WORLD RESOURCES INSTITUTE

WORKING PAPER

GREEN-GRAY ASSESSMENT: HOW TO ASSESS THE COSTS AND BENEFITS OF GREEN INFRASTRUCTURE FOR WATER SUPPLY SYSTEMS

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EXECUTIVE SUMMARY

A New Way to Evaluate Infrastructure

A growing body of research shows that healthy watersheds are a vital component of a well-functioning water supply infrastructure system. When green infrastructure is used to complement, substitute, or safeguard traditional gray infrastructure, it can achieve optimal service delivery and save water suppliers (and water customers) money (Browder et al. 2019). The strategic protection, management, and restoration of natural systems within watersheds (often referred to as green infrastructure) can, for example,

- better moderate sediment and nutrient fluxes and improve downstream water quality, thereby helping water suppliers meet water quality standards (McDonald et al. 2016; Neary et al. 2009);
- lower costs for water suppliers compared to gray infrastructure options (Talberth et al. 2013a) and recover investment costs (Kroeger et al. 2017; Ozment et al. 2018);
- help mitigate the impacts of climate change and natural hazards (e.g., droughts and floods) to avoid service disruptions and failures (American Forests 2003; EEA 2015); and
- generate numerous co-benefits for local communities and society such as recreation, public health improvement, and carbon sequestration (Abell et al. 2017; Ding et al. 2017).

CONTENTS

Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues. Working papers may eventually be published in another form and their content may be revised.

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Box 1 | **Highlights**

- The Green-Gray Assessment (GGA) is a six-step methodology that can be used for investigating and valuing the costs and benefits of integrating green (or natural) infrastructure into existing water supply systems to improve their performance.
- Quantifying the costs of green infrastructure investments in upstream watersheds and benefits for urban water supply systems can inform important investment decisions of water suppliers, water regulators, and land conservation and restoration organizations.
- Before conducting a GGA, one should first understand local contextual conditions, engage stakeholders, and ensure the right skill set for the GGA analysis team. These preassessment steps facilitate data collection and help ensure that GGA results reach targeted decision-makers and financiers.
- This document provides step-by-step guidance for how to conduct a GGA, including pre-assessment steps, and integrates experiences from four GGAs that examined the return on investment of upstream forest restoration and conservation for urban water suppliers in Brazil (Rio de Janeiro, São Paulo, Vitória) and Mexico (Monterrey).

Conversely, the cost of not protecting watersheds is very real: A global study found that land degradation and development in source watersheds have increased the cost per unit of water treated for large cities by about 50 percent (McDonald and Shemie 2014).

Cities and infrastructure service providers seeking to repair, upgrade, or extend water supply systems should consider green infrastructure as a water management option. The optimal solution for providing low-cost, clean water to urban residents may often require a balance between green and gray infrastructure. While some cities protect source watersheds through interventions like forest conservation and restoration, the case still needs to be examined for other cities (McDonald and Shemie 2014). Water suppliers and regulators often lack clear guidance on how to identify green infrastructure solutions, how to evaluate their benefits, and how to include green infrastructure in their financial analyses and broader decision-making processes. As a result, green infrastructure options often go overlooked.

There is a clear need for guidance on how to identify and value green infrastructure solutions and incorporate them into water suppliers' decision-making and management processes. This paper, and complementary financial analyses conducted by the World Resources Institute (WRI) in Latin America (Feltran-Barbieri et al. 2018; Morales et al. 2019; Ozment et al. 2018, 2019), aim to address this need through practical guidance on how to apply WRI's GGA.

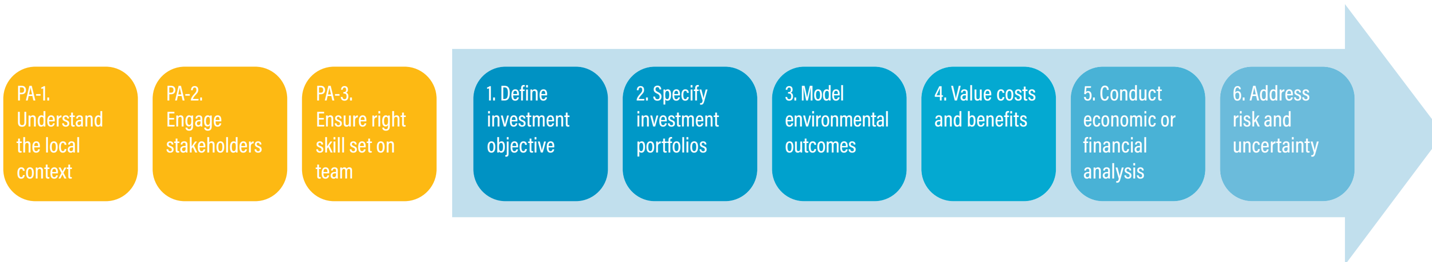
About This Working Paper

The GGA is a six-step process to compare the costs and/or benefits of green and gray infrastructure investments (see Figure ES-1)**.** The GGA can be used to compare any combination of green and gray (or hybrid) infrastructure investments or portfolios in terms of net benefits or cost-effectiveness so that a wise investment decision can be made. The GGA can be applied to financial analysis for a targeted user like a water supplier or to economic analysis to examine wider social costs and benefits.

Building on previous GGA guidance (Talberth et al. 2013a; Gray et al. 2014), this paper provides step-by-step guidance, including information and data needs, types of analysis, data sources, and recommendations for overcoming data collection challenges. This paper also discusses preassessment steps, including how to understand the local context, engage stakeholders, and develop the right team and skill set, to set up a GGA analysis for success (see Table ES-1).

The paper draws on experiences and results of several recent GGA studies (Talberth et al. 2013a; Talberthet al. 2013b; Kroeger et al. 2017), as well as new developments in the field based on application of the GGA to four new case studies in in Latin America (Table ES-1). While green infrastructure is applicable to a broad range of infrastructure services, this guidance document especially highlights application of the GGA for assessing the costs of integrating green infrastructure into built water infrastructure systems and the benefits for water suppliers (particularly water quality benefits from sediment management)—the focus of the four recent financial analyses conducted by WRI and partners in Latin America. (See Table ES-1 for an overview.) Details on these case studies are available in separate publications and are useful supplements for this paper (Feltran-Barbieri et al. 2018; Morales et al. 2019; Ozment et al. 2018, 2019).

Figure ES-1 | **Overview of GGA Preassessment (PA) and Analysis Steps**



Source: WRI, Based on Talberth et al. 2013a.

Table ES-1 | **Green-Gray Assessments Informing This Guidance**

STUDY LOCATION	WATER MANAGEMENT OBJECTIVE			
	Sediment pollution	Water quantity	Aquifer recharge	Flood control
São Paulo, Brazil (Cantareira Water Supply System)	X	X		
Rio de Janeiro, Brazil (Guandu Water System)	X			
Vitória, Brazil (Jucu Basin)	X			
Monterrey, Mexico (San Juan Basin)			X	X

Sources: Feltran-Barbieri et al. 2018; Morales et al. 2019; Ozment et al. 2018, 2019.

The audience for this paper includes both water supply system investors (e.g., water suppliers, cities, and governments) and those who typically implement decision support tools like cost-benefit analysis (CBA) to help or influence decision-makers in selecting the best infrastructure investments (e.g., consultants or nongovernmental organizations (NGOs) like land conservation organizations). Readers will find that some background in economic and financial analysis of water infrastructure investments is helpful, as well as an understanding of forest ecosystem services.

Beyond comparing infrastructure investment portfolios, there are several other uses of the GGA framework. The GGA can be used to

- provide a consistent framing of costs and benefits to facilitate easier comparison of green infrastructure values across study sites and benefits transfer analysis;
- standardize consideration of green infrastructure in water suppliers' existing decision support tools;
- facilitate critiques of financial and economic analyses of infrastructure investment decisions that do not properly consider green infrastructure investments;
- identify data collection needs to plan for the robust monitoring and evaluation of green infrastructure investments (that can later support a GGA); and
- better design green infrastructure interventions to address needs and concerns of relevant stakeholders, like would-be investors.

INTRODUCTION

The GGA was originally developed by WRI in 2013 with the motivation that infrastructure investors needed a consistent and robust way to incorporate green infrastructure into decision-making processes (Talberth et al. 2013a; Gartner et al. 2013). The GGA is a six-step methodology rooted in traditional financial and economic investment theory and decision support tools like CBA that enables easy comparison of green, gray, and hybrid infrastructure investment portfolios. Steps follow those traditionally found in CBA or cost-effectiveness analysis (CEA) for infrastructure decision-making.

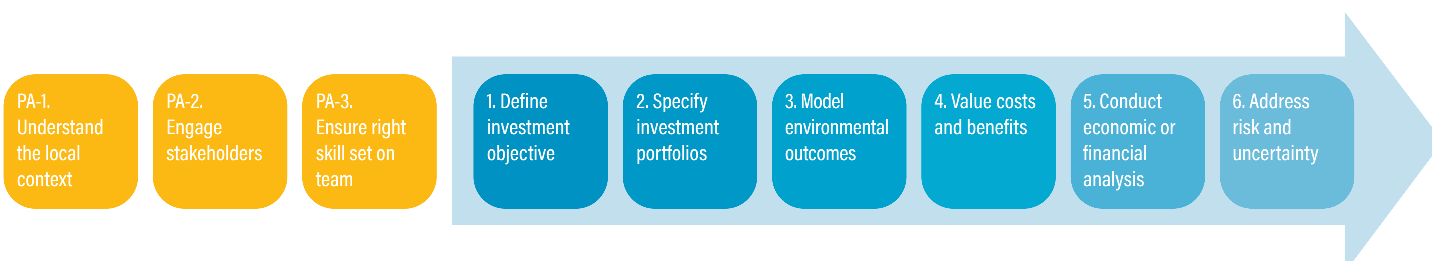
While informed by several recent studies (Talberth et al. 2013a; Talberth et al. 2013b; Kroeger et al. 2017), this paper highlights lessons learned from four financial analyses conducted by WRI and partners in Brazil (São Paulo, Rio de Janeiro, and Vitória) and Mexico (Monterrey) (see Table 1A–1D for an overview of these four studies). Partners of these GGAs included the FEMSA Foundation, The Nature Conservancy, the International Union for Conservation of Nature, Instituto BioAtlântica, the Boticario Group Foundation, and the Natural Capital Project. Each study posed the following research question: What are the costs of integrating green infrastructure into existing or planned water systems, compared to the benefits for water suppliers? Each study compared the costs of investing and maintaining green infrastructure or green-gray hybrid portfolios in upstream watersheds to the benefits or avoided costs for water suppliers (namely, the water utilities) in the metropolitan area.

The experience of conducting these analyses highlighted that three preassessment steps are also important for setting up a GGA for success: understanding the local context, engaging key stakeholders, and ensuring the right skill set on the analysis team. These preassessments and the six analysis steps are summarized in Figure 1.

Organization of This Paper

This paper walks the reader through the three preassessment steps and the six main GGA steps, providing an overview of information and data needs as well as outputs. Information and data needs are framed as questions or tasks that need to be answered by the analysis team. The paper concludes by providing recommendations on how to present results to key stakeholders and alternative uses of the GGA framework beyond conducting an economic or financial analysis.

Figure 1 | **Overview of GGA Preassessment (PA) and Analysis Steps**



Source: WRI, Based on Talberth et al. 2013a.

PREASSESSMENT STEPS

Before undertaking a GGA, steps to facilitate scoping the research context, collecting data, and communicating results include understanding the local context, engaging the right stakeholders, and ensuring the right skill set on the team. Figure 2 provides an overview of these steps, including information and data needs and outputs.

Understanding the Local Context

Collecting data on key contextual conditions prior to the analysis can save time down the road and ensure that the GGA research question is properly scoped for target decision-makers. The output of this scoping should be consolidated documentation of each of the contextual conditions described below that clarifies the GGA research question and analysis parameters.

Current and future water supply system

Understanding current and planned infrastructure components of the target water supply system helps to define the study area for analysis and may reveal water management challenges like sediment pollution or flooding that green infrastructure solutions could address, which could be the focus for the GGA.

Information and data needs:

- Describe the current water infrastructure supply system(s) and its (their) components (e.g., reservoirs, dams, aquifers, water treatment plants, pipelines).
- Are there any planned infrastructure investments, and if so what are the related timelines for implementation?
- Who are the owners and operators of current and planned water infrastructure?
- What are the underlying drivers for future water infrastructure investments (e.g., regulatory requirements)?

Figure 2 | **Overview of Preassessment Steps, Information and Data Needs, and Outputs**

Preassessment Step	1. Understand the local context	2. Engage stakeholders	3. Ensure right skill set on team
Information and data needs	- Current and future water supply system - Water governance structure - Watershed conditions and land uses - Water management challenges - Green infrastructure programs - Ecosystem valuation efforts - Existing data observation and modeling efforts.	- Investors - Land conservation and restoration suppliers - Coordinators - Approving bodies - Intermediaries - Technical experts - Public outreach groups - Project beneficiaries	- Environmental economics - Biophysical modeling/forest hydrology - Local expertise - Water supply system expertise - Strategy, management, and communications - Financing expertise
Outputs	- Scoping of research question and analysis parameters	- Stakeholder map - Stakeholder engagement strategy	- Specification of analysis team

Source: WRI.

Water governance structure

The legal and institutional elements that govern a water supply system define the political boundaries of a GGA, which may affect the selection of the study area, as well as key stakeholders and decision-makers to influence. Understanding local water governance also helps spot conflicts of interest among stakeholders and determine the legal feasibility of green infrastructure interventions.

Information and data needs:

- Describe the water-related regulatory boundaries.
- What are the approving and regulatory agencies and their roles in the water supply system?
- What are the legal limitations regarding green and gray infrastructure activities in the area?

Watershed conditions and land uses

Source watershed conditions and land uses for a water supply system refer to historical, current, and projected land uses and ecosystem types and services. Using this information on trends in land uses and threats to natural areas (e.g., agricultural development, urban development) can inform which types of green infrastructure investments are relevant for the study area.

Information and data needs:

- Provide spatial maps of historic and current land cover for source watersheds.
- Describe any land-use planning and forecasting efforts and their associated spatial maps.

Water management challenges

Analyst(s) must first understand the water management challenges that confront water suppliers, such as aging infrastructure, upstream land degradation, or growing water demand in order to develop possible green infrastructure solutions and investment objectives (i.e., the challenges that green infrastructure can address and the types of green infrastructure that make the most sense).

Information and data needs:

- Provide an overview of each water management challenge, including how long each challenge has been an issue and efforts to address each challenge.

Table 1A | **Overview of GGA Case Studies, Rio de Janeiro, BR**[a]

STEP 1	**Investment objective**		Sediment reduction to avoid dredging, turbidity treatment, and wear and tear
STEP 2	**Green infrastructure portfolio**		Targeted reforestation*: 3,000 ha
	Time horizon		30 years
STEP 3	**Biophysical outcomes**		Sediment yield to reservoirs reduced by 33%; Turbidity reduced by 32%
STEP 4	**Green Infrastructure cost**		US$32 Million
	Benefits (avoided costs)		US$781 Million
STEP 5	**Financial performance**	**ROI**	13%
		NPV	US$2 Million
		Payback	26 years
	Discount rate		8.5%
STEP 6	**Sensitivity analysis parameters**		▪ Discount rate: 5–12% ▪ Sediment retention (95% confidence): -12% to +11% reduction ▪ Green infrastructure costs: -63% lower to +5% higher ▪ Opportunity costs do apply to protected areas

Notes: * Target green infrastructure options were defined by local stakeholders based on existing conservation plans and feasibility.
Source: a. Feltran Barbieri et al. 2018.

Table 1B | **Overview of GGA Case Studies, Vitória, BR[b]**

STEP 1	**Investment objective**		Sediment reduction to avoid turbidity treatment and wear and tear
STEP 2	**Green-grey infrastructure portfolio**		Targeted reforestation: 1,200 ha; plus, installation of a new water storage reservoir
	Time horizon		20 years
STEP 3	**Biophysical outcomes**		Sediment yield to reservoirs reduced by 9%; Turbidity reduced by 43%
STEP 4	**Green Infrastructure cost**		US$9 Million
	Benefits (avoided costs)		US$23 Million
STEP 5	**Financial performance**	**ROI**	40%
		NPV	US$2.5 Million
		Payback	15 years
	Discount rate		8.5%
STEP 6	**Sensitivity analysis parameters**		▪ Discount rate: 5–12% ▪ Reforestation total of 3,000 ha ▪ Green Infrastructure costs higher

Table 1C | **Overview of GGA Case Studies, São Paulo, BR[c]**

STEP 1	**Investment objective**		Sediment reduction to avoid dredging, turbidity treatment, and wear and tear	Increase seasonal water flows
STEP 2	**Green infrastructure portfolio**		Targeted reforestation*: 4,000 ha	Targeted reforestation*: 4,000 ha
	Time horizon		30 years	30 years
STEP 3	**Biophysical outcomes**		Sediment yield to reservoirs reduced by 36%; Turbidity reduced by 50%	Total annual water flow impacted +/-0.2%; Impact seasonal water yield +1% to +1.2%
STEP 4	**Green Infrastructure cost**		US$37 Million	US$37 million
	Benefits (avoided costs)		US$106 Million	Not valued
STEP 5	**Financial performance**	**ROI**	28%	Financial analysis not possible due to lack of scientific data and modeling efforts
		NPV	US$4.6 Million	
		Payback	23 years	
	Discount rate		9%	
STEP 6	**Sensitivity analysis parameters**		▪ Discount rate: 5–12% ▪ Sediment retention (95% confidence): 20% to 43% reduction ▪ Green infrastructure costs: -51% lower to +35% higher ▪ Opportunity costs do apply to protected areas	▪ Fog capture vs. no fog capture

Notes: * Target green infrastructure options were defined by local stakeholders based on existing conservation plans and feasibility.
Sources: b. Ozment et al. 2019 (note: preliminary results subject to change); c. Ozment et al. 2018.

Table 1D | **Overview of GGA Case Studies, Monterey, MX**

STEP 1	**Investment objective**		Aquifer recharge[d]	Flood risk mitigation[e]
STEP 2	**Green infrastructure portfolio**		Revegetation, improved forest management, and forest conservation	Not identified
	Time horizon		30 years	30 years
STEP 3	**Biophysical outcomes**		Not modeled	Not modeled
STEP 4	**Green Infrastructure cost**		Not valued	Not valued
	Benefits (avoided costs)		Not valued	Not valued
STEP 5	**Financial performance**	**ROI**	A financial analysis to inform investments was not possible due to lack of scientific data. Outputs include a financial tool and technical note to evaluate financial performance of green infrastructure for aquifer recharge. The tool allows users to vary the parameters listed in the sensitivity analysis row.	A financial analysis to inform investments was not possible due to lack of scientific data. The output for this environmental outcome includes a white paper on how to estimate flood risk mitigation benefits.
		NPV		
		Payback		
	Discount rate		10%	10%
STEP 6	**Sensitivity analysis parameters**		▪ Discount rate ▪ Infiltration parameters ▪ Management and conservation costs ▪ Annual precipitation ▪ Sequencing of green infrastructure components ▪ Prioritization for each green infrastructure component ▪ Target area	▪ Not identified

Sources: d. Morales et al. 2019; e. internal technical note (unpublished).

Green infrastructure investment programs and planning efforts

There may already be ongoing efforts to invest in and plan for green infrastructure that can be used to inform a GGA. Perhaps green infrastructure portfolios have already been modeled, but no economic or financial analysis has been conducted. This can help the analyst(s) determine the degree to which new green infrastructure portfolios should be developed and whether new prioritization efforts will be needed.

Information and data needs:

- Describe any existing or planned green infrastructure projects, their objectives, and scale of funding.
- Describe any green infrastructure portfolios and rationale.
- Provide a projected timeline of activities.

Ecosystem valuation efforts

Increasingly, green infrastructure projects are implemented by multisector partnerships that co-invest in green infrastructure to achieve multiple benefits. Reviewing existing literature on various ecosystem service values can provide context on who the range of beneficiaries of green infrastructure could be and determine if any co-benefits should be valued in the GGA.

Information and data needs:

- Describe any relevant ecosystem service valuation studies from the targeted area and areas with similar climate and vegetation conditions.

Existing data observation and modeling efforts

Multiple biophysical models exist to understand how land-use change can affect provision of water-related benefits like sediment reduction and increased water supply. It is useful to research whether any models have been applied to the water supply system and source watersheds in case these efforts can be leveraged or improved upon.

Information and data needs:

- List and describe relevant biophysical modeling efforts

Engage the Right Stakeholders Early

Stakeholder buy-in is critical not only for supporting data collection and verification, but also for ensuring that results reach decision-makers and motivate stakeholders to invest in and implement green infrastructure solutions.

The outputs of this step should be a stakeholder map and a stakeholder engagement strategy. Stakeholder mapping helps identify those who should be engaged throughout the GGA process. Ozment et al. (2016) provide an overview of key stakeholders important for establishing watershed investment programs that address forest management for drinking water: investors (both project beneficiaries like landowners and financial institutions), land conservation and restoration suppliers, coordinators, approving bodies, intermediaries between investors and landowners, technical experts, and public outreach groups. It is critically important to engage the water supplier or utility from the outset to increase their confidence with the analysis results and hence increase the adoption of results into decision-making processes.

A stakeholder engagement strategy details which stakeholders to engage when, how, and why. Stakeholders should be engaged regularly throughout the analysis to verify and critique results and ensure buy-in of the analysis. Early engagement of stakeholders is also important for developing a communications strategy for sharing results and understanding what type of messaging works best for different decision-makers (Waite et al. 2014). The last section of this paper provides recommendations on presenting results for different audiences.

Ensure That You Have the Right Skill Set on the Team

The skill set needed for the GGA team will depend on local contextual conditions and willingness of stakeholders to participate. The output for this step is having an analyst or analysis team with the right skill set to conduct a GGA. In general, having the following roles or capacities is highly recommended (and one person may fill several roles):

- **Environmental economics:** Expertise in ecosystem service valuation, CBA and CEA, and sensitivity analysis, as well as familiarity with green and gray infrastructure costs and benefits.
- **Biophysical modeling/forest hydrology expertise:** Technical expertise in using results from biophysical models and forest hydrology literature and in interpreting biophysical outcomes and uncertainties. Someone may be needed to conduct or update a geospatial analysis or biophysical modeling exercise.
- **Local expertise and knowledge**: Capacity and connections to collect local data and meet with key stakeholders for understanding the local context, building trusting relationships to speed up data collection and verification, and sharing results.
- **Water supply system expertise:** Technical expertise to understand the relationship of forest investments, water outcomes, and impacts on water suppliers. An expert from the local utility or someone with engineering or other technical knowledge can fill this role.
- **Strategy, management, and communications:** Capacity to manage multiple team members' roles, convene stakeholders, and lead communication efforts for ensuring that the analysis is decision-relevant (e.g., timely and delivered to the right people by the right messenger).
- **Financing expertise:** Green infrastructure financing expertise to help in identifying and developing finance strategies to actually implement green infrastructure solutions.

STEP 1: DEFINE THE INVESTMENT OBJECTIVE

Step 1 specifies the investment objective to frame the analysis—that is, it identifies what the water supplier aims to achieve through their investment. Step 1 also frames the geographic and conceptual boundaries of the study area. The outputs of this step include a clear articulation of the research question and main analysis parameters, specification of the analysis type (i.e., financial vs. economic) and decision support tool, and a study area land-use map and description. Figure 3 provides an overview of these outputs and information and data needs.

Information and Data Needs

What are the investment objective(s) and environmental outcome(s)?

Water suppliers typically invest in new infrastructure for one or more of the following reasons (based on Talberth et al. 2013a); to

- Mitigate disaster risk (e.g., from flooding or drought events);
- Meet planning objectives (e.g., cost containment/ reduction, extending the useful life of existing infrastructure);
- Meet a regulatory compliance need; or
- Meet the water needs of a growing or changing urban population.

Investments are also made to achieve a specific outcome. Green-Gray Assessment cases are typically restricted to investments that seek an environmental outcome, and for water suppliers, these might include reduced water pollution, aquifer recharge, or flood risk mitigation. Investors may be interested in one or more outcomes.

An example investment objective might be to *reduce the total volume of sediment (m^3) arriving at a water supply reservoir to extend the useful life of existing infrastructure in a way that maximizes net benefits*. Specifying the objective in a quantitative way with a clear metric for the environmental outcome ensures all benefits and/or costs are accounted for and aids in the selection of an appropriate decision support tool (e.g., CEA or CBA). Using the example investment objective above, stating explicitly that maximizing net benefits is of interest highlights the need for CBA as opposed to CEA. Also, the environmental outcome (total volume [m³] of sediment arriving at the water supply reservoir) is expressed in terms of a specific metric that is relevant for a water supplier.

Who are the investor(s)?

Investors are those who may potentially finance or fund water management activities, including green infrastructure. Their decision-making criteria should inform the selection of the appropriate discount rate, time horizon, and other terms of the analysis (Step 5).

Who are the beneficiaries and payees?

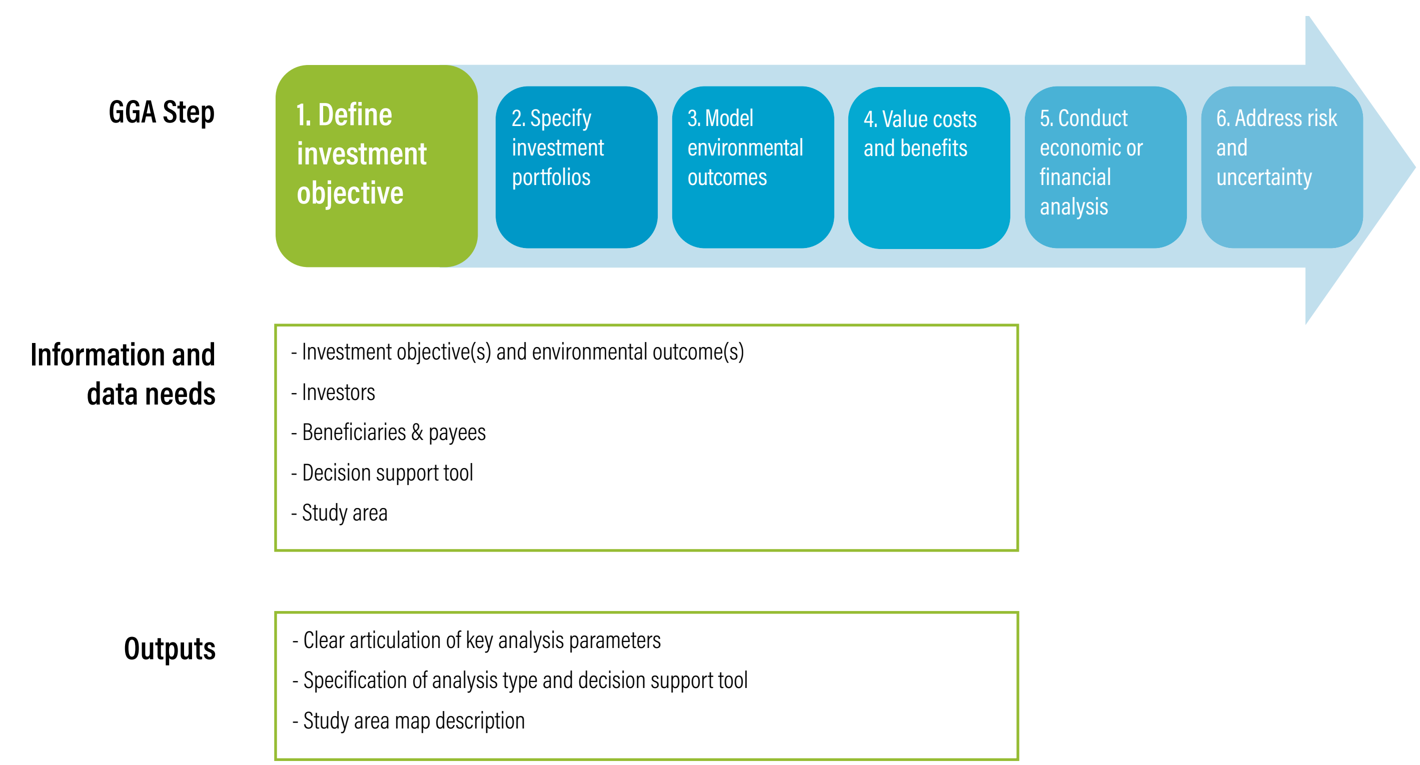
Identifying whose costs and benefits are relevant to the analysis is of key importance for determining whether a financial analysis or an economic analysis should be conducted. Beneficiaries are defined as stakeholders that stand to gain from an infrastructure investment. Payees are those who may need to be compensated for impacts of an infrastructure investment.

A financial analysis focuses on how an investment affects a specific entity or subset of stakeholders like water suppliers or other project beneficiaries. An economic analysis focuses on how an investment affects society or the economy as a whole and, thus, considers a much wider set of beneficiaries and payees, including those affected by positive and negative externalities or consequences of an investment.

What is the appropriate decision support tool?

The choice of investment objective along with the targeted beneficiaries and payees, should determine the most suitable decision support tool to use, such as CBA or CEA.

Figure 3 | **Overview of Step 1 Information, Data Needs, and Outputs**



Source: WRI.

For example, if the objective is to meet a regulatory target at lowest cost, CEA would likely be most appropriate. If analysts are also interested in understanding benefits, then CBA is the preferred method as it would compare the net benefits of different investment portfolios. Multi-criteria analysis is another tool that can be used where quantitative data are limited although it is not discussed in this paper.

What is the study area?

The study area refers to the geographic boundaries of interest for the GGA. Its limits are set by the water supply system and its source watersheds. The following information and data are needed to define the study area:

- the water supply system location
- the population served by the water supply system by consumer type (e.g., commercial, residential, agricultural, industrial—useful for identifying potential beneficiaries and payees from investments)
- source watersheds and their drainage areas
- the location of water intake(s) for the water supply system
- the water supply sources (both ground and surface water) for the water supply system
- political boundaries
- land use and land cover data, including current and historic land uses
- land ownership data for the source watersheds
- local climate and topography data

A current land-use map should be produced at the end of this exercise with specification of the water supply system location and intake points (note this may align with Step 3 on biophysical modeling). Other information and data may be relevant for discussions with stakeholders and for projecting future land uses (see Step 2).

STEP 2: DEFINE THE INVESTMENT PORTFOLIOS

The second step in the GGA is to define the right mix of potential green and gray infrastructure investment portfolios to model and compare. This entails defining

- a business as usual (BAU) or baseline investment portfolio (that is, in the absence of the alternative infrastructure investment portfolio, what happens to existing or planned infrastructure, land use and land cover change, and financial conditions?); and
- alternative infrastructure investment portfolios: An alternative portfolio may consist of green only or green and gray infrastructure components. For green infrastructure, common components include forest conservation, restoration, or agricultural or forest best management practices.

Alternative portfolios must be measured against BAU conditions to ensure that changes in the investment objective are related to the alternative infrastructure investment and not to other causes that would have happened without the investment.

Figure 4 provides an overview of the information and data needs and outputs for this step. Major outputs include spatial maps of the BAU and alternative infrastructure portfolio land-use conditions, identification of water supply infrastructure that would be affected by a change in the environmental outcome and BAU financial conditions for current or planned water supply infrastructure, the analysis time horizon, and annual data on the prioritization and sequencing of green and gray infrastructure components for each portfolio.

Information and Data Needs—BAU Investment Portfolio

The BAU investment portfolio represents what would happen in the absence of any new infrastructure investments. These conditions should be defined in terms of land use and land cover (LULC) trends, water supply infrastructure, and associated financial costs. Climate-change trends could also be addressed in this step or as part of a sensitivity analysis (Step 6).

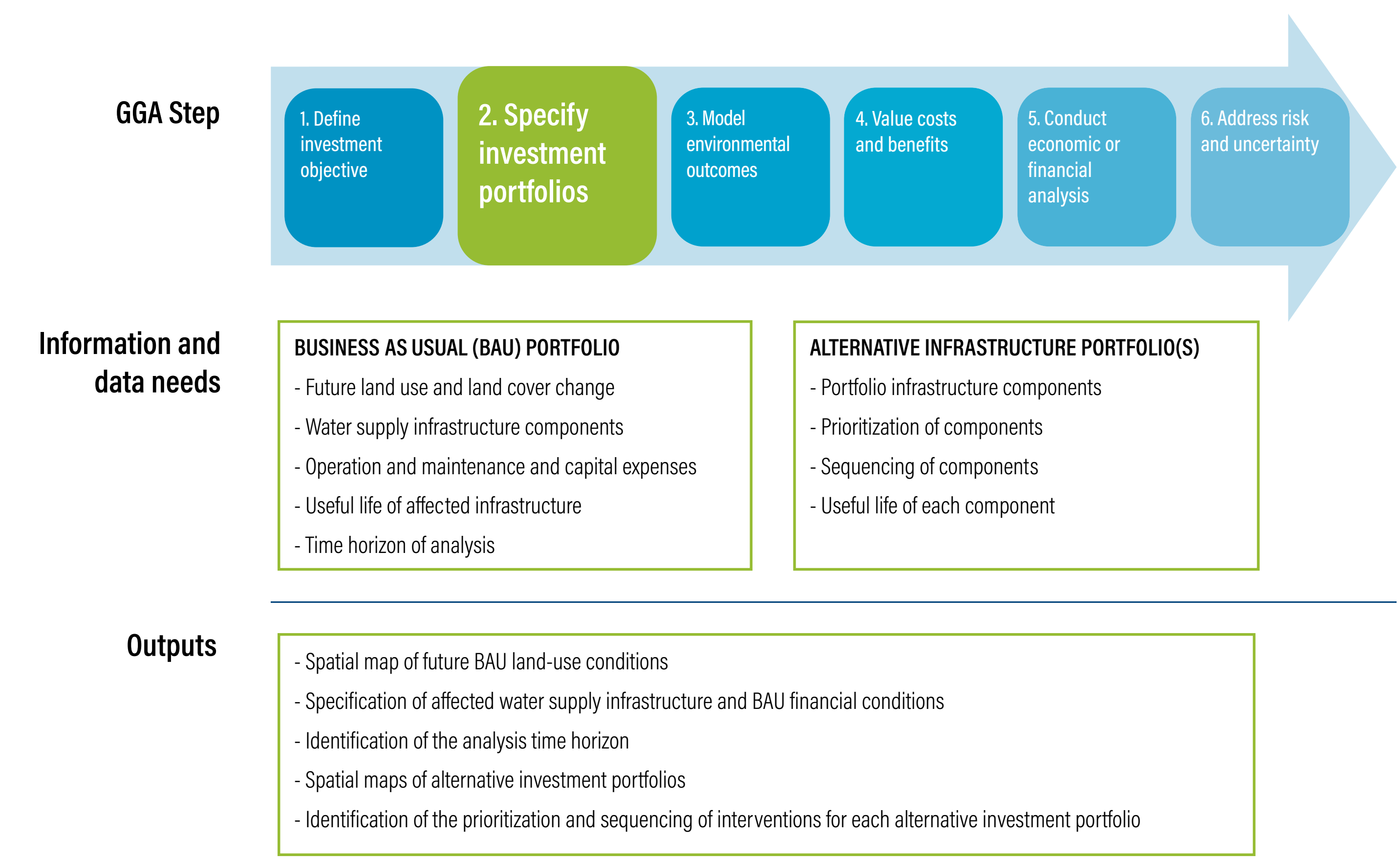
How will LULC change in the absence of alternative infrastructure investments?

Future LULC without alternative investments can be identified by projecting historic land-use trends (collected as part of the study area description) or by using more complicated modeling that takes into account factors like future land-use policies (see Kroeger et al. 2017). In some cases where projecting LULC is out of scope, it may be suitable to assume BAU LULC will not change over the time horizon.

What water supply infrastructure components are in place or being planned that will be affected by BAU LULC change and the identified environmental outcome(s)?

In other words, what impacts to the water supplier would be avoided by investing in alternative infrastructure? Box 2 provides an example of how to answer this question, based on Ozment et al. 2018, which assessed the costs and benefits of investing in green infrastructure for improved sediment control. Additionally, Table 6 in Step 4 exhibits the ways that green infrastructure objectives affect water supply infrastructure.

Figure 4 | **Overview of Step 2 Information and Data Needs and Outputs**

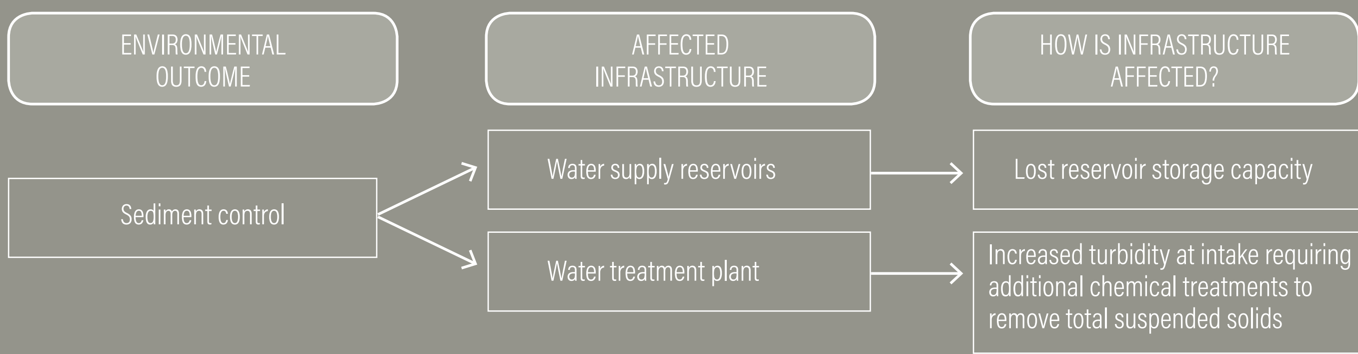


Source: WRI.

Box 2 | **Identifying Affected Water Supply Infrastructure**

Ozment et al. (2018) estimated the return on investment in green infrastructure for the water supplier in São Paulo in terms of reduced sediment pollution. Working with local stakeholders, the analysis team identified that if sediment loading increased due to continued BAU land-use change, the water supplier's reservoirs and water treatment plant would be affected through lost reservoir storage capacity and/or the need for dredging and turbidity remediation at the treatment plant's intake. Figure 1 provides a conceptual diagram for this process.

FIGURE 1 | CONCEPTUAL DIAGRAM EXAMPLE FROM SÃO PAULO (OZMENT ET AL. 2018) FOR IDENTIFYING WATER SUPPLY INFRASTRUCTURE AFFECTED BY GREEN INFRASTRUCTURE INVESTMENTS (OR LACK THEREOF)



Source: WRI.

What are the operation and maintenance and capital expenses associated with this affected infrastructure?

Specifying these infrastructure components that would face challenges can help set the research agenda on estimating the financial implications of green infrastructure impacts. Box 2 provides an example: identifying lost reservoir storage as an infrastructure impact helps focus the research needs around costs of reservoir maintenance such as dredging. Identifying increased turbidity as an infrastructure impact helps focus research needs on costs such as chemical and labor costs at the water treatment facility and sludge removal costs.

What is the useful life of affected water supply infrastructure?

Useful life of infrastructure is defined as the length of time an infrastructure component can perform its design function. The useful life of major water supply infrastructure should help identify the analysis time horizon (see below). It is also useful for understanding and estimating (in Step 4) how depreciation rates of these infrastructure may be affected by a change in the environmental outcome.

What is the time horizon of the analysis?

The time horizon of the analysis is the period over which costs and benefits are counted. It should tie to decision-making processes, which for water suppliers is typically tied to the useful life of major gray water infrastructure components. Box 3 provides a summary of some recent guidance on selecting an appropriate time horizon for assessing water infrastructure investment options. Keep in mind, however, that some green infrastructure components can generate benefits on long time scales (>30 years). Multiple time periods can be used in a GGA, and results can be compared, which can highlight the difference in costs and benefits when accounting for different time horizons.

Information and Data Needs—Alternative Infrastructure Investment Portfolios

An alternative infrastructure investment portfolio is composed of one or more green infrastructure components or a hybrid of green and gray infrastructure components that are intended to address the investment objective. Portfolios can be differentiated based on the type of components, the extent or geographic area of each component, and/or on the sequencing of component implementation.

The selection of portfolios should present realistic options for how to achieve the desired investment objective. That is, the portfolios should consider

- relevant regulations that affect land-use planning (e.g., The Brazilian Forest Code or Law of Native Vegetation Protection–12.651/12);
- current and historical planning for both green and gray infrastructure; and
- environmental and social impact assessments of possible infrastructure options.

Additionally, portfolios should have buy-in from local stakeholders and experts to ensure that results will be decision-relevant. Finally, portfolios should present a thorough scientific assessment or comparison of trade-offs.

What are the individual infrastructure components that constitute the portfolio?

As a first step, it is necessary to identify and define the specific infrastructure components (e.g., forest restoration, conservation, best management practices) that are suitable for the study area. At a minimum, the portfolio component should include the following suitability criteria:

- The component contributes to achieving the targeted investment objective.
- It is technically feasible to implement the component based on, for example, available land or willingness of private landowners to implement it.
- Stakeholders support implementation of the component (ERG 2015).

Box 3 | **Time Horizon Guidance**

Infrastructure investors (e.g., government agencies, development banks) and engineering organizations may have their own guidance for conducting CBA OR CEA to select the best investment option. For example:

- The European Commission (2014) advises that the time horizon for investment projects depends on the sector and internationally accepted practice. The commission recommends a 30-year time horizon for CBA of water and wastewater infrastructure projects.
- The American Society of Civil Engineers states that the average useful life of water treatment plants (mechanical and electrical) is 15 to 25 years (EDRG 2011).
- In Brazil and Mexico, a time frame of 20 to 30 years has been recommended for major water infrastructure investments like reservoirs (Sabesp 2011a; CEPEP 2015).

Stakeholders may define infrastructure components like forest restoration and forest conservation differently, so it is important to clearly define each green infrastructure component and the actions required for its implementation.

How are infrastructure components prioritized?

Prioritization of infrastructure components refers to how components in a portfolio are planned on a spatial scale such that location and area can be quantified. Ideally, the mix of infrastructure components would be prioritized to maximize benefits and minimize costs given a targeted investment objective (e.g., a 50 percent reduction in sedimentation from source watersheds). In practice, however, green infrastructure components are often prioritized based on the budget of a green infrastructure project.

For green infrastructure components, prioritization requires spatial mapping and optimization to achieve the greatest environmental outcome, given constraints like land suitability, water and land-use regulations, and cost. Spatial modeling software such as InVEST provides a means of prioritizing the highest impact areas to target green infrastructure strategies, though other approaches also exist.

The output of this exercise should be a spatial map of the alternative infrastructure portfolio and quantitative information on the area of green infrastructure component. There may also be special considerations for prioritization of green infrastructure, such as the need to incorporate redundancy (e.g., planting additional acres of forest in case of fire) (Talberth et al. 2013a).

If prioritization efforts for alternative infrastructure portfolios have already been conducted, the analysis team should work with stakeholders to understand their underlying assumptions and to make sure that prioritization efforts are still agreed upon. If prioritization efforts have not yet been established, it is necessary to work with relevant stakeholders to develop a strategy.

What is the sequencing of implementation for each component in the portfolio?

Sequencing refers to the order and timing of implementing specific infrastructure components. Infrastructure components may be installed over multiple years due to budget, staffing, and landowner participation constraints, as well as biological and physical considerations like establishing certain plantings before another round of plantings is possible. Likewise, sequencing green infrastructure should account for natural systems' seasonal or inter-annual variability, which can affect the level of benefits provided. Planned sequencing and timing for infrastructure installations should be discussed with project developers and other stakeholders, so that they can be accurately reflected in the cash flow analysis on a year by year basis.

What is the useful life of each infrastructure component?

Identifying the useful life of each major infrastructure component is important for understanding the flow of costs and benefits and when up-front investment costs would need to recur. Additionally, understanding the useful life of these components can help highlight an alternative time horizon for the analysis. Identifying the useful life for green infrastructure, however, can be difficult. Some components, like green infrastructure for storm water (e.g., bioswales), have specified lifetimes, while others, like forest conservation through conservation easements, last for centuries and depend on landowner behavior.

Table 2 | **Overview of Data Needs from Biophysical Model**

DATA	USAGE
Version of model used	For tracing the model's inputs, outputs, strengths, and weaknesses so that results can be verified by others.
Data inputs and assumptions	For understanding underlying data sources and getting stakeholder input. (Could data sources be improved? Were best available data used?)
Outputs (and units)	For understanding the change in environmental outcomes from baseline conditions due to investment portfolios. To determine if outputs need to be translated further into impacts on gray infrastructure (i.e., need to convert soil erosion to sediment yield, and sediment yield to turbidity).
Calibration approach and results	To verify if the model was calibrated using local data or not, and how well it performs against monitoring data.
Time step	For determining whether the model runs results daily, monthly, annually, or if the model is event based. This is necessary for interpreting results, where costs and benefits are measured annually.
Baseline conditions	To ensure that baseline conditions in terms of land use and other factors match with baseline conditions assumed for the analysis (specified in Step 2).
Sensitivity analysis results	For conducting a sensitivity analysis (Step 6).
Model limitations	For conducting a sensitivity analysis (Step 6) and reporting on results.

Source: WRI.

STEP 3: MODEL ENVIRONMENTAL OUTCOMES

Step 3 aims to show how implementation of each alternative investment portfolio will change the provision of environmental outcome(s) compared to BAU and is specific to green infrastructure components within a portfolio. The output of this step should be an annual quantification of the change in environmental outcome between BAU conditions and the alternative infrastructure portfolio (see Figure 5). Quantitatively establishing the relationship between the level of investment in any one alternative infrastructure portfolio and the investment objective requires biophysical modeling of scenarios with acceptable levels of uncertainty. Acceptable levels of uncertainty can be determined with expert and stakeholder input.

In situations where there are inadequate resources for robust biophysical modeling or lack of local studies on the performance of green infrastructure components, expert knowledge may be useful for developing rough estimates. This guidance focuses on the case where biophysical modeling is available.

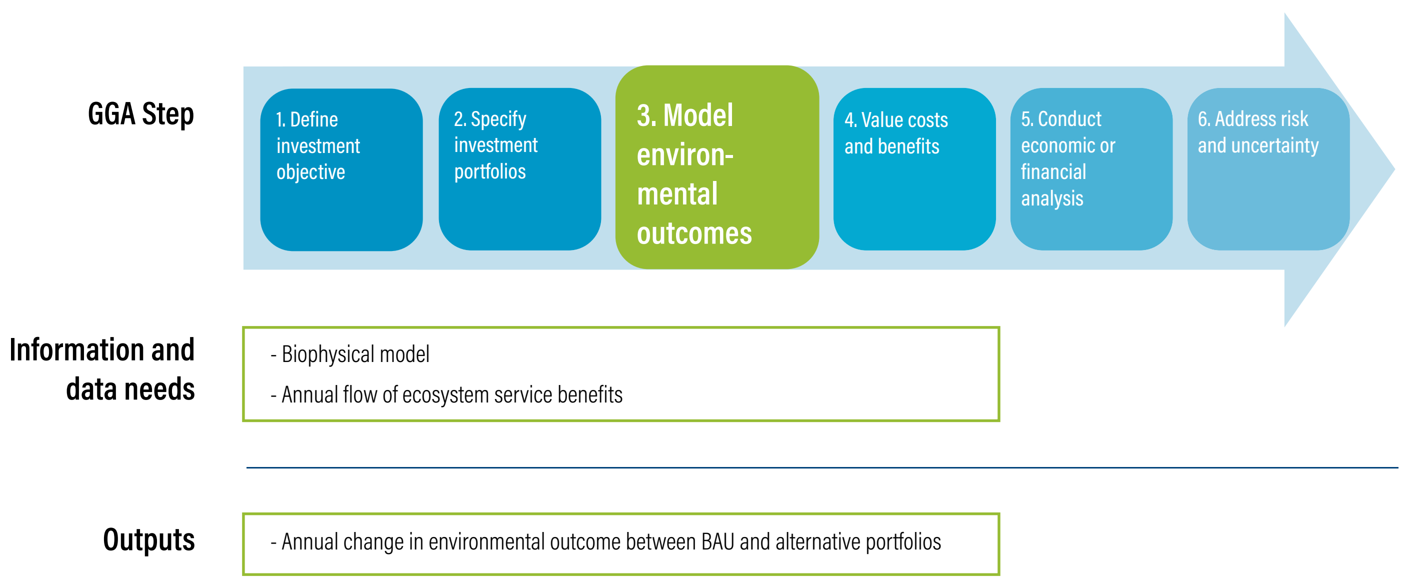
Information and Data Needs

What is the most appropriate biophysical model, and what are the required data inputs?

To select a biophysical model for designing and evaluating alternative infrastructure investment portfolios, it is important to consider the GGA team's capacity and whether the model will be respected and accepted by decision-makers. A variety of models are available for estimating hydrologic outcomes; a recent publication by Bullock and Ding (2018) provides guidance for selecting the best ecosystem service biophysical model.

In cases where stakeholders have already developed a model to assess green infrastructure project plans, it is still important to identify features and limitations of the model for understanding modeling impacts on GGA results and for conducting a sensitivity analysis (Step 6), and discussing GGA results with stakeholders. Table 2 provides an overview of key model features and data to track. Once a model is selected, it should be run for each investment portfolio defined in Step 2 to determine the change in environmental outcome between the beginning

Figure 5 | **Overview of Step 3 Information and Data Needs and Outputs**



Source: WRI.

and the end of the analysis period. Subsequently, the portfolios can be compared to arrive at the difference in environmental outcomes due to investing in the alternative portfolios.

How do environmental outcomes change over time?

The GGA needs to account for any time lag in benefit provision on an annual basis. Some types of green infrastructure, like restored forest, take time to mature and achieve full functionality or full provision of benefits. Gray infrastructure components, and some green infrastructure components like forest conservation realize full functionality immediately (Kroeger et al. 2017). The sequencing of infrastructure implementation over multiple years can also create a time lag in benefit provision.

These time-influenced dynamics can be modeled, and modeling assumptions likely need to be informed by available literature, ideally from the study area. In cases where relevant literature is not available, one may need to use proxies. In the case of forest restoration as a means to reduce sedimentation, for example, there may be insufficient data to understand how forest restoration results in sedimentation reduction over time as the forest matures. However, proxies such as forest structure or canopy density could be used to roughly characterize sedimentation reduction benefits over time (see Rafael-Barbieri et al. 2018).

STEP 4: VALUE COSTS AND BENEFITS

The output of Step 4 is a monetization of the annual costs of implementing each alternative investment portfolio and the annual benefits, so that costs and benefits can be compared in present value terms in Step 5. It is first necessary to identify all relevant cost and benefit components and their impacts on existing water infrastructure in the study area (identified in Step 2) and to select benefit valuation methods. Figure 6 provides an overview of information and data needs and outputs.

Information and Data Needs

What are the costs of implementing and maintaining alternative infrastructure investments?

Green and gray infrastructure costs refer to costs associated with implementing and maintaining the alternative infrastructure investment portfolio over the analysis time horizon. While gray infrastructure costs are fairly straightforward and typically include up-front investment and operation and maintenance costs, green infrastructure costs also include transaction costs and opportunity costs. Table 3 and the following subsections provide a definition for each cost component, as well as example expenses related to green infrastructure.

Rarely are cost data conveniently available in this categorical format. As a result, it is necessary to work with the implementing entity of the investment portfolio to determine how it organizes costs and, from that, determine costs specific to these four categories. Other costs, like communications and administrative expenses, that do not directly relate to the project should be omitted from the analysis.

Up-front investment costs

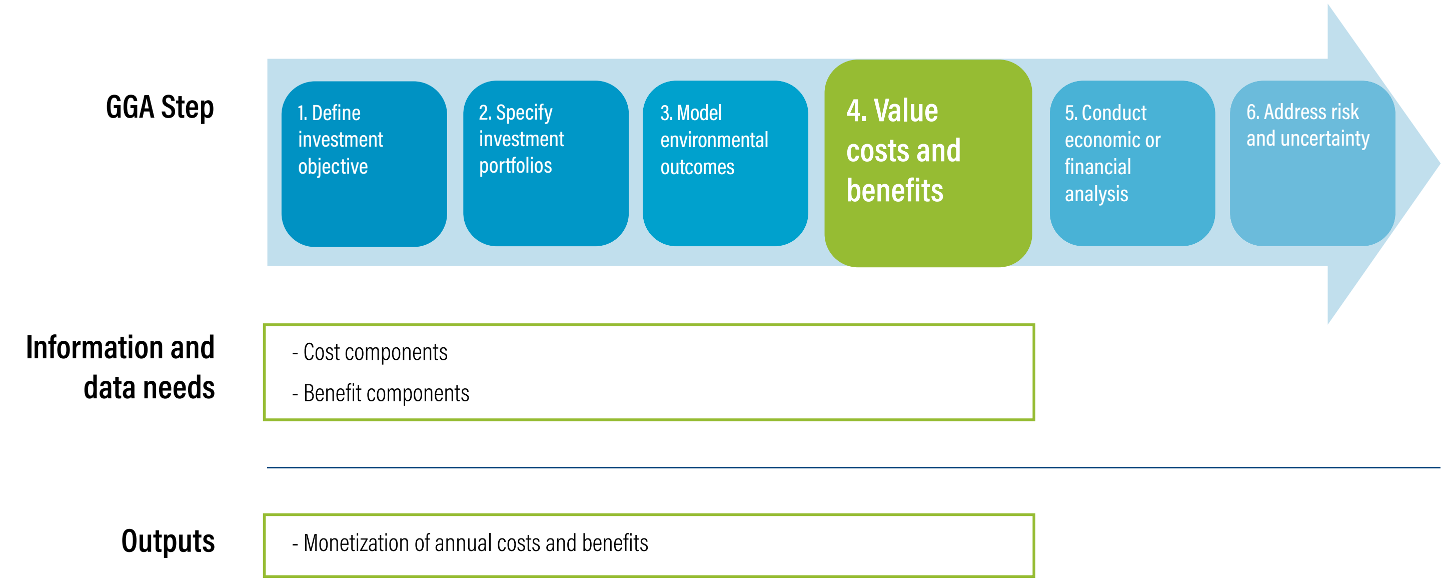
Up-front investment costs include initial capital and materials expenses and labor costs needed to implement green infrastructure activities like forest restoration and conservation. Ideally, unit cost data per expense ($/acre) as well as the useful life of each expense can be collected. For example, equipment like a tractor may have a useful life of 20 years, after which it must be replaced. If the analysis time frame is 30 years, then the GGA would need to capture when the equipment expense hits. Expenditures on land acquisition, however, would be a one-time purchase made at the beginning of the project. Some expenses like seedlings may be a one-time up-front expense with residual expenses in later years to cover reseeding.

The best valuation method is using market prices for these data. Possible data sources for green infrastructure implementation costs include land conservation and restoration suppliers. Local, national or even global datasets and literature may serve as a source of proxy data.

Recurring operation and maintenance (O&M) costs

O&M costs include recurring costs to ensure that green infrastructure components survive over time. Examples of O&M costs include reseeding, pest control, cleaning of seedlings, landowner payments, and monitoring systems. Like up-front investment costs, O&M expenditures should be captured ideally on a unit cost basis by infrastructure component. It is important to identify the recurrence of costs as some green infrastructure activities like fencing may need to be reinforced every 10 years as opposed to every year.

Figure 6 | **Overview of Step 4 Information and Data Needs and Outputs**



Source: WRI.

Table 3 | **Cost Components and Examples**

COST COMPONENT	DEFINITION	EXAMPLES
Up-front investment costs	Initial project expenditure costs for land and capital equipment associated with implementing the investment portfolio	Investments in land, seedlings, fencing; capital expenditures on equipment, materials, and infrastructure; labor costs for implementing infrastructure
Operation and maintenance costs	Costs of labor, equipment, and materials needed to ensure that infrastructure investments are maintained and operating well	Maintenance of interventions (e.g., follow-up inspections of trees to ensure survival; replanting); program payments to landowners
Transaction costs	Costs associated with the time, effort, and resources to search out, initiate, negotiate, and complete a deal and monitor and enforce that deal	Design, search, negotiation, approval, monitoring/verification, enforcement, certification, and insurance costs
Opportunity costs	Forgone value from implementing the investment portfolio	Next best use of land (e.g., rental price of land)

Source: WRI.

Box 4 | **Transaction Costs for Payment for Ecosystem Service Programs**

Transaction costs for green infrastructure initiatives may be quite high and make up a sizable portion of an implementing agency's budget. A review of transaction costs of payment for ecosystem services (PES) programs (Alston et al. 2013) for different ecosystem services (including biodiversity, carbon, and water services) across the world found that transaction costs made up anywhere from 1 to 66 percent of the income generated through the schemes. The highest transaction costs occurred in projects dealing with pure public goods and in cases where monitoring and enforcement faced difficulties. Low transaction costs were associated with projects that used preexisting institutions, were large-scale, and lacked a monitoring program. For PES schemes targeting water services in Mexico and Ecuador, the same study found that transaction costs varied between 4 and 17 percent.

Transaction costs

Transaction costs are typically more difficult to define and capture than investment and O&M costs. Generally, transaction costs for green infrastructure initiatives are defined as costs associated with the "time, effort, and resources needed to search out, initiate, negotiate, and complete a deal [for land conservation or restoration]" (Lile et al. 1998). These costs are the costs of doing business or operating a project.

Types of transaction costs may include the time and money that go toward program design; engaging landowners; contracting, monitoring, and enforcement; and certification and insurance. Alston et al. (2013), Jindal and Kerr (2007), and Milne (2002) provide detailed descriptions of green infrastructure transaction cost components.

If a project's budget does not have specific line items for transaction costs, transaction costs could be approximated based on expert consultation.

Opportunity costs

Opportunity costs are defined as forgone value from implementing the investment portfolio (i.e., watershed restoration or protection efforts) and reflect what the landowner is "giving up" (i.e., net revenues from competing land uses). Because there are several possible uses for any parcel of land, the opportunity cost is usually determined by the most common use or, in a more conservative approach, the most expensive or productive land-use category.

Opportunity costs should be estimated to approximate the net value of forgone activities on the land. In the case where the intervention requires the landowner to give up use of the land (or all activities), opportunity costs can be valued using land rental prices, which represent the income these lands could earn by not restoring or conserving forestland. Land rental price would be represented as an annual value as it represents an annual source of income. Land rental data are frequently available from agricultural agencies and extension services.

Legal requirements can affect opportunity costs. In Brazil, for example, the Brazilian Forest Code requires that some lands be restored and conserved. In this case, the opportunity costs of restoring these lands could be considered zero as legally there is no alternative land use allowed.

What are the benefits of implementing and maintaining alternative infrastructure investments?

Benefits of proposed alternative infrastructure investment portfolios fall into two categories: direct benefits and co-benefits. If conducting a financial analysis, direct benefits for the specific entity (or entities) are the primary focus. Co-benefits relate mainly to green infrastructure and may be included if there is a possibility of multiple investors co-investing in a project for different benefits or to make a broader social case for investment. Including co-benefits (as opposed to only direct benefits) in the scope of assessment may change the optimal number/location or priority areas, increase the return on investment (ROI), and/or increase the sources and level of investment. Regardless, it is recommended that co-benefits be described at least qualitatively for a financial analysis so that stakeholders can take a more holistic view of investment options and further distinguish among the green infrastructure portfolios. Additionally, presenting co-benefits is useful for raising awareness and engaging additional beneficiaries who may be willing to pay for these benefits.

Table 4 | **Examples of Green and Gray Water Supply Infrastructure Impacts, Costs, and Valuation Methods**

ENVIRONMENTAL OUTCOME	GRAY OR GREEN INFRASTRUCTURE AFFECTED	DESCRIPTION OF IMPACT (BAU CONDITIONS)	AVOIDED COSTS	ALTERNATIVE COSTS	OTHER VALUATION OPTIONS
Reduced erosion	Water storage reservoir	Lost reservoir water storage capacity	Avoided reservoir management costs (e.g., dredging)	Construction of a new reservoir	Public willingness to pay to improve water quality
	Hydropower reservoir	Lost energy production capacity	Avoided costs of lost energy generation	Costs of supplying energy from an alternative source	
	Water treatment plant	Increase in turbidity at water intake point	Avoided chemical, labor, and energy costs associated with treating turbidity	Engineering costs of water treatment	
		Enhanced depreciation of equipment	Avoided cost of replacing equipment earlier than the expected useful life	Costs of treating water at a different facility	
Improved seasonal water flow	Water supply sources (e.g., reservoirs, surface water sources)	Reduced water availability in times of scarcity	Avoided costs of water transfers	Alternative cost of supplying water from other water sources	Public willingness to pay to avoid drought
Improved groundwater infiltration	Aquifers	Reduced water availability in times of scarcity	Avoided costs of water transfers	Alternative cost of supplying water from surface water sources	Public willingness to pay to avoid drought
			Avoided costs of aquifer over-exploitation (e.g., costs of land subsidence or saltwater intrusion)	Alternative costs of maintaining aquifer levels through artificial methods (e.g., water injection)	
Flood risk mitigation	Water treatment plant, water distribution network, drainage and collection systems and reservoirs	Damage to water infrastructure	Repair costs for damages	Cost of improved levee systems downstream; relocation of valuable structures	Public willingness to pay to avoid service disruptions from flooding
		Lost use of facilities and infrastructure (i.e., downtime)	Costs associated with service disruption	Costs of having to treat water elsewhere or install a temporary treatment measure	

Sources: CWC 2016; ERG 2015; Feltran-Barbieri et al. 2018; Kroeger et al. 2017; Monetization Working Group 2015; Morales et al. 2019; Ozment et al. 2018, 2019; Rodriguez-Osuna 2014.

Direct benefits

Direct benefits refer to those benefits accrued to the targeted beneficiary/ies due to the change in environmental outcome. There are several valuation methods for quantifying impacts on water infrastructure. The following methods are most common (CWC 2016):

- Avoided cost: Reduction in costs relative to the BAU conditions that would occur because of investment in a green infrastructure portfolio
- Alternative cost: The cost of the least-cost means of providing at least the same amount of physical benefit
- Willingness to pay: the amount the study area population would be willing to pay for the physical benefit

Table 4 provides examples of impacts on water systems (*without* any new infrastructure investment), categorized by the four environmental outcomes examined in our case studies.

Co-benefits

Co-benefits include additional ecosystem services provided by watershed restoration activities. To identify which co-benefits are relevant, first conduct a literature review specific to the area's key ecosystems (identified in Step 2); and second, consult local experts familiar with the watershed.

For quantification, co-benefits must represent the *change* in provision of ecosystem services between BAU and alternative investment portfolios. As a result, a baseline and counterfactual trends must be established.

Table 5 provides an overview of potential co-benefits from watershed restoration. Multiple guidance documents are available to assist with ecosystem service valuation (Ding et al. 2017; Markandya 2016). In addition to environmental impacts, social and economic benefits can also be considered, but this will require additional data collection.

Table 5 | **Example of Co-benefits from Forest Restoration**

ECOSYSTEM SERVICE BENEFIT CATEGORY	CO-BENEFITS	
Provisioning	▪ Wild foods ▪ Timber and other wood fibers ▪ Non-wood forest products ▪ Biomass fuel	▪ Genetic resources ▪ Biochemicals, natural medicines, and pharmaceuticals
Regulating	▪ Maintenance of air quality ▪ Global climate regulation ▪ Regional/local climate regulation ▪ Water purification ▪ Disease mitigation	▪ Maintenance of soil quality ▪ Pest mitigation ▪ Pollination ▪ Natural hazard mitigation
Cultural	▪ Recreation and tourism (e.g., hiking, hunting, fishing) ▪ Amenity	
Supporting	▪ Species/ecosystem protection	

Sources: Pascual et al. 2010; Waite et al. 2013.

STEP 5: CONDUCT ECONOMIC OR FINANCIAL ANALYSIS

After valuing each cost and benefit component, the next step is to compare alternative infrastructure investment portfolios in present value terms using either CBA or CEA. Investment portfolios can be compared based on one or more decision criteria such as net present value (NPV) or ROI. This allows stakeholders to select the optimal investment portfolio based on greatest net benefits or lowest implementation costs. This section provides guidance on selecting a discount rate and which decision rule criteria to use to compare costs and/or benefits.

The output from this step includes either a present value comparison of costs and benefits for CBA or a comparison of all costs for CEA (see Figure 7).

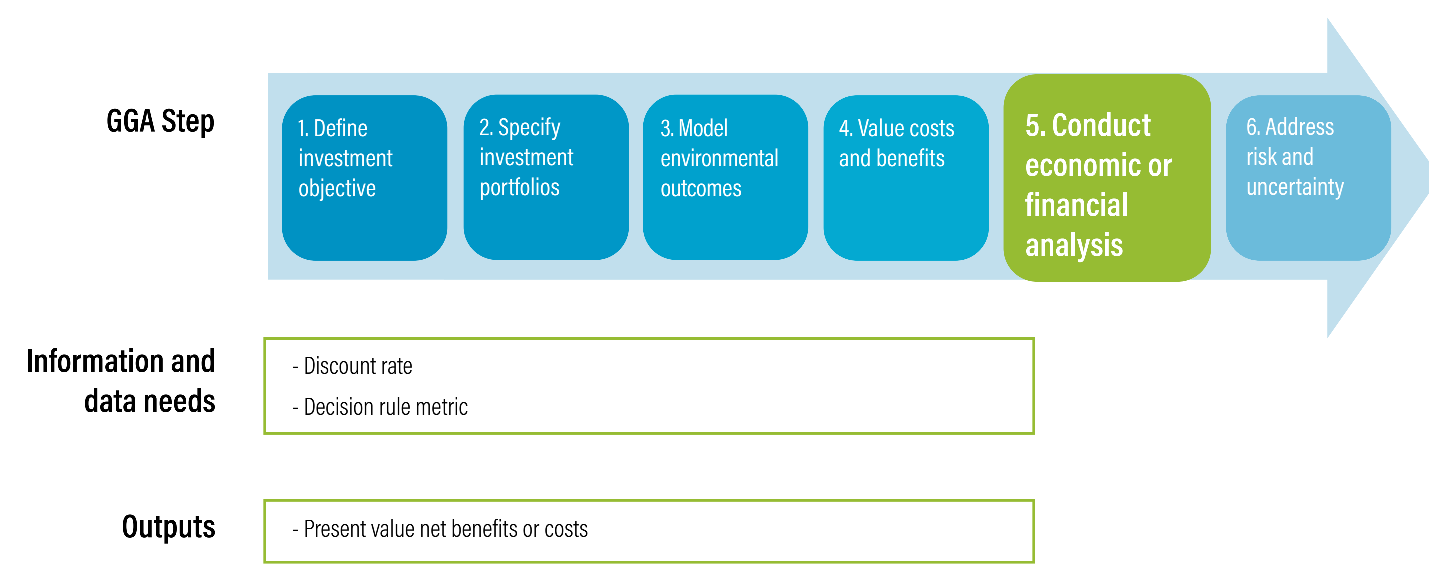
Information and Data Needs

Select a discount rate

The stream of costs and benefits over the time period must be discounted to the present value so that they can be compared (and so that investment portfolios can be compared). A benchmark discount rate should be used in Step 5, but additional discount rates may be applied during Step 6 (sensitivity analysis). The benchmark discount rate should be selected based on the discount rate employed by the potential green infrastructure investor(s), be it water utility, government, impact investor, development bank, or some combination thereof.

The discount rate should align with the opportunity cost of capital if the utility is a private entity. If the utility is publicly owned, one could use the recommended social discount rate from the federal government or from financial institutions operating in the region. The social discount rate reflects how society values time and is typically applied when considering ecosystem restoration initiatives (U.S. EPA 2010; Verdone 2015). Typically, social discount rates for green infrastructure initiatives will have a lower discount rate (0–4 percent) than the social discount rates used for public gray water infrastructure investments (3–15 percent), which reflects the long-term nature of green infrastructure benefits (Campos et al. 2015; Verdone 2015). Box 5 provides additional guidance on selecting a discount rate for water infrastructure investments based on recent literature.

Figure 7 | **Overview of Step 5 Information and Data Needs and Outputs**



Source: WRI.

Box 5 | Discount Rate Guidance for Water Infrastructure Investments in Latin America

Multilateral institutions like the World Bank and Inter-American Development Bank have traditionally used a constant standard discount rate (SDR) of between 10 and 12 percent for CBA, but often without in-depth justification (Campos et al. 2015). Lopez (2008) provides more detailed guidance and estimates that an appropriate SDR for the Latin American region is 3–7 percent, depending on growth expectations for the region (with a higher discount rate being more applicable to a higher growth scenario). The paper argues for using a higher discount rate for analyses using a shorter time horizon, with a 4.4 percent SDR recommended for a time horizon of 25 years.

For water-specific public and private investment decisions, the Mexican Federal Government recommends a discount rate of 10 percent (Campos et al. 2015). Spain uses a 4 percent SDR for water projects (Campos et al. 2015). In Brazil, the water utility, Sabesp, uses an opportunity cost of capital of around 9 percent (Sabesp 2011b). Financial experts in Brazil also recommend accounting for the Brazilian risk premium, which has averaged 2.56± 0.904 percent per year in the last 10 years according to the Brazilian Institute for Applied Economic Research (IPEA 2017).

Select decision rule metrics to compare costs and benefits

Several metrics can be used to compare present value costs and benefits (Pearce et al. 2006):

- **NPV** compares the present value of costs to the present value of benefits. A positive NPV indicates a net gain for the investor(s).
- **Cost-benefit ratio** divides total present value benefits by total present value costs. A ratio greater than one indicates a net gain.
- **Return on investment** measures the gain or loss of an investment by dividing the net benefits by the investment costs. This is calculated as a percentage.
- **Internal Rate of Return** estimates the discount rate at which the NPV is zero. This can be compared with the social discount rate.
- **Payback period** (years) expresses how long it takes to recover investment costs.

To determine which metric(s) to use, it is best to discuss with stakeholders to understand which are most important for key audiences.

STEP 6: ADDRESS RISK AND UNCERTAINTY

Risk is related to the probability distribution of an outcome occurring, whereas uncertainty exists when the probability distribution is unknown (Waite et al. 2014). Risks to green infrastructure can include fire, drought, floods, and insect outbreaks (Talberth et al. 2013a). For uncertainty, three types pertain to green infrastructure (Polasky and Binder 2012):

- Behavioral: Uncertainty about how an investment may influence human behavior (e.g., how landowners will respond to a watershed restoration program)
- Scientific: Uncertainty about how human actions (i.e., restoration activities) will affect ecosystems and their provision of ecosystem services
- Value: Uncertainty about how changes in environmental outcomes affect human well-being (i.e., economic and financial values)

Because these sources of risk and uncertainty can have a high influence on project outcomes, often the results of a risk and/or sensitivity analysis are more valuable to stakeholders than a final NPV or ROI value. This is because a risk or sensitivity analysis helps to better illuminate the relationships between variables and outputs and, as a result, helps to indicate where more or better information would improve decision-making.

The output from this step includes calculation of the changes in final net benefits and costs based on adjustments to uncertain variables (see Figure 8).

Information and Data Needs

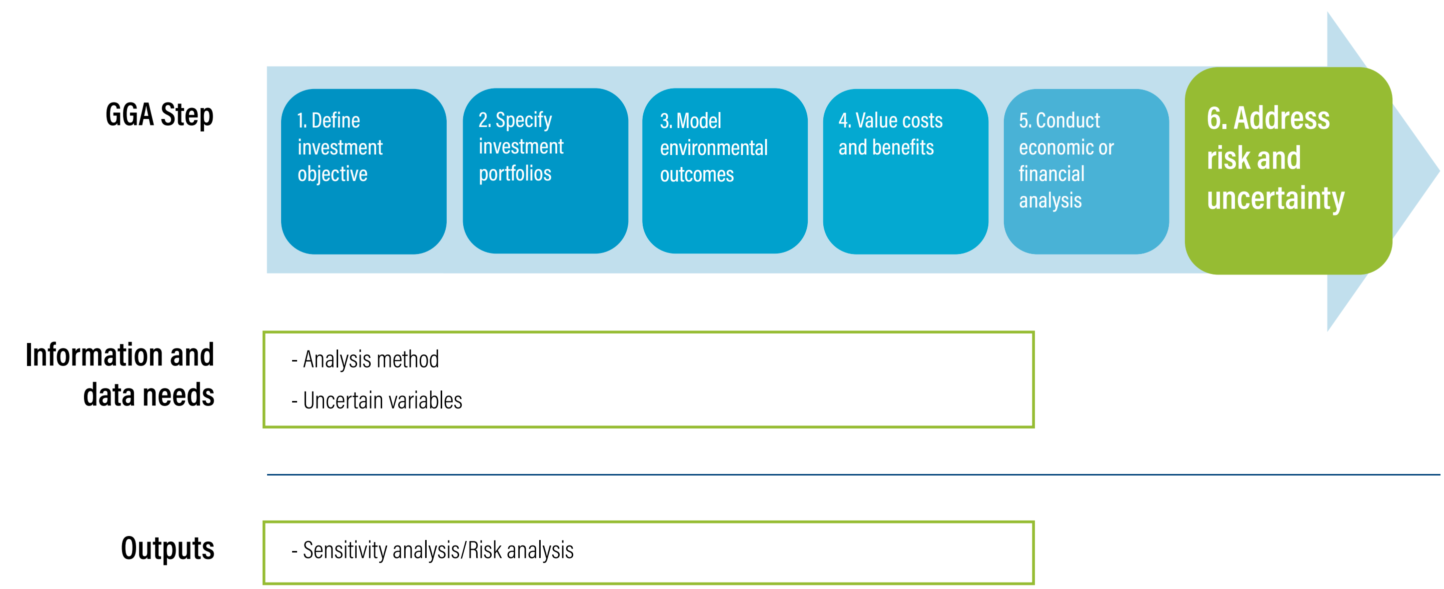
Select analysis method for addressing risk and uncertainty

Risk and uncertainty can be addressed through different types of analysis. Below are two common methods:

- **Probabilistic or risk analysis:** Risk analysis is appropriate when summary statistics (i.e., probability distribution) of a variable are known and when a variable is thought to be highly random. Risk analysis allows variation of more than one uncertain variable at a time. Monte Carlo simulation is a popular method for risk analysis; it estimates a range of possible results by substituting values based on the variable's probability distribution. An expected utility framework could also be employed, which weights the value of each potential outcome with its probability of occurrence. This approach requires information on probabilities as well as values of potential outcomes (Polasky and Binder 2012).

- **Sensitivity analysis** is appropriate for uncertain variables that lack a probability distribution. It is conducted by changing one independent variable at a time to see how results change. The selection of which variables to include should be based on the following factors:
  - There is medium to high uncertainty.
  - The variable displays nonlinear behavior.
  - The variable represents a high proportion of total costs or benefits.
  - The variable has a high impact on total costs or benefits.

Figure 8 | **Overview of Step 6 Information and Data Needs and Outputs**



Source: WRI.

Select variables to include in risk and/or sensitivity analysis

Some analyses may have many variables that make it too complicated or time-intensive to include all of them in a sensitivity analysis. In such cases, select the top three to five variables with the highest uncertainty or impact on results. We recommend consulting key decision-makers, such as the water supplier, in this process.

PRESENTING RESULTS AND INFORMING DECISIONS

There are multiple ways to display analysis results, and ultimately this should depend on needs of the targeted stakeholders. Water suppliers, technical experts, and approving bodies may wish to see more detailed results and underlying analysis assumptions while advocating partners may wish to see condensed materials with headlining messages and numbers for easy dissemination. For project developers aiming to improve green infrastructure designs, there should be a focus on presenting areas for improvement.

Below, we provide recommendations on presenting and communicating GGA results. These recommendations are based on the authors' experiences overcoming perceived risks of adopting green infrastructure solutions for water suppliers and overcoming challenges of incorporating gray infrastructure financial considerations into green infrastructure planning.

- Because green infrastructure can be a new concept for water suppliers and infrastructure investors, it is important to be transparent about analysis assumptions and uncertainties when presenting results to address the perceived scientific and financial risks of green infrastructure. We recommend the following ways to present results and encourage buy-in by these stakeholders:
  - Display sensitivity analysis results alongside main analysis results to show a range of findings.
  - Provide a technical appendix that provides detailed assumptions, equations, and findings to facilitate easy replication of the analysis (see for example, Feltran-Barbieri et al. 2018; Ozment et al. 2018).
  - Present the flow of benefits, costs, and net benefits over time, rather than just presenting final GGA results. Understanding the annual change in costs, benefits, and net benefits is important for would-be investors to understand when a positive ROI can be expected. This information is also generally useful for improving stakeholders' understanding of the behavior of green infrastructure investments in terms of ecosystem service provision.
- Stakeholders, especially decision-makers, should be involved in developing final GGA materials and a communications strategy to promote uptake of results in decision-making processes. This will help ensure that targeted audiences get the information they need to make more informed decisions. Engaging these stakeholders early on may even facilitate data collection during the GGA process. Using an iterative process to jointly examine results and assumptions can lead to final results being accepted by a wider range of stakeholders (Waite et al. 2013).
- Visual displays of results are an effective communication mechanism. Using a combination of tables with quantitative data combined with graphics displaying annual changes in biophysical outcomes, costs, and benefits is recommended to reach different types of audiences. Additionally, stakeholders can use these graphics for their own presentation purposes. The WRI Latin American case studies (see for example, Feltran-Barbieri et al. 2018; Ozment et al. 2018, 2019) provide examples of visual displays that can be replicated.

While this document guides readers on how to conduct GGAs, information in this paper can be used for other purposes as well:

- Water suppliers and water regulators can use guidance on cost and benefit categories and valuation methods to include green infrastructure in their decision-making processes and standardize consideration of green infrastructure.
- Green infrastructure suppliers can use this guidance to set up data collection mechanisms from the outset to facilitate GGA. Additionally, they can use the GGA to better incorporate financial data on water management and water sector investors' decision-making processes into their conservation plans.
- Wider adoption of the GGA approach by all relevant stakeholders could facilitate easier comparison of green infrastructure values across study sites and benefits transfer analysis. Applying consistent valuation methods and cost and benefit categories across study sites will allow analysts to compare cost and benefit values and increase the accuracy of results.
- Green infrastructure project developers can use the GGA to design interventions that address the needs and concerns of relevant stakeholders, such as would-be investors.
- NGOs and academics can use this guidance to critique and verify financial and economic analyses of green and gray infrastructure.

GLOSSARY

Alternative costs: The least-cost means of providing at least the same amount of physical benefit (CWC 2016).

Assisted forest restoration: An active form of forest restoration, typically applied to areas where natural regeneration is not feasible, that includes interventions such as fencing, soil preparation, tree planting, applying pesticides and fertilizers, and irrigation (Ozment et al. 2018).

Avoided costs: Costs that would be incurred by water infrastructure managers in baseline conditions without green infrastructure interventions (CWC 2016).

Business as usual: What happens in the absence of an infrastructure investment. Commonly referred to as counterfactual or baseline conditions.

Cost-benefit analysis: A decision support tool that estimates and compares the costs and monetized value of the target outputs of a single or multiple investment(s) or policy actions.

Cost-effectiveness analysis: A decision support tool that estimates and compares the costs and outputs of a single or multiple investment(s) or policy actions.

Counterfactual conditions/trends: See "business as usual."

Direct benefits: Benefits derived from an infrastructure investment portfolio that are directly intended or, in other words, match with the environmental outcomes of interest.

Discounting: The process of estimating the present value of a future value or future stream of values.

Ecosystem services: Goods and services provided by ecosystems, typically classified into provisioning services, regulating services, cultural services, and supporting services (Reid et al. 2005).

Environmental outcomes: Water-related outcomes from infrastructure investments that can be provided by green and/or gray infrastructure investments such as water filtration, reduced pollution, aquifer recharge, or flood risk mitigation. For green infrastructure, environmental outcomes are akin to ecosystem services provided by forest ecosystems.

Forest conservation: Preventing the conversion of forests to an alternate land use or degradation by protecting that area through, for example, easements, purchase, or rental. This is often referred to simply as protection (McDonald and Shemie 2014).

Green infrastructure: "Actions to protect, sustainably manage, and restore natural and modiied ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al. 2016). Green infrastructure is also sometimes referred to as natural infrastructure, nature-based solution, or ecosystem-based adaptation. Green infrastructure examples for source watershed protection include forest and ecosystem restoration, conservation, and forest and agricultural sustainable management practices. Green infrastructure can also apply to water supply infrastructure, such as natural aquifers, lakes, and wetlands.

Green infrastructure program or project: A program or project that identifies, plans, and/or implements green infrastructure interventions. Examples include payment for ecosystem service programs, payment for water services programs, or water funds.

Gray infrastructure: Human-engineered or built infrastructure (Gartner et al. 2013). Examples of built infrastructure include water supply and hydropower reservoirs, dams, pipelines, and water and wastewater treatment plants.

Hybrid infrastructure: Green infrastructure in conjunction or combination with gray infrastructure. Examples include bioswales, green roofs, rain gardens, constructed wetlands. A hybrid investment portfolio, however, refers to a combination of green and gray infrastructure components and can include, for example, forest restoration and built water treatment plants.

Implementation costs: The initial capital and land expenditure costs associated with implementing an infrastructure investment portfolio (Verdone 2015).

Indirect benefits: Benefits derived from an infrastructure investment portfolio that are considered complementary or co-benefits.

Investment objective: The objective behind investing in infrastructure, expressed in quantitative terms with a desired environmental outcome or outcomes (Talberth et al. 2013a).

Investment portfolio: An investment portfolio is a unique suite of infrastructure components that could be put together to address the investment objective(s) and provide the targeted environmental outcome(s). A portfolio may consist only of gray infrastructure components, only of green infrastructure components, or a combination of both (Talberth et al. 2013a).

Natural forest regeneration: A passive form of forest restoration that is defined by Ozment et al. (2018) as fencing off a degraded area that was previously forested to allow it to return to forest.

Operation and maintenance costs: Recurring costs of labor, equipment, and materials needed to ensure that an infrastructure investment portfolio is maintained and operated well.

Opportunity cost of capital: The rate of return that could have been earned by putting the same money in an alternative investment with a similar risk profile (Pure H20 2019).

Opportunity costs: Foregone income from implementing the investment portfolio (Verdone 2015).

Private discounting: Discounting from the perspective of a private individual or firm (U.S. EPA 2010).

Return on investment analysis: A decision support tool commonly used for financial analysis that estimates the return on an investment relative to that investment's cost.

Risk: Describes a situation where the probability distribution of an outcome occurring is estimated.

Sensitivity analysis: A study of how the uncertainty in the output of a mathematical model can be apportioned to different independent variables.

Social discounting: Discounting from the perspective of society as a whole (U.S. EPA 2010).

Source watershed: A watershed that drains into a body or bodies of surface or ground water that are used by a water supply system.

Time horizon: The time period to be used for the analysis. The time horizon should correspond with the useful life of major gray infrastructure components affected by green infrastructure investments as this aligns with the time over which decisions are likely to be made by water infrastructure managers (Talberth et al. 2013a). Time horizon is also frequently referred to as planning horizon or time frame.

Transaction costs: Costs associated with the time, effort, and resources to search out, initiate, negotiate, engage, and enable stakeholders to complete a deal (Lile et al. 1998).

Uncertainty: Describes a situation where the probability distribution of an outcome occurring is not known or estimated.

Useful life: The length of time a piece of infrastructure can be productively used; also called lifespan.

Water suppliers: Owners, operators, and managers of public and private water supply systems.

Water supply system: A system for the collection, transmission, treatment, storage, and distribution of water from source to consumers (OECD 2001).

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.