 1, 1970.

[43] General Accounting Office, Land Exchanges Need to Reflect Appropriate Value and Serve the Public Interest, GAO/RCED-00-73, June 2000, at 28. ("The agencies did not follow their requirements that help show that the public benefits of acquiring the nonfederal land in an exchange matched or exceeded the public benefits of retaining the federal land, raising doubts about whether these exchanges served the public interest"), at 4.

2.4 Natural Resource Damages

Several United States environmental statutes establish liability for injury to natural resources. The Deepwater Port Act of 1974 and the Clean Water Act amendments of 1977 introduced natural resource damage (NRD) liability to federal law.[44] Subsequent to, and in most ways superseding those statutes, liability for NRDs was established under CERCLA,[45] OPA,[46] and the National Marine Sanctuaries Act.[47]

In both economic and legal terms, the goal of natural resource damage liability is to "make the environment and public whole" following a pollution event.[48] This standard is straightforward and consistent with legal and economic theories of deterrence, such as in torts, that emphasize the desirability of social cost internalization by injurers. Ecosystem service valuation is triggered by the statutes because they create a compensable liability for ecosystem damage—liability that must be calculated for the purposes of recovery. NRD injuries can take a variety of forms, but typically relate to adverse changes in the health of a habitat or species population and in the underlying ecological processes on which they rely.[49]

OPA and CERCLA directed the National Oceanic and Atmospheric Administration (NOAA) and the Department of Interior (DOI), respectively, to develop rules governing natural resource

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[44]. For the CWA, see 33 U.S.C. § 1251-1387 (1994 & Supp. IV 1998). Section 311 of the CWA regulates the discharge of oil and other hazardous substances into navigable waters, allows the government to remove the substance, and holds the responsible parties liable for that removal. The removal cost is defined to include "costs or expenses incurred… in the restoration or replacement of natural resources damaged or destroyed." Id. at 1321(f). The Deepwater Port Act of 1974, which preceded the CWA, established liability for damages to natural resources to be recovered by a federal trustee and used for restoration. 33 U.S.C. § 1501-1524 (1994 & Supp. IV 1998).

[45] 42 U.S.C. §§ 9601-9675 (1994 & Supp. IV 1998). Section 107 of the Act establishes NRD liability and authorizes federal trustees to recover damages for assessing and correcting natural resource injuries. 42 U.S.C. § 9607(f)(1) (1994).

[46] 33 U.S.C. §§ 2701-2761 (1994 & Supp. IV 1998). Section 1002 of the Act establishes liability for "injury to, destruction of, loss of, or loss of use of natural resources." 33 U.S.C. § 2702(b)(2)(A) (1994).

[47] 16 U.S.C. §§ 1431-1445(a) (1994 & Supp. IV 1998). Section 1432(6) defines damages and Section 1443 establishes liability and authorizes civil actions to pursue cost recovery.

[48] 15 C.F.R. § 990.53 (2000) (relating to NRDs under OPA). For the CERCLA rules see 43 C.F.R. § 11.80 (2000) ("Damages may also include, at the discretion of the authorized official, the compensable value of all or a portion of the services lost to the public for the time period from the discharge or release until the attainment of the restoration, rehabilitation, replacement, and/or acquisition of equivalent of the resources and their services to baseline.").

[49] See 15 C.F.R § 990.51(c) (2000) ("Potential categories of injury include, but are not limited to, adverse changes in: survival, growth, and reproduction; health, physiology and biological condition; behavior; community composition; ecological processes and functions; physical and chemical habitat quality or structure; and public services.").

damage compensation.[50] DOI published damage assessment rules in 1986.[51] These rules, published during the Reagan administration, took a relatively narrow view of the types of injuries that were compensable, the scope of compensation, and the methods to be used in damage assessment. The rules strongly favored a market-oriented approach to damages and established a hierarchy of assessment methodologies. If there was a competitive market for the resource, a diminution in the resource's value (the damage) was to be captured by observable market data, such as changes in prices and quantities. If this was inappropriate or impossible, standard appraisal methods were to be used. Only when neither of these was determined by the trustee to be appropriate would "nonmarket" procedures be used. In addition, damages were not to include those associated with nonuse values (e.g., option, existence, or bequest values). Two 1989 cases, *Ohio* v. *Department of Interior* and *Colorado* v. *Department of Interior,* forced DOI to revise those rules in 1994.[52] In court in *Ohio* strongly favored the use of restoration as the basis for damages, even if restoration is more expensive than monetary estimates of lost use value.[53] The *Ohio* court also invalidated the exclusive reliance on market- or priced-based definitions of damage. Under the current rules nonuse values such as option, existence, and bequest values are compensable.[54] The revised rules acknowledge that "the mere presence of a competitive market [for resources] does not … ensure the price will 'capture fully' the value of the resource."[55]

In 1996, NOAA followed the 1994 DOI rules with rules of its own, to be applied to assessments authorized under OPA.[56] The rules strongly favor restoration over remedies that require monetary compensation or off-site mitigation. However, off-site restoration is typically needed to

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[50] Compensable value includes "all of the public economic values associated with an injured resource, including use values and nonuse values such as option, existence, and bequest values." 56 FR 19760, April 29, 1991.

[51] 61 FR 20609, 1986.

[52] *Ohio* v. *Department of Interior* (880 F.2d 432, 442 (D.C. Cir. 1989) and *Colorado* v. *Department of Interior* (880 F.2d 481 (1st Cir. 1989). For the purposes of this analysis, the *Ohio* case is more important, since it related to Type B assessment procedures. The *Colorado* case came to broadly similar conclusions regarding the original DOI rules but relates primarily to the more limited Type A procedures.

[53] The NRDA rules' current focus on the replacement cost of resources, rather than their estimated market value, is a direct outgrowth of these cases. H.R. Conf. Rep. No. 653, 101st Cong., 2d Sess. 108 (1990). Also, see discussion in Russell Randle, The Oil Pollution Act of 1990: Its Provisions, Intent, and Effects, 21 ELR News and Analysis 10119, 1991.

[54] Compensable value includes "all of the public economic values associated with an injured resource, including use values and nonuse values such as option, existence, and bequest values." 56 FR 19760, April 29, 1991.

[55] 56 FR 19759, 1991.

[56] The rules are codified at 15 CFR 990 (the NOAA rules for OPA damages) and 43 CFR 11 (the DOI rules for CERCLA damages).

achieve full social compensation. First, complete physical restoration of the injured resource may be impractical. If so, some form of compensating restoration will be pursued, usually involving the enhancement of another comparable, but not identical, resource. Second, even when on-site restoration is pursued interim natural resource service losses must be compensated.[57] Compensation for interim losses, by definition, cannot be achieved via restoration. Accordingly, interim losses require a search for comparable, off-site restoration actions. Under OPA, governmental agencies pursuing a claim, must "consider compensatory restoration actions to compensate for the interim loss of natural resources and services pending recovery [and] … trustees must consider compensatory restoration actions that provide services of the same type and quality, and of comparable value as those injured."[58] NRD assessment rules describe a variety of methods by which this "scaling" can occur, many relying on the value of ecosystem services as the relevant metric.[59]

The use of service-based approaches marks federal NRD rules as the peak of sophistication when it comes to the use of ecosystem valuation in regulatory decision-making.[60] It is important to note, however, that NRD liability and assessment is not broadly applicable to land use decisions. NRD assessment is triggered only under a narrow set of conditions, most typically large pollution events to which OPA and CERCLA apply. Also, ecosystem valuation is relatively sophisticated in the NRD assessment process largely because the large size of injuries to which they apply fosters significant expenditure on damage estimation. More run-of-the-mill land use changes rarely warrant large investigative expenditures.

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[57] Defendants found liable for natural resource damages are liable for the cost of resource restoration to baseline conditions as well as the social cost of "interim losses," that is, the lost value of injured resources pending full restoration. CERCLA §101(6); OPA §1001(5), §1002(b)(2).

[58] 15 CFR 990.53(c).

[59] 43 C.F.R § 11.71(e) (2000) ("[S]ervices include provision of habitat, food and other needs of biological resources, recreation, other products or services used by humans, flood control, ground water recharge, waste assimilation, and other such functions that may be provided by natural resources."); see also id. § 11.70(a) ("Upon completing the Injury Determination phase, the authorized official shall quantify for each resource determined to be injured and for which damages will be sought, the effect of the discharge or release in terms of the reduction from the baseline condition in the quantity and quality of services . . . provided by the injured resource . . . ."). For examples of damage assessment that employ scaling exercises, see Brian Julius, National Oceanic and Atmospheric Admin., Report on U.S. vs. Melvin A. Fisher et al. (Jan. 29, 1997); David Chapman et al., Calculating Resource Compensation: An Application of the Service-to-Service Approach to the Blackbird Mine Hazardous Waste Site, National Oceanic And Atmospheric Admin., Technical Paper 97-1, 1998.

[60] This claim is based on NRD liability's unique statutory basis and on the relatively large government expenditures devoted to the assessment of NRD damages. Compare the resources spent to evaluate the Exxon Valdez oil spill with the resources available for individual wetland permit decisions.

3. Existing Evaluation Techniques

sssBecause we are developing and evaluating a method of ecosystem evaluation, it is important to place that method in the context of other methods that are, or can be, used to perform evaluation. The evaluation context is defined by two broad sets of methods: first, biophysical assessment, which is predominately ecological in content, and second, economic valuation, which uses the tools and principles of economics to value services derived from environmental assets. Our method borrows from both sets of methods. It borrows its principles and overall perspective from economic valuation. It borrows the use of indicators based on easily observable data from biophysical assessment methods.

3.1 Biophysical Assessment Techniques

While there is a large literature on biophysical characterization, there is no universally accepted procedure for describing, much less ranking, any particular type of ecosystem based on its biological components and physical features.[61] If a general statement can be made, it is probably that sites supporting a large number of species, particularly rare or endangered species, and defined by natural boundaries are considered the most biologically valuable. But such simple, general statements do not provide an adequate litmus test. The complexity of ecosystems tends to quickly defeat simplicity. In fact, ranking systems based on state of the art ecological science typically involve the collection of a wide array of site data. Currently no single, or even small set of indicators, is considered to be a definitive measure of ecosystem quality. The lack of consensus on a set of procedures to bio-physically characterize ecosystems is indicative of the complexity of those systems and the challenge for analysis.

Historically, characterizations of species have long been considered a relatively good indicator of other ecosystem features. Accordingly, most early attempts at ecological functional assessment focused on animal populations and were based on field surveys (or, more recently, remote sensing) to detect the presence or absence of certain species.[62] Population surveys are now

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[61] See Stephen Polasky, Biodiversity Bibliography: Ecology, Economy and Policy, at http://www.apec.umn.edu/faculty/spolasky/Biobib.html (providing a comprehensive summary of the literature on this subject).

[62] See Walter E. Westman, Ecology, Impact Assessment, and Environmental Planning, 1985; see also Jan Bakkes et al., An Overview of Environmental Indicators: State of the Art and Perspectives National Institute of Public Health and Environmental Protection, Environment Assessment Technical Reports UNEP/EATR, 1994.

often supplemented or replaced by methods focused on more permanent biophysical and landscape characteristics—characteristics that signal the suitability of sites as habitat.[63] And increasingly, assessment focuses on habitat function analysis, or measures of the ability of an ecosystem to provide quality habitat.

Consider the development and variety of methods to evaluate wetlands. Wetland assessment methods focus on measuring the physical, chemical, and biological structure of wetlands, and the wetlands' resulting ability to provide natural functions. Assessment procedures are numerous and varied.[64] The Habitat Evaluation Procedures (HEP), developed in 1980, was one of the first and most comprehensive attempts to show that wetlands provide services beyond those associated with recreation or land market values.[65] HEP is still a widely used method for establishing habitat value. However, HEP focuses primarily on site characteristics that satisfy the needs and preferences of wildlife species (e.g., breeding and feeding conditions), not on site and landscape characteristics that determine how improved habitats are likely to satisfy the needs and preferences of people. A significant amount of conceptual work went into the development of a component of HEP called the "human use and economic evaluation" (HUEE) module, which does incorporate human values. However, the concepts underlying HUEE were never fully developed or field tested; and, unlike the rest of the HEP method, the HUEE module has not been widely used.[66]

Numerous wetlands assessment procedures have been developed since HEP. Some attempt to address wetland values based on the presence or absence of notable features, such as endangered species or designated historic or archeological areas.[67] A few procedures include analysis used to assign scores to wetlands based on social categories such as recreation, aesthetics, agricultural

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[63] Under the most widely used approach, a Habitat Suitability Index (HSI) and the total area of habitat are used to quantify habitat. U. S. Dep't of Interior, Fish and Wildlife Service, Habitat Evaluation Procedure (HEP), 1980.

[64] See Department of Agriculture, Methods for Evaluating Wetland Functions, WRP Technical Note WG-EV-2.2, May 1994; Candy C. Bartoldus, Comprehensive Review of Wetland Assessment Procedures: A Guide for Wetland Practioners, 1999 (providing an overview of thirty wetland assessment methods); see also World Wildlife Fund, Statewide Wetland Strategies: A Guide to Protecting and Managing the Resource, 1992.

65 U.S. Fish & Wildlife Services, Dept. of the Interior, Habitat Evaluation Procedures 102, 1980.

[66] See U.S. Fish & Wildlife Services, Human Use and Economic Evaluation Handbook, 1985, available at http://policy.fws.gov/872fw1.html (visited Apr. 23, 2001).

[67] E.g., Anna L. Hicks, New England Freshwater Wetlands Invertebrate Biomonitoring Protocol, 1997; Ted T. Cable, et al., Simplified Methods for Wetland Habitat Assessment, 13 Envtl Mgmt. 207, 1989.

potential, and educational values.[68] These kinds of analyses relate to the social value of ecosystems, either explicitly or implicitly. Some of them also weave concepts of function and value into a measure called "functional value."[69] However, the criteria for assigning relative values to different wetlands or distinguishing between levels of function and associated values are not clearly defined in any of these methods.

The current state of the art in wetland evaluation is functional analysis, as exemplified by the hydro-geomorphic (HGM) approach to wetland assessment.[70] The HGM is notable for several reasons. First, it employs the notion that a wetland's value is related to its position in the landscape.[71] Second, because the HGM approach measures various functions, it is a good starting point for analysis of services that flow from those functions. Third, the HGM method has been developed specifically to support regulatory decision-making by allowing functional or qualitative comparisons between wetlands of the same class in a given region.[72] More typical of other assessment methods, however, the HGM model is not designed as an economic evaluation tool, but rather as a biophysical evaluation tool.[73]

This brief review of bio-physical assessment procedures is offered as an illustration of their number, variety, and typical lack of content directed toward economic valuation of ecosystem services. As discussed below, the biophysical focus of traditional ecosystem evaluation is reinforced by regulatory requirements and procedures.

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[68] E.g., Minn. Bd. of Water and Soil Resources, Minnesota Routine Assessment Method for Evaluating Wetland Functions, Draft version 2.0, 1998; Emily Roth et al., Oregon Freshwater Wetland Assessment Methodology, 1996; Alan P. Ammann, et al., Method for the Evaluation of Inland Wetlands in Connecticut, Conn. Dep't of Envtl. Protection Bull. No. 9, 1986; Alan P. Ammann & Amanda L. Stone, Method for the Comparative Evaluation of Nontidal Wetlands in New Hampshire, N. H. Dep't of Envtl Services NHDES-WRD-1991-3, 1991; G.G. Hollands & D. W. Magee, A Method for Assessing the Functions of Wetlands, in Proceedings of the National Wetland Assessment Symposium 108, J. Kusler & P. Riexinger eds., 1985.

[69] See, e.g., Ammann and Stone, supra note 68.

[70] See Mark M. Brinson, A Hydro-geomorphic Classification for Wetlands, Wetlands Res. Program Technical Rep. No. WRP-DE-4, 1993.

[71] See Mark Brinson & Richard Rheinhardt, The Role of Reference Wetlands in Functional Assessment and Mitigation, 6 Ecological Applications 69, 71, 1996 (explaining that the first step in relating functional assessments and reference wetlands is to "classify wetlands according to similarities in their landscape settings, water sources, and hydrodynamics, following the general hydro-geomorphic approach…")

[72] The National Action Plan to Implement the Hydro-geomorphic Approach to Assessing Wetland Functions, 62 Federal Register 33607-33613, June 20, 1997.

[73] To quote the National Action Plan for implementing the approach, "the functional capacity indices resulting from the HGM approach cannot be equated to the societal or economic value of that wetland function." 62 Fed. Reg. 33,607, 33608 (June 20, 1997).

3.2 Valuation – the Economic Approach

Economic evaluation seeks to uncover the social value of an ecosystem's functions and qualities.[74] An ecosystem can be thought of as an asset with various characteristics. These characteristics yield services that are valuable to individuals and to society collectively. If the value of those services can be revealed and expressed in a common metric then that metric can be used to evaluate and rank the value of different ecosystems. Dollars are that metric, hence the desire for monetized estimates of ecosystem value.

The assumptions built into economic valuation are relatively transparent and the methods used to estimate value are objective in the sense that they are replicable and internally, logically consistent. This by no means answers all of the criticisms of valuation as a paradigm for evaluation, but it does elevate economics over most other alternatives; alternatives that are typically more ad hoc. Unfortunately, ecosystem valuation is difficult, due to the nature of the asset or services being valued.

Methodological difficulties arise because ecosystem services are typically not traded in markets and thus do not "reveal" their monetary value in the way conventional economic goods and services do. For this reason, economists over the last twenty years have been experimenting with methods to estimate the dollar value of non-marketed ecological services. Attempts at "non-market" valuation fall into three general categories: revealed, expressed, and derived willingness to pay.[75]

Revealed willingness-to-pay studies look at the price people are willing to pay for marketed goods that have an environmental component. From those prices, inferences about the environmental benefits associated with the good can be made. For example, when people purchase a home near an aesthetically pleasing ecosystem home prices reflect that environmental amenity.[76] Alternatively, when people spend time and money traveling to recreation they reveal a willingness to pay the time and travel costs to access the recreational services. "Travel cost" studies are used to make a benefit estimate based on those expenditures.[77] The travel cost method requires data and analysis linking

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[74] Sound ecological analysis is a necessary input to sound economic evaluation, since the functions and characteristics of ecosystems are the basic inputs to what is being valued.

[75] For a good overview of these methods see A. Myrick Freeman, The Measurement of Environmental and Resource Values: Theory and Methods, Resources for the Future, 1993.

[76] Hedonic analysis is used in this type of study. See, e.g., Brent Mahan, Stephen Polasky & Richard Adams, "Valuing Urban Wetlands: A Property Price Approach," 76 Land Econ. 100, 2000.

[77] There is a large methodological literature on this subject. See, e.g., Kenneth McConnell, "On-Site Time in the Demand for Recreation," 74 Amer. J. Agr. Econ. 918, 1992.

the number of trips to a site with the quality, size, or location of a site. Changes in these attributes can be valued if there is a perceptible change in the number, length, or cost of trips taken to the site. The drawback to these kinds of analyses is that they require a great deal of data and econometric sophistication.[78] They also tend to focus on the benefits of only a subset of services because the methods used to estimate, for example, recreational values, avoided flood damage benefits, improved water quality benefits, and aesthetic value tend to differ depending on the services in question. Also, the value revealed by observed behavior will almost always understate the true social value of an asset, since most environmental assets are public goods, and many are provided, not by markets, but by governments. As one example, hedonic analysis will only capture the value of services internalized in private housing prices. The true social value of an ecosystem will usually be greater than the amount that is locally internalized in private property values.[79]

One way around these problems is to move away from reliance on preferences revealed in markets. Expressed willingness-to-pay studies are one such alternative. Expressed willingness-to-pay studies ask people, in a highly structured way, what they would be willing to pay for a set of environmental improvements. Contingent valuation studies are an example. Surveys of expressed willingness-to-pay are expensive, controversial, and are most reliable when the questions concern specific ecological services provided in specific contexts. The more complex and holistic the improvement, or change, the more difficult the methodological challenge. A principal drawback to this approach is the risk that people may misunderstand the precise service being valued when undisciplined by the need to spend their own real money. For the same reason, they may also overstate their willingness to pay.[80] Nevertheless, these methods are a distinct improvement relative to evaluation techniques that ignore social preferences.[81]

One other alternative is to derive the social value of an ecosystem service indirectly. If an ecosystem prevents a social cost, an estimate of that cost places a lower bound on the ecosystem's

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[78] An important issue in travel cost studies, for example, is the definition of relevant substitutes for the sites in question. See Northeast-Midwest Institute and NOAA, supra note 6, ("omitting the prices and qualities of relevant substitutes will bias the resource valuations"), at 73.

[79] The value of some ecosystem services, such as flood protection and aesthetic beauty, may be internalized in property values.

[80] See generally Raymond J. Kopp et al. eds., Determining the Value of Non-Marketed Goods, Kluwer, 1997 (presenting a good collection of articles relating to the contingent valuation method).

[81] See Richard Carson, Nicholas Flores, and Norman Meade, Contingent Valuation: Controversies and Evidence, 19 Environmental and Resource Economics, 173-210, 2001 for a review and defense of contingent valuation's role in the evaluation of environmental goods and services.

value. For instance, if we want to know the value of having a wetland reduce flood damages we can, in principle estimate the dollar value of damage due to a flood and siltation event, and estimate the greater likelihood such an event will occur if the wetland is destroyed. Clearly, the weakness of this kind of analysis is that it is highly speculative, relies heavily on technical analysis, and requires data that usually does not exist.

Economic valuation methods, such as revealed, expressed, and derived willingness to pay studies, are a desirable approach to ecosystem evaluation because the econometric tools employed are objective and have been extensively tested, criticized, and improved over a period of decades. Unfortunately, methods seeking monetary estimated of ecosystem benefits are technically challenging, fraught with dangers that may not be obvious to non-practitioners, and require significant amounts of data collection.[82] In other words, economic valuation methods are expensive, difficult to do well, and intimidating to non-economists.[83]

"Benefit transfer" studies are one way to harness the benefits of econometric estimation while minimizing the need for costly new data collection. The benefit transfer method essentially takes the results of pre-existing studies and translates them into a new context. For example, if a study of trout fishing in Colorado yields a per-person benefit of $100 a day, this result can be transfered, with some adjustments, to say something about the value of a fishing day in California. The relationship of our methods to benefit transfer techniques is discussed in more detail in section Seven.

4. The Benefit Assessment Perspective

As the previous sections indicate, there is a potential, but largely unexploited, role for ecosystem service benefit assessment in regulatory decision-making. Some programs already employ this framework and are engaged in service valuation (as in the case of NOAA's NRD assessments, for example). Other agencies have a mandate to pursue benefit-based evaluation but do

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[82] For an interesting case study of real world ecological service damage assessment see David Chapman and W. Michael Hanemann, Environmental Damages in Court: the American Trader Case, in Anthoney Heyes ed., The Law and Economics of the Environment, Elgar, 2001.

[83] See Carson, et al, supra note 81 ("we believe that at this point in the development of CV, the key objective in terms of methodological development should shift to trying to determine how to reduce the cost of conducting CV studies while still maintaining most of the quality of the very best studies now being conducted"), at 196.

not currently use social benefits as a metric for decision-making (the COE's wetland mitigation programs). Other agencies, such as the USDA and Forest Service, seem poised to use, if not require, more service benefit assessment in their planning.

Despite the virtues of monetary valuation, the rarity of its use in routine regulatory decision-making is not surprising. Monetization efforts are time-consuming and require costly site-specific studies. To re-coin a phrase, economic precision is the enemy of the possible. Individual ecosystem losses are relatively large in number and are often only a small number of acres in size. From a regulatory decision-making standpoint, the cost of econometric studies will frequently exceed the benefits. But monetization is not the only solution. What is needed is a methodological middle ground: evaluation tools that can be easily implemented by non-economists using existing data sources to identify, based on sound economic principles, likely differences in the social benefits of ecosystems.

This section lays out the basic principles of valuation and relates those principles to ecosystem benefit assessment.

4.1 The Role of Benefit Assessment in Ecosystem Trading and Compensation Procedures

This research is concerned with one component of a larger array of factors necessary to evaluation of ecosystem compensation and trade. Specifically, we are concerned with the estimation of *ecosystem service benefits due to differences in an ecosystem's location in the landscape*. This is an important part of valuation, but by no means the only part. To illustrate this truth, and place our research effort in its proper context, consider the following "appraisal framework" for the evaluation of ecosystem compensation and trading.

4.1.1 An Appraisal Framework

The following is framework for ecosystem valuation and the evaluation of trades and compensation. At the greatest level of generality, appraisal requires knowledge of the net social cost of ecosystem degradation at the "impact site" and the net social gain of ecosystem preservation, restoration, or creation, at the "compensation site."

The basic unit of analysis is the value of an individual ecosystem service, denoted $A(\mathbf{u};\mathbf{v})$. Because services are made possible by the existence and quality of biophysical functions and characteristics, the value of a service can be expressed as depending on a collection, or vector, of these functions, $\mathbf{u}$. Accordingly, as the characteristics of this vector change, so too will the value of services derived from it. As an example, the value of recreational services may be expected to increase as the number of species supported by the site increases. "Number of species" would therefore be an important element of the vector $\mathbf{u}$. A service's value also depends on economic and other social variables, which we summarize as a vector of variables $\mathbf{v}$. As examples, these variables might include the number and proximity of individuals able to enjoy the service. With these basic definitions in place, we now turn to the calculation of benefits and costs.

The cost of degradation at the impact site

The social cost of ecosystem degradation is a function of changes in the value of the collection of services provided by the site over time. If individual services are indexed by *i* and time periods by *t*, let

$A_t^i(\mathbf{u};\mathbf{v})$ = the expected monetary value of ecosystem service *i* in period *t*, if the impact site is left undisturbed.

The value of services is an "expected" value for two reasons. First, the vector of future biophysical characteristics is uncertain. Encroachment, natural hazards, invasive species, and a host of other factors can alter the functional characteristics of the site, making those characteristics uncertain. Second, holding biophysical characteristics constant, the value of the service itself is uncertain. Demographic, technological, and other social factors (the vector $\mathbf{v}$) can change over time in ways that affect the services' value. With this basic notation, let

$\sum_i A_t^i(\mathbf{u};\mathbf{v})$ = the expected value of all ecosystem services in each time period, if undisturbed.

This term denotes the baseline ecosystem service benefits of the site. In order to measure the value lost, it is necessary to measure the loss in service value if the site is injured, developed, or otherwise degraded. In a manner analogous to the definition of $A(\cdot)$, let

$\sum_i B_t^i(\mathbf{u};\mathbf{v})$ = the expected value of all ecosystem services in each time period, if degraded.

Note that in many cases, as when a wetland is filled to allow construction of housing or roads, the expected value of ecological services will be zero. The loss in ecosystem value, for each period t is

$$Y_t = \sum_i [A_t^i(\mathbf{u};\mathbf{v}) - B_t^i(\mathbf{u};\mathbf{v})]$$

The full loss in ecosystem service value over time can now be denoted

$$\mathrm{L} = \sum_{t=1}^{\infty} \frac{Y_t}{(1-r)^t}$$

where L discounts and sums the future stream of service value losses. This is the loss that must be compensated.

The benefit of improvements at the compensation site

Define the value of services at the compensation site in a manner similar to the value of services at the impact site. In particular, let

$C_t^i(\mathbf{u};\mathbf{v})$ = the expected value of ecosystem service i in period t, if the compensation site is created, restored, preserved, or otherwise ecologically enhanced.

and

$D_t^i(\mathbf{u};\mathbf{v})$ = the expected monetary value of ecosystem service i in period t, if no improvement is made to the compensation site.

It follows that the gain in ecosystem value, for each period t is

$$Z_t = \sum_i [C_t^i(\mathbf{u};\mathbf{v}) - D_t^i(\mathbf{u};\mathbf{v})].$$

Thus, the summed, discounted net social benefit of ecosystem improvements are

$$\mathrm{G} = \sum_{t=1}^{\infty} \frac{Z_t}{(1-r)^t}.$$

G is the gain, per acre, that offsets losses at the impact site.

This kind of "before and after" comparison of sites and their benefits requires knowledge of baseline conditions. This creates a significant challenge for estimation. First, knowledge of future conditions is clearly imperfect due to natural variability in the health of the ecosystem. Second, future conditions are a function of regulatory standards that may or may not protect the ecosystem in the future. If regulation strictly prohibits degradation caused by construction, drainage, or other actions by a landowner, the baseline can reasonably be approximated by its current natural condition, plus or minus some natural variability.[84] In other cases, however, regulation will not restrict future landuse changes. In this kind of case, baseline predictions should account for the possibility of future degradation due to entirely legal land development activities.

4.1.2 Compensation Ratios

It is rare to find sites that yield the same amount of ecological (or economic) lift as the loss experiences at an impact site. For this reason, trades and compensation typically involve the use of compensation or conversion ratios. These ratios are multipliers that convert losses into equivalent gains by adjusting the amount of acreage preserved, restored, created, or enhanced.

Consider a multi-acre impact site where there is a per-acre loss l and a potential compensation site which will yield a per-acre gain g. If $g < l$, as is often the case, an acre-for acre exchange is inadequate. One solution is to adjust the acreage being used for compensation. If total losses are to be compensated by an equivalent gain, the following relationship must hold

$$\mathrm{L} = \mathrm{x} \cdot l = \mathrm{y} \cdot g = \mathrm{G}$$

or

$$y/x = l/g$$

where x is the number of acres lost and y is the number of acres to be used for compensation.

Note that if the per-acre loss at the impact site is greater than the per-acre gain at the compensation site, then $y > x$. In other words, the compensation ratio will be greater than 1 for 1.

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[84] Encroachment in the form of neighboring land use changes may also yield predictable changes in a site's future natural condition.

When $l > g$, an acre degraded at the impact site implies the need for more than an acre of improvements at the compensation site.

In this economic valuation framework, compensation is adequate and ecosystem trade fair if the value of ecosystem services lost is offset by the value gained. This is an idealized conception of the problem and ignores important institutional, informational, scientific, and ethical issues. Nevertheless it summarizes, the basic economic problem: namely, the need to “make the public whole” by replacing lost ecosystem benefits.

4.1.3 The Role of Biophysical Assessment

Biophysical assessment is concerned with the measurement of biophysical characteristics and functions (the vector $\mathbf{u}$). When trades or compensation are judged in a purely biophysical way, the goal is to achieve biophysical enhancement, or “lift,” equal to the biophysical loss. This is analogous, but not equivalent, to the economic gain and loss comparison defined above. As an example, consider one possible biophysical, functional measure of lift and loss: the provision of wading bird habitat. If an acre of this function is lost, the biophysical replacement goal is creation of an acre of that function elsewhere. In some cases, biophysical function is a good proxy for social value. But this is not always true. After all, the social value of wading habitat may depend on the site’s location relative to population, different types of land use, recreational access, etc. Put another way, biophysical assessment does not reveal differences in the social value of *functionally equivalent* ecosystems.

This is not to say that biophysical assessment is an easy or simplistic approach to assessment. As described earlier, biophysical assessment methods are enormously complex and contentious in their own right. They are also the foundation for an economic evaluation of service benefits, since services arise from biophysical functions. It should be emphasized, however, that biophysical analysis is not the principal subject of this study.

4.1.4 Compensation Issues Not Addressed by This Study

This study focuses on the relationship between an ecosystem’s location in the landscape and the value of its services. For this reason, most of the analysis concerns methods designed to reveal the impact of economic and social factors (the vector $\mathbf{v}$) on the value of ecosytem services. In the case studies presented in sections 6 and 8 we will make an important simplifying assumption: namely, that functional losses at impact sites are equivalent to functional gains at compensation sites. In the real world, this assumption almost never holds true. Also, we make the assumption not to deny the importance of biophysical factors and biophysical differences, but to isolate – for expositional purposes – the importance of economic and social factors normally not accounted for in ecosystem assessments.

There are several more specific issues – related to biophysical evaluation – that we do not address in this study, but that are of great importance to ecosystem evaluation. First, we do not address the difficulty of guaranteeing biophysically effective restoration.[85] Second, we do not address the relative quality of different kinds of enhancement. These are issues best addressed by functional assessment. Nevertheless, they deserve to be noted due to their importance to the evaluation of compensation and trades.

Restoration, enhancement, and creation of biologically valuable ecosystems are extremely difficult. Restoration is biologically and technologically difficult.[86] The effectiveness of restoration is also undermined by poor planning and inadequate long-term monitoring and enforcement.[87] The appraisal framework described above illustrates the importance of these issues to the determination of appropriate compensation ratios. Incomplete, delayed, or ineffective restoration reduces the functional quality of the compensation site. In more formal terms, the value of service enhancements described by $C_t^i(\mathbf{u};\mathbf{v})$ should be adjusted downward to account for the difficulty of ecosystem restoration, enhancement, and creation. An implication of inadequate, uncertain, or delayed functional lift is that the compensation ratio x should increase. In other words, more acreage should be enhanced to compensate for the difficulty of enhancement.

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[85] See notes 86 and 104 infra.

[86] It is particularly difficult to replace lost wetland functions. See Teresa Magee et al., Floristic Comparison of Freshwater Wetlands in an Urbanizing Environment 19 Wetlands 3, 517-34, 1999 (indicating that after five years at recently restored sites more than 50% of the plant species present were invasive species, and thus sites were not providing the habitat and functions typical of the region); also see J.A. Kusler and M.E. Kentula, eds., Wetland Creation and Restoration: The Status of the Science. Island Press, 1990; and Mary Kentula, et al., Wetlands: An Approach to Improving Decision Making In Wetland Restoration and Creation, Island Press, 1992.

[87] Proposal to Issue and Modify Nationwide Permits, 64 FR 39251, July 21, 1999 ("Much of the failure of past compensatory mitigation projects is due to poor site selection, planning, and implementation"), at 39271. Also see National Academy of Sciences, Compensating for Wetland Losses Under the Clean Water Act, National Academy Press, 2001 ("Monitoring is seldom required for more than five years, and the description of ecosystem functions in many monitoring reports is superficial. Legal and financial mechanisms for assuring long-term protection of sites are often absent, especially for permittee-responsible mitigation"), at 5; and General Accounting Office, Wetlands Protection: Assessments Needed to Determine Effectiveness of In-Lieu Fee Mitigation, GAO-01-325, 2001.

Similarly, compensation ratios should adjust for differences in enhancement likely to arise at the compensation site. For example, preservation is inherently less valuable than ecosystem creation. This follows because preservation involves less functional improvement than creation.[88] In the terminology defined above, a preserved site has more baseline functional quality (and all else equal a higher baseline expected stream of service values $D_t^i(\mathbf{u};\mathbf{v})$) than a created site. Thus, the functional lift expected from preservation is lower than that from creation or restoration. Accordingly, the compensation ratio x should be higher when lands are preserved, as opposed to created or restored.

Adjustments to compensation, based on these kind of functional differences, are already a well-established goal of some regulatory programs.[89] Federal wetland mitigation guidance, for example, suggests that

> "In the absence of more definitive information on the functions and values of specific wetland sites, a minimum of 1 to 1 acreage replacement may be used as a reasonable surrogate for no net loss of functions and values. However, this ratio may be greater where the functional values of the area being impacted are demonstrably high and the replacement wetlands are of lower functional value or the likelihood of success of the mitigation project is low. Conversely, the ratio may be less than 1 to 1 for areas where the functional values associated with the area being impacted are demonstrably low and the likelihood of success associated with the mitigation project is high."[90]

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[88] An exception is if the land to be preserved is under imminent threat of degradation. If so, the relevant baseline is the highly probable, degraded state. This is the reasoning behind the regulatory guidelines which allow preservation only when the property in question is "under demonstrable threat of loss or substantial degradation due to human activities that might not otherwise be expected to be restricted." Federal Guidance for the Establishment, Use and Operation of Mitigation Banks, 60 FR 58605, November 28, 1995, at 58609.

[89] See Environmental Law Institute and Institute for Water Resources, Corps of Engineers, National Wetland Mitigation Banking Study Wetland Mitigation Banking: Resource Document, 1994 (Federal guidelines define compensation ratios as "the quantity of wetland credits that must be debited from the wetland mitigation bank to offset the losses from the debiting wetland. A 2:1 ratio, for example, means that for every unit of natural wetlands (e.g., habitat units, acres) destroyed by development, two units must be obtained from the bank"), at 2.

[90] Memorandum of Agreement Between the Environmental Protection Agency and the Department of the Army Concerning the Determination of Mitigation Under the Clean Water Act 404(b)(1) Guidelines, 55 FR 9210-01, 1990.

Note the emphasis on differences in function as the basis for these compensation adjustments. It should also be noted that conversions of this kind, even based on the most basic functional differences, are the exception not the rule.[91]

Our research leaves differences in functional quality aside and argues that *additional, complementary* adjustments should be made to trades and compensation projects. To be sure, adjustment should be made for the above factors. But this study argues that additional adjustments should be made for differences in the social value of services arising from a site's biophysical functions. The evaluation methods we propose are one way to make such adjustments.

4.1.5 Economic Issues Not Addressed by This Study

The appraisal framework described above, while including numerous factors not normally considered in ecosystem evaluation, is nevertheless incomplete. First, it does not include the costs of achieving ecological enhancement. Ecological improvement projects require both up-front and long-run expenditures. These costs are important to the determination of optimal (efficient) improvement projects and the adequacy of compensation. Second, it does not include the measurement of non-environmental benefits associated with ecosystem degradation. When ecosystems are degraded as a result of development or construction there are social benefits associated with the development. We do not concern ourselves with these benefits.[92] Third, our appraisal framework and analysis does not include the "opportunity costs" of development foregone when ecological improvements are put in place. When ecosystems are preserved, restored, or created there is an opportunity cost associated with the environmental restrictions placed on the property.[93] This opportunity cost is the benefit foregone by not employing the property in its most productive alternative use. For example, if a preserved site would be worth $200,000 if developed, $200,000 is the opportunity cost of preserving the land in its natural state.

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[91] See Phillip Brown and Christopher Lant, The Effect of Wetland Mitigation Banking on the Achievement of No-Net-Loss, 23 Environmental Management, 333-345, 1999 (a study of 68 mitigation banks, finding that the majority use a 1:1 acreage ratio, that ratio accounting for 73% of all acreage in banks as of 1996), at 336. Also see Ruhl and Gregg, supra note 8.

[92] If regulation is effective, the environmental costs of a development project will be internalized by the developer (this is an objective of compensation requirements and any sound ecosystem trading system). If development proceeds under this condition, it can be assumed that the benefits of development exceed the environmental costs.

[93] See Boyd, Caballero, and Simpson, supra note 4.

Restoration costs, opportunity costs, and non-environmental benefits are important components of a complete economic valuation of preservation, development, and compensation decisions. This study is focused on a more limited goal, however: the measurement of benefits associated with ecological services. As will be clear, measurement of these benefits alone represents a significant challenge for decision-making.

4.2 Principles of Ecosystem Benefit Assessment

Even imperfect application of valuation principles will improve decision-making related to ecosystem preservation. This section summarizes the fundamental elements of a benefit assessment exercise and illustrates how biophysical characterization can best be integrated with economic analysis. The key link between economic and biophysical analyses is the concept of a production function.

4.2.1 The Production Function

Production functions describe the manner in which an output is related to the quantity and nature of inputs used to create it.[94] For example, a production function describes the way in which a company can deploy labor and capital investments to create a final product. Production functions are at the core of most economic studies of particular firms and industries.[95] How many employees are needed to create a thousand automobiles? How does investment in new machines change the number of employees needed? Do increases in inputs create proportionally greater levels of output, or are there economies of scale? With knowledge of a production function these kinds of questions can be answered.

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[94] See The New Palgrave: A Dictionary of Economics, 1998, ("The traditional starting point of production theory is a set of physical technological possibilities, often represented by a production or transformation function. The development of the theory ...leads to input demands (and output supplies) constructed from an explicit consideration of the underlying technology"), at 995.

[95] *See generally* E. Mansfield, Managerial Economics, Norton, 181-85, 1990 (describing the concept of the production function as a general relationship between inputs and outputs); see also Gregory Ellis and Anthony Fisher, Valuing the Environment as a Input, 25 Journal of Environmental Management 1987, 149-156; and C. Clark, Mathematical Bioeconomics: The Optimal Management of Renewable Resources 35-39, 235-43, 1990 (describing the use of mathematical production functions in natural resource industries where the results of natural processes provide a basis for developing indices of critical inputs).

Wrapped in industrial terminology, the concept may seem foreign to ecologists. But in fact, ecologists are intimate with the concept. Economic analysis is often concerned with the engineering and financial relationships that determine production. Ecological analysis, of course, is concerned with the biological, chemical, and hydrological relationships that determine biological production.[96] While economic and biological systems are clearly different in important respects, both economics and ecology seek to understand the activity or productivity of systems by understanding the systems' basic components and the functional relationships between those components. However, because the systems they study involve different types of interrelationships (e.g., biological vs. engineering) ecologists and economists can have trouble establishing a terminological common ground.

One source of confusion relates to the nature of inputs and output. Typically, ecologists relate site characteristics to the production of an ecological function, such as the ability to improve water quality. To ecologists, both the inputs (site characteristics) and output (the ecological function) are biophysical. When economists evaluate ecosystem services, it is typical to view the biological functions of the ecosystem as inputs, with ecosystem services being the outputs. To economists, nutrient cycling and water filtration, both biophysical functions, are inputs to a more complex output: namely, services such as improved drinking or irrigation water quality.

4.2.2 Preferences

Understanding the contribution of inputs to output is a partial, but incomplete, step toward valuation. With knowledge of the way in which inputs are translated into outputs – via analysis of production functions – the question then becomes: what is the value of additional production? Preferences are the other side of the valuation question. Individuals' and society's collective preferences determine the value of an additional unit of an ecosystem service. These preferences depends on a variety of factors including income, the scarcity of the good or service, and the availability of substitute and complementary goods and services.

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[96] There is also a long history of integrated economic and biological production function analysis, associated primarily with agricultural economics. Among other things, such studies show how substitution of one farm input for another (e.g. land for fertilizer, tractors for man-hours) affects production levels, or how landscape characteristics affect yields. For a general overview see Introduction to Agricultural Economics, John Penson, et al. eds., 1999.

Scarcity and substitution

First, valuation requires an understanding of input and output scarcity and the ability to make input and output substitutions. All else equal, greater scarcity and a relative lack of substitutes increase the value of an ecosystem service. Consider a wetland capable of improving drinking water quality in an aquifer used by a residential community. The value of this service is dependent on the number and acreage of other wetlands within the area and whether there are other water filtration options available to residents. If there are few other wetlands and mechanical filtration is unavailable, the value of this wetland's services will be high.

The preceding example focuses on the relative scarcity of inputs to drinking water quality. Valuation also requires an assessment of output scarcity, the scarcity of the service itself. Alternatives to well-drawn drinking water, such as bottled or municipal supplies, reduce the value of water quality improvements by providing close substitutes for well-drawn water. In all of these cases, valuation goes beyond biophysical analysis and requires analysis of a site's demographic and geographic context.

Complementary goods and services

Second, valuation requires an assessment of complementary goods and services. Many ecosystem services become valuable, or increase in value, when enjoyed in combination with other goods or services. For example, a forest generates recreational and aesthetic services only when there is access to it. Consequently, roads, trails, and adjoining navigable waters are complementary goods to the forest's recreational and aesthetic services. A completely inaccessible forest, while valuable for other reasons, creates no on-site recreational benefit; it has no recreational value in the absence of complementary goods necessary for recreational enjoyment. As another example, aquifer purification becomes a valuable ecosystem service only if there is access to the water for drinking or irrigation. Accordingly, wells are a necessary, complementary good to an ecosystem's aquifer purification services.[97]

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[97] Water purification is also valuable for non-consumptive reasons. But consumptive water quality improvements have value only if there is human access to the water.

Income Effects

Preferences for most goods and services exhibit what are called income effects. That is, as incomes change so does the service's value. These changes can be either positive or negative, though most ecosystem services are likely to be "normal" goods: that is, their value increases in income.[98] Positive income effects imply that the rich benefit more from environmental improvements than the poor. Most economists would not disagree with this statement but would balk at the suggestion that income effects call for environmental improvements directed disproportionately at the wealthy. In fact, there is some sentiment within the economics profession that the relationship between income and well-being are poorly understood and subject to significant ethical critique.[99] In general, the role of income effects in analyses of environmental welfare is fraught with methodological and interpretive difficulties.[100]

Governmental decision-making is unlikely to embrace income-related factors as a determinant of ecosystem services compensation. If anything, environmental justice concerns – which favor the provision of services to lower-income communities – can be expected to predominate in decision-making relating to income effects.[101]

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[98] See generally, William Baumol and Wallace Oates, The Theory of Environmental Policy, Prentice Hall, 1975, Chapter 13, Environmental Protection and the Distribution of Income. For an example of an ecosystem service that may have a negative relationship to income see Clifford Russell and William Vaughan, The National Recreational Fishing Benefits of Water Pollution Control, Journal of Environmental Economics and Management, 1982, 328-354 (finding a negative relationship between income and the probability of fishing for specific species and days fished per season).

[99] See a recent collection of essays on this topic, 107 Economic Journal, 1997. For an analysis of these issues in an explicitly environmental context see Olof Johansson-Stenman, The Importance of Ethics in Environmental Economics with a Focus on Existence Values, 11 Environmental and Resource Economics, 1998, 429-442.

[100] Nancy Bockstael, Kenneth McConnell, and Ivar Strand, Recreation, in Measuring the Demand for Environmental Quality, John Braden and Charles Kolstad, eds., Elsevier, 1991 ("Income leves are more likely to distinguish participants in a recreational activity from nonparticipants than they are to affect the number of recreational trips a participant takes in a season"), at 240. Also see Nicholas Flores and Richard Carson, The Relationship Between the Income Elasticities of Demand and Willingness to Pay," 33 Journal of Environmental Economics and Management, 1997, 287-295 (on the distinction between the ordinary income elasticity of demand for environmental goods and the income elasticity of willingness to pay for those goods and the complications implied for empirical analysis).

[101] Clinton's Executive Order 12898, February 11, 1994 called for examination of disproportionately high and adverse impacts to minority and low-income communities. For a statement of the EPA's current views on environmental justice issues see Memorandum, August 9, 2001, EPA's Commitment to Environmental Justice, available at http://es.epa.gov/oeca/main/ej/epacommit.pdf.

4.2.3 Other Basic Principles

Valuation also requires an understanding of marginal analysis and a inter-temporal appreciation of costs and benefits. We now turn to a motivation of these basic principles, principles important to the analysis of both production functions and preferences.

The Need for Marginal Analysis

Third, valuation requires a "marginal" analysis of ecosystem benefits. Marginal analysis is fundamental to ecosystem valuation because it examines the way in which a service's benefits vary with the aggregate level of the service available.[102] For example, marginal analysis reflects the typical truism that the value of a wetland acre or individual in a biotic population is a decreasing function of the number already protected. In other words, the value of the only existing songbird or wetland is greater than the value of the millionth.

Like many principles of economics, the concept of marginality is familiar to ecologists. As another example, if there is a minimum habitat area necessary to support a species, the marginal benefit of preserving an additional acre of habitat depends crucially on whether that acre is needed to meet the minimum. The marginal benefit of the first acre of preserved panther habitat is zero, since one acre is not sufficient to support panthers. At the scale where the habitat becomes viable, however, the marginal benefits of preservation accelerate enormously. At the other extreme, marginal benefits will decline (the millionth acre of habitat will have a smaller marginal benefit than the thousandth). The marginal value of an additional acre preserved thus depends on the aggregate level of preservation to which it is added.

Marginal analysis is not easy to do, particularly when complex biological and economic relationships are involved. Nevertheless, it provides a necessary discipline to the valuation process. In effect, it guards against reckless extrapolation of benefit or cost estimates. For instance, consider a study showing, accurately, that the value of a particular wetland is $100,000. It is tempting to say that the value of a thousand wetlands is a thousand times that value. Marginal analysis argues against such an inference.

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[102] See R. David Simpson et al., "Valuing Biodiversity for Use in Pharmaceutical Research," 104 J. Pol. Econ. 163, 164, 1996 (describing the importance of marginal analysis in the valuation of preserved species and lands as a source of pharmaceutical discovery).

Tomorrow's benefits will not be the same as today's

Investment or asset analysis is a framework for calculating the present value of a stream of benefits and costs that will occur over time. Accordingly, the investment analysis paradigm is directly applicable to ecosystem service valuation. Since ecosystems are long-lived assets, the services they provide yield benefits over years and decades. These future benefits will change relative to their value today.

Analysis of ecosystem service benefits requires sensitivity to the temporal nature of the underlying biophysical functions that give rise to the service (as depicted in the vector **u**). For example, most restoration projects restore ecosystem functions only after a period of several to many years.[103] Even if full restoration is assured, there is a social cost associated with the interim loss in the ecological asset's function. More typically, full restoration cannot be guaranteed at all.[104] Some wetlands, such as forested wetlands, floodplain systems, and sea grass, can be very difficult to re-establish.. When success is not assured, the risk of incomplete restoration must also be accounted for in determining the appropriate level of restoration effort.

Uncertainties and changes in the temporal flow of ecosystem benefits are also associated with the non-biophysical determinants of value (as depicted in the vector **v**). For example, demographic and technological changes can alter the flow of ecosystem service benefits over time. Accordingly, the value of a particular ecosystem may decline due to urban encroachment, man-made water diversions, or the discovery of substitutes for services generated by the ecosystem.[105] The expected value of an ecosystem in a protected location, even if the site is of mediocre service quality, may be higher than the expected value of pristine habitat in a rapidly deteriorating landscape. On the other hand, value may increase due to greater demand for recreation, carbon sequestration, or habitat support. There are several sources of reliable information about the likely magnitude of future benefits. For example, the existence of land use regulations and zoning, road construction plans, and population projections can suggest a great deal about future changes in a service's value.

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[103] Leslie Roberts, "Wetlands Trading is a Losing Game, Say Ecologists," 260 Science 1890, 1890-92, 1993.

[104] In practice, wetland restoration has proven difficult, often falling far short of regulatory goals. See Stephen Brown and Peter Veneman, Effectiveness of Compensatory Wetland Mitigation in Massachusetts, USA, 21 Wetlands, 508-519, 2001.

[105] As a perhaps fanciful example, a radical water purification innovation might reduce the social value of water purification services provided by a wetland.

Finally, future costs and benefits must be discounted. Economists favor discounting for a variety of reasons. Perhaps the most intuitive is that people generally prefer consumption today to consumption tomorrow. Accordingly, future benefits should be given less weight, all else equal, than currently enjoyed benefits. The precise degree to which environmental benefits should be discounted is a question of active debate within the economics profession.[106]

4.3 Ecosystem Benefit Assessment Requires Spatial Analysis

Perhaps the greatest challenge associated with ecosystem benefit assessment is the need for spatial analysis. Spatial analysis is fundamental to ecosystem service valuation because both the production of biophysical functions and the social determinants of service benefits depend upon the landscape context in which those functions and services arise.[107] In fact, the consumption of services typically occurs off-site. Water purification, flood damage reduction, pollination, pest control, and aesthetic enjoyment are all services typically enjoyed in a larger area surrounding the ecosystem in question. To ignore, or minimize, the importance of off-site factors misses much that is central to a complete valuation of benefits.

5. Indicator Development: A Case Study

The principle aim of this research is to propose, implement, and critique a specific set of ecosystem benefit indicators. The preceding discussion has argued that there is a need for easily-implemented site evaluation techniques. We have also argued that the ecosystem service valuation perspective provides a desirable set of principles to guide evaluation.

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[106] Too much can be made of these disagreements. The need to discount at some level is almost universally agreed upon. See Discounting and Intergenerational Equity, Paul Portney & John P.Weyant eds., Resources for the Future, 1999.

[107] For a more detailed expression of this perspective, see Nancy E. Bockstael, "Modeling Economics and Ecology: The Importance of a Spatial Perspective," 78 Amer. J. Agr. Econ. 1168, 1996.

5.1 Overview

In the way that conventional "ecological indicators" use observable site characteristics to signal a site's bio-physical qualities, the indicators we explore are readily-observable indicators of an ecosystem's social value. As noted earlier, ecological indicators are themselves indicators of social value. A site's ability to support diverse species, for example, is not only an indicator of biological health, but also an indicator of the site's social value. After all, the more diverse and the healthier a site is, the more resilient it will be and the better able to provide a range of valuable services over time. But there is a much wider range of benefit indicators that can be brought to bear on ecosystem evaluations. Accordingly, we explore this wider range of indicators, focusing on indicators of ecosystem service value. These landscape indicators – some socio-economic, some bio-physical – will say relatively little about a specific site's biological health. We leave that task to existing evaluation tools derived from the ecological sciences. The indicators we propose are a complement to that kind of ecological analysis.

Our working hypothesis is that GIS data can be used to evaluate the scarcity of services in the landscape, the availability of features that complement the value of services, land use configurations likely to influence future benefits, and the ecosystem's marginal impact on a larger area's provision of ecosystem services. Put another way, our work suggests that the valuation principles described in Section 4 can be combined with existing data sources to improve our understanding of the relative value of different parcels.

An ecosystem benefit indicator system can be broadly outlines as follows: First, an ecosystem is characterized in terms of its bio-physical characteristics. This is the goal of conventional assessment methodologies, such as the hydro-geomorphic method.[108] Second, "off-site" data is assembled which describes the ecosystem's social, economic, and bio-physical landscape. These layers of landscape data can be depicted visually and often yield a particularly intuitive assessment of the way in which a site contributes to conditions in the broader landscape. Third, the services provided by the ecosystem are identified. Fourth, indicators of service benefits are calculated, based on data contained in the GIS data layers.

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[108] See section 2.

5.2 Wetland Mitigation in Lee County, Florida

To both illustrate and evaluate the ecosystem benefit indicator approach, we now apply these concepts to a specific case: a wetland mitigation bank used to compensate for wetland losses in Lee County, Florida. As described in section 2, wetland mitigation programs create a need for ecosystem benefit evaluation. When wetland “impact sites” are destroyed, the Clean Water Act requires compensating mitigation to replace the lost wetlands. This case study uses ecosystem benefit indicators to address the following question: namely, are the social benefits of the lost wetland impact sites being adequately replaced by the wetland mitigation bank? A more purely methodological question is also being asked: how effective are GIS-based indicators in evaluating ecosystem trades and compensation?

Little Pine Island (LPI) was chosen for analysis for several reasons. First, GIS data for Florida is abundant, well organized, and readily available. Florida is unusual – but becoming less so – in that many different government agencies have collected a large variety of geo-coded (spatial) data suitable for GIS analyses. The wealth of GIS data is due largely to the activities of Florida’s water management districts and the Florida Geographic Data Library, described below. Second, LPI has a unique landscape configuration, since it is an uninhabited island. Wetland gains at LPI are used to mitigate wetland losses on the mainland. Accordingly, LPI starkly illustrates the importance of landscape context for ecosystem benefit estimation: inland wetland losses – generally in close proximity to population, homes, and businesses – are compensated by restoration in a more physically and socially isolated setting.

LPI is a 4,670 acre, uninhabited island located just offshore of the southwest Florida mainland near the city of Ft. Myers (See Figure 1).[109] The island contains four distinct wetland types: coastal forested freshwater, coastal forested saltwater, herbaceous freshwater/brackish coastal, and herbaceous saltwater. LPI has been owned by the state of Florida since 1974. Prior to state ownership, private landowners had drained the island with canals and excavation in an effort to control mosquito breeding. As a result, the island's wetlands were colonized by invasive species, including melaleuca and Brazilian pepper. The invasive colonization further altered the island’s hydrology, displaced native vegetation, and reduced habitat quality. Under state ownership, the island’s wetlands have degraded further. 1,600 acres of LPI has been transformed from "wet savannas dotted with hammocks and pine islands to a thick impenetrable exotic forest."[110]

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[109] Note that information presented here is based on bank documents and one brief visit to the bank site.

[110] Kevin Erwin, The Restoration of Little Pine Island Florida, 1998.

There is one public 2-lane road on LPI which provides the only land-based connection between the mainland and Pine Island, a larger residential island to the West of LPI. The road that crosses LPI is connected by bridges to the mainland and to Pine Island and is used primarily by residents of and visitors to Pine Island. There is an abandoned waste treatment plant near the center of LPI and no other permanent structures.

In 1993 a developer reached agreement with the state of Florida and the federal government to form a wetland mitigation bank on LPI. The developer agreed to restore wetlands on the island in return for the right to sell wetland mitigation credits to permit-seekers wishing to develop wetlands elsewhere in the bank's service area. The extent of the bank's service area is in dispute, but documents prepared by the bank sponsors define the bank's service area to include portions of coastal Collier, Lee, Charlotte, and Sarasota Counties inland from the coast to the 100-year flood plain boundary.

Bank credits are being earned by restoring up to 1,616 acres of wetland, or roughly 1/3 of LPI over a period of seven to ten years. Using the hydrogeomorphic (HGM) wetland classification system these areas are as follows:

Table 1: LPI Wetland Types

Wetland Type (HGM class)	*Acreage*
Forested freshwater/ Coastal fringe	117
Forested saltwater/ Coastal fringe	347
Herbaceous freshwater/ Brackish coastal fringe	504
Herbaceous saltwater/ Brackish coastal fringe	630
Total	1598

Wetland restoration at LPI began in 1997 and involves the removal of exotic vegetation and the restoration of the island's natural hydrology. Natural re-growth of native species from dormant seed banks in the soil is expected in most areas. Where fire or other historical disturbances have destroyed the natural seed bank, the areas are being re-vegetated.

Since 1997 more than 400 acres or 25 percent of the most heavily impacted areas on LPI have been restored and more than 3,000 meters of canals and backfill areas have been filled to restore historical elevation. Although there is no documentation of wildlife on LPI prior to restoration, over 100 species of wildlife, including a nesting pair of bald eagles, have been documented on LPI since the restoration efforts began.

Banking documents describe the three-step process for arriving at the number of LPI credits required to offset wetland impacts in the bank's service area. First, establish that the impacted wetlands are similar in type to those at LPI. Second, determine that the impact site is within the LPI bank service area. Third, perform a functional assessment of the impact site. The functional assessment method used to score wetland trades at LPI is among the best we encountered for assessing gains and losses in functional capacity, and seems well-suited for the wetlands in this region.. However, like other wetland assessment methods, it does not effectively address larger patterns of wetland gains and losses. For example, the eventual sale of 1,616 acres of wetland mitigation at LPI could constitute a significant relocation of wetlands off the mainland. The rules of exchange governing wetland mitigation trades at LPI are already established. The purpose of the case study is not to alter those rules. However, the case study illuminate the way in which relocation of wetland functions from impact sites to LPI affects wetland service benefits. Accordingly, the case study speaks to ways in which future trades could be scored and, potentially, improved.

The wetland assessment method used to define debits and credits and mitigation ratios at LPI is referred to as the "Assessment Procedure for Wetland Mitigation Banks." It was developed prior to the HGM wetland assessment method, but is similar and focuses on the same general classification of wetland functions as HGM. Documentation of the way in which the method was applied to score trades at LPI is thorough and focuses on nine wetland functions:

- Habitat for wetland-dependent species
- Support of food chains
- Support of native plant populations
- Provision of landscape heterogeneity
- Maintenance of biological integrity
- Access to aquatic refugia
- Maintenance of natural hydrology
- Maintenance of water quality
- Support for soil processes

Note that while some of these functions can be construed as having a landscape component (e.g., provision of landscape heterogeneity), the indicators that are used to score sites are predominately site-based. Application of the assessment method, in other words, requires little consideration of landscape features.

At LPI, the number of credits produced are determined by applying the above-mentioned wetland functional assessment method before restoration and estimating the expected change following restoration. The method results in a per acre score for the increase in functional capacity that ranges from zero (0) to one (1) for each of the nine wetland functions listed above. Scores for each function are then summed (un-weighted) and the sum is divided by nine to get an overall (average) score. This overall score represents the change in functional capacity (the environmental “lift") for each wetland acre restored and is multiplied by the number of acres restored to arrive at the number of credits produced. For example, 3 acres of freshwater wetland restored from a score of 0.3 to 1.0 would provide an "environmental lift" or overall credit score of 2.1 [Calculated as (1.0 – 0.3) X 3]. The number of LPI credits required by a permit-seeker to offset wetland losses is estimated in the same way. A development project that will impact 4 acres of saltwater wetland with a site score of 0.8 would require 3.2 credits; an impact that destroys 2 acres of freshwater wetlands with a site score of 1 would require 2 acres, and so on.

The site-specific accounting of gains in wetland functional capacity at the LPI bank and resulting credit values are described in bank documents. For our purposes, note only that the method used to score trades at LPI takes only limited account of landscape context and does not attempt to extend the consideration of wetland functional capacity to measures of service benefits.

The LPI wetland mitigation bank is being used to offset wetland impacts under regulations implemented by the state of Florida, two regional water management districts, and the federal government. We examined only those wetland mitigation trades that fell under federal jurisdiction and were regulated by the U.S. Army Corps of Engineers. In order to simplify data collection and analysis we only calculated indicators for wetland impact sites that fell within Lee county and we truncated watershed boundary analyses at the Lee county boundary. There were nine of these trades. The location of each impacted wetland site and LPI are shown in Figure 1.

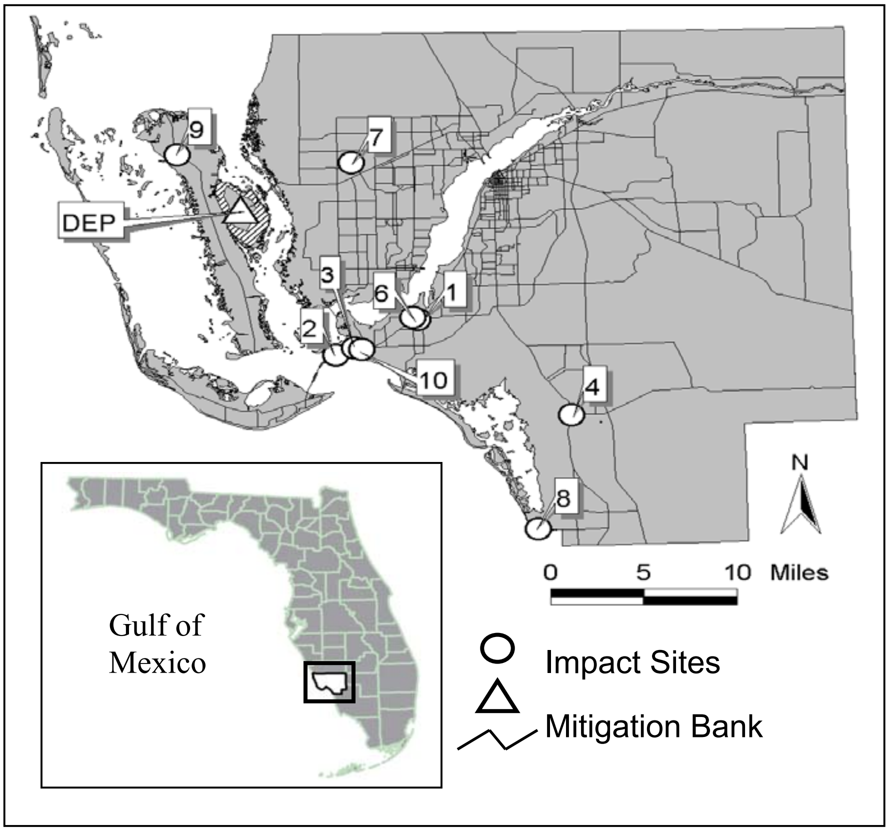

Figure 1: Little Pine Island and impact sites

Wetland impacts mitigated at LPI were generally quite small. Since our research focuses on landscape context, not differences in functional capacity, we decided to ignore the size of individual sites and relative gains and losses in functional capacity associated with mitigation trades. We assume, in other words, that gains and losses in wetland functional capacity resulting from each mitigation trade are equal, and that the only potential source of differences in wetland values are differences in location. It deserves emphasis that this assumption is made for simplicity only. A complete analysis of wetland benefits would necessarily include analysis of site-specific functional differences.

The case study follows the outline described above. First, we assemble a set of GIS maps that describe the sites' physical, biological, social, and economic landscape. Second, we identify a set of services provided by the sites. Third, we define and calculate a set of benefit indicators, using the GIS maps, based on principles of benefit estimation. These indicators speak to the relative benefits generated by the lost wetland impact sites and the benefits provided by the wetland mitigation bank. Fourth, we evaluate the likely impact of impact site losses and bank gains on these ecosystem services, using the indicators. In Section 6, we critique the indicators, highlight potential weaknesses in the method, and summarize the approach's desirability as a regulatory decision-making tool.

5.3 Data sources

The majority of GIS data used in the case study was acquired from the Florida Geographic Data Library (FGDL). The FGDL, run out of the University of Florida, is a central repository for spatial data related to the state of Florida, organized by county.[111] There are more than 200 layers of GIS data available from the FGDL, including census data, state tax data, a variety of remotely sensed images, such as LandSat coverage, and a variety of biological and physical coverages. These coverages included data that one might find for any area of the U.S., such as land cover and land use classifications. However, for Florida they included exceptionally detailed land cover categories that included cover types for invasive plant species, the location of recreational paths (driving, paddling and hiking), aggregate land values for each section-township-range, the locations of sensitive species of fish, bird, and fur-bearing animals, and biodiversity hotspots. The Florida data consortium also provided census data, including a full range of socioeconomic and demographic information and residential housing information, that was in a format far less cumbersome than census databases purchased directly from federal agencies. We used only a subset of these layers, but were fairly comprehensive in our use of layers that spoke to ecosystem benefits. It should be noted that centralized GIS libraries such as the FGDL greatly simplify the implementation of spatial analysis.

In addition, we complemented the FGDL data with several datasets provided by the South Florida Water Management District (SFWMD). The SFWMD's, Lower West Coast Water Supply Plan provided planning information that depicts expected changes in land use characteristics, as of the year 2020. The Water Quality Functional Assessment provided data on wetland de-nitrification capacity and risks to wetland functions.[112] SFWMD also provided the watershed map used in our analysis. A GIS coverage showing locations of public water supply wells and wells used for agricultural, landscaping and commercial/industrial uses was also provided by SFWMD. Additional

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[111] See www.fgdl.org.

[112] See www.sfwmd.gov/org/pld/proj/wetcons/waterq/wq_summary.htm. The Assessment is a joint effort involving SFWMD, U.S. EPA, U.S. COE, and the Florida DEP.

data were collected from a variety of government web sites.[113] Some of this web-based information was used in tabular form and correlated with GIS files or GIF files. Other web-based maps and data were visually compared to examine locations (e.g. the location of impaired river reaches).[114] Most census data was included in the FGDL, but some was not (e.g., data on incomes). Most census data can be easily downloaded from a variety of census-related websites.[115] Some EPA data were included on the FGDL data disks. Other EPA files were downloaded directly from the EPA website or were requested directly from EPA. Finally, it was necessary to create a mapping of the wetland impact sites associated with LPI, since no such mapping existed. In this regard, we did not use precise geo-spatial coordinates to locate each site, but rather located them based on maps and other information available in mitigation trade records. One important simplifying assumption was the mapping of long linear impacts (e.g., road widening impacts) as point impacts.

5.4 Map Construction

This section describes and depicts a list of 40 maps considered for our ecosystem benefit indicators. In some cases, the maps are identical to coverages acquired from the FGDL and SFWMD libraries. In many cases, however, the maps are based on either extractions from these coverages or fields constructed from the source data.

5.4.1 Direct source maps

Source maps are mapped directly from publicly-available data sources. They require no secondary operations, in contrast to the types described below. Many of the maps, including most of the census maps, used in this case are direct source maps.

5.4.2 Extractions

Many of the GIS maps described below are formed by extraction. This means that the mapped features are a subset of a larger set of features depicted by the GIS coverage. As an

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[113] See www.epa.gov/surf3

[114] Our impaired river reach calculations were based on the EPA Office of Water's website

[115] http://factfinder.census.gov/servlet/BasicFactsServlet.

example, the FGDL data includes a coverage which maps "points of interest." These points of interest are classified by type. For example, museums, bus stations, and stadiums are distinct types within the points of interest coverage. If we are interested just in mapping museums, it is necessary to extract museums from the larger coverage.[116] We document these extractions in our description of the data layers.

5.4.3 Constructions

Some maps involve the manipulation of source data to construct new types of data. A constructed map thus involves an operation performed on the underlying data set. For example, consider census data, which includes the number of college educated residents and the total number of residents, but does not include the percent of college educated residents per block group. Note that the source data can be easily used to construct the "percent of college educated residents data."[117] We call these maps "constructed" to distinguish them from maps directly mapped or extracted from source data. Constructions are documented in our description of the maps.

5.5 Inventory of Maps

We now list, describe, and display the 40 data maps used to build ecosystem benefit indicators for the Lee County wetland mitigation trades. The maps are organized into 7 broad categories: demographic, real estate, bio-physical, land use & land cover, infrastructure, public sites, and planning. The maps are summarized in Table 2.

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[116] Extractions are easily performed within the GIS software.

[117] This is done via a straightforward spreadsheet calculation, dividing the total number of college educated residents by the total number of residents.

Table 2: Maps

Demographic

1. Total Population
2. Population Density
3. Households
4. Children
5. Income
6. Educational Attainment
7. Race

Real Estate

8. Housing Units
9. Median Housing Value
10. Median Rent
11. Commercial Units
12. Value of Commercial Units

Bio-Physical

13. Watersheds
14. Wetlands
15. Floodplains
16. Elevation
17. Seagrass
18. Invasive Species
19. Rare Species
20. Wetland Ability to De-Nitrify
21. Wetland Risk from Phosphorus
22. Wetland Risk from Nitrogen

Land use & Land cover

23. Crop & Pastureland
24. Livestock Operations
25. Developed Land cover
26. Non-Ag Natural Land cover
27. Natural and Pasture
28. Upland Forest
29. Aquatic Preserves
30. Protected Lands

Infrastructure

31. Major Roads
32. Trails
33. Permitted Wells
34. Private Drinking Wells
35. Density of Private Wells

Public Sites

36. Recreational Areas
37. Schools
38. Culturally Important Sites

Planning

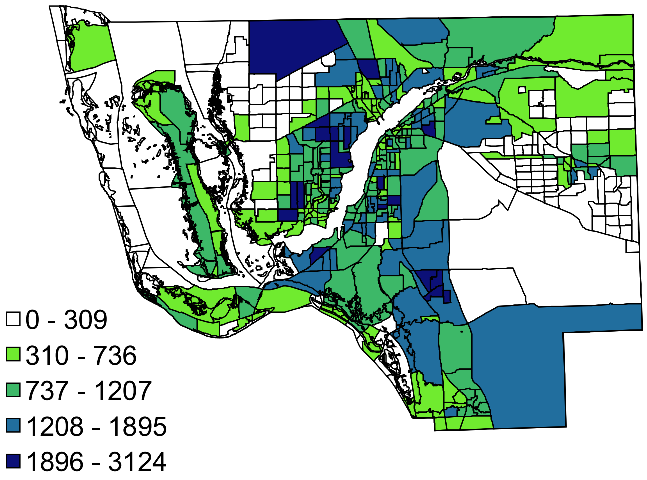
39. Future Citrus Plantations
40. Future Developed Land

These maps provide a starting point for the evaluation of ecosystem benefits. Methodologically, they represent the first step in assembling a system of benefit indicators

5.5.1 Demographic maps

The demographic maps are based on U.S. census data from the 1990 Census, displayed by census block group, or in the case of the income map, by census tract. Block groups are a smaller geographic entity than tracts. For the 1990 census, the were 229,466 delineated block groups, as compared to 50,690 tracts.[118]

For each of the maps we have displayed the data source, data layer, and field used to construct the map.[119] Accompanying discussion describes any extractions or constructions used in the map's compilation.

1 Total Population Total population in census block group Data source:FGDL Layer: BLKGRP Field: POP1990	

The *Total Population* map depicts the total population in each census block group. It is a direct source map from the FGDL BLKGRP data layer.

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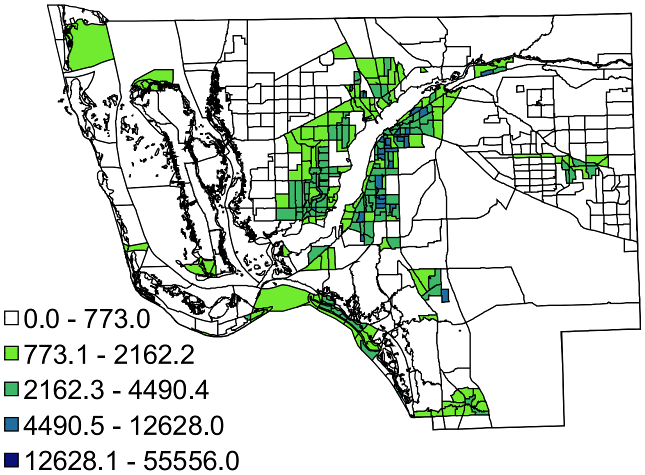
[118] U.S. Department of Commerce, Bureau of the Census, Geographic Areas Reference Manual, 1994, pp. 10-1, 11-1.

[119] Detailed descriptions of census fields can be found at http://www.census.gov/td/stf3/tbl_mtx.asc.

2 Population Density Population density per square mile in census block group Data source: FGDL Layer: BLKGRP Field: POP90_SQMI	

The *Population Density* map depicts the population density of individual census block groups. It is a direct source map from the FGDL BLKGRP data layer.

An important characteristic of block groups and tracts is that they vary widely in terms of their area. The size of tracts is determined largely by the density of settlement – less dense areas tend to yield larger tracts.[120] This makes some block group and tract information less than ideal for spatial analysis. To see why, consider the *Total Population* and *Population Density* maps. If one is interested in the proximity of population to a given site the population density map is preferable to the total population map. For example, the city of Ft. Myers (straddling the Caloosahatchee River) emerges more clearly from the density map than from the total population map. The density map is clearer for the simple reason that it adjusts for differences in block group area. In general, fields that are directly sensitive to area should be interpreted with caution. Maps that depict density or that depict block group percentages or averages (e.g., median house value) are not sensitive in the same way to block group area.

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[120] See http://www.census.gov/geo/www/cen_tract.html.

3

Income

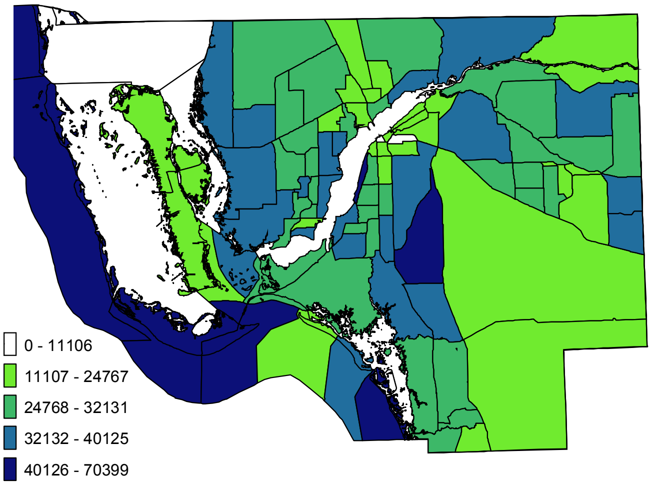
Median household income in census tract

Data source: 1990 Census of

Population and Housing

STF 3A

Field: P080A001



The *Income* map depicts the median income of households in a given census tract. It is a direct source map from 1990 census files. This income data was downloaded directly from the Census Bureau. The FGDL data library does not include the full range of census fields. In particular, it does not include median income numbers. Block group data is available for all fields from the Census Bureau. But tract data for Lee County was significantly easier to download from the census website. The *Income* map, aggregating data at the tract level, highlights the finer resolution provided by block group data (compare with the preceding maps).

4

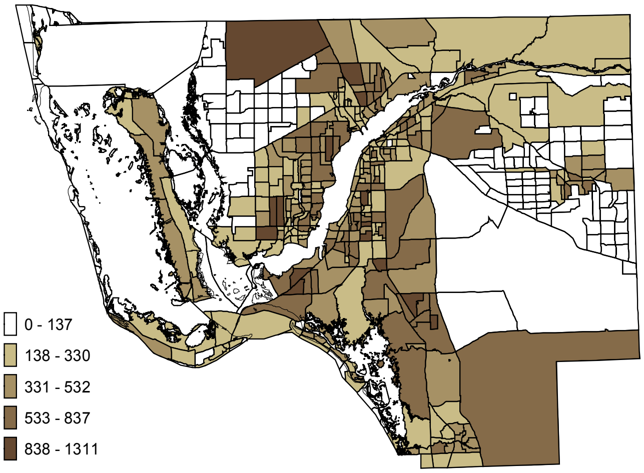
Households

Number of households in census block group

Data source: FGDL

Layer: BLKGRP

Field: HOUSEHOLDS



The *Households* map depicts the number of households in each census block group. It is a direct source map from the FGDL BLKGRP data layer. Because *Households* is a special kind of population measure – that is, the number of households rather than the number of persons – it is in most cases less useful than measures of total population. And, as argued above, the most appropriate measure of "households in proximity" would be a household density measure, rather than a household block group count.

5

Children

Number of children aged 5 to 17 in census block group

Data source: FGDL

Layer: BLKGRP

Field: AGE_5_17

The *Children* map depicts the number of children between the ages of 5 and 17 in each census block group. It is a direct source map from the FGDL BLKGRP data layer.

Note that the *Households* and *Children* maps reflect differences in block group area and would therefore ideally be adjusted for block group area differences. The results would be maps of "household density" and "density of children" in each block group. Though we did not do so, such density maps can be constructed from the FGDL BLKGRP data layer. For an example of a constructed density map see map 35, the *Density of Private Drinking Wells* map.[121]

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[121] The population density map is not a constructed map, it is a field included in the census block group data.

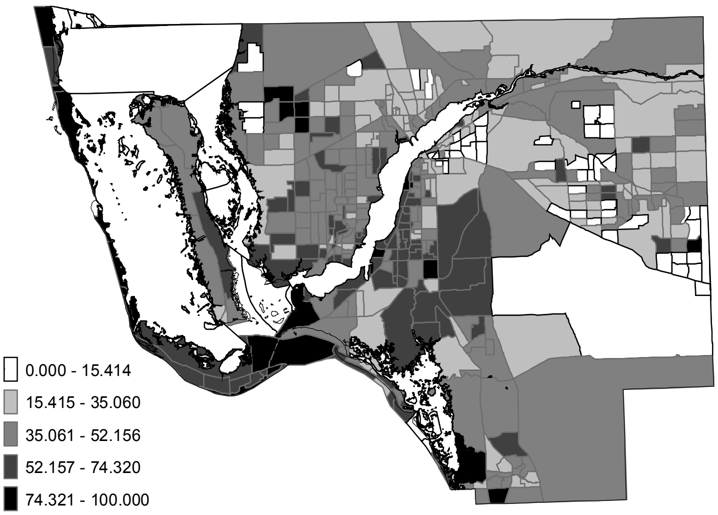
6

Educational Attainment

Percent of persons in block group with at least some college education

Data source: 1990 Census of Population and Housing STF 3A

Field: constructed



The *Educational Attainment* map depicts the percentage of persons in each block group with at least some college education. The field was constructed from census data. Specifically, census fields P0570004 through P0570007 were summed and divided by the total block group population.

7

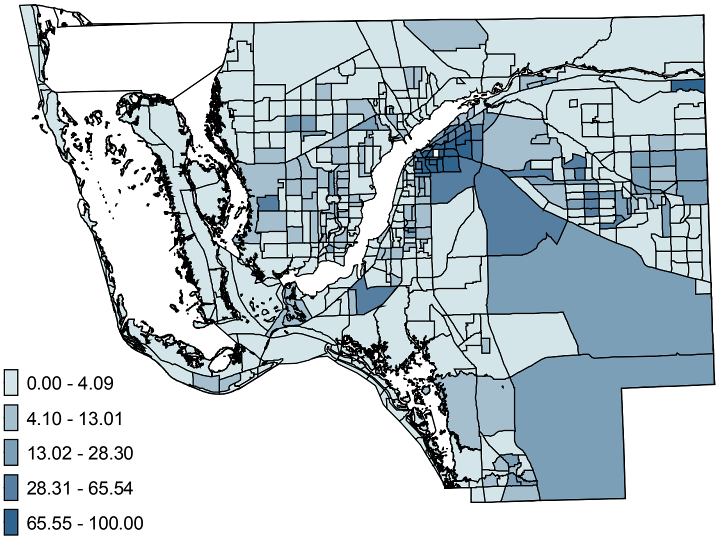
Race

Percent of persons in block group who are black or Hispanic

Data source: FGDL

Layer: BLKGRP

Field: constructed



The *Race* map depicts the percentage of persons in each block group who identify themselves as either Black or Hispanic. The field was constructed from the FGDL BLKGRP data layer. Specifically, census fields BLACK and HISPANIC were summed and divided by the total block group population.

6.5.2 Real estate maps

Data on real estate comes from the census and from the Florida Department of Revenue. All of these maps are directly mapped or constructed from data included in the FGDL library.

8

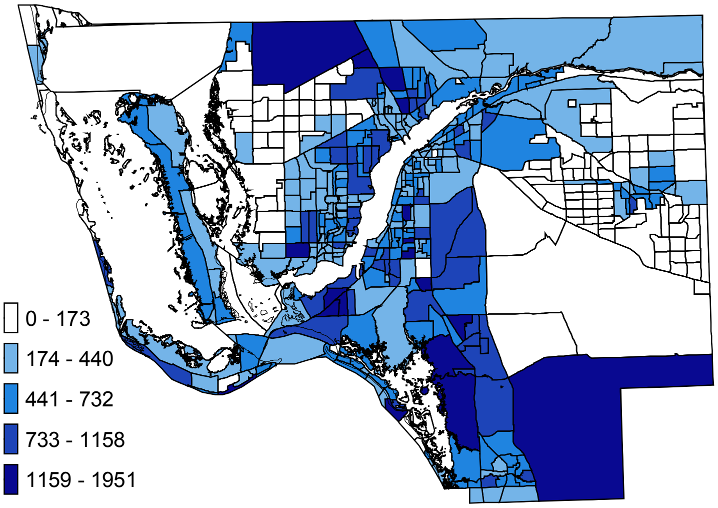
Housing Units

Total number of housing units in census block group

Data source: FGDL

Layer: BLKGRP

Field: HSE_UNITS



The *Housing Units* map depicts the number of housing units (e.g., condominiums, detached homes, mobile homes) in each census block group. It is a direct source map from the FGDL BLKGRP data layer. Like several of the preceding maps, this map would ideally be adjusted for differences in block group area, yielding a "density of housing units" map.

9

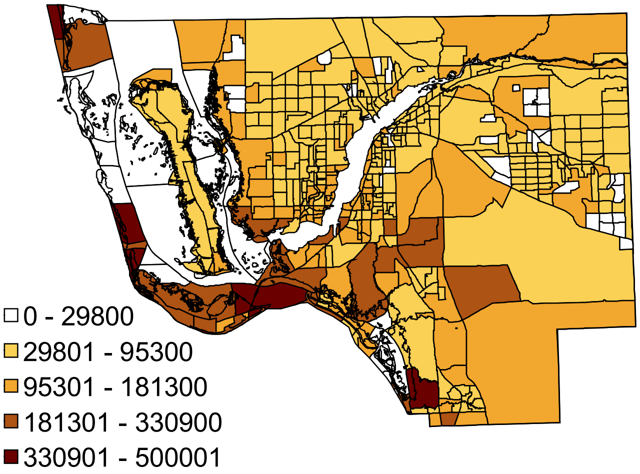
Median Housing Value

Median housing value in census block group

Data source: FGDL

Layer: BLKGRP

Field: MED_VAL



The *Median Housing Value* map depicts the median value of all housing units in a block group. It is a direct source map from the FGDL BLKGRP data layer.

10

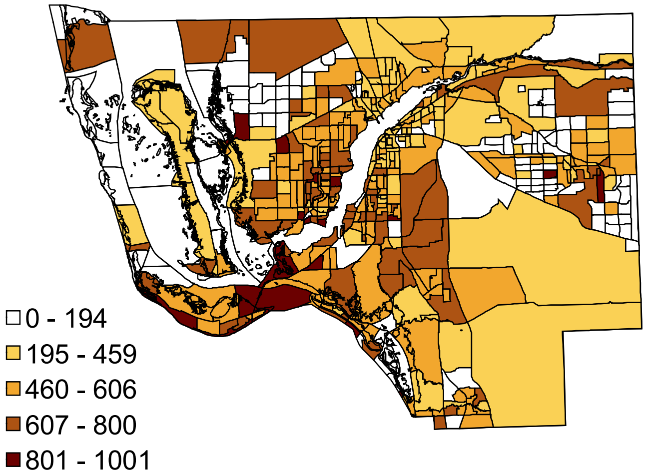
Median Rent

Median rent in census block group

Data source: FGDL

Layer: BLKGRP

Field: MEDIANRENT



The *Median Rent* map depicts the median rent of rented housing units in a block group. It is a direct source map from the FGDL BLKGRP data layer.

11

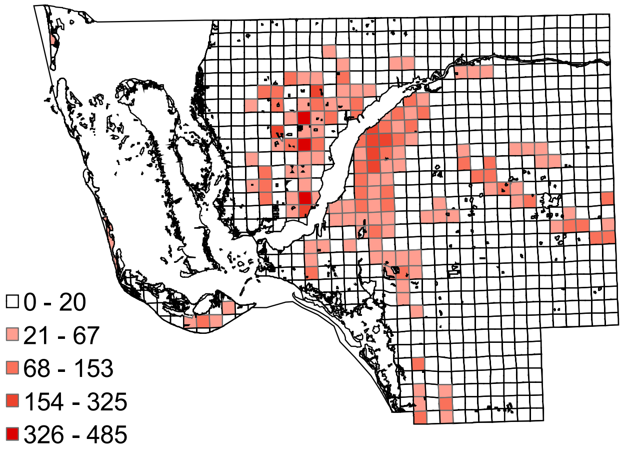
Commercial Units

Total number of commercial units in section

Data source: FGDL

Layer: TAXS97

Field: constructed



The *Commercial Units* map depicts the number of commercial, as opposed to residential, structures for individual sections of Lee County. The map is based on Florida Department of Revenue data and required construction. The construction involved the extraction of commercial units from datawhich included both commercial, public, and residential units, and then an aggregation of the unit counts by section.[122]

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[122] A subset of value codes was extracted from the TAXS97 data layer, corresponding to commercial units. Specifically, the fields 10-35, 37, 39-70, 71-73, 76, 80-82, 86-90 were included. Having made that extraction the FREQUENCY field was used to calculate the number of units in each section.

12

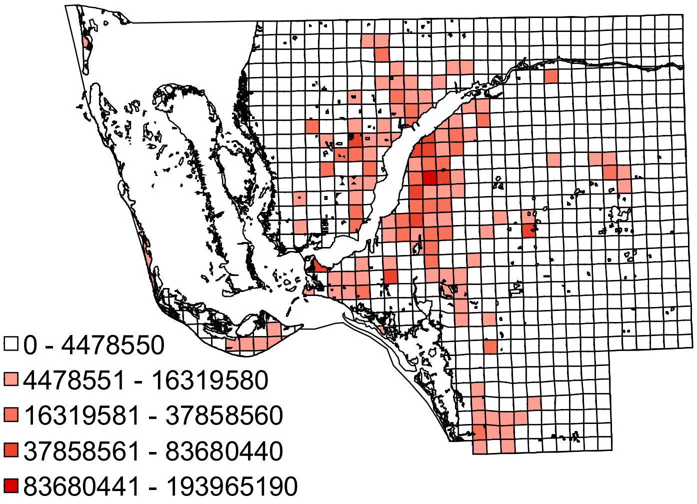
Value of Commercial Units

Value, in millions of dollars, of commercial units in section

Data source: FGDL

Layer: TAXS97

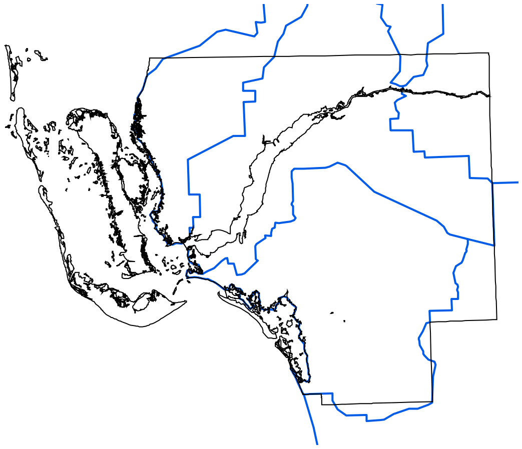
Field: constructed



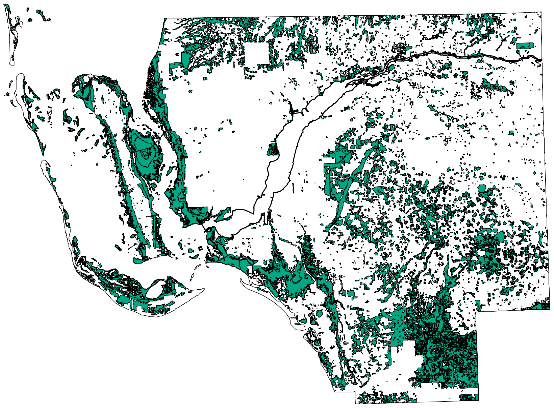
The *Value of Commercial Units* map depicts the value of the aforementioned commercial units, aggregated by section. This map is based on the same Florida Department of Revenue data set and the same extraction as the *Commercial Units* map. For each unit, value was constructed by subtracting the TAXS97 field LAND_VAL from the TAXS97 TOTAL_VAL field.

6.5.3 Bio-physical maps

The following set of bio-physical maps depict physical features of the landscape and the presence of a variety of species. This set of maps is again predominately based on data from the FGDL library, though several are from the South Florida Water Management District.

13 Watersheds Watershed boundaries Data source: SFWMD Layer: DBASINS	

The *Watersheds* map outlines watershed boundaries and was provided by the South Florida Water Management District. The map depicts watersheds to the eight-digit level, the smallest unit of watershed in the U.S. Geological Survey's (USGS') system of watershed classification. A watershed map is also part of the FGDL library.

14 Wetlands Location of National Wetland Inventory wetlands Data source: FGDL Layer: NWIP	

The *Wetlands* map depicts wetlands identified by the National Wetlands Inventory (NWI) and identifies wetlands of specific type (e.g., emergent, scrub-shrub). The NWI, run by the US Fish and Wildlife Service, is the nation's centralized and congressionally mandated wetland data repository.[123]

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[123] See http://www.nwi.fws.gov/index.html.

15

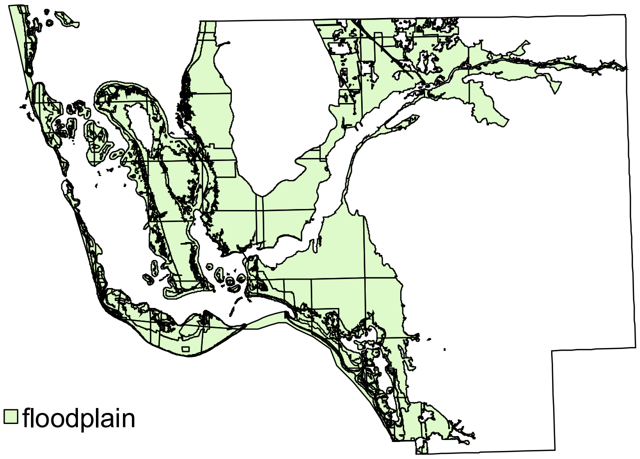
Floodplain

Coverage of 100-year floodplain

Data source: FGDL

Layer: FEMA96

Field: ZONE extraction



The *Floodplains* map is based on US Geological Survey flood data. The map depicts areas "inundated by 100-year flooding." It is an extraction from the FGDL FEMA96 layer, based on ZONE classification.

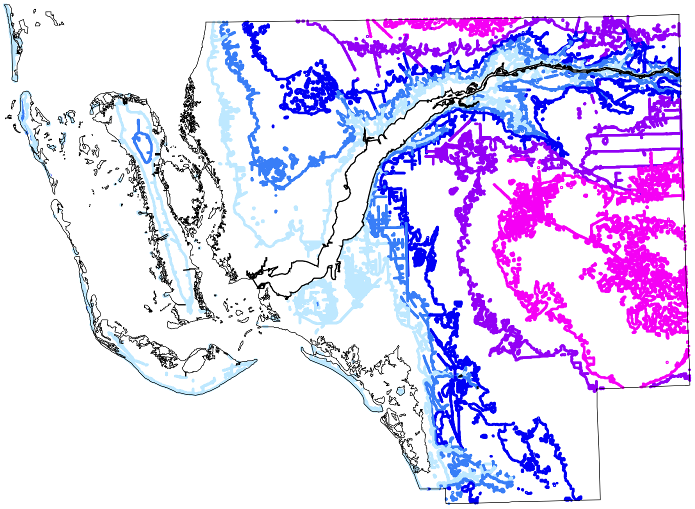
16

Elevation

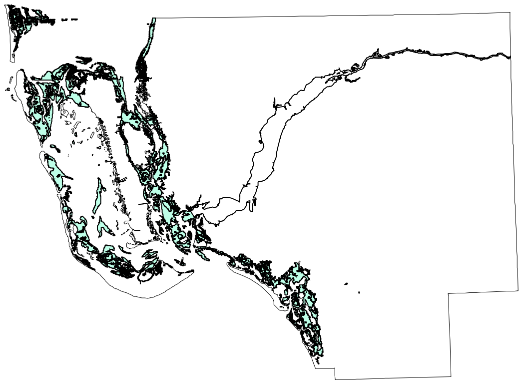
Topographical map in 5-foot increments

Data source: FGDL

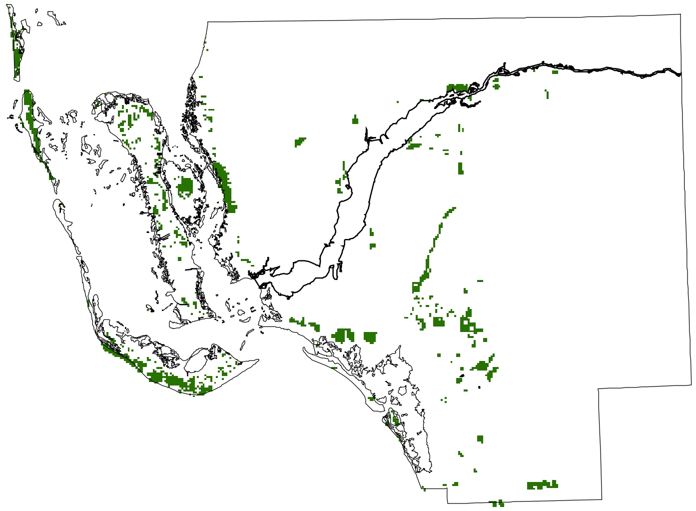
Layer: TOPO



The *Elevation* map denotes changes in elevation, in five-foot increments. It is a direct source map from the FGDL TOPO data layer.

17 Seagrass Location of seagrass beds Data source: FGDL Layer: SEAGRS	

The *Seagrass* map describes the location of seagrass beds in coastal waters. It is a direct source map from the FGDL SEAGRS data layer, based on data from the Florida Marine Research Institute.

18 Invasive Species Location of areas with exotic species invasion Data source: FGDL Layers: SFLU RINVPL GFCHAB Field: constructed	

The *Invasive Species* map described the location of areas invaded by exotic species, including melaleuca, brazilian pepper, and australian pine. The map is constructed from 3 data layers included in the FGDL library. These include extractions from the SFLU, RINVPL, and GFCHAB layers.[124] The construction can distinguish between species.

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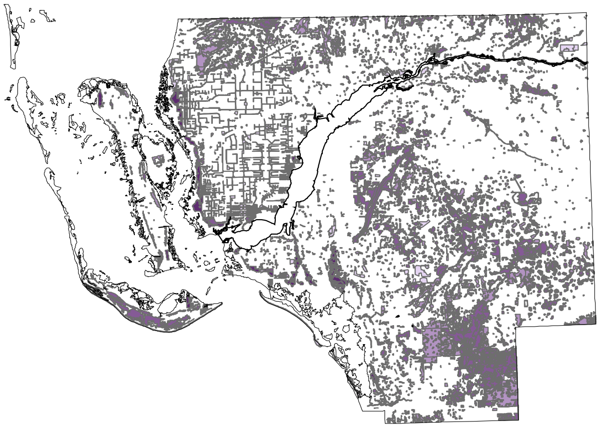
[124] The SFLU extraction is FLUCCS1 codes 422, 424, and 437 (brazilian pepper, melaleuca, and australian pine, respectively). The RINVPL extraction is of invasives-related restoration sites. The GFCHAB extraction is value 21, corresponding to “exotic plant communities.”

19 Rare Species Location of globally rare, and state rare species habitat Data source: FGDL Layer: FLEO98 Field: extraction	

The *Rare Species* map depicts occurrences of endangered or rare species, based on data from the Florida Natural Areas Inventory, a cooperative effort of the Florida Department of Environmental Protection and The Nature Conservancy.[125] The map is an extraction, corresponding to "globally rare" and "state rare" species occurrences, from the FGDL FLEO98 layer. Progressive levels of rarity and endangerment can be mapped.

20 Wetland Capacity to DeNitrify Wetland ranking based on capacity to de-nitrify Data source: SFWMD Layer: WCS Field: DENIT_CAP	

This map classifies wetlands based on their ability to reduce, degrade, or provide long-term storage of nitrogen from neighboring sources. The map is based on a classification scheme and analytic effort conducted by the South Florida Water Management District's, Water Quality Functional Assessment. The map is based on the Wetlands Conservation Strategy (WCS) data set for Lee County and directly maps the DENIT_CAP field.

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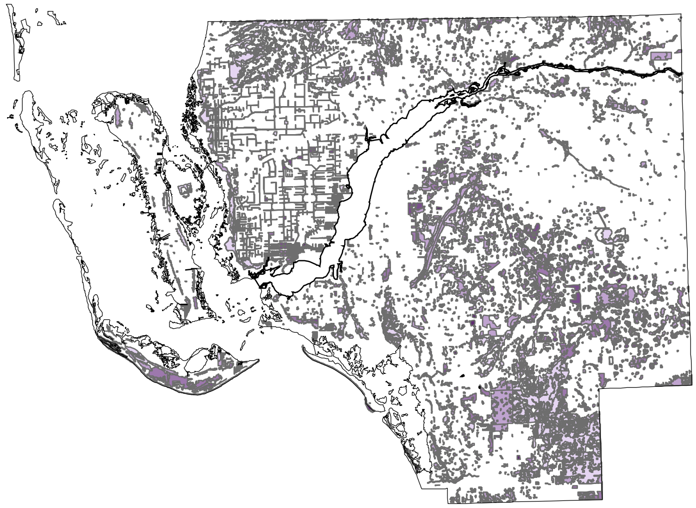
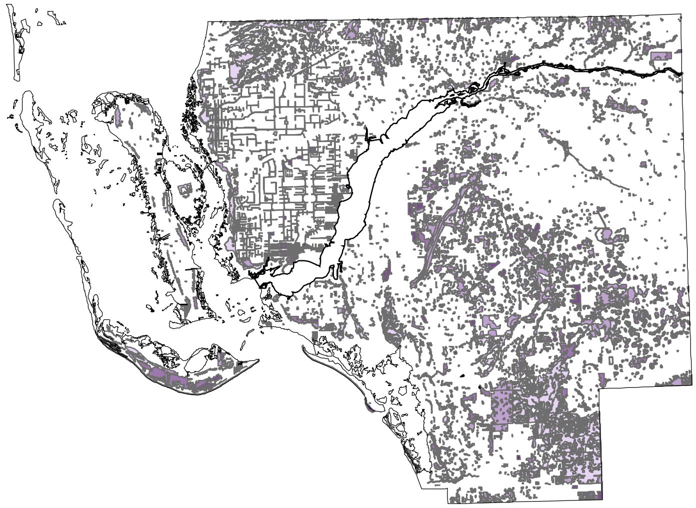
[125] http://www.fnai.org/.

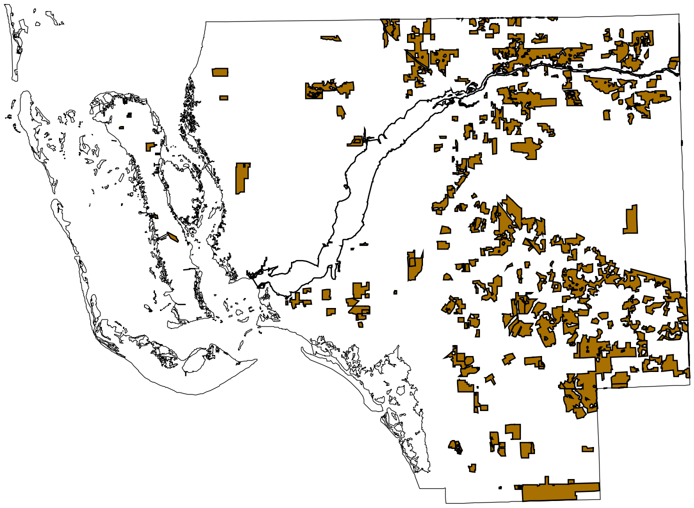
21 Risk to Wetland from Phosphorus Phosphorus risk to wetlands Data source: SFWMD Layer: WCS Field: TP_RISK	

This map, and the one following it, come from the same SFWMD Assessment. They depict a wetland's risk of receiving phosphorus and nitrogen loadings capable of damaging the wetland. The maps are derived from the WCS and directly map the TP_RISK and TN_RISK fields, respectively.

22 Risk to Wetland from Nitrogen Nitrogen risk to wetlands Data source: SFWMD Layer: WCS Field: TN_RISK	

6.5.4 Land use and land cover maps

The following land cover maps are based almost exclusively on data from the FGDL library and the South Florida Land Use layer, which classifies land cover using the Florida Land Use Cover and Forms Classification System FLUCCS.

23 Crop and Pastureland Location of cropland and pastureland Data source: FGDL Layer: SFLU Field: FLUCCS extraction	

The *Crop and Pastureland* map describes the location of row crops, field crops, livestock pasture, citrus plantations, and nurseries. It is an extraction of specific land use codes from the FGDL SFLU layer.[126]

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[126] FLUCCS1 codes 210s, 221, 222, and 0 (unimproved pasture).

24

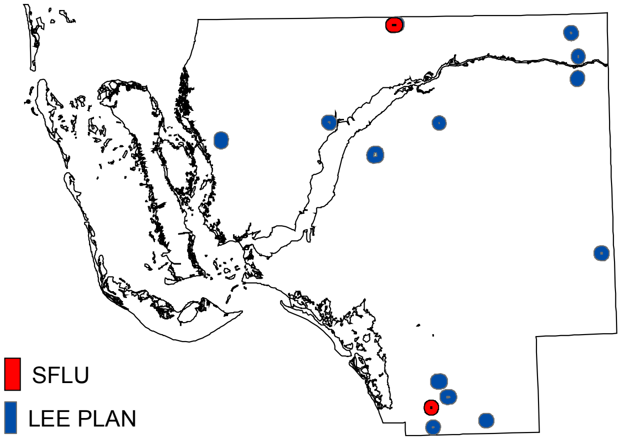
Livestock Operations

Location of intensive livestock operations

Data sources: FGDL & SFWMD

Layers: SFLU & LEE_PLAN

Field: :extractions



The *Livestock Operations* map describes the location of livestock feeding operations and dairies. The map is created from two sources. The first is an extraction of specific land use codes from the FGDL SFLU layer. The second is an extraction from the SFWMD's LEE_PLAN layer.[127]

25

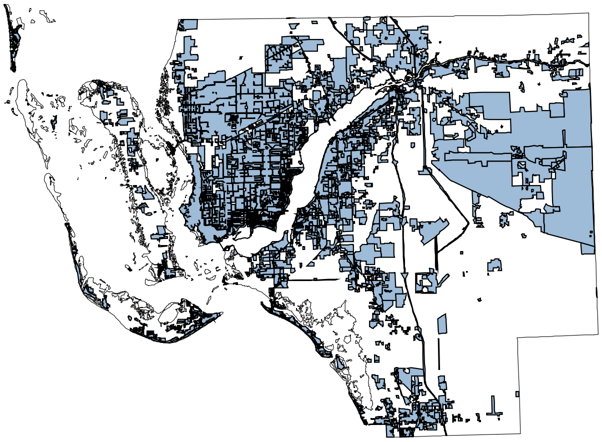
Impervious (Developed) Land use

Location of areas in developed land use

Data source: FGDL

Layer: SFLU

Field: FLUCCS extraction



The *Impervious Land use* map describes the location of developed land uses, including residential, commercial, industrial, and transportation-related land uses. It is an extraction of specific land use codes from the FGDL SFLU layer.[128]

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[127] Specifically, FLUCCS1 codes 210-223 and 240-246 from the SFLU layer and LU_DES = "Intensive Livestock Operations" from the LEE_PLAN layer.

[128] Based on FLUCCS1 designations, with adjustments for specific land uses.

26

Non-Ag Natural Land cover

Location of natural land cover

Data source: FGDL

Layer: SFLU

Field: FLUCCS extraction

The *Non-Ag Natural Land cover* map depicts un-developed land cover and excludes agricultural land. The mapped lands include rangeland, upland forests, water, wetlands, and beaches. It is an extraction of specific land use codes from the FGDL SFLU layer.[129]

27

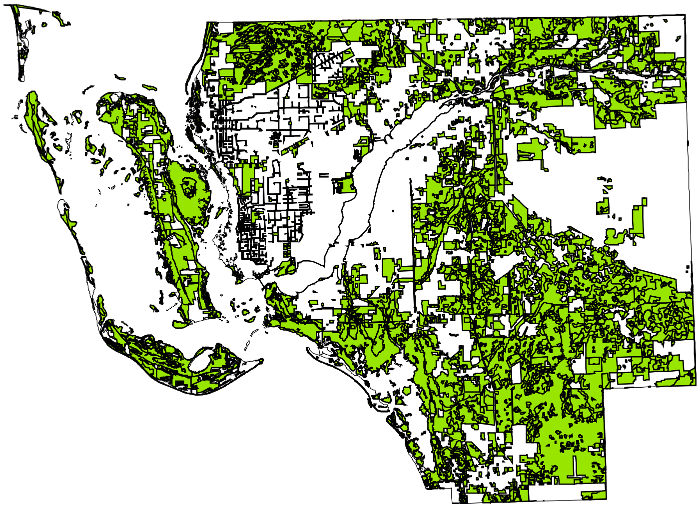
Natural Land cover & Pasture

Location of natural land cover and pasture

Data source: FGDL

Layer: SFLU

Field: FLUCCS extraction



The *Natural Land cover and Pasture* map is the same as the preceding map, except for the inclusion of pastures.[130]

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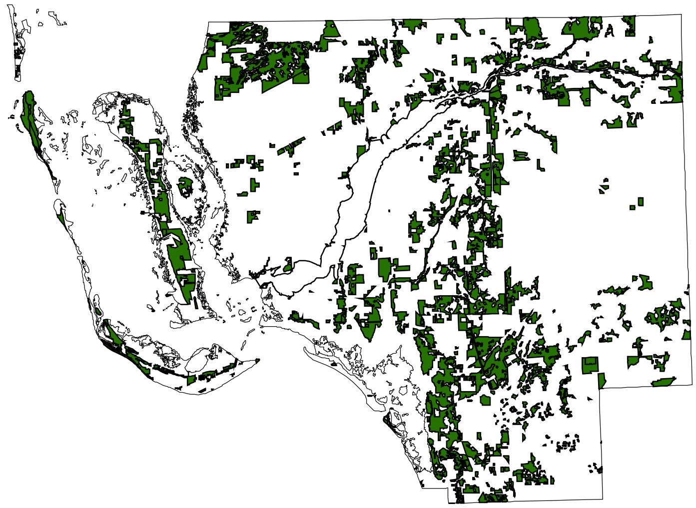
[129] FLUCCS1 = 300s,400s,500s,600s, 710,720,730.

[130] Same as above, with the addition of FLUCCS1 codes 211, 212, and 213.

28

Upland Forest

Upland forests
Data source: FGDL
Layer: SFLU
Field: FLUCCS extraction

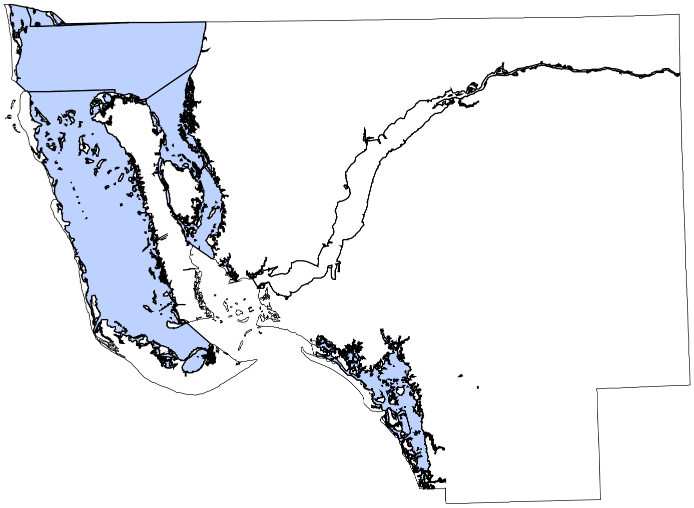


The *Upland Forest* map describes the location of upland forests. It is an extraction of specific land use codes from the FGDL SFLU layer.[131]

29

Aquatic Preserves

Location of aquatic preserves
Data source: FGDL
Layer: CLAN98
Field: ATTRIBUTE extraction



The *Aquatic Preserves* map shows the location of preserved coastal and estuarine areas as defined by the Conservation and Recreation Lands dataset. It is an extraction from the FGDL CLAN98 data layer.[132]

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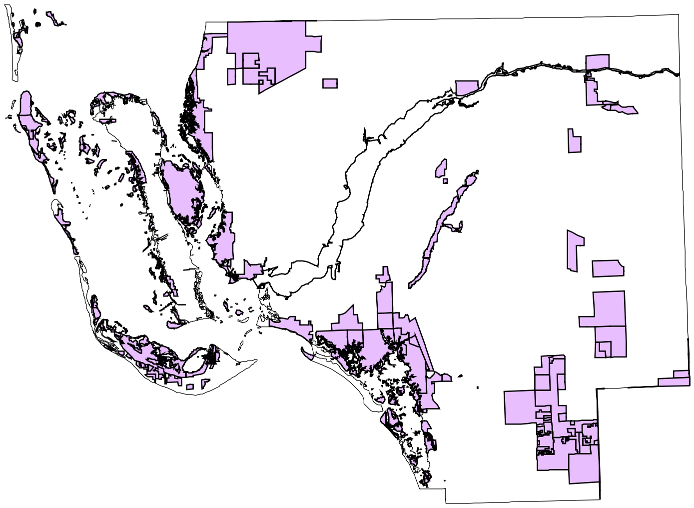
[131] FLUCCS1 codes 410-445.

[132] Specifically, attribute = water.

30 Protected Lands Lands with protection against future development Data source: FGDL Layer: CLAN98 Field: ATTRIBUTE extraction	

The *Protected Lands* map shows the location of protected lands, including publicly-owned parks, forests, recreation areas, and lands subject to conservation easement, as defined by the Conservation and Recreation Lands dataset. It is an extraction from the FGDL CLAN98 data layer.[133]

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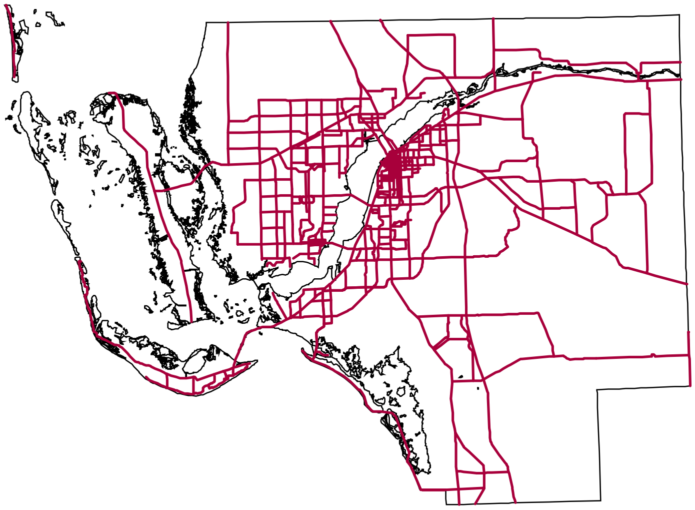
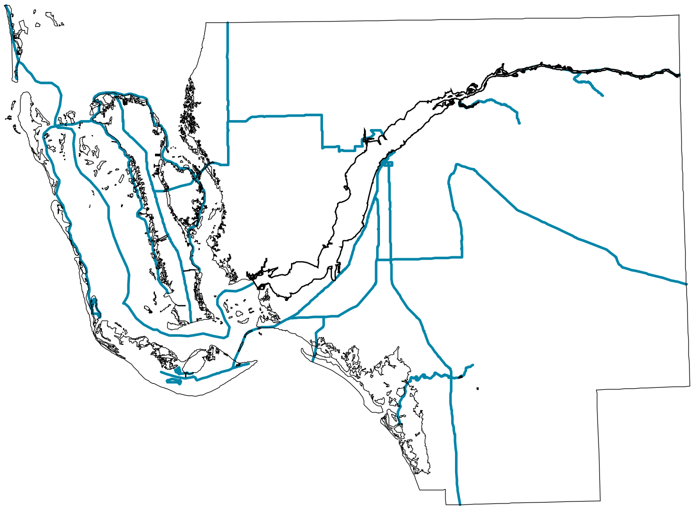
[133] Specifically, attribute = none or land.

6.5.5 Infrastructure maps

Maps of infrastructure – roads, trails, wells – can be derived from a variety of data sources. Data on roads and trails are part of the FGDL library. Permitted well data is available from the SFWMD and private residential drinking well data is available from the U.S. census.

31 Major Roads Location of major roads Data source: FGDL Layer: MAJRDS	

The *Major Roads* map describes the location of interstate highways, U.S. roads, and major state county and local roads. It is a direct source map from the FGDL MAJRDS data layer.

32 Trails Location of recreational trails Data source: FGDL Layer: TRL98	

The *Trails* map describes the location of recreational trails, including hiking, biking, and boating trails. It is a direct source map from the FGDL TRL98 data layer.

33

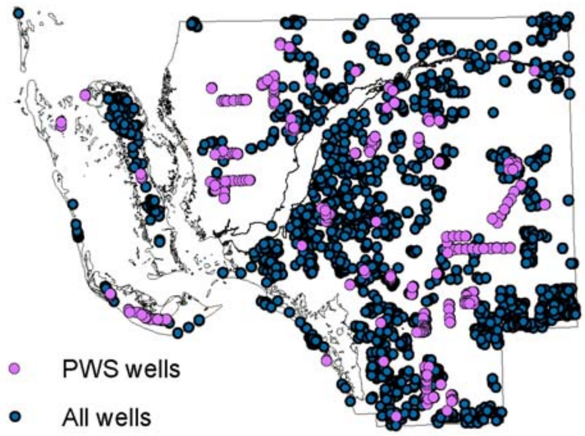
Permitted Wells

Location of permitted water supply wells

Data source: SFWMD

Layer: LEE_WELLS

Field: LU_CODE



The *Permitted Wells* map shows the location of all permitted wells within Lee County, including public water supply, agricultural, and industrial wells. Public water supply wells are highlighted and represent an extraction from the SFWMD's LEE_WELLS layer.[134]

34

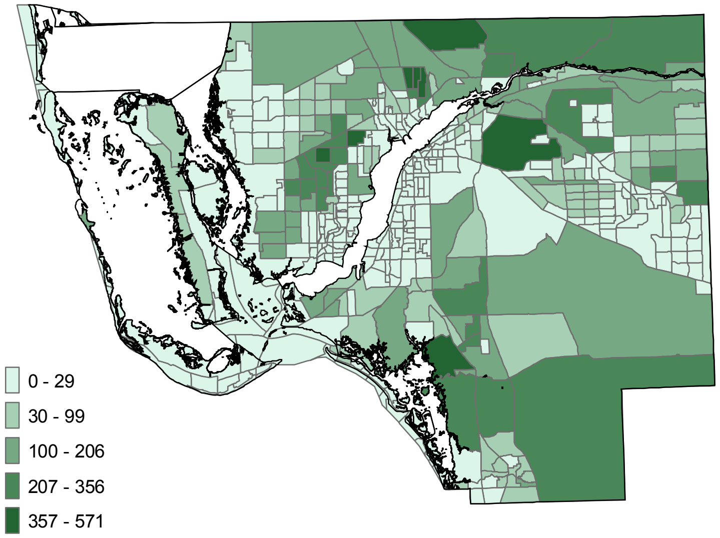
Private Drinking Wells

Number of private drinking water wells in census block group

Data source: 1990 Census of Population and Housing

STF 3A

Field: HO230002 & HO230003



The *Private Drinking Wells* map shows the number of housing units with either drilled or dug private water supplies, as opposed to publicly-supplied water. The data is from the U.S. census and corresponds to the number of well-supplied housing units in each census block group. The field is constructed by aggregating the numbers of units using both "drilled" and "dug" wells.

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[134] LU_CODE = PWS.

35

Density of Private Drinking Wells

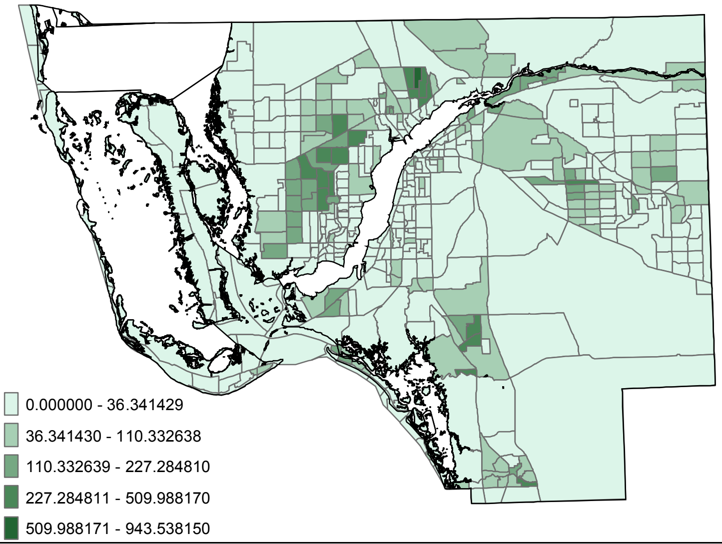
Density per square mile of private drinking wells in census block group

Data source: 1990 Census of

Population and Housing

STF 3A

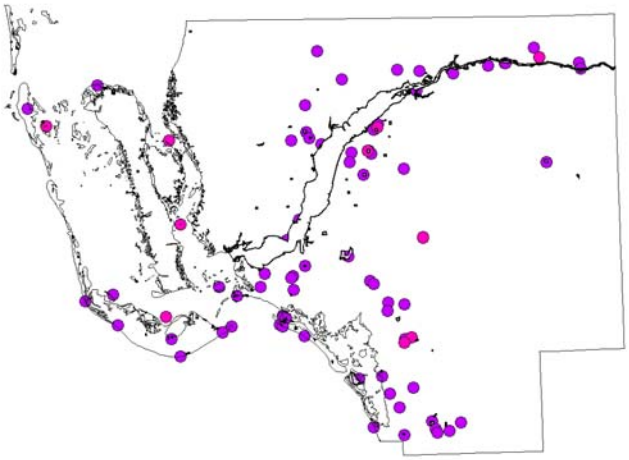
Field: HO230002 & HO230003



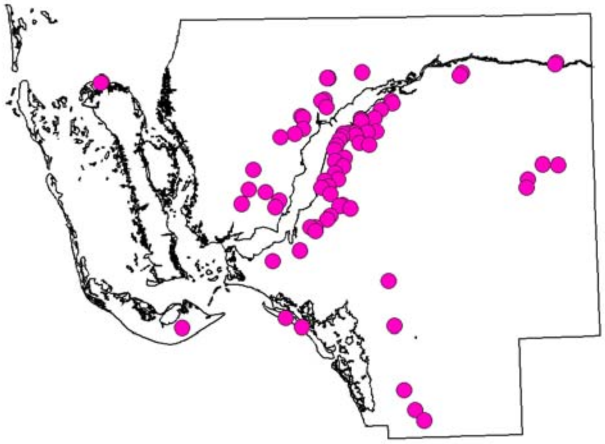
As noted earlier, block group data is often best displayed as a density. Accordingly, the previous data was adjusted by block group area to give a measure of the “density of private residential water supply wells” for each block group. This involved a simple construction of a data field equal to the total number of private residential wells drilled and dug, divided by the block group’s area in square miles.

6.5.6 Public site maps

A variety of public sites and facilities can be mapped with data from the FGDL library.

36 Recreational Areas Location of beaches, parks, and other public recreation areas Data source: FGDL Layers: PTSINT GNIS SFLU Field: extractions	

Recreational Areas includes the location of boat ramps, beaches, parks, campgrounds, zoos, marinas, and recreation centers. The map is based on extractions from three different layers – PTSINT, GNIS, and SFLU that are included in the FGDL.[135]

37 Schools Location of schools Data source: FGDL Layer: GNIS Field: DESIG extraction	

The *Schools* map shows the location of primary and secondary schools. It is based on the GNIS data layer included in the FGDL and is an extraction based on site designation.[136]

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[135] The PTSINT extraction is TYPE=CC,BR, LPRB,LPUB,MRA,RCC,SRA, ZBPI. The GNIS extraction is DESIG=park, and the SFLU extraction is FLUCCS1 = 181, 184, 185.

38 Culturally Important Sites Location of culturally valuable sites Data source: FGDL Layer: PTSINT Field: TYPE extraction	

The *Culturally Important Sites* map shows the location of museums, cultural centers, and historic sites. It is based on the PTSINT data layer included in the FGDL and is an extraction based on site type.[137]

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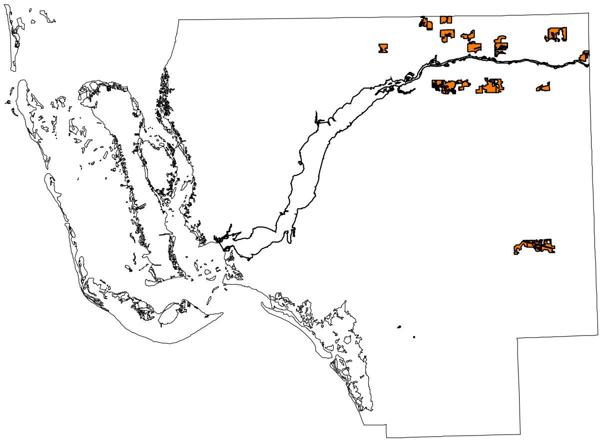
[136] DESIG=school.

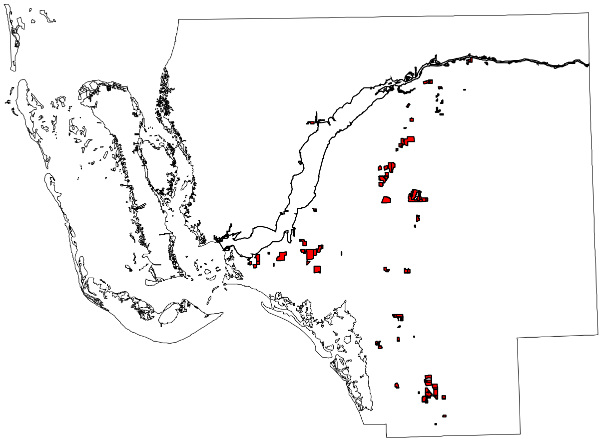
[137] TYPE=MSM,BTF,INM,HTS,CULS.

6.5.7 Planning Maps

The South Florida Water Management District's Lower West Coast Water Supply Plan provides planning information that depicts expected changes in land use, as of the year 2020.

39 Future Ag (Citrus) Likely location of future citrus plantations Data source: SFWMD Layer: LEE_PLAN Field: LU_DES extraction	

The *Future Ag* map is a depiction of lands likely to be converted to citrus plantation by the year 2020, according to the West Coast Water Supply Plan. The map is an extraction from the SFWMD's LEE_PLAN layer.[138]

40 Future Impervious (Developed) Land use Cropland likely to be lost to development Data source: SFWMD Layer: LEE_PLAN Field: LU_DES extraction	

The *Future Impervious* map is a depiction of formerly agricultural lands likely to be unavailable for agriculture in the year 2020, according to the West Coast Water Supply Plan. The map is also an extraction from the SFWMD's LEE_PLAN layer.[139]

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[138] LU_DES="new citrus."

5.6 Wetland Ecosystem Services

As described in Section 5, ecosystems provide to society a wide range of valuable services. Our analysis of wetland trades in Lee County focuses on a subset of these services; flood damage avoided, improved drinking water supply, enhanced recreational fishing, and the provision of aesthetic benefits. This list of services does not necessarily exhaust the list of possible services provided by these sites, but does represent what are likely to be the major sources of benefits associated with wetland sites.

5.6.1 Flood damage avoided

Wetlands retain standing water and reduce the velocity of surface water flows more effectively than other land types. The services provided by this function are primarily associated with flood damage avoidance. Surface and sub-surface water flows are difficult to characterize with precision, particularly in regard to specific events. Nevertheless, wetland losses are thought to increase flooding and erosion, and the social costs associated with flooding and erosion. All else equal, wetlands that are in a position to protect against flooding and that protect the most numerous and valuable buildings, roads, etc. will yield the largest flood damage benefits.

Physical flood-related damages impose costs on society. Avoiding damages – and thereby avoiding costs – is a form of utility enhancement. In some cases, the benefit arises from avoiding the damage itself. In other cases, however, characterizing the potential losses from wetland destruction may over-estimate the benefit, since damages may be avoided in a variety of ways. In other words, there may be substitute actions (e.g., construction of levees) that can be used in lieu of floodwater retention. Improved floodwater retention may create value by allowing fewer resources to be spent on these alternative damage avoidance strategies. If so, the avoided cost of these alternative actions is the benefit of the service.

5.6.2 Improved drinking water supply

Wetlands, by trapping water that would otherwise be lost to drainage or evaporation, are an important source of freshwater to underground aquifers. This is particularly important in Florida, where saltwater intrusion can significantly degrade the quality of aquifer waters. Also, wetlands trap

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[139] LU_DES="cropland lost not available for agriculture."

nutrients and filter impurities, thus improving aquifer water quality. Wetlands in proximity to sources of water quality impairment and that feed aquifers used for drinking water will yield the greatest drinking water supply benefits.

Consider first the value of improvements in drinking water quality. Improved water quality has social value, due to health and aesthetic improvements, whenever quality is impaired. These quality improvements may be achieved in a variety of ways, however. Water treatment, whether by municipalities or households, is a substitute service. To the extent that artificial water treatments are available, the value of aquifer water quality improvements is reduced. But evidence that resources are expended to improve water quality (e.g., municipal wastewater treatment) is also evidence that improvements in water quality have value.

In terms of water quantity improvements, greater aquifer supply has value whenever there is water scarcity. Farms and industry employ water as a key input to their production. Aquifer recharge is valuable since it reduces the costs of extracting water (lower aquifer levels generally mean that more energy will be required to pump water to the surface). Water availability also directly improves the yield and quality of agricultural crops. Aquifer recharge also benefits households that rely on well water or that experience constrained municipal supplies in drought conditions.

Often, the amount of aquifer recharge may affect surface water quality. Wetlands influence surface water quality indirectly by routing runoff water to aquifers which filter and later discharge water into streams and estuaries. A reduction in aquifer recharge can reduce stream baseflow levels and result in less dilution of stream contaminants between storm events. Further, a change in the proportion of water reaching streams directly through surface runoff versus through infiltration and aquifer discharge, frequently results in greater amounts of pollutants reaching surface water.[140]

5.6.3 Enhanced Aquatic Recreation

Because wetlands influence surface water quality directly through filtration of runoff and indirectly by increasing the quantity of streamflow that is filtered through aquifers, they have the ability to enhance the health of species dependent on surface waters. Improved surface water quality provides aesthetic and health benefits for swimmers and boaters. In estuarine areas, the influence on

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[140] See Dunne and Leopold, 1978.

surface water salinity can change the abundance and nature of recreational fishing species. Further, riparian wetlands provide organic matter inputs that serve as an energy input to aquatic food webs.

Improving, or simply preserving, the quality of recreational fishing is economically valuable. Many Floridians directly benefit from healthy fishing stocks, because they themselves enjoy this type of recreation. There are large indirect benefits associated with fishing-related tourism, as well. Tax revenues, employment, and commercial activity are at some level sensitive to the quality of recreation provided by local waters.

5.6.4 Provision of aesthetic benefits

Wetlands may provide amenities such as open space and opportunities to view wildlife. Open space can generate benefits by providing opportunities for recreation, and by providing privacy and scenic beauty. Wetlands are also open spaces that provide habitat for a wide variety of species that can themselves have recreational value (e.g., rare birds and plant communities).

The value of these services is enhanced if the wetland exists where open space and scenic vistas are scarce, and where the wetland attracts wildlife that adds to visual amenities and recreational benefits. Access is an important determinant of these benefits. All else equal, beautiful wetlands in remote, inaccessible areas are less valuable than beautiful wetlands where they can be seen and otherwise enjoyed. There are obvious tradeoffs between this wetland service and others, such as endangered species protection, where less accessibility may be preferred.

For each of the aforementioned services we now develop and present a set of indicators that speak in some way to the benefits provided by the individual wetland sites. The initial goal is simply to illustrate the availability and characteristics of such data. From this exercise several conclusions emerge. First, that numerous indicators of ecosystem benefits exist in a reasonably accessible form. Second, that these kinds of indicators would be useful to decision-makers if they were to incorporate the analysis of ecosystem service benefits into their analysis of wetland and other ecosystem trades. Third, that individual indicators are inherently limited in the information they provide. When used indiscriminately, most indicators can be easily misinterpreted. Later sections of the study deal with the way in which indicators are ideally aggregated and interpreted. Later sections also deal concretely with the inherent limitations and methodological dangers associated with non-monetary indicators of ecological benefits.

5.7 The Construction of Indicators

Indicators are based on calculations applied to one or more GIS maps. We have already described the available GIS maps and defined the ecosystem services of interest. We now turn to a description of the calculations used to derive specific indicators.

5.7.1 Calculations

GIS analysis permits a wide variety of spatial calculations, several of which we have employed for the analysis of the LPI mitigation bank. These types of calculations fall into the following broad categories: (1) The *distance* between two points or areas. This kind of calculation is self-explanatory; (2) The *presence* of a certain feature, or the *number* of features, within a specified distance. This kind of calculation requires the choice of a radius within which you count the features of interest. The specific radius chosen is important, and often somewhat arbitrary. For this reason, it can be useful to derive calculations at a variety of distances in order to determine the sensitivity of the indicator to that radius; (3) The *percentage* of an area that has a particular characteristic. The area may be a physical feature, such as a watershed, or a floodplain, or it may be a constructed feature, such as a ½ mile radius around a certain point. The latter we refer to as a *vicinity*; (4) It may also be useful to measure the *connectivity* of a certain feature with other landscape features. Measures of connectivity can take several forms, such as "the distance to the nearest feature of interest," the length of a boundary shared by two features, or the interior area of a landscape patch defined by a particular land cover type.

Figure 2 depicts the neighborhood of impact site 4. The map is based on the SFLU land cover dataset and depicts impervious (developed) land uses, agriculture, and forested land cover in the vicinity of the site. These land uses were mapped by aggregating more specific land use types into these general categories.[141] (The SFLU data has more than 80 distinct land cover designations.) Within any GIS program it is straight-forward to measure distances, although the accuracy of the measurements depends on the source data and its handling within the GIS software.

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[141] Specifically, this figure depicts all SFLU 100- and 800-level land uses as "impervious," all 400-level cover as "forest," and all 210-level areas as "agriculture."

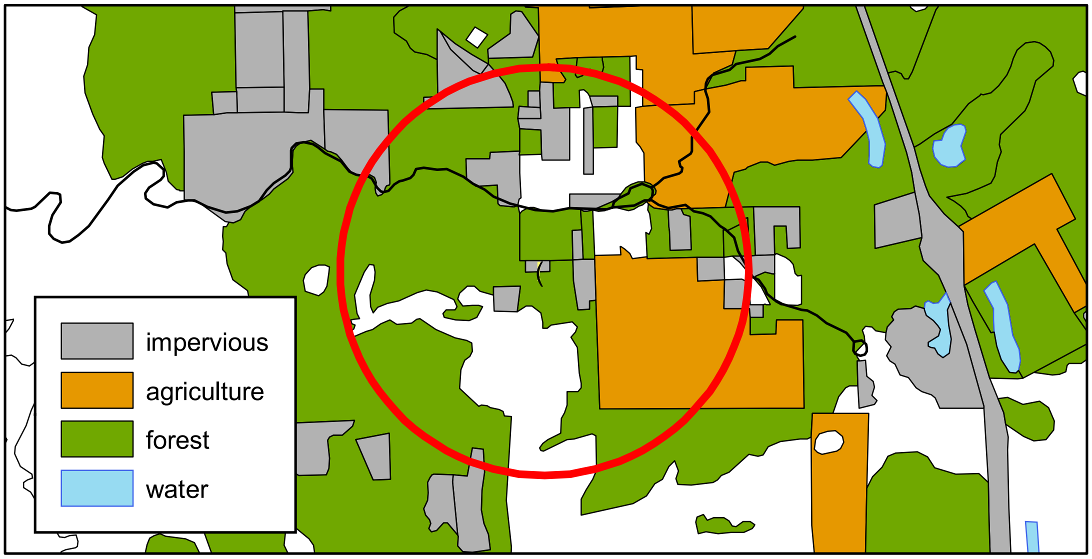

Figure 2: Land use in radial area

With the proper map, it is easy, for instance, to measure the distance from a wetland site to the nearest row crop agriculture. It is also straightforward to measure the percent of a given area covered by a particular land use. Consider the circular 1-mile radius of site 4. Calculations will show a relatively high percentage of forested land cover in the site's vicinity, and a relatively low percentage of impervious land cover. With this kind of mapping, an indicators corresponding to the "percentage of land use x in a 1-mile vicinity" can be calculated. Other maps would allow us to calculate a variety of other indicators, such as the number of permitted wells, public parks, etc. within the same area.

Other indicators involve calculations based on a combination of several different maps (multiple data sets). For example, one indicator we calculate is the "percentage of a watershed's riparian areas that are wetland." Riparian wetlands can be particularly valuable. Understanding the percentage of such areas that are wetlands speaks to the scarcity of wetlands in a particular hydrological area. To make the calculation several maps are combined: a map delineating watershed boundaries; a wetland map; and a riparian map. In this case, the riparian area is defined as a half-mile deep buffer around the county's major rivers.[142]

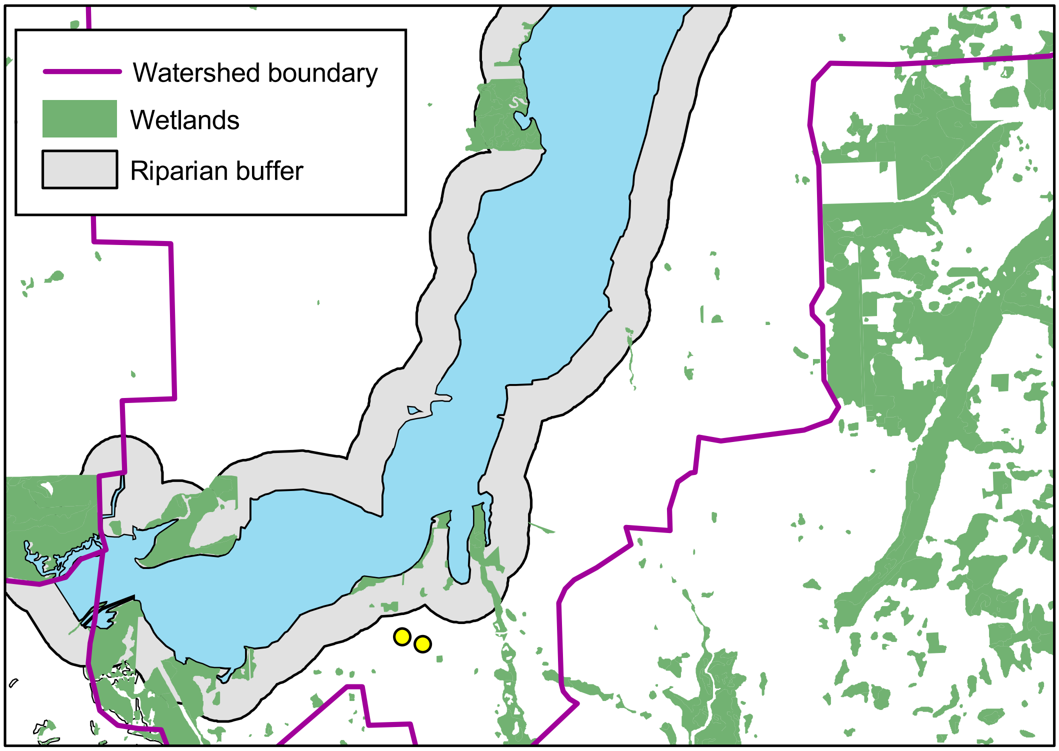

Figure 3: Riparian areas in a given watershed

Figure 3 depicts an area surrounding impact sites 1 and 6 (the sites are depicted in yellow). The calculation first involves the isolation of an area that is, in effect, an intersection between two different sets: riparian areas and a specific watershed. Specifically, we define and isolate the area that is both riparian buffer and within the same watershed as the wetland impact sites. This area corresponds to the buffer area below the Caloosahatchee and to the right of the coastal plain. Once isolated, we calculate the percentage of this particular area that is wetland, yielding an indicator of wetland scarcity.

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[142] In our analysis we use a ¼ mile, rather than ½ mile, buffer to denote areas that can be considered riparian. The riparian area is constructed by the GIS software program. The river map can be "buffered" at a specified distance and mapped as a separate data layer.

The use of multiple maps in this way enables a variety of useful benefit indicators. For instance, in addition to the above, we can – and do – calculate indicators such as the "percentage of a watershed's floodplain that is wetland" and the "percentage of local trail buffer that is in wetland." No single map allows for these kinds of calculations. Luckily, the merging of multiple maps is a basic function of most GIS software programs.

5.7.2 Measurement issues

The use of GIS data requires a sensitivity to differing levels of accuracy, or resolution, offered by different sources of data. It is typical in both ecological and economic analysis to use the finest data scale available for each variable being measured. In this case study, that results in some data being aggregated over 1 square mile (in the case of data in a township-range-section format) and other data being aggregated over the area of a census block or census tract. Census blocks typically have a 2 square mile area, but as noted earlier, areas range widely – in our study area on block group has an area of 80 square miles. If the site of interest falls within an atypical section of a larger area this can lead to bias. For instance, it is possible that a site is in a demographic "pocket" with very different characteristics than those depicted in block group data. While unavoidable, this lack of super-fine resolution can in some cases matter greatly to the conclusions one would hope to draw from a landscape analysis. This is one of several reasons why indicators must be interpreted with caution. It also underscores the desirability of involving individuals with local knowledge in the interpretation of the data.

Another common source of potential bias can arise from sites that are near the edge of a particular area. Consider a magnified view of impact sites 1 and 6 (in blue) and the block groups in their immediate vicinity:

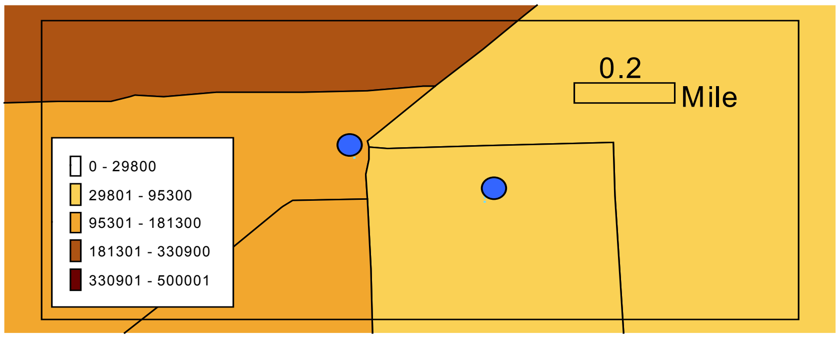

Figure 4: Edge effects

Figure 4 depicts median housing value in the block groups. Note that site 6 sits at the confluence of 3 block groups and is within two tenths of a mile of 2 additional block groups. Further note that housing values vary dramatically across the block groups. Site 6's own block group median is \$108,300. Neighboring block groups range from \$67,000 to \$187,500. It should be emphasized that we took a simplistic approach to our indicator calculations. For example, we used the median value of site 6's own block group as the indicator of median housing values in its neighborhood. It is possible, and may be more accurate, to construct an indicator based on a weighted average of median values in a larger number of block groups surrounding the site. Again, the larger lesson is that specific indicators should be interpreted with caution.

Another, related issue that pervades this kind of analysis is the choice of geographic scope for measurement. Since we are trying to determine the benefits of ecosystem services, the definition of "service area" is an important issue. In general, the relevant service area will differ depending on the service in question and for individual indicators of that service's benefits. The appropriate area will sometimes be determined by physical constraints, and other times by demographic constraints. Boundaries are needed to define the likely users of a service, areas in which access to a service is possible, and the area over which services might be scarce or have substitutes. Physical boundaries vary according to the nature of the bio-physical function that gives rise to a particular service. Consider the benefits of floodwater retention. Here, floodplain and watershed boundaries place natural physical limits on the relevant area used to determine benefits.

We use different spatial scales for different services and types of data: the local neighborhood, the watershed, the floodplain, or the county. For example, only a local population is counted if only a local population benefits. This would be the case for example, with certain aesthetics benefits, such as the enjoyment of scenic vistas or open space that require ownership, access, or adjacency. We use a ½ -mile radius circular neighborhood for most services related to viewing and aesthetic services, assuming that wetlands within one half mile of a park or public trail have the potential to increase the presence of birds and other wildlife at those public areas. The presence of parks indicates that more people will have access to those services than they would if the service were provided in remote or inaccessible areas. We assume that proximity to wetlands improves aesthetic benefits to neighborhood homeowners. The presence of school-age children and/or schools in the vicinity of a wetland is assumed to indicate greater potential demand for educational opportunities.

When recreational benefits are at issue, the service area is not always easily defined. Knowledge of demographic factors, access via roads and trails, the determination of substitute sites for recreation, and local preferences is needed to determine the relevant service area. These issues are frequently confronted in econometric analyses of recreational benefits. The so-called travel cost method is a common non-market valuation technique that seeks to estimate the demand for recreation based on travel costs, including the distance traveled by boaters, hikers, and anglers. A key methodological issue in any recreational benefits study is the determination of the appropriate "choice set" facing anglers, hunters, hikers, and birders.[143] Choice sets are the set of substitutes for recreation at the site in question. Defining these sets appropriately is important because they describe the relative scarcity of recreational services provided at a particular location. Put more intuitively, if improvements in catch rates at site A improve, how much value does this have to persons within 10 miles of the site, a hundred miles, or a thousand? The answer depends in part on the substitutes available to recreators across those different scales. Fishing holes a day away are substitutes for fishing holes an hour away. The question is how close are they as substitutes and how does that translate into the value of improvements in site A? Accordingly, a key challenge for such studies is the determination of the range over which recreational sites are substitutes for one another. Changes in the range assumed to be relevant can significantly affect the results of travel cost analyses.[144]

Because all of our study sites are in fairly close proximity, they are all likely to be in the same service area. In other words, on the basis of travel costs, they are all close substitutes. Thus, we have not had to confront the recreational service area challenge in this case study. The choice of service area will more important, and difficult to resolve, when ecosystem trades take place across a wider area, such as a state. Nevertheless, in situations where wetland trades take place across a broad geographic area, a great deal of data reported at the county level are available that would permit inter-county comparisons of likely users.[145] Note, however, that it will typically be difficult to identify the proximity of fishers, boaters, and birders to specific recreation sites, although we consider the locations of boat ramps, hiking trails, and other features that reflected local access to wetlands and fishing.

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[143] For a good collection of studies that address this issue see the special issue of Marine Resource Economics, volume 14, no. 4, 1999.

[144] See V. Kerry Smith & Raymond J. Kopp, "The Spatial Limits of the Travel Cost Recreational Demand Model," in Estimating Economic Values for Nature 234, V.Kerry Smith ed., 1996.

[145] For example, county-level information can be used to examine recreational use rates as collected by the US Fish and Wildlife Service.

We use watershed and floodplain boundaries in cases where surface water movement is at issue.[146] The watershed is clearly not the best scale for dealing with issues related to terrestrial habitat or human movement, since terrestrial organisms will freely cross watershed boundaries. However, the watershed is an appropriate boundary for services dependent on surface water movement. Groundwater, on the other hand, does not necessarily remain within watershed boundaries. However, in the absence of information about the extent of "ground-watersheds," we used a circular neighborhood to define the service area for groundwater recharge.

In some cases, biophysical information can be used to create measures of a particular wetland's service area that are more detailed than a simple circular neighborhood. For example, a wetland's immediate service area for surface water purification services can often be delineated using elevation data and GIS analysis techniques.[147] Source and sink sub-watershed boundaries are useful for the determination of areas that contribute runoff to, or receive runoff from, specific wetlands. These boundaries identify neighboring areas whose nutrients, sediments, and contaminants can be sequestered by a specific wetland. They identify downstream areas that would be protected by sequestration.

Unfortunately, the relatively straightforward GIS technique that makes this delineation possible relies on fine scale elevation data (i.e., Digital Elevation Model data of 1:24000 resolution or better), which were not available for Florida. Even if such elevation data were available, however, the flat terrain and the numerous canals in the region, which strongly influence water flow, may still have precluded accurate delineation of contributing and receiving areas. For these reasons we used the ½ mile neighborhood of the site as the likely range of receiving waters for a particular wetland site. Other researchers have been forced to make similar compromises.[148]

We make this kind of simplifying assumption often. When, as is often the case, no obvious boundary exists, we favor the use of a standard "vicinity" of ½ mile for measurement. Consider

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[146] The watersheds we used were defined by the SFWMD and were generally smaller than the 8-digit HUC code watersheds defined by the USGS and used by the EPA in the Index of Watershed Indicators web site. *See* U.S. Environmental Protection Agency, *Index of Watershed Indicators*, http://www.epa.gov/iwi (visited Apr. 16, 2001).

[147] An elevation map can be manipulated to generate an outline of the areas from which surface water would drain into the wetland (contributing areas) and the areas that are likely to receive runoff downslope of the wetland (receiving areas). The contributing areas represent the areas from which wetlands can sequester nutrients, sediments and contaminants in order to protect downstream resources in the receiving areas or beyond.

[148] See, e.g., Comprehensive Conservation, Permitting and Mitigation Strategy, A Water Quality Functional Assessment of South Florida Wetlands, at http://www.sfwmd.gov/org/pld/proj/wetcons/waterq/wq_techpub.pdf (visited Apr. 16, 2001) (using a 300-meter (0.2-mile) circular neighborhood to study wetland risks from nutrient and toxic runoff).

another example. For drinking water benefits, aquifer boundaries and knowledge of groundwater flows could be used to define the most relevant area for measurement. Unfortunately, precise data on aquifer boundaries and groundwater flows is often not available. For this reason, we use a ½ mile radius as the relevant range over which a given wetland will contribute to drinking water quality improvements from well water. Because this range is arbitrary, it is desirable to test the sensitive of an indicator to the range chosen.

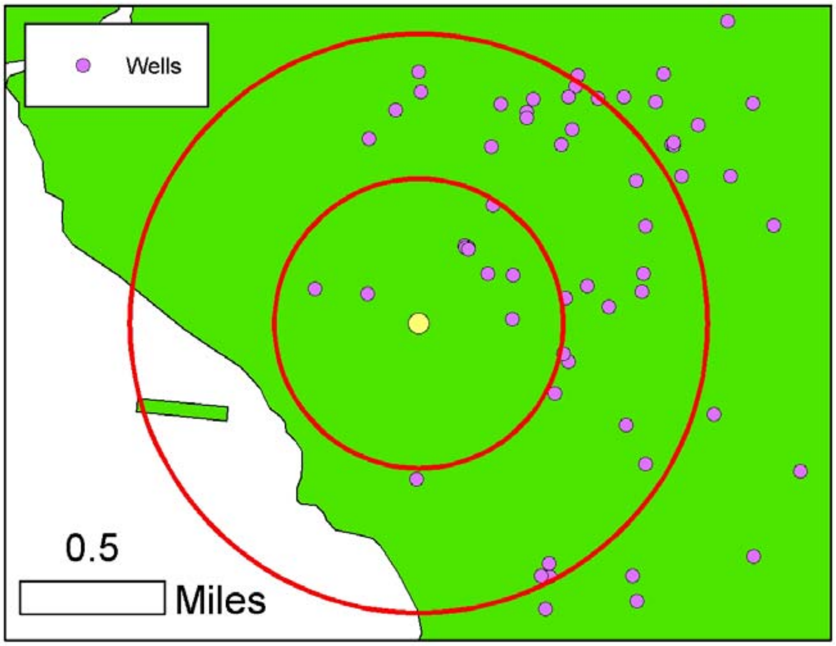

Figure 5: Choice of range

Consider figure 5, which is a magnification of permitted wells in the vicinity of impact site 9. The two circles denote the ½ mile and 1 mile vicinities of the site. Because ½ mile is an arbitrary range, it is useful to see what the effect of a larger radius would be on an indicator of "number of wells in vicinity." In this case, the impact is quite large. Ten wells are within ½ mile, while 40 wells are within 1 mile of the site.[149] For this reason, some of the indicator data is reported at more than one scale.

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[149] At this resolution it is difficult to see several of the wells which lie in close proximity to one another.

To summarize, the definition of boundaries relevant to the measurement of service benefits poses a significant challenge. The sources of this challenge include lack of data and fundamental scientific uncertainty regarding the processes involved. Ground- and surface-water interactions are a good example. It is difficult with precision to identify water flows given the inherent uncertainties associated with site-specific hydrology. We know that site-specific hydrology is important to a determination of benefits, but cannot with confidence identify the physical linkages at issue with GIS data. Similarly, determining the population of users who will enjoy a particular service is complicated by the movement of users, and a lack of data on specific preferences. Well-known difficulties associated with the estimation of recreational benefits underscore this point.

5.7.3 Buffer-related adjustments

For sites located near open water we make an adjustment to the radial area used for "site vicinity" calculations . Specifically, we calculate the relevant percentage (e.g., of agriculture) based only on the land area within the circular vicinity, rather than on the full circular vicinity. For example, we exclude open water from the calculation of land use in the vicinity of site 2.[150] Also, site 8's vicinity includes an area that is not in Lee County. For expedience, we exclude the non-Lee County area from that site's vicinity.[151]

Little Pine Island is not buffered in the same way as the impact sites. Little Pine Island's buffer is not circular, because the mitigation bank is large and covers, roughly, the entire shore of the island. LPI is also unique because it has an interior buffer, owing to the bank's donut-like shape. Because it is an island, the exterior buffer is not always relevant. When the service requires some kind of hydrological connection, for example, looking at land use on Pine Island, while technically within a ½ mile of the bank, is inappropriate since the two islands are hydrologically isolated. We also exclude numerous small islands encircling LPI. Only land area contiguous to LPI proper is characterized. For indicators that do not rely on a hydrological connection, and there are several, the buffer is the ½ mile buffer around the island, which includes other islands. We also make a simplifying assumption regarding the interior buffer. The bank's ½ mile interior buffer covers all

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[150] Open water is coded in the SFLU data set. Specifically, we exclude FLUCCS1 codes 500, 510, 540, and 542, which denote different types of "open water."

[151] Analysis of another county's data, while straightforward, involves a significant amount of additional data manipulation.

but a very small fraction of Little Pine Island. For this reason, we allow the interior buffer to be all of the island that is not the bank itself. This simplifies calculations significantly.

5.7.4 Data issues

Finally, it deserves emphasis that any analysis is only as good as the data on which it is based. There is no reason to question the accuracy of any of the data used in this analysis, but data sets will always differ in terms of spatial resolution, the degree to which they are current, and the overall care with which they are assembled. Consider the data on wetlands presented in Table 3. The FGDL library includes wetland coverages from two sources, the SFLU and NWIP data sets. We have no way to distinguish the two sets on the basis of their overall quality, but note that they are not in perfect agreement. They are in broad agreement – that is, they yield a very similar ranking of sites, but there are significant differences. For most of the indicators we calculate we have used the SFLU data. It was our impression that the SFLU data possessed a finer spatial resolution. It may also be subject to more ongoing scrutiny by local planners, since it is possesses a wide variety of highly detailed land use data. For most of the data used in our analysis we do not have multiple data sets from which to choose.

Table 3: Data Comparison

SITE	*Percent wetland in vicinity (SFLU)*	*Percent wetland in vicinity (NWIP)*
1	0	1
2	65	53
3	87	77
4	17	12
6	0	3
7	0	0
8	60	38
9	0	2
10	85	79
LPI	78	98

6. Analysis of the Sites' Ecosystem Service Benefits

This section uses quantifiable indicators to evaluate the benefits of specific ecosystem services. The indicators are organized as follows: First, a subset of the assembled indicators is selected on the basis of their relevance to an evaluation of a specific service's benefits. Since we consider four types of wetland service, there will be four larger sets of indicators. Second, we subdivide each of these larger sets, organizing the indicators around valuation-based concepts. These concepts include indicators of locational advantage, scarcity, complementary inputs, risks and changed future conditions, and income and equity. Organized in this way, it is easier to evaluate the sites' benefits in a way that reflects valuation principles.

Details regarding data and methods of calculation for the individual indicators are available in the appendix – though not all of the indicators derived in the appendix are used in this analysis. Also, some indicators are used in the analysis of more than one service. Finally, it should be emphasized that these sites may provide more than four ecosystem services, and that other non-wetland sites may yield very different types of services than those described in this case study. Nevertheless, our analysis demonstrates an approach that can be applied – with additional types of data – to non-wetland sites and sites that provide other kinds of ecosystem service benefits.

6.1 Valuation Concepts

Before turning to an analysis of the sites' services we first briefly describe the valuation concepts used to organize the indicators. First note that biophysical function assessment is the foundation of any evaluation method. Functional capacity is distinct from the exercise performed here, however. Because functional capacity measures were not developed for all of these sites, and because functional capacity is not the focus of our analysis, we assume that all sites have equal functional capacity. Our focus is on off-site determinants of service benefits. With the assembled quantifiable indicators we explore the sites' following characteristics.

6.1.1 Locational advantage

As described earlier, ecosystems produce benefits that are determined in large part by the landscape context in which they reside. Ecosystem functions yield beneficial services only when there is demand for such services. Demand for ecosystem services is determined largely by the characteristics of a site's surrounding physical and cultural landscape. Because there are no markets for the ecosystem services we analyze there are no prices available for the estimation of benefits. Instead, we assume that proxies for monetary benefit estimates can be derived from landscape and demographic data. Some sites are inevitably better located for the provision of certain services. Or are located in areas where demand is likely to be higher for the service. Spatial analysis illuminates these advantages.

6.1.2 Service scarcity

Scarcity increases the value of a service. For this reason, we consider a set of indicators that relate to scarcity and the availability of substitutes. We examine scarcity by measuring the abundance of wetlands at various scales. We examine substitutability by measuring the abundance of other natural land uses that can in some cases provide similar services to those generated by wetlands (e.g., open space amenities). Close substitutes are more relevant to the determination of benefits than distant substitutes.

6.1.3 Complementary inputs

Some services can be enjoyed only if accompanied by complementary landscape characteristics. This is particularly important in the case of recreation, where access is an important determinant of the ability to enjoy the service. Trails, docks, adjacent parks and beaches are examples of complementary inputs. These kinds of complementary inputs are easily and clearly revealed by analysis of a site's location in the landscape.

6.1.4 Risks and changed future conditions

Ideally, the analysis of benefits is dynamic. Current landscape conditions speak to the benefits provided by a site today. But the site's value is also a function of the benefits it will generate in the future. Future benefits depend on risks to the functions provided by the site. Analysis of risks addresses questions such as whether or not a wetland will remain a wetland in the future and the degree to which it will be functionally similar to its current state. Medium- and long-term hydrological, biological, and chemical changes can degrade future wetland function. Demographic conditions can also change over time. Land use, population, and infrastructure changes will affect the benefits generated by sites in the future. If information on likely changes is available they should be included in the analysis.

6.1.5 Income and Equity

Demand for goods and services can vary with changes in income. Income and other socio-economic characteristics, such as race, may also be important to decision-makers concerned with the distributional consequences of ecosystem trades and compensation. From an environmental justice perspective, for example, it is undesirable to move natural areas away from relatively poor minority communities. Income and equity indicators can be used to evaluate the environmental justice consequences of trades.

6.2 Improved Drinking Water Quality and Abundance

Ideally, ecosystem trading and compensation programs would analyze sites' hydrology, received surface water contamination, and ability to biologically and chemically improve water quality. In practice, these analyses are time-consuming and costly. As an alternative, we present proxy indicators of ground water quality benefits likely to arise from a wetland site.

A wetland's ability to improve and protect drinking water quality yields both health and aesthetic benefits when quality is impaired. Moreover, a wetland's ability to increase drinking water quantity through aquifer recharge is valuable wherever there are users with non-artesian wells or declining water tables. Aquifer recharge reduces the costs of extracting water since deeper wells are more expensive. Recharge is also valuable if it prevents the need for costly desalinization in aquifers put at risk by salt water intrusion due to insufficient recharge. These linkages between the aquifer recharge function of wetlands and social benefits provide a basis for defining wetland value indicators.

Several conditions are necessary for a site to create drinking water benefits. A necessary, but not sufficient, condition is that the site be hydrologically connected to an aquifer used for drinking water.[152] Assuming that condition is satisfied, the landscape setting must also allow delivery of the service in a location where people use and value it. In this case, a wetland's ability to increase recharge and purify incoming water becomes increasingly valuable as more and more people use the water for drinking and as the water entering the wetland becomes more and more polluted. Therefore, locational advantage indicators for drinking water quality benefits should reflect both the number of water users and the quality of waters received by the wetland.

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[152] Except for Little Pine Island, all of the sites in the case study satisfy this basic condition. The fact that LPI does not is a strong indicator that drinking water quality benefits may be lost by ecosystem exchanges involving the bank.

Locational advantage

The locational advantage indicators take two general forms: indicators of landuses likely to generate drinking water contamination and indicators of local demand for well-drawn water. Consider first indicators of neighboring land uses, as presented in Table 4.

Table 4: Threats to Water Quality

SITE	*Percent crop and pasture land in vicinity*	*Percent impervious landcover in vicinity*	*CAFOs in vicinity*	*Distance to nearest CAFO*	*Percent watershed in crop and pastureland*	*Percent watershed impervious groundcover*
1	36	23	0 / 0	8.9	13	14
2	0	14	0 / 0	10.5 *	24	6
3	0	4	0 / 0	10.3 *	13	14
4	27	2	0 / 0	4.2	24	6
6	25	30	0 / 0	9.0	13	14
7	0	8	0 / 0	2.6	4	10
8	0	11	0 / 0	3.3	24	6
9	36	3	0 / 0	7.0 *	3	4
10	0	3	0 / 0	10.5 *	13	14
LPI	0	0	0 / 0	2.5 *	0	0
	(40)	**(41)**	**(44)**	**(45)**	**(49)**	**(50)**

*Nearest CAFO not hydrologically connected to site.

Also, sites 9 and LPI are located on islands. For watershed calculations these islands define the relevant "watershed."

For wetlands to generate water quality benefits, there must be a water quality problem in need of improvement. These indicators speak to the likelihood of such problems. Developed land uses, which are associated with a high proportion of impervious surfaces, and agriculture are more likely to generate water quality problems.[153] Of particular concern are concentrated animal feeding

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[153] See Suzanne B. Bricker et al., Special Projects Office & the Nat'l Centers for Coastal Ocean Science, NOAA, National Estuarine eutrophication Assessment: Effects of nutrient Enrichment in the Nation's Estuaries, 1999; Pamela A. Matson et al., "Agricultural Intensification and Ecosystem Properties," 277 Science 504, 1997; William T. Peterjohn & David L. Correll, "Nutrient Dynamics in an Agricultural Watershed: Observations on the Role of a Riparian Forest," 65 Ecology 1466, 1984.

operations which can generate large amounts of animal waste, an important source of water contamination. Fertilizer, pesticide, toxic, and sediment runoff are less likely to arise from more natural land uses. The first 3 indicators measure conditions at a very local level, within ½ mile of the site. The latter indicators measure conditions at a larger scale.

Potential sources of water contamination are a necessary, but not sufficient condition for there to be drinking water quality benefits. The water must also be used for drinking, or at least commercial or agricultural use. Aggregate demand for drinking water improvements is a function of the number persons drawing water from aquifers fed by surface waters improved by a wetland site. Several indicators can be used to measure this demand.

Table 5: Drinking Water Demand

SITE	*Population density*	*Permitted wells*	*Public supply wells*	*Vulnerable public wells*	*Private drinking wells*	*Density of private wells*
1	1782	7 / 9	0 / 0	0 / 0	14	16.9
2	128	1 / 1	0 / 0	0 / 0	0	0
3	128	1 / 1	0 / 0	0 / 0	0	0
4	90	4 / 11	1 / 1	1 / 1	284	33.0
6	2484	8 / 16	0 / 0	0 / 0	160	153.6
7	68	0 / 0	0 / 0	0 / 0	40	22.2
8	1294	0 / 0	0 / 0	0 / 0	35 **	60.1 **
9	234	10 / 40	0 / 0	0 / 0	17	4.4
10	128	1 / 2	0 / 0	0 / 0	0	0
LPI	0	3 / 17 *	0 / 4 *	0 / 0	0	0
	(2)	**(16)**	**(17)**	**(18)**	**(19)**	**(20)**

* LPI is hydrologically isolated from these wells

** Site 8 is a coastal site, and thus is likely to have a more limited impact on water quality

The residential population in the site's vicinity is one such indicator. It acts as a rough proxy for local water consumption. The greater the population, the more likely large volumes of water are locally withdrawn. Ideally, however, it is desirable to measure the location of actual wells. The data we have assembled allows for a variety of such measurements. SFWMD data identifies the location of any well requiring a permit. Indicator (16) measures this relatively large universe of wells, which includes industrial, landscaping, and agricultural wells. Because public drinking supply wells are of more direct relevance to drinking water benefits we isolate the number of public drinking water supply wells in indicator (17). A further refinement to this indicator is to select public supply wells that are also particularly "vulnerable." A vulnerable public supply well is one drawn from relatively shallow aquifers, shallow aquifers being more susceptible to contamination than deep wells. The SFWMD data allows for this kind of fine distinction to be drawn. While aquifers may be recharged by wetlands located throughout the aquifer's recharge zone, wetlands in close proximity to wells is likely to be particularly valuable as a means to prevent local drawdown and contamination.[154]

A weakness of the SFWMD data is that it does not describe the location of private drinking water wells. Census data does identify such wells, at the blockgroup level. The last two indicators speak to the presence of private drinking wells in the sites' vicinity. The density of such wells (indicator (20)) is the preferred measure.[155]

Service Scarcity and Substitutes

The above indicators describe threats to water quality and the number of persons demanding clean drinking water. Sites, like site 6, which score relatively highly on these dimensions are likely to be valuable. Before arriving at such a conclusion, however, it is also important to explore the degree to which wetland functions are scarce in the site's vicinity. If there is a great abundance of nearby wetlands the loss of one area may not lead to a significant loss of water quality benefits. If wetlands are scarce, the benefits lost will tend to be more significant.

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[154] U.S. Corps of Engineers, Central and Southern Florida Project Comprehensive Review Study, Final Integrated Feasibility Report and Programmatic Environmental Impact Statement, at 3-26, 1999. (Hereafter S FLA FR/PEIS.) Drawdown refers to lowered water tables that occur in the vicinity of a well when pumping rates exceed the rate at which water can flow in from the surrounding aquifer.

[155] See discussion above.

Table 6: Scarcity

SITE	*Percent wetland in vicinity*	*Percent watershed in wetland*	*Percent watershed in non-ag natural land use*
1	0	8	20
2	65	36	60
3	87	8	20
4	17	36	60
6	0	8	20
7	0	16	37
8	60	36	60
9	0	34	72
10	85	8	20
LPI	78	91	100
	(42)	**(51)**	**(52)**

The most direct scarcity measure is the percent of the site's local vicinity that is also wetland. At a larger scale, the percent of the site's watershed that is wetland can be calculated. The scarcity of other natural land types is also relevant. Other natural land types may improve water quality less than wetlands. They may still act as a substitute for wetlands, however, since they are capable of water filtration, nutrient capture, and sediment removal. In Florida, where shallow aquifers are used for drinking water, the linkage between land use and water supply is unusually direct. According to the Corps of Engineers, any natural area in this area has the potential to be a groundwater recharge area to shallow aquifers.[156]

Changed Future Conditions

The aforementioned indicators speak to current conditions. A site's benefits, however, are also a function of future demand conditions and risks to the site's bio-physical functions. The

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[156] See S Fla FR/PEIS, note 154 supra.

landscape can create a set of risks to the future characteristics of a wetland site. We turn to indicators of these risks first.

Table 7: Risks to Wetland Function

SITE	*Distance to nearest exotics*	*Percent exotic community in vicinity*	*Phosphorus risk*	*Nitrogen risk*	*Elevation*
1	2.1	0	n/a	n/a	5-10
2	1.8	0	n/a	n/a	0-5
3	.7	0	n/a	n/a	5-10
4	.1	8	n/a	n/a	15-20
6	2.1	0	n/a	n/a	5-10
7	1.3	0	1.086	21.6	10-15
8	.3	1	n/a	n/a	10-15
9	.3	2	n/a	n/a	5-10
10	.4	1	n/a	n/a	0-5
LPI	0	18	n/a	n/a	0-5
	(21)	**(22)**	**(23)**	**(24)**	**(25)**

Without being purposefully filled or otherwise destroyed, wetlands can be degraded over time in a variety of more natural ways. Exotic species invasions, in some cases encouraged by the introduction of nutrients, can significantly alter wetland functions. In some cases the changes are significant enough to degrade the functions normally associated with wetlands, such as provision of wetland species habitat, surface water retention, and water filtration. The first two indicators describe the current proximity of exotic communities. Invasion by woody exotic species (melaleuca, Brazilian pepper, Australian pine) can lower the water table and potentially allow salt water intrusion. All else equal, the closer and more dense are such communities, the more likely it is they will propagate onto a site. The phosphorus and nitrogen risk indicators, based on SFWMD analysis, highlight runoff-created risks to the site's biology. Low-elevation sites, and particularly low-elevation coastal sites, are more vulnerable to future sea-level rise and other major hydrological changes.

Future economic, demographic, and cultural conditions will also tend to alter the sites' benefits. In terms of drinking water quality benefits, future changes in land use are important to understand, for the same reasons that current land use configurations are important – as source of contaminated runoff. Future demographic trends are also important. In Lee County as a whole, the scarcity of safe and abundant drinking water is apparent from growth projections and remaining aquifer capacity as reported in a recent water supply assessment.[157] Population is expected to grow by almost 60% by 2020 and industrial, commercial and agricultural needs are also projected to increase for a total increase in demand of 54%

Table 8: Land Use Changes

SITE	*Additional future agriculture (citrus)*	*Additional future impervious groundcover*
1	0	35
2	0	0
3	0	0
4	0	0
6	0	29
7	0	0
8	0	0
9	0	0
10	0	0
LPI	0	0
	(46)	**(47)**

Lee County planning studies have identified likely future land configurations. These indicators highlight changes in agricultural and developed land cover. The first identifies additional citrus plantations slated for development by the year 2020. The second identifies neighboring areas that are likely to be converted from agriculture to more developed uses. It should be noted that planning studies are inherently speculative. Nevertheless, planning projections, including zoning studies, population projections, and water supply plans, are of direct relevance to an understanding

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[157] District-wide Water Supply Assessment Team, District-wide Water Supply Assessment: South Florida Water Management District, West Palm Beach 227, 1998.

of the sites' benefits. Zoning analysis, in particular, can identify the degree to which existing land use configurations are a good guide to future land use patterns.

Income and Equity

Distributional concerns may be important in the analysis of trades. Particularly for drinking water improvements, environmental justice issues may be of concern. Movement of sites toward, or away from, socio-economically disadvantaged sites is relatively easy to detect with GIS analysis.

Table 9: Environmental Justice

SITE	*Median income (‘000s)*	*Percent Black or Hispanic*
1	26	9
2	30	4
3	30	4
4	32	8
6	30	4
7	37	0
8	30	0
9	22	1
10	30	4
LPI	23*	n/a
	(13)	**(15)**

* LPI is uninhabited, a fact which is clear in blockgroup data, but not in tract data.

The first indicator describes local median incomes. The second, the racial composition of the site's blockgroup. Because LPI is uninhabited, interpretation of this data requires analysis of surrounding areas.

Implications of the Indicator Analysis – Drinking Water Quality Benefits

The purpose of the indicators is to reveal characteristics of the sites' landscape that are likely to affect ecosystem service benefits. For drinking water quality improvements, in this case study, the importance of landscape is clear. Little Pine Island – the bank site – receives no runoff from agricultural or developed lands. This limits the scope of possible water quality problems that could be alleviated by the site. More importantly, however, the bank site is unpopulated and hydrologically isolated from wells used for drinking water. Even if there were water quality problems to be mitigated, the site produces no drinking water benefits because of its isolation from groundwater withdrawals.

From a trade and compensation perspective, the question is, did the impact sites, where wetland functions were lost, generate drinking water benefits? The answer appears to be yes. Consider first landscape-related water quality threats. Here, sites 1 and 6 stand out. For both sites, agricultural and developed land uses comprise more than 50 percent of the sites' immediate (1/2 mile) vicinity. Thus, nearby land uses are relatively likely producers of contaminated runoff. Only sites 3 and 10 rival LPI in their isolation from areas capable of producing water-quality impairing runoff.[158]

At the watershed scale, sites 1, 2, 3, 4, 6, 8, and 10 are in watersheds where approximately 30 percent of land area is agricultural or developed. Sites 7 and 9 are in watersheds where these percentages are significantly lower.[159] The relevant watershed for LPI is Little Pine Island itself. As noted above, there is no agriculture and only a very small amount of impervious surface on the island.

In terms of demand for well-drawn water, sites 1 and 6 are again noteworthy. The two sites are surrounded by the highest population densities of all the sites. Site 6 also has the highest density of private well-drawn water.[160] Site 4 is noteworthy due to the close proximity of a public water supply well. Site 9 has a number of permitted well in its vicinity, but none of these are drinking supply wells.[161] Site 8 as proximity to drinking water wells, but it is a coastal site. As such, it may help prevent saltwater intrusion to the inland aquifer.

What about the scarcity of the service? Here again, there are fairly stark differences across the sites. Sites 1, 6, 7, and 9 are isolated wetlands, within their immediate vicinity. Accordingly, the

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[158] Concentrated animal feeding operations do not appear to be a significant threat to water quality in the vicinity of any site. Site 7 is the closest to a CAFO, but still at a distance of 2.6 miles.

[159] Specifically, 14 and 7 percent, respectively.

[160] Site 1 is in close proximity to site 6 and has a much lower well density. Note that this may be an artifact of the sites' location near blockgroup boundaries.

[161] They are predominately agricultural wells.

local provision of any services provided by these wetlands is quite scarce. LPI and sites 3 and 10 located in areas where wetlands are relatively plentiful. At the watershed level sites 1, 3, 6 and 10 are located in the watershed where both wetlands and other natural landcover are most scarce.

Indicators of future risk to the wetlands' function highlight a set of risks to LPI and again identify sites 1 and 6 as being particularly desirable. Exotic plant communities already exist on and in close proximity to LPI.[162] Site 4 is also at high risk with a community a tenth of a mile away. In contrast, the nearest exotic infestations to sites 1 and 6 are more than 2 miles away. LPI, being at a low elevation, is also at risk from increased sea levels. This is true of all the coastal impact sites, as well. Sites 1 and 6 are also distinctive in terms of the future land use indicators. They are the only sites with planned future development nearby. This future development means that water quality improvements from these sites are likely to be in even greater demand in the future.

There are no obvious environmental justice implications of the trades. This is due, first, to the fact that LPI is isolated from residential development. Second, the nearest inhabited area (Pine Island, location of site 9) is at the low end of the income scale. Thus, the bank area is, if anything, moving wetlands toward lower income areas. Finally, all of the sites are in areas characterized by relatively low minority populations. No shift toward, or away from, minority populations is evident.

To summarize, based on an analysis of our landscape benefit indicators, the LPI mitigation site scores quite poorly in terms of it ability to provide drinking water quality benefits. In contrast, two of the impact sites, 1 and 6, stand out as being particularly beneficial, currently and given future development patterns. But all of the impact sites – not just sites 1 and 6 – are likely to provide more drinking water benefits than the bank site.

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[162] The exotic concentration calculation for LPI was based on the non-bank interior of the island. If instead, we also include a ½ mile external buffer around the island, the percentage drops to 6.5%. Note that the external buffer includes a large percentage of open water.

6.3 Reduced Flood Damage

Wetlands have been shown to reduce the likelihood and severity of flood events.[163] Because flood-related damages to homes, commercial buildings, farms, and public infrastructure is costly, a wetland's ability to reduce flood risk and severity is a socially beneficial service. As with any of the services we study, the most desirable form of analysis is a detailed, site-specific analysis of local conditions. The way in which a specific wetland reduces flood risks is principally a function of its location relative to sources of receiving water, coastal surges, and the local hydrology of the site itself. Surface and sub-surface water flows are difficult to characterize with precision even when site-specific studies are conducted. In our case, we seek more general indicators of flood conditions and a site's ability to reduce flooding.

Our indicators also place an emphasis on the kinds of damages that can arise from flooding. Landscape analysis allows us to determine the proximity – and in some cases, the value – of housing, commercial buildings, roads, and agriculture. The closer and more valuable are vulnerable properties, the larger the benefits of flood risk improvements. At a larger scale, the impact of specific wetlands is more difficult to assess. Wetlands distant from a watershed outflow point and not in the floodplain can nevertheless be valuable because they absorb or slow waters eventually destined for the floodplain. Again in this case, more precise hydrological information is desirable, but was unavailable to us in this case study.

The necessary condition for there to be flood damage reduction benefits is that there be valuable structures, infrastructure, or arable lands within the 100-year floodplain and in the same watershed as the site. This conditions is somewhat imprecise in that it assumes flood reduction benefits arising throughout a watershed's floodplain. A given wetland will not create such widespread benefits, however. But this condition cannot be made more precise given the limitations of the hydrological models available to us.

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[163] See Demissie, M. And A. Khan, "Influence of Wetlands on Streamflow in Illinois," Illinois Department of Conservation. Illinois State Water Survey, Hydrology Division: Champaign, Il, 1993 (who found volume of water conveyed downstream during peakflow and floodflow decreased 3.7% and 1.4% respectively for each 1% increase in wetland area); lack of wetlands has been implicated in the flooding of the Upper Mississippi and Missouri River Basins, Parrett, C., Melcher, N.B., and James, R.W., Jr., "Flood Discharges in the Upper Mississippi River Basin," U.S. Geological Survey Circular 1120-A, 14 p., 1993; Also see generally Mitsch, W.J., and J.G. Gosselink, Wetlands, Van Nostrand Reinhold, 1993.

Locational Advantage

The locational advantage indicators are grouped at two different scales. The first set of indicators relate to local flood reduction benefits; that is, benefits in the same vicinity, blockgroup, or section as the wetland site. A given wetland may not be able to protect neighboring areas from particularly damaging flood events. We assume, however, that there is at least a marginal decrease in the risk and severity of flooding that arises from the existence of a local wetland.

Table 10: Local Flood Damage Avoidance

SITE	*Site in floodplain?*	*Housing units in blockgroup*	*Median housing value*	*Commercial units in section*	*Value of commercial units*	*Important sites in vicinity*
1	Y	1006	67	46	13.7	0 / 0
2	Y	404	275	6	16.2	0 / 0
3	Y	404	275	12	.3	0 / 0
4	N	977	101	10	.8	1 / 1
6	Y	1703	108	46	13.7	0 / 0
7	N	40	64	3	17.4	0 / 0
8	Y	612	93	4	.2	0 / 0
9	Y	556	68	n/a	n/a	0 / 0
10	Y	404	275	12	.3	0 / 0
LPI	Y	0	n/a	1	n/a	0 / 0
	(62)	**(5)**	**(10)**	**(6)**	**(12)**	**(7)**

These local indicators are relevant only if the local area floods. For this reason, the first indicator describes whether or not the wetland site is within the floodplain.[164] Note that by this reasoning sites 4 and 7 are unlikely to produce any local flood protection benefits. We then turn to the types of damages that are likely to be avoided by a reduction in flood risk and severity. The number of local housing units and non-housing buildings are indicators of possible structural

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[164] Wetland not in the floodplain may also yield flood protection benefits, but these benefits are best evaluated at the watershed scale.

damage. The value of these structures is measured in indicators (10) and (12).[165] Important sites, including museums, are those that are in some way irreplaceable. Their proximity is of particular note.

An additional indicator, not presented here, is indicator (40), displayed in table 4. This indicator describes the amount of agricultural land use in the site's vicinity. Specific attention could be paid to the presence of row crops and nurseries in the vicinity, which are particularly vulnerable to flooding. We now turn to indicators at the floodplain and watershed scale. Because wetlands will have more than just an impact on local flooding, analysis at this larger scale is important.

Table 11: Floodplain Damage Avoidance

SITE	*Percent floodplain in same watershed that is impervious*	*Distance to watershed outflow or shore*	*Important sites in floodplain & watershed*	*Miles of major road in floodplain & watershed*
1	14	4.6	1*	153
2	8	0	0	42
3	14	0	0	153
4	8	2.5	0	42
6	14	4.3	1*	153
7	17	4.1	0	22
8	8	.4	0	42
9	4	.6	0	13
10	14	0	0	153
LPI	.15	0	0	2
	(56)	**(32)**	**(8)**	**(61)**

*For each of these sites there is an additional observation, but at a greater distance than 5 miles.

The first indicator relates to the likelihood of flooding. Impervious surfaces promote quick runoff and inhibit the absorption of rain and surface water into the groundwater table. For this reason, impervious surfaces are a rough indicator of flood risk. The second indicator measures the degree to which the sites are upstream or downstream in their watersheds. This can be a determinant

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[165] The coverage used to generate commercial property counts and values did not include Pine (site 9) or Little Pine Islands. From other sources, however, we know of a single commercial utility-related facility on the island.

of the benefits for the watershed produced by a given wetland. Some studies suggest that flood control services provided by wetlands decrease as location moves downstream.[166]

The next two indicators measure the presence of important sites and major roads in the same watershed as the wetland site that are at risk from flooding. We only considered important sites that were within 5 miles of the wetland as being at risk. The distance, while arbitrary, was an attempt to acknowledge that there is presumably some limit to a given wetland's beneficial effects on flooding. A similar adjustment could be made (but wasn't) for the next set of indicators, as well.

The next set of indicators extends the analysis of housing and non-housing structural damage to the watershed level.

Table 12: Floodplain Damage Avoidance

SITE	*Housing units in floodplain & watershed*	*Approx. median value of housing units in floodplain('000s)*	*Commercial units in floodplain & watershed*	*Approx. value of commercial structures in floodplain (millions$)*
1	65623	94	2841	1,575
2	18808	130	918	599
3	65623	94	2841	1,575
4	18808	130	918	599
6	65623	94	2841	1,575
7	2412	104	310	74
8	18808	130	918	599
9	2900	88	n/a	n/a
10	65623	94	2841	1,575
LPI	0	0	1	n/a
	(57)	**(59)**	**(58)**	**(60)**

These indicators measure the number and value of structures likely to be protected from flooding, when wetlands are assumed to produce flood reductions throughout the watershed. The indicators are based only on structures found in the floodplain of the same watershed as the site. We do not have an indicator for the amount of agriculture in the floodplain, but this could be calculated in a manner similar to our other agricultural indicators.

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[166] Ogawa, W. and J.W. Male. "Simulating the Flood Mitigation Role of Wetlands," Journal of Water Resource Planning and Management, 112, 114-28, 1986.

Service Scarcity and Substitutes

As in the analysis of drinking water benefits it important to explore the degree to which wetland functions are scarce in the site's vicinity. If there is a great abundance of nearby wetlands the loss of one area may not lead to a significant loss of flood reduction benefits. On the other hand, if wetlands are scarce, the benefits lost will likely be more significant. In other words, indicators (42), (51), and (52) – as presented in Table 6 – are relevant for the analysis of scarcity in the flood reduction case, as well.

Table 13: Flood Reduction Scarcity

SITE	*Percent floodplain in same watershed that is wetland*
1	13
2	40
3	13
4	40
6	13
7	7
8	40
9	39
10	13
LPI	91
	(55)

(in addition to indicators presented in table 6)

The prevalence of other wetlands in the watershed is an important additional indicator of scarcity, however. The more prevalent such wetlands are, the greater the ability of the watershed to absorb flooding events. Within the floodplain, the prevalence of wetlands is an indicator of the floodplain's ability to slow flood pulses, and thereby reduce damages. This indicator was not previously presented in the analysis of scarcity (Table 6). Other types of natural land cover can also absorb flood waters, though typically not as effectively as wetlands.

Stormwater management infrastructure (drainage systems, retention areas, tiling, canals) is a substitute for flood reduction services provided by wetlands. With more information that was available to us, it is possible to characterize the existing infrastructure. Where such infrastructure is non-existent, or ineffective, the benefit of wetland services will be higher.

Changed Future Conditions

These indicators are the same as in the analysis of drinking water quality benefits. Risk to a wetland's function due to changes in its biology, for instance, will degrade its ability to provide flood protection services. Accordingly, the functional risk indicators (21)-(25) presented in table 7 are relevant in the analysis of this service, as well. One indicator that would be desirable is information on increases in impervious surfaces. Models that predict development are increasingly common, so this kind of indicator will be increasingly available.

Income and Equity

The analysis of income and equity implications is identical to that for drinking water benefits.

Implications of the Indicator Analysis – Flood Reduction Benefits

In the analysis of flood reduction benefits LPI again scores poorly. Because the island is hydrologically isolated and uninhabited and undeveloped, save for the road bisecting it, it is in a poor landscape position to supply flood-related benefits. Several of the impact sites are better position to provide benefits.

In terms of local benefits, sites 4 and 7 can be excluded because they do not lie within the floodplain. While there is a culturally important site near site 4, it has little or no impact on the site's benefits because neither site lies in the floodplain. Locally, these two sites can be viewed as roughly equivalent to LPI in that they will provide no flood reduction benefits.

Not surprisingly housing numbers closely track population numbers, with the most populated and housing-intensive blockgroups being those around sites 6, 1, 8, and 9, in that order. Site 4 has a relatively high housing and raw population count. But note that its blockgroup has a low population density. These facts are easily reconciled by noting that the blockgroup has a particularly large area. Accordingly, site 4 should not be thought of as a location with particularly high housing or population densities. We should also be careful to conclude that sites 6, 1, 8, and 9 are protecting the most housing *value* from damage. While there is more housing in these areas, the blockgroups associated with sites 2, 3, and 10 have the highest housing property values. More families will be protected from flooding at the former set of sites. But a clear distinction cannot be drawn between the two sets of sites based on the value of property damage avoided.

In terms of commercial and industrial buildings, the areas around sites 1 and 6 are densely developed. Looking at the value of buildings protected, sites 1 and 6 score particularly well, primarily due to the large number of buildings in those sections. However, site 2 scores well because the few buildings in that section are relatively valuable.[167]

At a broader geographic scale, sites 1 and 6 again score well, as does site 7. The percentage of impervious landcover is highest in site 7's watershed. The watershed containing sites 1, 3, 6, and 10 is a close second. The floodplain of this watershed also has the largest number of road miles exposed to flood risk. Of these sites, however, only sites 1, 6, and 7 are "upstream" in the watershed. Sites 3 and 10 are basically coastal sites, and thus unlikely to provide flood protection for their watershed's floodplain. Sites 1 and 6 have yet another benefit, since they may help protect an "important site" located in their watershed's floodplain.

In terms of property value protected at the floodplain scale, sites 1, 3, 6, and 10 score most highly. These sites score highest in terms of number of housing units protected, number of commercial units protected, and aggregate commercial building value protected. Again, we should be careful to conclude that these sites protect the most housing value from damage. While there is more housing in these areas, the median housing value protected is higher for sites 2, 4, 7, and 8. For this service we also present an additional watershed scarcity indicator, which speaks to the scarcity of wetlands in the watershed's floodplain. Here, site 7 scores highest, followed by sites 1, 3, 6, and 10.

To summarize, the LPI bank site again scores poorly, this time in terms of it ability to provide flood damage protection benefits. The same two impact sites that scored well in terms of drinking water benefits – sites 1 and 6 – also score well for flood damage benefits. Also scoring well are site 2 at the local scale and site 7 at the watershed scale.

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[167] Site 7 is also in proximity to high value commercial structures. These structures are not in the floodplain, however.

6.4 Improved Aquatic Recreation

The wetland functions associated with drinking water improvement also generate surface water quality improvements. These surface water quality improvements can yield a variety of recreational benefits. For aesthetic reasons, cleaner waters are more swimmable and fishable. For biological reasons cleaner waters improve fish populations and catch rates, improvements that are valued by recreational anglers. Because recreational fishing is an important generator of tourism revenue and benefits for year-round residents, we have organized indicators that speak to the wetland sites' impact on surface waters where there is likely to be fishing and other types of aquatic recreation.

A wetland can improve aquatic recreation in two basic ways. When in direct biological contact with waters used for fishing, wetlands are a source of high quality habitat for fish and other species on which they depend. Even when there is no such direct connection, wetlands improve surface water quality for those species by sequestering runoff pollutants.

Locational Advantage

Assuming water quality improvements find their way to surface waters from inland and other non-riparian wetlands, locational advantage indicators should reflect the quality of waters received by the wetland. The more impaired the received runoff, the higher the benefits. For example, the proportion of a watershed covered by impervious surfaces is a known risk factor for aquatic habitats.[168] Note that these kinds of indicators were important to the analysis of drinking water quality benefits, as well. Accordingly, indicators (40), (41), (44), (45), (49), and (50) – presented in Table 4 – can be used for the analysis of aquatic recreation benefits. In order to avoid duplication we do not reproduce those indicators here.

As direct habitat support, wetlands that are in riparian or coastal zones are likely to be particularly beneficial. Wetlands filtering nutrients in riparian zones have been shown to have a greater ability to

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[168] Impervious surfaces create greater runoff volumes and shorter runoff times, leading to more polluter and warmer surface water deposition. See Soil Conservation Service, Urban Hydrology for Small Watersheds, U.S. Department of Agriculture, Technical Release 55, 1975.

prevent nutrient deposition than wetlands further inland.[169] Wetlands upstream from sensitive aquatic habitats are also particularly desirable.

Table 14: Riparian & Coastal Benefits

SITE	*River or shore in vicinity?*	*Distance, if non-tidal, to nearest major river*	*Impaired waterbody in vicinity?*
1	N / Y	.9	N / N
2	Y / Y	n/a	Y / Y
3	Y / Y	n/a	Y / Y
4	Y / Y	.3	N / N
6	N / Y	.9	N / N
7	N / N	5.2	N / N
8	Y / Y	n/a	Y / Y
9	N / Y	.6	N / N
10	Y / Y	n/a	Y / Y
LPI	Y / Y	n/a	N / Y
	(31)	**(33)**	**(26)**

The first two indicators describes the sites' proximity to coasts and rivers. Note that many of the sites can be classified as riparian, site 7 being the lone exception, with sites 1, 6, and 9 as intermediate cases. The third indicator describes the proximity of impaired surface waters, as defined by state water quality standards. These are waters where current water quality is a known problem.

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[169] Lowrence et al., "Water Quality Functions of Riparian Forest Buffer Systems in the Chesapeake Bay Watershed, Chesapeake Bay program Nutrient Subcommittee, Technical Report, EPA 903-R-95-004, 1995; Correll et al, "Nutrient Flux in a Landscape: Effects of Coastal Land Use and Terrestrial Community Mosaic on Nutrient Transport to Coastal Waters," Estuaries, 15:4, 431-442, 1992.

Table 15: Proximity to Sensitive Aquatic Areas

SITE	**Seagrass beds in vicinity?**	*Percent seagrass in vicinity*	*Aquatic preserves in vicinity?*	*Percent aquatic preserve in vicinity*
1	N / N	0	N / N	0
2	Y / Y	14	N / N	0
3	Y / Y	23	N / N	0
4	N / N	0	N / N	0
6	N / Y	0	N / N	0
7	N / N	0	N / N	0
8	Y / Y	0.23	Y / Y	19
9	N / Y	0	N / Y	0
10	Y / Y	8	N / N	0
LPI	Y / Y	37	Y / Y	61
	(27)	**(28)**	**(29)**	**(30)**

These indicators describe the proximity of sensitive aquatic areas. Among other things, seagrass beds function as particularly effective fish nurseries. They are also sensitive to water quality degradation. For these reasons, wetlands that improve water quality near seagrass beds may play a disproportionately large role in the preservation of healthy and diverse aquatic ecosystems. This is of clear benefit to the health of recreational fish populations. The presence of nearby aquatic preserves also signals relatively high benefits to continued water quality preservation. In an estuary with significant water movement, any coastal wetland is likely to benefit wetland habitat by improving water quality. Nevertheless, immediate proximity to seagrass beds yields a more direct protection of a particularly valuable type of habitat.

With one exception, we do not present location-specific indicators of recreational demand. For many ecosystem services, local demand is an important variable to be considered. But for aquatic recreation, the service area is likely to be relatively large. Since most recreators travel to aquatic areas for access and, when boating, are mobile across rivers and along streams, very local demand conditions (i.e., within a mile or half mile of a site) are of less relevance than for other services, such as drinking water improvements. When the trading or compensation area is larger, say at the scale of a state, local recreation demand characteristics will tend to be more important. As an example, income levels and education attainment may be related to demand for recreational fishing. Income levels are provided in the previous section.

Table 16: Educational Attainment

SITE	*Percent with some college*
1	34
2	91
3	91
4	44
6	53
7	51
8	42
9	36
10	91
LPI	n/a

(14)

In particular, some studies have found a negative relationship between income and the probability of fishing for specific species and the days of fishing per season.[170] Because we have data on incomes at the census tract level and educational attainment at the blockgroup level, we could rank sites on the basis of income- and education-related demand at that scope. We do not do so, however, because localized demand differences are unlikely to matter at the scale of this case study's area. Because the sites included in this case study are all within easy driving distance of one another we do not draw local distinctions between the sites: the one important exception, the proximity of shore-based recreational access, is discussed below.

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[170] See Clifford Russell and William Vaughan, "The National Recreational Fishing Benefits of Water Pollution Control," 9 Journal of Environmental Economics and Management, 1982, p. 328-354. For a refinement to this kind of result see Nancy Bockstael, Kenneth McConnell, and Ivar Strand, "Recreation," in Measuring the Demand for Environmental Quality, John Braden and Charles Kolstad, eds., Elsevier, 1991. ("Income levels are more likely to distinguish participants in a recreational activity from non-participants than they are to affect the number of recreational trips a participant takes in a season," at 240).

Complementary Inputs

For aquatic recreation to be enjoyed, anglers, swimmers, and boaters must have aquatic access. Access facilities are thus an important complementary input to recreational enjoyment. Very local access is not always necessary. For instance, boaters may easily have a recreational range of 5 miles or more from a dock or ramp. But for non-boaters, access to shoreline is very important.

Table 17: Aquatic Access

SITE	*Boat ramps, beaches, shoreline parks in vicinity*
1	0 / 1
2	3 / 4
3	2 / 4
4	1 / 3
6	0 / 1
7	0 / 0
8	0 / 0
9	0 / 1
10	1 / 2
LPI	0 / 3

(37)

This indicator measures the proximity of a site to areas where there is direct access to beaches, parks, and boat ramps. These points of access signify locations where there is likely to be higher than average demand for aquatic recreation. Accordingly, water quality improvements generated in close proximity to such access can be expected to be of higher recreational value than benefits produced elsewhere.

Service Scarcity and Substitutes

Indicators of wetland and natural land cover scarcity at both the local and watershed levels are important to this analysis, as they were to the analysis of the previous services' benefits. Indicators (42), (51), and (52) are not reproduced here.

Table 18: Aquatic Recreation Scarcity

(in addition to indicators presented in table 6)

SITE	*Percent of watershed's riparian & coastal areas in wetland*	***Percent of county land area that is wetland***
1	21	26
2	59	
3	21	
4	59	
6	21	
7	82	
8	59	
9	68	
10	21	
LPI	99	
	(34)	**(43)**

Two additional scarcity indicators are relevant to the analysis of aquatic recreation benefits. The first describes the scarcity of wetlands in riparian and coastal areas. Because riparian and coastal wetlands are particularly valuable as both aquatic habitat and contaminant buffers their scarcity is of particular importance to surface water quality. Since surface water quality can be affected by impairments across a fairly broad landscape we have also included a county-level scarcity indicator.

Changed Future Conditions

The functional risk indicators (21)-(25) presented in table 7 are pertinent in this analysis, as well. Also, the indicators of future agricultural and developed land use presented in the analysis of drinking water quality (indicators (46) and (47)) are indicators of future risks to surface water quality. Additional indicators that would be particularly valuable to an analysis of recreational benefits would relate to planned waterfront developments and new recreational access points, such as new parks, or docks.

Income and Equity

For reasons discussed above, local socio-economic differences, in general, will be of less importance in this instance. Recreational demanders are highly mobile over the scale of this study area.

Implications of the Indicator Analysis – Aquatic Recreation Benefits

As a source of indirect benefits due to surface water quality improvements LPI does not score well. Since there is no agriculture and very little development on the island, there is relatively little need for this kind of quality improvement. The sites that scored well in the drinking water improvement analysis will better provide surface water quality improvements. However, the Little Pine Island bank site is well situated to provide aquatic recreation benefits by acting as a source of high quality habitat for fish and other species on which they depend. The island is nearly surrounded by both seagrass beds and aquatic preserve.[171] If the bank site were degraded by development, for example, the biological integrity of these resources would be threatened.[172] The island is also easily accessible by boat and possesses an extensive shoreline.

Most of the sites in the study area are coastal or riparian. Site 7 is the exception. All others are within a mile of a coast or major river. Moreover, sites 2, 3, 8, and 10 are within close proximity of impaired coastal waters (LPI is within a mile of an impaired coast). Accordingly, these sites are likely to be particularly valuable as sources of water quality protection. Sites 2, 3, 8, and 10 are also in proximity to seagrass, and site 8 is in proximity to aquatic preserve. The sites are also distinguished by their relative proximity to coastal and riverine access points. Sites 2 and 3, and to a lesser extent sites 4 and 10, score well on this dimension. All sites, though, except for 7 and 8, are within at least a mile of an access point.

In terms of scarcity, LPI does not score particularly well. This is due to the fact that nearly the entire island is wetland. Nevertheless, in comparison to the very small flood- and drinking water-related benefits it generates, LPI in this case will generate more significant benefits. The same can also be said, however, of several of the impact sites, due to their proximity to impaired waters, sensitive marine areas, and recreational access points.

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[171] These two calculations were based on a ½ mile buffer around the exterior of the main island.

[172] It is important to keep in mind that the LPI site has always been public land. For this reason, there was relatively little risk that farms or condominiums would be developed on the island.

6.5 Open-Space Recreation, Aesthetic, and Existence Benefits

Valuation studies have found that wetlands can generate aesthetic benefits.[173] While wetlands can generate dis-amenities, such as odors and insects, most economic studies find that land values increase with proximity to wetlands.[174] This is not particularly surprising since wetlands are open spaces that may be visually appealing or yield localized recreational benefits. Also, wetlands are not swimmable or fishable, but they do provide high-quality habitat for "charismatic" species valued by hikers, bikers, and bird-watchers.

Wetlands that are connected to other wetlands or other protected natural sites may be part of a larger habitat mosaic capable of producing particularly diverse and sensitive biological communities. For this reason, a wetland, even if relatively small, can support a larger refuge for keystone species or threatened and endangered species. Since these species are valuable not only for recreation, but for their very existence, the relationship of a wetland to a larger pattern of natural land uses will determine its habitat-related benefits. For recreational and aesthetic enjoyment, a necessary condition for benefits is that a site must be accessible, or at least visible. Existence benefits do not even require this condition. By definition, existence benefits are unrelated to active enjoyment of the resource.[175]

Locational Advantage

Open space benefits to local residents can be indexed by population density and the number of local households (indicators (2) and (5)). Recreational benefits are related to the quality of habitat provided by the site and by complementary inputs that yield access to the site – and thereby greater local demand.

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[173] Mahan, Polasky & Adams, supra note 76.

[174] See Cheryl Doss and Steven Taff, "The Influence of Wetland Type and Wetland Proximity on Residential Property Values," Journal of Agricultural and Resource Economics, 10, 261-270, 1996 who find that decreasing a property's distance to a wetland by one block increases property value by between $960 and $2900. The value depends, among other things, on the type of wetland.

[175] Existence benefits arise from "passive use."

Table 19: Habitat

SITE	*Globally rare species*	*State rare species*
1	0 / 0	0 / 1
2	0 / 0	1 / 1
3	0 / 0	0 / 1
4	1 / 1	1 / 2
6	0 / 0	0 / 2
7	0 / 0	0 / 0
8	1 / 1	1 / 1
9	0 / 0	0 / 0
10	0 / 0	0 / 0
LPI	3 / 5	7 / 14
	(35)	**(36)**

These indicators signal the existence of rare and threatened species in proximity to the sites. They serve both as an indicator of nearby habitat quality (the species may be rare because they can only survive in high-quality habitats) and as indicators of recreational benefits, since rare species will tend to have a greater value as targets for observation (e.g., by birdwatchers).

Complementary Inputs

As was the case with recreational fishing, inland recreation also requires access. Here, trails, parks, and schools act as magnets for outdoor enthusiasts. Proximity to this kind of access can be expected to increase local demand for open space and the fruits of wetland habitat.

Table 20: Complementary Inputs

SITE	*Trails in vicinity*	*Parks and recreational facilities in vicinity*	*Distance to nearest park, beach, public forest*	*Schools in vicinity*	*Children ages 5-17*
1	1 / 1	0 / 3	.6	0 / 0	125
2	1 / 1	3 / 4	.1	0 / 0	25
3	1 / 1	2 / 5	.2	0 / 0	25
4	2 / 2	1 / 3	.2	1 / 1	47
6	1 / 1	0 / 3	.8	0 / 1	233
7	0 / 0	0 / 0	1.3	0 / 0	20
8	0 / 0	0 / 0	.3	0 / 0	76
9	1 / 1	0 / 1	.6	0 / 0	49
10	1 / 1	1 / 3	0	0 / 0	25
LPI	1 / 2	0 / 3	0	0 / 0	0
	(63)	**(38)**	**(39)**	**(9)**	**(4)**

Coastal and riparian sites are accessible for shore-based for the enjoyment of shore-based recreation and open-space benefits, so some of the indicators used in the recreational fishing analysis (indicators (31) and (37)) should be consulted to determine a site's accessibility by boat or beach. For inland sites, however, proximity to trails is an important access indicator. Indicator (38) describes the proximity of a broader set of access points, including parks and recreation facilities. Because wetlands are often used for educational purposes, proximity to schools and school age children is also measured.[176]

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[176] In some cases, school actually "adopted" a wetland as a site for ecological eduction.

Table 21: Habitat Connectivity

SITE	*Distance to nearest NWI wetland*
1	.2
2	.1
3	.1
4	.2
6	.3
7	.7
8	.2
9	.3
10	0
LPI	0

(66)

Nearby natural habitats, in conjunction with a wetland site, are a complementary input to a larger habitat function. Therefore, a wetland's connectivity to neighboring natural areas is an important habitat function indicator. In turn, greater habitat function points to greater species existence and recreational benefits arising from the species dependent on the habitat. This indicator "distance to nearest other wetland," in combination with the "percentage of circular vicinity that is wetland" indicator, serve as connectivity measures.

Income is another determinant of demand for recreation. In the analysis of aquatic recreation we references studies showing that fishing demand may be negatively related to income. In this context, we introduce the possibility that demand for aesthetic services may be positively related to income. Income effects should be treated with particular caution, largely because they have important distributional consequences when used as a basis for environmental and other resource allocations.[177] But it deserves mention that a variety of studies show a positive relationship between incomes and demand for aesthetic amenities.[178]

Service Scarcity and Substitutes

Several of the previously-discussed scarcity indicators are relevant to the analysis of this service, including the scarcity of wetlands at various scales, from the local (indicator (42)) to the county-level (indicator (43)). For the analysis of open-space and terrestrial recreation, however, several additional scarcity indicators are relevant.

Table 22: Open Space Recreation Scarcity

SITE	*Percent watershed in natural use (includes pasture)**	***Percent of county trail buffer in wetland***	***Percent of local trail buffer in wetland***
1	31	13	13
2	79		21
3	31		13
4	79		21
6	31		13
7	44		n/a
8	79		n/a
9	73		4
10	31		13
LPI	100		91
	(53)	**(64)**	**(65)**

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[177] See Nancy Bockstael, Kenneth McConnell, and Ivar Strand, "Recreation," in Measuring the Demand for Environmental Quality, John Braden and Charles Kolstad, eds., Elsevier, 1991. ("Two individuals with precisely the same preference functions but different income endowments will offer different compensating variation for an increase in the quality of or access to a public resource … Using a welfare measure based on simple aggregation of consumer surpluses to select among … projects has serious distributional consequences over the long run." at 270).

[178] See Roger Vaughan, "The Value of Urban Open Space," 1 Research in Urban Economics, 1981, 103-130 (showing that for a $1000 increase in median income, there is an $800 increase in the value placed on residential location next to a park, at 122). Also see Majid, I., J.A. Sinden, and Alan Randall, "Benefit Evaluation of Increments to Existing Systems of Public Facilities," 59 Land Economics, 1983, 377-392 (showing that income has a significant, positive impact on willingness to pay for public parks).

The first of these indicators speaks to the scarcity of open space within the watershed. Here, we have included not only natural land cover as open space but also pasture, since pasture may be as aesthetically-pleasing as more natural land cover types. Ideally, we would derive a similar indicator at the full range of different scales, including local and county-level. Locally, the scarcity of open space is particularly valuable to residents, since it can be enjoyed on a daily, non-recreational basis. County-level scarcity may be more relevant as an indicator of aesthetic benefits enjoyed by tourists or active recreators.

To measure the scarcity of wetlands enjoyed by hikers, bikers, and bird-watchers we measure the scarcity of wetlands that are accessible by trail. The last three indicators speak to scarcity at different landscape scales. Certain "non-linearities" in the benefits experienced by recreators should be kept in mind. For instance, trail buffers with very high wetland proportions may imply less benefit than more moderate wetland proportions. Some survey work has shown that people prefer mixed, rather than homogenous, land use configurations.[179]

Changed Future Conditions

Again, the functional risk indicators (21)-(25) presented in table 7 are relevant to the open space recreation and aesthetic benefits analysis. Changes in the connectivity measures over time will highlight threats to the refuge and habitat functions that are important to this service. Analysis of future additions to, or loss of, recreational access are also be important, but were unavailable to us.

Implications of the Indicator Analysis – Open-Space Recreation, Aesthetic, and Existence Benefits

LPI is clearly unique in terms of its location relative to rare and threatened species habitat. For this reason, the site can claim relatively high existence-related benefits, at least in relation to the impact sites. This is particularly true since LPI is well-connected to high-quality habitat areas.

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[179] Louise Mendel and James Kirkpatrick, "Assessing Temporal Changes in the Reservation of the Natural Aesthetic Resource Using Pictorial Content Analysis and a Grid-Based Scoring System," Landscape and Urban Planning, 43, 181-190, 1999; Janet Geoghan, Lisa Wainger, and Nancy Bockstael, "Spatial Landscape Indices in a Hedonic Framework: An Ecological Economics Analysis Using GIS," Ecological Economics 22:3, 251-264, 1997; Santos 1998.

Moreover, because it is an island, there may be fewer man-made, future threats to the site's functions than for the other sites.[180]

In terms of open-space recreation and aesthetic benefits, the case is less clear. Sites 2 and 3 are proximate to several park-like recreational access points. Site 4 is well-situated for trail-based recreational enjoyment. Only sites 7 and 8 yield little in the way of proximity to recreation. Sites 4 and 6 are near schools, and site 6 is in proximity to a particularly large school-age population. LPI, as before, does not score well in terms of scarcity. Site 9 is the outlier for this indicator, with only 4 percent of local trail buffer being wetland.

LPI's primary benefit seems to arise from its ability to provide habitat to a diverse array of species likely to have relatively significant existence values (because they are rare or threatened). Aesthetically, LPI suffers from its relative isolation from housing. As a source of open-space recreation it is unlikely to be as valuable as sites with greater access, particularly since a fence-line currently prevents access to the site.

6.6 Summary of the Indicator Analysis

Before summarizing, we once again emphasize that this analysis does not incorporate any on-site analysis of the sites' biophysical functions. Functional assessment is necessary to a complete evaluation of service benefits. We have focused on a complementary set of issues: namely, how do the sites' locations in the larger landscape contribute to their ability to provide social benefits.

The landscape analysis raises questions about LPI's desirability as a source of mitigation credits. LPI is hydrologically isolated from land uses that cause surface and ground water quality problems. It is uninhabited and undeveloped, so there is no opportunity for the site to provide flood protection benefits. And in its immediate vicinity wetlands are particularly abundant, so the site does not provide a locally scarce biophysical function. Finally, the site is particularly exposed to two potentially important natural risks: sea-level rise and exotics infestation. These results are not conclusive, but they do indicate that trading and compensation ratios involving the use of LPI should take into account its almost singular inability to provide certain kinds of service benefits.

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[180] Again, though, it deserves emphasis that the mitigation bank did not create these characteristics. The island was public land prior to its development as a mitigation bank. Also, the island is exposed to natural threats due to its relatively low elevation and the presence of nearby exotic species infestations.

In contrast, impact sites 1 and 6 seem particularly beneficial from the perspective of a landscape analysis. They are located in proximity to large populations that can benefit from water quality improvements, are in proximity to lands uses that can degrade water quality, and provide locally scarce wetland functions. Based on their ability to provide drinking water, flood protection, and open-space amenities, these sites should be candidates to receive large compensation multipliers.

Site 4 is valuable as a potential source of drinking water improvement. It is the only site near a public water supply well and has a high proportion of agricultural land use in its vicinity. Wetland function is locally scarce. The site also borders a nature preserve and is close to 2 trails. Counting against site 4 are its relative isolation from commercial and residential buildings (which matter to flood protection benefits) and the fact that, at the watershed scale, wetland functions are abundant.

Sites 2, 3, 8, and 10 score well on the aquatic and open-space recreation indicators. They are all coastal sites and in a position to improve water quality in locations where that is likely to be recreationally beneficial. All four sites are in proximity to both impaired waters and recreational access points like beaches, docks, and trails.

Given the landscape-related virtues of many of the impact sites, does that mean that LPI is a bad mitigation bank site? The answer is no, not necessarily. First, the site has particularly good connectivity because it is a large wetland site and is surrounded by a sensitive marine environment – as indicated by the presence of seagrass beds and the surrounding waters' designation as an aquatic preserve. Second, LPI is situated in an area that appears to provide particularly desirable habitat for rare and threatened species. Accordingly, LPI is uniquely positioned to provide species existence benefits and recreational benefits related to the enjoyment of such species. These benefits may outweigh LPI's relatively poor performance as a source of drinking water, flood prevention, and open space benefits. Note that the indicators say nothing about the relative importance of different factors. We turn to this important issue in the next section.

We can conclude, however, that a landscape analysis of services yields a much more complete picture of the likely benefits provided by the sites. Moreover, there are defensible reasons to believe that compensation for a range of lost social benefits will not be possible unless the trades take into account these landscape factors. Most notably, spatial analysis allows us to clearly see that the LPI mitigation site provides only a subset of the services formerly provided by the lost impact sites. Services that rely on the presence of resource users and sources of pollutants in order to be valuable will not be provided when wetlands are shifted to isolated, undeveloped, and uninhabited locations such as Little Pine Island.

7. Benefit Indicators – A Critique

We leave the ultimate evaluation of the landscape indicator method to others, but feel that the case study was a successful proof of concept. Landscape indicators provide a more complete understanding of the portfolio of changes associated with an ecosystem bank program. This is desirable for compensation programs and regional planning, where it is also important to understand broad patterns of landscape change. Certainly, the landscape analysis yields a richer description of the sites than functional assessments limited to on-site characteristics. First, the analysis fosters an appreciation of the way in which on-site functions are related to the bio-physical characteristics of the larger landscape, such as watershed hydrology, floodplain characteristics, and exotic species communities. Second, landscape analysis highlights the human dimension of the surrounding environment. Ecosystem services can be described only if we have data on both the physical and social environments. Third, the analysis does a good job of revealing extremely good and extremely poor landscape scenarios. From a landscape perspective, LPI is in an extremely poor position to provide flood protection and drinking water benefits – a fact that emerges clearly from an indicator analysis. Several of the wetland sites are in close proximity to population, water quality threats, and structures vulnerable to flooding – this also emerges clearly. On the other hand, LPI is clearly better situated than several of the impact sites to support habitat-related services.

These distinctions should matter to regulators and land use planners. If the social value of ecosystems – not just acreage – is to be preserved, then sites' relative ability to generate benefits must be explored. It is our belief that a visual and numerical presentation of landscape characteristics fosters an intuitive, non-technical appreciation of these benefits. Better understanding of benefits should be an input to the determination of ecosystem trade and compensation ratios. Determining trading and compensation ratios is currently more an art than a science. With our landscape analysis determining those ratios is still an art, but an art based on more complete information regarding the sites' ability to provide ecosystem service benefits.

Viewed in isolation, a given indicator is useful information that can almost always inform decisions. They are also useful as inputs to more rigorous valuation methodologies such as benefit-transfer studies or so-called multi-attribute utility analyses. But indicators should not be oversold. While they are an organized and empirical approach to evaluation, indicators are not an end in themselves. Regulators and planners are often under pressure to "generate a number" – in this case, a compensation or trading ratio. Landscape indicators are a potentially desirable source of material for such calculations.

Done right, an aggregate index could serve as an important input to trading ratio calculations. However, when a larger set of indicators is generated numerous questions arise regarding which indicators are most relevant and how the information in different indicators should be weighted.[181] For this reason, indicator tools must address the methods by which decision-makers weight non-comparable indicator rankings. There are also a set of important questions related to the scaling of indicators. Scaling issues relate to the "shape' of the underlying relationship being described by an indicator. For example, if one recreational site is found to have double the trail access of another, it is probably more valuable, but not doubly valuable, as a recreational site. Unless the relationship between an indicator and the benefit it describes is linear, interpretation of the indicator requires subtlety. Indicators, whether evaluated individually or aggregated into indices, can introduce a false formality that obscures fundamental weaknesses in indicator-based methods. For this reason, we now turn to a more detailed discussion of those weaknesses.

7.1 From Indicators to Indices: An Example

From a decision-making standpoint, there is a natural tendency to "boil the numbers down" in order to summarize a set of results in a more compact way. This is understandable. Comprehending, weighing, and summarizing an array of data, such as that presented for the LPI case study, is a challenge. It is tempting to collapse an array of data into a smaller set of summary statistics. A set of summary "indices" is one way to summarize the data in a quantitative manner.

Consider a particularly crude way of aggregating the data in order to rank the sites: an ordinal ranking of the sites, one through ten, followed by calculation of an average rank. As an example, we derived the average rank for the indicators associated with improved drinking water quality. Several of the indicators have been excluded, either because of missing data or because of obvious redundance with other indicators (e.g., we used population density alone, rather than both population and population density).[182] When more than one site received the same score, we assigned the site the average ranking score for that group. For example, with respect to indicator (47), site 1 was

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[181] There is a substantial literature in economics relating to the constructing of indices, mostly related to the construction of price indices. See Roy Allen, Index Numbers in Theory and Practice, MacMillan, 1975.

[182] We used all of the indicators associated with drinking water quality except (13), (15), (17), (19), (23), (24), (44), (46).

assigned rank 10, site 6 rank 9, and the rest rank 4.5 – the average of ranks 1 through 8.[183] The average rank for the sites' water quality indicators is as follows.

Table 23: Drinking Water Improvement Average Indicator Rank

SITE	*Average Rank*
1	**7.8**
2	5.2
3	5.5
4	5.4
6	**8.1**
7	5.2
8	5.2
9	5.0
10	5.1
LPI	**2.2**

This exercise confirms the notable nature of sites 1, 6 for the provision of drinking water benefits. It also quickly reveals LPI as a particularly poor generator of drinking water benefits. The rest of the sites appear to be nearly indistinguishable. Had we calculated this summary statistic earlier in the analysis it would have focused our attention on sites that emerged from the more detailed, narrative description. So might we just dispense with the broad, narrative analysis? Perhaps, but a summary statistic can obscure as easily as it can enlighten, and may give the data a more "scientific" appearance than it deserves. The interpretation of indicator data, particularly when it is aggregated, poses numerous challenges. In fact, the entire method suffers from some important drawbacks as a scientific decision tool. It is to these drawbacks that we now turn.

First, note that a variety of other indices are possible, and defensible. Desirable alternatives to the above include indices that weight more important indicators more heavily. Also, assigning a simple ordinal rank removes a great deal of information from the indicators. For example, extreme values are poorly reflected in the ordinal weighting scheme (e.g., the top ranked site gets the top ranking regardless of whether it is the top site by "a lot" or "a little." A preferable ranking scheme

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[183] Every indicator column is designed to have an average ranking of 5.5.

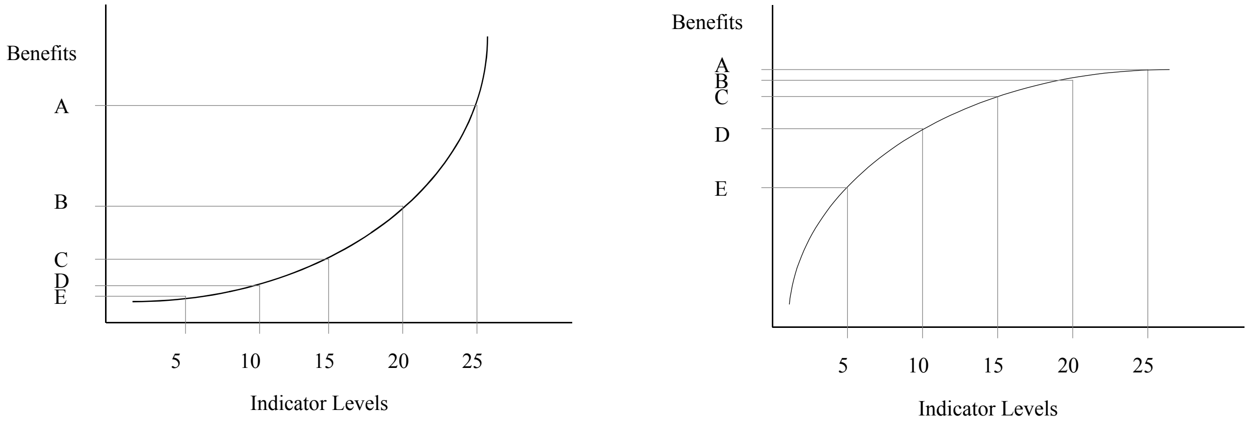
would weight rankings based on degree to which a site's indicator measure differs from, say, the mean of the observations.

7.2 Indicator and Index Interpretation

Indicators are observable characteristics that correspond to, but are not the same as, the thing we really want to know about. In this study we observe biophysical and social landscape data and argue that the data tell us something about the unobservable thing we want to describe – the social benefits created by these ecosystems. Unfortunately, the nature of the correspondence (i.e., the relationship) between an indicator and the thing we care about (benefits) is not always clear. For instance, it is natural, but usually incorrect, to look at a column of indicators and think that a site with twice the score creates twice the benefit. This interpretation is natural because, consciously or not, there is a tendency to view indicators as being linearly related to the thing being indicated. When a relationship is linear, twice the score means twice the benefit. But it is probably more common for an indicator to be non-linearly related to its subject.

7.2.1 Interpretation of individual indicators

As an example, consider our use of population density as an indicator of demand for certain ecosystem services. In some cases, population density may be linearly related to demand. If the wetland purifies a large aquifer used for household drinking water, twice the population may indeed mean twice the benefit. But now consider how population density relates to the benefits associated with open space. If the benefit of open space stays constant as the number of people enjoying it increases, a linear interpretation is still appropriate. Twice the population implies twice the benefit. But benefits may not increase proportionally as the total surrounding population increases. A reasonable assumption may be that open space becomes more valuable for each individual as the number of people in the area increases. In other words, the more congestion, the more valuable open space is to every individual who can enjoy it. If this is indeed the case, the indicator will exhibit a convex relationship to benefits, as in Figure 6a below.



(a) **(b)**

Figure 6: Convex and Concave Relationships

This changes the interpretation of the indicator. Now, a change in population means a *more than proportional* increase in benefit. Sites with scores of 5 and 10 are relatively similar in terms of the benefits they generate. Sites exhibiting the same difference, but with scores of 20 and 25, are very different in terms of the relative benefits they generate. When the relationship is convex, decision-makers should not only think of a higher score as being better, but weight higher scores more heavily, since they imply more-than-proportional increases in benefits.

The relationship of an indicator to benefits may also be concave. If so, a proportional increase in an indicator implies a less-than-proportional increase in benefit, as in figure 6b. In this case, decision-makers should think of higher scores as being better, but weight the benefits of higher scores less highly as the scores increase. Access as an indicator of recreational benefits may be a good example of such a relationship. Aesthetic enjoyment requires access, so the benefit of some basic access is large. As more access is added, however, the additional benefits may become smaller and smaller. In fact, additional access may at some point begin to actually diminish benefits, particularly if access leads to degradation of the area’s aesthetic or recreational qualities. If so, the relationship is not only concave, but also non-monotonic.

A non-monotonic relationship is one where over some initial range higher indicator values imply more benefits, but where eventually benefits decrease in the indicator – unlike the relationships depicted in figure 6. Another example of a non-monotonic indicator might be the “percentage of impervious groundcover in the site’s vicinity.” Over an initial range, more impervious groundcover means that the wetland has an opportunity to purify more runoff pollutants, thus yielding greater social benefits. As the proportion increases, however, impervious groundcover may generate surface water impairments so significant that they degrade the wetland's ability to filter contamination. In other words, in extremely developed areas, wetland functions may be at risk and therefore the site's expected benefits may be small. Note that these non-monotonic relationships have a unique ability to undermine the straightforward interpretation of an indicator. They mean that more is not always better.

There are large uncertainties associated with the way in which indicators relate to benefits. Complex hydrological and other physical processes and difficulties with the characterization of individual preferences for environmental goods means that precision will always be elusive. Of course, this is true of any methodology, not just indicator-based methods. Nevertheless, it is important to interpret even individual indicators with care.

7.2.2 Interpretation of aggregated indices

The indicators explored in the previous section are individual sources of data that in some way point to the value of a wetland site's services. Individually, the indicators tell us something about whether the service is present, its relative magnitude, and the need to adjust value for scarcity or risk. Having compiled an inventory of indicators, the issues of index construction and indicator aggregation present themselves. A composite index is desirable for a variety of reasons. By their very nature, composite indices summarize a complex array of data and rankings into a smaller set of more easily-digested information. In principle, the indicators developed in the previous section can be aggregated to derive a single number that indexes a site's wetland value. In practice, aggregation is fraught with methodological difficulties.

We do not advocate aggregation, except perhaps as a way to quickly identify sites likely to be low-benefit or high-benefit outliers. If aggregation is to take place, however, certain principles should apply. Perhaps most importantly, an aggregate index will achieve institutional validity only if it is constructed with a transparent methodology. In general, the value of a given methodology is often determined by its ease of use, its ability to help interpret masses of data, and its broad-scale acceptance. A sound scientific basis should guide the judgments made in the index's construction.

First, a fundamental issue is the degree to which aggregation is pursued. The more aggregation, the greater the simplicity of the final result. The tradeoff is that aggregation obscures potentially valuable data and insights. Data that is more condensed (aggregated) may be more easily presented and digested by decision-makers. Less condensed data has greater scientific utility. The question is, how is the appropriate balance of complexity and simplicity to be achieved? One desirable form of simplicity is the elimination of redundant indicators.

As an example, consider table 5, which presents population density. We could also have presented total population in the blockgroup. Clearly, these indicators measure very similar things. Not only are the two variables close proxies conceptually, but comparison reveals that they provide a nearly identical operational ranking of sites. An aggregate index must ultimately cull redundant indicators that provide relatively little incremental information regarding benefits. A more subtle example is the close (-.92) correlation between the "percent watershed that is impervious," and "percent watershed that is wetland" indicators. The close correlation arises because these indicators measure complementary features of the landscape. Wetlands, agriculture, and impervious land uses are mutually exclusive. More wetlands means less area available for agriculture or development. Closely correlated indicators can be culled ex ante as long as the correlation can be been established conceptually or empirically.

Second, meaningful aggregation requires an understanding of indicators' comparability. For instance, to be valid, a simple additive weighting model requires that indicators be standardized. Standardization ensures that equal changes in the level of different indicators reflect equal changes in the social value they measure.[184] Unfortunately, as described earlier, this requires a great deal of information regarding the relationship of an indicator to benefits. This kind of information is usually unavailable. Too often, the specific weighting used is implicitly presented, rather than explicitly derived. For instance, a simple average across indicators implies that each indicator indexes benefits equally. This will never be true. In principle, different weights should be assigned to different indicators based on statistical analysis or some other type of formal analysis.

Third, to arrive at a composite score, it is not just the indicators within each service that must be aggregated. The benefits of the individual services must also be assigned weights. Aggregation at this level is particularly inadvisable. Individual indicators allow for an unambiguous ranking of sites only under special circumstances. One circumstance is that the sites are identical in all respects but one. But, in general, sites will be better than others in certain respects and worse in others. When this is the case, the overall ranking must consider the different weights given to values derived from

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[184] See Scott Leibowitz and Jeffrey Hyman, "Use of Scale Invariance in Evaluating Judgment Indicators," Environmental Monitoring and Assessment, 58, pp. 283-303, 1999 (discussing the use of standardization to compare ecological end points).

a set of different services. Is a site that provides more effective flood prevention preferred to one that more effectively supports drinking water supply?

Ultimately, there is no substitute for direct survey information designed to reflect public preferences and assign relative benefit weights to specific services. Ranked preference surveys can be used to assign relative weights to service benefits. Such surveys can be simple and inexpensive and can yield defensible indicators associated with individual and community preferences for ecosystem services. As an example, respondents can be asked to express the intensity of their preferences for one service over another by ranking pairs of services on a 1-5 scale (equal importance to absolute importance). Various statistical methods can be applied to the results of paired preference surveys to arrive at relative service weights or rank orderings of services.[185] Benefit comparisons across services create the same problems as any non-market valuation exercise, because revealed values are unavailable. There is no entirely satisfactory method by which "true" social preferences can be elicited.

A formal, scientifically defensible index is clearly at odds with one of this study's principal goals: namely, the development of a method that is simple, transparent, and easily replicable by non-economists. This inherent tension can be relieved only by keeping the indicator analysis in its proper perspective. Unless wedded to more formal analytic techniques (such as those described below) landscape indicators should be viewed as qualitative evaluation tool, not a formal means of generating benefit estimates.

7.3 Formal Use of Indicator Data – Multi-Attribute Valuation Techniques and Benefit Transfer Studies

While we caution against the use of indicators as an end in themselves, an indicator analysis such as those we presented can serve as useful inputs to more formal (and methodologically complex) benefit studies. We now in some sense step away from tools that would be useful to non-economists. Nevertheless, a brief description of the ways in which indicator data could be more formally used is instructive.

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[185] Paul Smith and John Theberge, "Evaluating Natural Areas Using Multiple Criteria: Theory and Practice," Environmental Management 11:4, pp. 447-460, 1987.

First, indicators can be statistically evaluated in order to establish a more scientific justification for their use as proxies for monetized benefit estimates.[186] In principle, statistical analysis can determine the success of specific indicators as predictors of a known set of ecosystem benefits. What is needed is meta-analysis, taking established benefit estimates from existing studies, and testing the degree to which indicators are predictive of those benefit estimates across a range of studies and locations. The results of such an analysis would validate or reject individual indicators' predictive value, on average, across different study areas.

Second, indicators can be used inputs to so-called benefit transfer studies. Economists have argued for the use of benefit transfer methods as way to avoid site-specific monetization exercises.[187] Accordingly, the benefit transfer method is very much in the same spirit as our indicator-based approach to assessment. Benefit transfer methods reside on the more formal – and thus costly and difficult – end of the assessment spectrum, however. Benefit transfer methods essentially take the benefits estimated at a well-studied reference site and relate those benefits to the benefits likely to be found at a site of interest for preservation, mitigation, or exchange. The "transfer" of the benefits is made a function of differences in the reference site and site of interest. For example, if an exhaustive analysis of recreational benefits at the study site found a benefit of $10 million dollars, the value of the new site may be more or less, or close to the study site, depending on observed differences in the sites. Note that landscape indicators, such as those we present, are data relating to site differences. Accordingly, they could be used to characterize differences in sites as an inputs to the benefit transfer exercise.[188]

Note that while benefit transfer methods are similar in spirit to an indicators approach they rely on econometric methods that, while desirable, are difficult for non-economists to implement. Because of their cost and difficulty, benefit transfer studies can also suffer from a narrowness of scope: for example, focusing just on the transfer of recreational benefits. This is understandable but is one reason we favor additional, more holistic – and admittedly more impressionistic – assessment

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[186] See Paul Murtaugh, "The Statistical Evaluation of Ecological Indicators," Ecological Applications, 6:1, 132-139, 1996.

[187] For an overview of benefit transfer methodologies, see the special issue of Water Resources Research devoted to it, vol. 28, 1992. Also see S. Kirchhoff, B. Colby, and T. LaFrance, "Evaluating the Performance of Benefit Transfer: An Empirical Inquiry," Journal of Environmental Economics and Management l 35, 1997, pp. 75-93, and Ray Kopp and V. Kerry Smith, Valuing Natural Assets: The Economics of Natural Resource Damage Assessment, Resources for the Future, 1995, p. 329.

[188] See the Environmental Valuation Reference Inventory for a compilation of monetized benefit estimates and detailed descriptions of study characteristics and sites evaluated (http://www.evri.ec.gc.ca/evri/english/about.htm).

methods such as ours.[189] Benefit transfer studies require a great deal of econometric sophistication. This is particularly true because the methods used to estimate recreational values, flood damage and water quality benefits, and aesthetic value tend to be different depending on the service in question.

Nevertheless, the relationship between our indicator-based assessment method and benefit-transfer valuation methods is clear: benefit transfer requires adjustments based on observable site differences, whether they be physical, biological, or social. Our indicators seek to identify characteristics that speak to these kinds of site differences.

Third, a principle weakness of indicator-based methods is that they do not easily allow for the analysis of tradeoffs. Without a common metric, such as dollars, it is impossible to say whether a site scoring highly on one measure is better or worse than a site scoring highly on another measure. More specifically, consider two sites, one that scores highly in terms of likely drinking water improvement benefits but is undistinguished in other respects, and another that is undistinguished except for its provision of high quality habitat for the support of rare and threatened species. How much high quality habitat offsets a loss in drinking water benefits? If trading ratio is to be established, this kind of question must be answered.

The ideal approach is to monetize benefits associated with each service. Barring that, there are a variety of methods that have been proposed for government decision-makers to make such tradeoffs.[190] One approach is via the use of multi-attribute utility analysis, which is a formal method for evaluating options in decision context involving multiple objectives. Ecosystem benefits arising from different services represent such "multiple objectives." Multi-attribute utility analysis, using indicator data as an input, can in principle be used to quantify the degree to which sites achieve a broader objective – in this case the provision of ecosystem service benefits. The method is a

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[189] For an excellent description of the challenges associated with benefit transfer studies see David Chapman and W. Michael Hanemann, Environmental Damages in Court: the American Trader Case, in Anthony Heyes ed., The Law and Economics of the Environment, Elgar, 2001. ("It is sometimes claimed that the benefit transfer approach provides a convenient solution when the requisite data are lacking. But in this case there was considerable disagreement over basic issues such as whether or not beaches in Florida are 'substantially dissimilar' from beaches in Southern California. If this benefits transfer is problematical, how much more so others! It is striking that, although both parties initially decided to use benefits transfer, as the trial approached they each felt compelled to undertake original research to re-analyze the data and re-estimate the models used in the benefits transfer studies ...", at 355.)

[190] See Ralph Keeney and Howard Raiffa, Decisions with Multiple Objectives: Preferences and Value Tradeoffs, John Wiley and Sons, 1976; Thomas Saaty, The Analytical Hierarchy Process: Planning, Priority Setting, Resource Allocation, McGraw-Hill, 1980; and M. Granger Morgan, Baruch Fischoff, Lester Lave, and Paul Fischbeck, "A Proposal for Ranking Risk within Federal Agencies," in Comparing Environmental Risks: Tools for Setting Government Priorities, Resources for the Future, Washington, DC, 111-147, 1996.

procedure for quantifying the degree to which specific sites meet each objective (the provision of specific service benefits) and combining the results in a way that is logically consistent with the values of the decision-maker. Typically, this kind of analysis relies on expert groups to make technical judgments and value judgments.[191] Survey methods can be used to reveal value judgments.

One particular method of generating preferences (tradeoffs) across various attributes is the use of conjoint analysis (CA). CA presents a set of subjects with "objects" or "goods" composed of multiple quality attributes.[192] The subjects then are presented with a set of scenarios designed to reveal their preferences for these different attributes. This is done by varying the levels of the attributes and evaluating the subjects' responses statistically.[193] The kinds of indicators we use in our study could be thought of as indicators of these different quality dimensions. Conjoint analysis of ecosystem benefit indicators could form the basis of a more statistically defensible indicator-based assessment method.

Ecosystem benefit indicators are a potentially desirable input to more formal and scientific valuation techniques. It should be noted, however, that such techniques re-introduce many of the methodological hurdles that prompted our search for an easier-to-apply assessment method.

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[191] Miley Merkhofer and Ralph Keeney, "A Multi-attribute Utility Analysis of Alternative Sites for the Disposal of Nuclear Waste," Risk Analysis 7, 173-194, 1987.

[192] See Ric van Poll, The Perceived Quality of the Residential Environment: A Multi-Attribute Evaluation, Chapter 3, PhD. Dissertation, University of Groningen, 1997 (available at http://www.ub.rug.nl/eldoc/dis/science/h.f.p.m.van.poll/); Kevin Boyle, Thomas Holmes, Mario Teisl, and Brian Roe, "Assessing Public Preferences for Timber Harvesting Using Conjoint Analysis: A Comparison of Response Formats," American Journal of Agricultural Economics, forthcoming; F. Reed Johnson, William H. Desvousges, Lisa L. Wood and Erin E. Fries, "Conjoint Analysis of Individual and Aggregate Environmental Preferences," Triangle Economic Research, Working Paper 9502, 1998.

[193] Paul Green and V. Srinivasan, Conjoint Analysis in Marketing: New Developments with Implications for Research and Practice," Journal of Marketing 54, pp. 3-19 (defining conjoint analysis as "any decompositional method that estimates the structure of a consumer's preferences, given his or her overall evaluation of a set of alternatives (objects) that are pre-specified in terms of levels of different attributes").

8. Conclusion

This study has explored GIS data as a source of information on ecosystem service benefits. Our pilot study establishes a methodological middle-ground between econometric valuation methods and purely bio-physical site assessments. The project's goal was to derive indicators of ecosystem benefits that are rooted in the basic principles of economics but also easily implemented and interpreted by non-economists using existing data sources. Organized around the concepts of ecosystem services and valuation principles we show how GIS mappings of the physical and social landscape can improve understanding of the ecosystem benefits arising in specific locations. The pilot analysis derived and applied these kinds of indicators, yielding an organized, descriptive, and numerical depiction of sites involved in specific wetland mitigation projects.

In the way that conventional "ecological indicators" use observable site characteristics to signal a site's bio-physical qualities, the indicators we explore are observable characteristics that speak to the social benefits created by specific ecosystems. The ecosystem benefit indicator method can be broadly outlined as follows: First, an ecosystem is characterized in terms of its bio-physical characteristics. Second, data is assembled that describes the ecosystem's social, economic, and bio-physical landscape. These layers of landscape data can be depicted visually and often yield a particularly intuitive assessment of the way in which a site contributes to conditions in the broader landscape. At this stage, indicators are organized around several basic topics: population; housing, commercial and industrial buildings, and important sites; the value of homes and buildings; demography; wells; bio-physical function; riparian and coastal characteristics; rare and endangered species; recreation; land cover; future land use; watershed land cover; floodplain characteristics; trails; and connectivity. The report defines a set of 70 potential benefit indicators, derived from public sources. It applies a subset of these to the evaluation of wetland mitigation actions. All of the indicators point in some way to the value of a wetland site's services.

Third, the services provided by the ecosystem are identified. Fourth, indicators of service benefits are calculated, based on data contained in the GIS data layers. This stage involves the organization of indicators by service type. We then subdivide each of these larger sets, organizing the indicators around valuation-based concepts. These concepts include indicators of locational advantage, scarcity, complementary inputs, risks and changed future conditions, and income and equity. Organized in this way, it is easier to evaluate the sites' benefits in a way that reflects valuation principles.

Individually, the indicators tell us something about whether the service is present, its relative magnitude, and the need to adjust value for scarcity or changed future conditions. Compilation of this set of indicators paints a more detailed picture of wetland value than is provided by site-based functional assessment. In particular, the collection of indicators provides a much richer sense of the landscape-driven service benefits created by the wetland sites.

The GIS landscape analysis is an improvement over assessment methods that ignore landscape context when assessing trades and compensating mitigation. First, landscape analysis allows for qualitative analysis of benefit tradeoffs. Second, in some cases, the indicators allow for relatively unambiguous improvements in decision making – e.g., when tradeoffs are minimal and one ecosystem can be seen to clearly dominate another. Third, the data and tools foster a spatial, holistic approach to benefit assessment. Fourth, we have high confidence that this kind of tool can lead to more transparent and consistent evaluations than crude standardized trading ratios or reliance on “best professional judgment.”

Nevertheless, it is important to emphasize that indicator-based “evaluation” is not the same as economic “valuation.” There are significant limitations associated with indicator-based assessment tools, many of which we discuss. Indicators, by their vary nature, sacrifice precision and raise methodological issues that are more explicitly – and better – handled by conventional monetization (econometric) tools. These limitations must be appreciated if indicator-based methods are to be defensibly applied.

Measuring Ecosystem Service Benefits: The Use of Landscape Analysis to Evaluate Environmental Trades and Compensation
M-Appendex

James Boyd and Lisa Wainger

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Appendix

A Set of Potential Benefit Indicators

This section defines and calculates a set of 70 potential benefit indicators for the nine wetland impact sites and Little Pine Island. At this stage, we present a relatively extensive list of indicators, based on the maps described in section 5. In the section that follows we more selectively choose from this larger list and organize the indicators around specific ecosystem services. The more extensive list described here highlights the wide variety of indicators that can be constructed. All of these indicators point in some way to the value of a wetland site's services. Individually, the indicators tell us something about whether the service is present, its relative magnitude, and the need to adjust value for scarcity or changed future conditions. Compilation of this set of indicators paints a more detailed picture of wetland value than is provided by site-based functional assessment. In particular, the collection of indicators provides a much richer sense of the landscape-driven service benefits created by the wetland sites.

This section organizes the indicators and data around several basic topics: population; housing, commercial and industrial buildings, and important sites; the value of homes and buildings; demography; wells; bio-physical function; riparian and coastal characteristics; rare and endangered species; recreation; land cover; future land use; watershed land cover; floodplain characteristics; trails; and connectivity. For each indicator, a brief description is provided and the source of data described. The indicators are numbered for subsequent reference.

Population indicators

Population is a primary indicator of demand for ecosystem services. Different indicators are available, however. For example, population numbers for different age groups are directly available from the census.

(1) Total population in the same census blockgroup as the site

Data source: FGDL BLKGRP
Field:POP1990

(2) Population density – per square mile – in the same census blockgroup as the site

Data source: FGDL BLKGRP
Field:POP90_SQMI

(3) Number of households in the same census blockgroup as the site

Data source: FGDL BLKGRP
Field:HOUSEHOLDS

(4) Number of children between the ages of 5 and 17 in the same census blockgroup as the site.

Data source: FGDL BLKGRP
Field:AGE_5_17

These indicators are based on census blockgroup data. As described in section 6, population density is probably the preferred indicator of the number of persons residing in proximity to a site.

Housing, commercial and industrial buildings, and important sites

These indicators differentiate the sites on the basis of their proximity to a variety of structures. This is of interest when judging the flood prevention benefits of a particular site. They are also useful indicators of proximity to population that can enjoy open-space or other aesthetic amenities. Empty cells indicate zero observations.

(5) Number of housing units in same census blockgroup as the site.

Data source:FGDL BLKGRP
Field:HSE_UNITS

(6) Number of commercial units in the same section as the site.

Data source: TRSValues3a constructed data source, based on FGDL TAXS97
Field:COM_FREQ_1a constructed field

(7) Number of culturally important sites in vicinity of the site (vicinity defined by a ½ and 1 mile radius, respectively).

Data source:FGDL PTSINT
Field:TYPE = MSM,BTF,INM,HTS,CULS[1]

(8) Number of culturally important sites in 100-year floodplain, in same watershed, and within a 5 mile vicinity.

Data source:FGDL FEMA96
Field:ZONE = A, AE, or VE

Data source:SFWMD dbasins

Data source:PTSINT
Field:TYPE = MSM,BTF,INM,HTS,CULS

(9) Number of schools in site vicinity (vicinity defined by a ½ and 1 mile radius of the site).

Data source: FGDL GNIS
Field: DESIG = school

The first of these is a direct calculation from census data. Indicator (6) was one of the more complex to construct. It required the "joining" of two data sets from the FGDL, namely TAXS97 and PLSS, with the TRS field as the common field. We then excluded non-commercial structures[2] and aggregated the resulting FREQUENCY field by section. Note that sections usually represent a smaller area than blockgroups. Data on LPI and Pine Island, the location of impact site 9, are not included in this coverage. Indicator (7) involved an extraction from a map identifying "points of interest." Indicator (8) required the simultaneous use of the floodplain, watershed, and points of interest maps. Indicator (9) involved an extraction from the FGDL

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[1] Museums, battlefields, Indian mounds, historic sites, and cultural centers.

[2] We excluded types 1-9, 36, 38, 70, 74, 75, 77-79, 83-85, and 91.

GNIS dataset. Note that, unless otherwise indicated, all vicinity calculations for LPI are within a ½ mile and 1 mile customized buffer of the bank site (i.e., we did not use a radial buffer for LPI).

The value of homes, industrial facilities, and commercial buildings

Indicators of real estate value can speak to the costs avoided when wetlands protect against flood damage.

(10) Median housing value, in thousands of dollars, in site's census blockgroup

Data source: FGDL BLKGRP
Field:MED_VAL

(11) Median rent of rental housing units in site's census blockgroup

Data source: FGDL BLKGRP
Field:MEDIANRENT

(12) Aggregate value of commercial and industrial buildings in site's section, in millions of dollars.

Data source:TRSValues3a constructed data source, based on FGDL TAXS97
Field:PROP_VALCa constructed field

The first two indicators are census data and relate only to housing value. Indicator (12) calculates the value of commercial and industrial buildings and is based on the PLSS and TAXS97 datasets. This data was constructed in the same manner as the "number of commercial units" indicator described in the previous subsection, except that the total value of properties was calculated, rather than the number of properties. Note that these values represent the value of the buildings alone, not the combined value of the buildings and property. This adjustment was made by subtracting the LAND_VAL field from the TOTAL_VAL field in the TAXS97 dataset. Data on LPI and Pine Island, the location of impact site 9, are not included in this coverage.

Demographic indicators

Demographic indicators speak to the income, education, and race of individuals living in proximity to the sites. These factors may be of importance when assessing distributional issues (for instance, environmental justice concerns) and may also act as indicators of the value placed on a particular service.

(13) Median household income in the site's census tract.

Data source:Fltract_1990

Field:MED_INC

(14) Percentage of individuals over 25 years of age with some college education, in site's blockgroup.

Data source:FLbg_educ90

Field:PER_HIGHERa constructed field

(15) Blacks and Hispanics as percent of site's total blockgroup population

Data source:BLKGRP

Field:PER_BLHSa constructed field

These indicators come from census data. The first is reported for the tract level, rather than the blockgroup level, because the dataset to which we had access did not included income data. Tract level data was downloaded from the census website, blockgroup data was available, but in a more cumbersome format. Indicator (14) involved the aggregation of several educational attainment categories from the census, which yielded the number all individuals reporting some college education. This was divided by the total number of persons over age 25 in the blockgroup to arrive at the percentage reported. Similarly, indicator (15) summed the total number of persons identifying themselves as Black or Hispanic and divided that number by the total number of persons in the blockgroup to arrive at the percentage.

Wells

The type and number of private and public wells serve as indicators of the benefits of groundwater quality improvements provided by wetland sites.

(16) Number of permitted wells in the site's vicinity (1/2 and 1 mile radius, respectively).

Data source:SFWMD LEE_WELLS

Field:LU_CODE = ALL

(17) Number of public water supply wells in vicinity (1/2 and 1 mile radius, respectively)

Data source:SFWMD LEE_WELLS

Field:LU_CODE = PWS

(18) Number of vulnerable public water supply wells in vicinity (1/2 and 1 mile radius, respectively). "Vulnerable" wells are defined as those drawn from surficial and sandstone aquifers.

Data source:SFWMD LEE_WELLS

Field:LU_CODE = PWS and

AQUIFER_GR = "sandstone aquifer" or "water table / surficial"

(19) Number of households served by private drinking water wells in the site's census blockgroup.

Data source:flbg_wat90census data

Field:WTR_PRIa constructed field, including wells drilled and dug

(20) Density of households served by private wells, per square mile, in the site's census blockgroup.

Data source:flbg_wat90census data

Field:WTRPR_SMa constructed field

wells drilled and dug adjusted for blockgroup area

The first three indicators are based on data from the South Florida Water Management District. Indicator (16) includes the widest array of wells in the site's vicinity, including agricultural and industrial wells. Indicator (17) is a subset of the aforementioned, namely the number of public water supply wells in the site's vicinity. Indicator (18) represents a further refinement, counting only public water supply wells that are drawn from aquifers that are relatively vulnerable to contamination from surface water intrusion. Indicators (19) and (20) are based on census data relating to the source of household water supplies. Census data indicates the number of households supplied by well water. These two indicators are based on a constructed field since they aggregate both drilled and dug wells. Indicator (19) is the number of such households in the site's census blockgroup. Indicator (20) adjusts these counts for blockgroup area, yielding a density of such households in the site's blockgroup.

Biophysical function

Several landscape-scale biophysical indicators are potentially useful predictors of risks to a wetland's ability to provide services in the future. Exotic species invasions and excessive deposition of nitrogen and phosphorus can biologically degrade wetland functions over time. A coastal wetland's vulnerability to changes in sea level is a function of its elevation.

(21) Distance in miles to location of nearest exotic species invasion.

Data source:allinvasa constructed data source

Field:all values

(22) Percentage of circular vicinity that is invaded by exotic species (vicinity defined as within a ½ mile radius of the site).

Data source:allinvasa constructed data source
Field:all values

(23) Risk to wetland function due to phosphorus runoff from neighboring landuses

Data source:SFWMD Risksconstructed by wetlands conservation strategy
Field:TP_RISK

(24) Risk to wetland function due to nitrogen runoff from neighboring landuses

Data source:SFWMD Risksconstructed by wetlands conservation strategy
Field:TN_RISK

(25) Elevation of site in feet.

Data source:FGDL TOPO

Field:ELEV

Indicators (21) and (22) are based on the aggregation of several data sources on the location of invasive species. Three data sets from the FGDL library include invasives maps. These were brought together and their proximity to the sites was measured. Indicators (23) and (24) are based on an analysis done by the SFWMD's Wetland Conservation Strategy. The WCS maps rank wetlands based on their proximity to lands likely to present nitrogen and phosphorus loadings.[3] The elevation indicator (25) is based on a topological map included in the FGDL.

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[3] The methodology used to score the wetlands is described in more detail in the SFWMD's publication, A Water Quality Functional Assessment of South Florida Wetlands, available at www.sfwmd.gov/org/pld/proj/wetcons/waterq/wq_techpub.pdf.

Riparian and coastal characteristics

A site's proximity to vulnerable riparian and coastal areas can determine its ability to preserve or enhance functions provided by those area. For this reason, it is desirable to characterize sites in terms of their relationship to streams, rivers, and estuaries. Vulnerable or biologically significant riparian and coastal areas should be noted in particular. The loss of wetland water filtration services is a particular concern when nearby waters already suffer from excessive pollutant loadings.

(26) Is there an "impaired" waterbody in the site's vicinity

(vicinity defined by a ½ and 1 mile radius of the site)?

Data source:EPA Water Office website

(27) Are there seagrass beds in the site's vicinity

(vicinity defined by a ½ and 1 mile radius of the site)?

Data source:FGDL SEAGRS

(28) Percentage of circular vicinity that is seagrass bed
(vicinity defined as within a ½ mile radius of the site).

Data source:FGDL SEAGRS
Field: Descript= Land were excluded

(29) Are there aquatic preserves in the site's vicinity

(vicinity defined by a ½ and 1 mile radius of the site)?

Data source:FGDL CLAN

Field:ATTRIBUTE = water

(30) Percentage of circular vicinity that is aquatic preserve
(vicinity defined as within a ½ mile radius of the site).

Data source:FGDL CLAN
Field:ATTRIBUTE = water

(31) Is there a river or coastal shoreline in vicinity

(vicinity defined by a ½ and 1 mile radius of the site)?

Data source:FGDL CNTBND & MJRIVL

(32) Distance in miles to the mouth of the Caloosahatchee (sites 1 & 6) or nearest coastal shoreline (all others).

Data source:FGDL CNTBND & MJRIVL

(33) Distance in miles to the nearest major river or shore, if site is a non-tidal site. Non-tidal determination made via NWIP classification. (Site 9 distance is to shore, all others to rivers).

Data source:FGDL CNTBND & MJRIVL

(34) Percent of same watershed's coastal and riparian areas (within ¼ mile of coast or major river) that is wetland.

Data source:SFWMD dbasins

Data source:FGDL MJRIVP & CNTBND(both to construct riparian buffer)

Data source:FGDL NWIP
Field:Class1_D = emergent, forested, or scrub-shrub

The EPA's Office of Water identifies water quality-impaired waters, impaired waters being those that do not meet state water quality standards.[4] Impaired water maps can be viewed

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[4] The Clean Water Act's section 303(d) requires states to develop lists of impaired waters.

on the Office's Website. Indicator (26) lists proximity to a water quality impairment of any type. It is easy using EPA data to more closely identify the type of impairment (e.g., nutrient, sediment, toxic) and relate that to a neighboring wetland's ability to reduce pollution loadings. Indicator (27) is based on FGDL data that identifies the location of seagrass beds in coastal and estuarine waters. Seagrass beds are both crucial to aquatic health and vulnerable to chemical and sediment deposition from surface water runoff. Indicator (28) describes the concentration of seagrass beds in the site's vicinity. Indicators (29) and (30) describe the proximity and neighboring concentration of protected aquatic areas. Protected aquatic areas are likely to be protected because they are either vulnerable or have a particularly high biological or recreational value.

Indicators (31), (32), and (33) are based on maps of major coastal and river features. These indicators describe the sites' location in terms of proximity to riparian areas. Indicator (32) roughly describes the degree to which a site is "upstream" in its watershed. Indicator (34) measures the scarcity of wetland riparian areas. This indicator is based on the same data as that described in the text associated with Figure 3. Riparian areas are defined as those with ¼ mile of the river or coast.

Rare and endangered species

The site's proximity to habitat for rare and endangered species is of clear importance if we are concerned with the way in which the site's contribute to the quality of habitat for such species. The data is available in a format that permits different degrees of endangerment to be presented. For example, it is possible to measure observations of only the most endangered species (rank G1).

(35) Number of occurrences of globally endangered or rare plants and animals in vicinity (vicinity defined by a ½ and 1 mile radius of the site).

Dataset:FGDL FLEO
Field:GRANK = G1, G2, or G3

(36) Number of occurrences of state-wide endangered or rare plants and animals in vicinity (vicinity defined by a ½ and 1 mile radius of the site).

Dataset:FGDL FLEO

Field:SRANK = S1, S2, S3, or S4

These indicators are based on data included in the FGDL. Indicator (35) relates only to globally rare species. Indicator (36) relates to species that are rare within the state of Florida.

Recreation

A variety of indicators can speak to the site's ability to enhance local recreation. If water quality improvements are being generated, proximity to beaches and boat ramps signals the likely presence of fishing and swimming that will benefit from such water quality improvements. Proximity to inland parks is beneficial in that it is likely to increase species diversity and open space in the vicinity of these areas where such outputs are likely to be enjoyed by above-average numbers of people.

(37) Number of boat ramps, public beaches, marinas, and shoreline parks in vicinity (vicinity defined by a ½ and 1 mile radius of the site).

Data source:FGDL PTSINT
Field:TYPE = BR, LPRB, LPUB, MRA, SRA
(boat ramps, local park resource-based,* local park user-based,* multi-use recreation areas,* single-use recreation areas*)
*Note: only measured if connected to coastal shoreline or major river

Data source:FGDL SFLU
Field:FLUCCS1 = 181, 184, 185 (swimming beach, marinas, parks and zoos*)
*Note: only measured if connected to coastal shoreline or major river

Data source:FGDL GNIS
Field:DESIG = park

(38) Number of public parks and recreational facilities in vicinity (vicinity defined by a ½ and 1 mile radius of the site).

Data source:PTSINT
Field:TYPE = CC, BR, LPRB, LPUB, MRA, RCC, SRA, ZBPI
(commercial campgrounds, boat ramps, local park resource-based, local park user-based, multi-use rec. areas, recreation centers, single-use rec areas, zoos/botanical parks)

Data source:SFLU
Field:FLUCCS1 = 181, 184, 185 (swimming beach, marinas, parks and zoos)

Data source:GNIS
Field:DESIG = park

(39) Distance in miles to nearest park, beach, preserve, or recreation area.

Data source:PTSINT
Field:TYPE = CC, BR, LPRB, LPUB, MRA, RCC, SRA, ZBPI
(commercial campgrounds, boat ramps, local park resource-based, local park user-based, multi-use rec. areas, recreation centers, single-use rec areas, zoos/botanical parks)

Data source:GNIS
Field:DESIG = park

Data source:SFLU
Field:FLUCCS1 = 181, 184, 185 (swimming beach, marinas, parks and zoos)

Indicator (37) measures the proximity of water-related recreation sites. It is based on a map constructed by the aggregation of extractions from three FGDL datasets. Indicator (38) is similarly constructed, but with a focus on inland parks and recreation. Indicator (39) measures distance to the nearest recreation of any type.

Land cover

The land use and land cover in the site's vicinity often determines the type of benefits likely to be provided by the site. For instance, runoff from nearby agriculture or impervious surfaces, such as roads and parking lots, will tend to increase the benefits of a wetland since there is more likely to be a demand for water quality improvements. Of particular interest, due to their ability to generate large amounts of waste runoff, are concentrated animal feeding operations.

(40) Percentage of circular vicinity in cropland and pastureland (vicinity defined as within a ½ mile radius of the site).

Data source: FGDL SFLU
Field:FLUCCS1 = 210s, 221, 222, and 0 (unimproved pasture)

(41) Percentage of circular vicinity that is impervious (vicinity defined as within a ½ mile radius of the site).

Data source:FGDL SFLU
Field:FLUCCS1 with proportions impervious calculated for specific land uses

(42) Percentage of circular vicinity that is wetland (vicinity defined as within a ½ mile radius of the site). The SFLU data was used for most calculations.

Data source: FGDL SFLU
Field:FLUCCS1 = 600s

Data source:FGDL NWIP
Field:Class1_D = emergent, forested, or scrub-shrub

(43) Percent of county land area that is wetland.

Data source: FGDL SFLU
Field:FLUCCS1 = 600s

(44) Number of animal feeding operations in vicinity (vicinity defined by a ½ and 1 mile radius of the site).

Data source:SFLU

Field:FLUCCS1 = 231,232, or 233

(cattle, poultry, and swine feeding operations, dairies)

Data source: LEE_PLAN

Field:LU_DES = Intensive Livestock Operations

(45) Distance in miles to nearest animal feeding operation.

Data source:SFLU

Field:FLUCCS1 = 231,232, 233, 252

(cattle, poultry, and swine feeding operations, dairies)

Data source: LEE_PLAN

Field:LU_DES = Intensive Livestock Operations

Indicator (40) describes the concentration of agriculture likely to produce fertilizer and pesticide runoff in the site's vicinity. Indicator (41) describes the concentration of impervious land cover in the site's vicinity. The indicators are based on extractions from the FGDL SFLU map. The impervious surface indicator translates specific land use types – as identified in the SFLU data – into likely percentages of impervious groundcover. The conversion factors used to make this translation are included in the Appendix.[5] Indicators (42) and (43) describe the relative scarcity of wetland functions locally and regionally. Indicators (44) and (45) are based on landuse data from the FGDL and on SFWMD planning data that identifies the location of concentrated animal feeding operations. Note that for sites located near open water we make an adjustment to the radial area used for these calculations. The percentage is based only on the land area within the circular vicinity, rather than on the full circular vicinity. Open water is excluded area for the purposes of these calculations.[6]

Future land use

Similarly, it is desirable to know future land uses likely to affect the services provided by sites. Land use planning data from the SFWMD, while inherently speculative, provides a credible estimate of changes in landuse in the county. In particular, the planning map identifies additional agriculture, in the form of planned citrus groves and losses to cropland that will be converted to a non-agricultural use, presumably some form of developed land use.

(46) Percentage of circular vicinity, previously non-ag expected to be in new citrus plantation in the year 2020 (vicinity defined as within a ½ mile radius of the site).

Data source:SFWMD LEE_PLAN
Field:LU_DES = citrus added

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[5] There is a source of bias introduced by using the SFLU land use coverage as the foundation for this calculation. Unfortunately, the SFLU coverage does not map roads. In a relatively natural area with a major road passing through it, our impervious surface calculation will tend to be too low. This is the case with LPI itself. For LPI, the SFLU data shows no road, only a small utility-related land use. A road 2 miles in length crosses the island, however. The number we report for LPI is therefore a potentially significant underestimate of impervious surface on the island.

[6] Open water is coded in the SFLU data set. Specifically, we exclude FLUCCS1 codes 500, 510, 540, and 542, which denote different types of "open water." Also, non-Lee County land is excluded from the analysis of site 8's vicinity.

(47) Percentage of circular vicinity previously agriculture, but not expected to be in agriculture as of the year 2020 (vicinity defined as within a ½ mile radius of the site).

Data source:SFWMD LEE_PLAN
Field:LU_DES = cropland lost not available for agriculture

(48) Wetland's capacity to denitrify surface runoff.

Data source:SFWMD Risksconstructed by wetlands conservation strategy
Field:DENIT_CAP

The future land use indicators come from the Lee County planning map constructed by the SFWMD. Included here is also an indicator of the wetland's capacity to denitrify surface runoff. This comes from the SFWMD's Wetland Conservation Strategy data and is based on their methodology for identifying this wetland functional capacity.[7]

Watershed land cover

As described in section 5.7, it is often desirable to have data at various scales. Most of the indicators described above are indicators of local conditions, such as within the area of a census blockgroup or within a ½ mile vicinity of the sites. We now turn to a larger scale: namely, the watershed. Watershed-level indicators are important because many of the functions and services provided by wetlands are strongly influenced by hydrological conditions.

(49) Percentage of watershed in cropland and pastureland.

Data source: SFLU
Field:FLUCCS1 = 210s, 221, 222, and 0 (unimproved pasture)

(50) Percentage of watershed that is impervious.

Data source:SFLU
Field:FLUCCS1 with proportions impervious calculated for specific land uses

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[7] The methodology is outlined in the Water Quality Functional Assessment, note 3.

(51) Percentage of watershed that is wetland.

Data source: FGDL SFLU
Field:FLUCCS1 = 600s

(52) Percent of watershed in non-agricultural natural use.

Data source:FGDL SFLU
Field:FLUCCS1 = 300s,400s,500s,600s, 710,720,730

(53) Percent of watershed in natural use, including pasture land.

Data source:SFLU
Field:FLUCCS1 = 211, 212, 213, 300s,400s,500s,600s, 710,720,730

(54) Approximate population residing in watershed.

Data source:FGDL BLKGRP
Field:POP_1990adjusted for different blockgroup and watershed boundaries

For all of the above, watershed boundaries are based on the SFWMD dbasins map. Sites 1, 3, 6, and 10 are in the Tidal Caloosahatchee watershed, sites 2, 4, and 8 in the Estero watershed, and site 7 in the Northern coastal watershed. Because LPI and impact site 9 are located on islands, watershed calculations are based on features of the entire, contiguous islands. Thus, we consider these islands to be their own watersheds. Indicators (49) and (50) measure the prevalence of agricultural and developed land uses in the site's watershed. Agriculture and developed land uses have the potential to introduce various contaminants (nutrients, sedimentation, toxic runoff) into the watershed. For this reason, the degree to which the watershed is associated with such land uses is of inherent importance. Indicator (51) yields another measure of scarcity, in this case at a watershed-level scale.

Indicators (52) and (53) are also watershed-level indicators of scarcity. In this case, the scarcity of open space is being measured. Two types of open space are considered. Indicator (52) describes relatively natural areas, including forests, prairies, shrub and brushland, open water, wetlands, and barren land, such as beaches and rock outcroppings. The second category, described in indicator (53) adds pastureland to this list, since pasture is often visually attractive and can confer open space benefits.[8] These indicators are based on FGDL land use data. Indicator (54) is a population measure for the watershed, which can be viewed as related to local demand for recreation and aesthetic benefits.

Floodplain characteristics

The next set of indicators explores the sites' landscape at the floodplain-scale. Floodplain-scale indicators are important principally to the analysis of flood damage benefits. Wetland scarcity in the floodplain, and the degree to which the floodplain is covered by impervious surfaces, speaks to the benefits provided by a specific site capable of absorbing floodwater velocity and pulses. Measures of housing, commercial units, their value, and the presence of large public infrastructure, such as roads, speak to the value of properties likely to be protected from flood damage.

(55) Percent of floodplain that is wetland, in same watershed as site.

Data source:FGDL FEMA
Field:ZONE = A, AE, or VE

Data source: FGDL SFLU
Field:FLUCCS1 = 600s

(56) Percent of floodplain that is impervious, in same watershed as site.

Data source:FGDL FEMA
Field:ZONE = A, AE, or VE

Data source:FGDL SFLU
Field:FLUCCS1 with proportions impervious calculated for specific land uses

(57) Number of housing units in floodplain and in same watershed as site.

Data source:FGDL BLKGRP
Field:HSE_UNITS

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[8] Additional land use categories could be added to this indicator. For instance, we did not include ornamental nurseries or tree crops in this indicator. To the extent these land uses are visually attractive, however, it may be desirable to include them.

Data source:FGDL FEMA
Field:ZONE = A, AE, or VE

(58) Number of commercial units in floodplain and in same watershed as site.

Data source:TRSValues3a constructed database
Field:COM_FREQ

Data source:FGDL FEMA
Field:ZONE = A, AE, or VE

(59) Approximate median value of housing units in floodplain and in the same watershed as site.

Data source:FGDL BLKGRP
Field:MED_VAL

Data source:FGDL FEMA
Field:ZONE = A, AE, or VE

(60) Approximate value of commercial units in floodplain and in the same watershed as site.

Data source:TRSValues3a constructed database
Field:PROP_VALC

Data source:FGDL FEMA
Field:ZONE = A, AE, or VE

(61) Miles of major roads in floodplain and in same watershed as site.

Data source:FGDL MAJRDS

Data source:FEMA
Field:ZONE = A, AE, or VE

(62) Is the site in the 100-year floodplain?

Data source:FGDL FEMA
Field:ZONE = A, AE, or VE

For all of the above, watershed boundaries are based on the SFWMD dbasins map. Indicators (55) and (56) index the relative scarcity of land uses capable of slowing floodwater pulses. Scarce wetlands, and a high proportion of impervious surfaces, suggest areas where wetlands would be particularly valuable due to their ability to absorb flooding. Indicators (57) and (58) measure the number of residential and non-residential buildings likely to be protected from flooding by the presence of a wetland. Similarly, indicators (59) and (60) measure the value of those structures, and thereby index the dollar value of damages avoided.[9] Indicator (59) is an "approximate median value" because it is the simple average of the median value of the blockgroups in the floodplain. This is not statistically equivalent to the median income over that area. Indicator (61) measures the number of miles of major roads likely to be protected from damage. All of these indicators are based on maps that merge a collection of data layers.

Trails

Recreational benefits typically depend on access. For this reason, proximity to local trails is an important indicator of a site's recreational benefits. Indicators of the degree to which trail-to-wetland access is scarce are also provided.

(63) Number of trails in vicinity (vicinity defined by a ½ and 1 mile radius of the site).

Dataset:FGDL TRL
Field:Only terrestrial trails

(64) Percent of county's ¼ mile trail buffer that is wetland.

Data source:FGDL TRL
Field:Only terrestrial trails

Data source: FGDL SFLU
Field:FLUCCS1 = 600s

(65) Percent of ¼ mile trail buffer in vicinity that is wetland (within 5 mile radius).

Data source:FGDL TRL
Field:Only terrestrial trails

Data source: FGDL SFLU
Field:FLUCCS1 = 600s

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[9] The methodology used to calculate indicators (d) and (f) is described in note 2 supra.

These indicators are based on a trail map included in the FGDL. Indicators (64) and (65) are scarcity indicators. A ¼ mile trail buffer is used as a measure of aesthetic, open space, and habitat support enjoyable from a given trail. All of the area within the buffer, including open water, is included in the calculations.

Connectivity

The biological productivity of a site is often a function of the biological characteristics of lands to which it is connected. Wetlands that are isolated from other wetlands, protected areas, or upland forests, for example, will tend to be less productive as habitat for certain species than more connected wetlands.

(66) Distance in miles to the nearest National Wetland Inventory wetland.

Data source:FGDL NWIP
Field:Class1_D = emergent, forested, or scrub-shrub

Indicator (66) is a crude, but effective, connectivity measure, since it is a simple measure of distance to other wetlands. The closer are neighboring wetlands, the more likely it is that the site will support a biologically rich set of plant and animal communities.