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TECHNICAL NOTE

# NATURAL INFRASTRUCTURE FOR AQUIFER RECHARGE FINANCIAL CALCULATOR: METHOD, DATA, AND ASSUMPTIONS

**ANA GABRIELA MORALES, SUZANNE OZMENT, AND ERIN GRAY**

## EXECUTIVE SUMMARY

This document provides information on the methods, data, and assumptions used to create the Natural Infrastructure for Aquifer Recharge Financial Calculator, a flexible financial model that estimates the private costs and benefits, including the return on investment (ROI), of natural infrastructure interventions designed to enhance aquifer recharge.

This calculator was designed to help water-sector decision-makers of Nuevo León and the Monterrey Metropolitan Water Fund (Fondo de Agua Metropolitano de Monterrey) better understand the role that natural infrastructure (also called green infrastructure) can play in water security. Its flexible design also has the potential to produce similar assessments for other territories in the future.

The calculator can perform several functions:

- Communicate to policymakers and water-sector decision-makers the benefits that natural infrastructure can have for aquifer recharge, which is a key element of water security. The calculator translates aquifer recharge impacts into easy-to-understand financial terms to evaluate its related ROI.
- Improve natural infrastructure program design. It provides an analytical framework to determine the ideal type and scale of intervention and to estimate the necessary amount of funding to implement different natural infrastructure strategies.

## CONTENTS



*Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.*

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Box 1 | **Abbreviations**

| | |
|---|---|
| **CONAFOR** | National Forestry Commission of Mexico (Comisión Nacional Forestal) |
| **CONAGUA** | National Water Commission (Comisión Nacional del Agua) |
| **CP** | conservation and protection |
| **DOF** | Diario Oficial de la Federación |
| **HF** | hydro forest |
| **I&E** | investment and establishment |
| **IRR** | internal rate of return |
| **ROI** | return on investment |
| **MIA** | maximum impact area |
| **MMWF** | Monterrey Metropolitan Water Fund (Fondo de Agua Metropolitano de Monterrey) |
| **NPV** | net present value |
| **O&M** | operation and maintenance |
| **PES** | payment for ecosystem services |
| **RV** | revegetation |
| **SADM** | Water and Drainage Services of Monterrey (Servicios de Agua y Drenaje de Monterrey) |
| **SF** | surface |
| **SMN** | National Meteorological Service (Servicio Meteorológico Nacional) |
| **TNC** | The Nature Conservancy |
| **UG** | underground |

- Identify key data gaps and sources of uncertainty (e.g., data, scientific, and behavioral uncertainty) that would have an impact over the business case, and which should be addressed in the program's design process.

The inputs required for the tool's performance fall into three categories: general assumptions, to constrain the analysis to a specific case; biophysical assumptions, to establish the characteristics of the territory; and economic assumptions, to conduct a financial evaluation relevant to the prevalent market conditions. The financial results given by the tool derive from the valuation of two main benefits: avoided costs and profits gained.

This calculator is currently a prototype, as the local data required for its validation is not available. For example, observed data regarding the impact that natural infrastructure has on aquifer recharge rates is missing for this site, as well as for other places in Mexico. Without this site-specific data or reasonable proxy data, we cannot affirm the accuracy of the calculator's estimates and related ROI. Due to these data gaps, this prototype should mainly be used to demonstrate a process and raise awareness among Monterrey's water stakeholders about the potential role of natural infrastructure; it may also help prioritize research efforts to address decision-relevant data gaps. It should not be used as a stand-alone tool for making investment-related decisions.

To compensate for the uncertainties, the tool provides users the flexibility to test a wide range of hypothetical scenarios using informed assumptions from local experts. The calculator is also able to accommodate customized parameters and local data inputs, which can be easily updated as new information becomes available.

A pilot test of the calculator with the best available (but still incomplete) data and hypothetical assumptions revealed that natural infrastructure only needs to produce a modest increase in infiltration rates of 2.5 percent in order to achieve a positive net present value (NPV). Further research is needed to confirm whether natural infrastructure can indeed achieve this increase.

Despite ample room to improve the methods and assumptions used, we expect the prototype calculator to illuminate the numerous arguments for using natural infrastructure as a cost-effective option for leveraging water resilience and meeting cities' water security goals.

## INTRODUCTION

The Natural Infrastructure for Aquifer Recharge Financial Calculator was designed to evaluate the potential private costs and benefits of investing in natural infrastructure for aquifer recharge in the San Juan River Basin of Nuevo León, Mexico. In doing so, it provides a way to analyze the role natural infrastructure plays in securing water in the Monterrey metropolitan area.

The tool aims to inform the strategy of the Monterrey Metropolitan Water Fund (MMWF), a multistakeholder program that promotes investment to preserve the upper watershed ecosystems and groundwater infiltration areas.

The goal is to "guarantee the quality and quantity of the water supply for Monterrey, while reducing the risk of disaster due to flooding events" (Latin America Water Funds Partnership 2017).

The MMWF was established by The Nature Conservancy (TNC), the FEMSA Foundation, the National Forestry Commission of Mexico (Comisión Nacional Forestal; CONAFOR), the state government, and others. It now has about 80 partners, including many businesses that operate locally in Monterrey and donate funds to support the work. The fund aims to engage local water beneficiaries to participate and coinvest in fund activities.[1] These beneficiaries include the following organizations:

- The state water utility, the Water and Drainage Services of Monterrey (Servicios de Agua y Drenaje de Monterrey; SADM), which is responsible for operating the state's water distribution system, making it the most direct financial beneficiary of successful natural infrastructure strategies.
- The state government of Nuevo León, which oversees and shares the political and budgetary responsibilities of the water utility and would benefit from having a more resilient, efficient, and secure water distribution for its population.
- The National Water Commission (Comisión Nacional del Agua; CONAGUA), the federal entity in charge of granting the water-body concessions within the country, which would also benefit from lowering the budgetary, technical, and political pressures burdening a water system at risk of overexploitation.

These entities are already searching for cost-effective solutions to maintain groundwater supply into the future as well as to increase surface water supply, considering the growing gap between supply and demand in Monterrey.

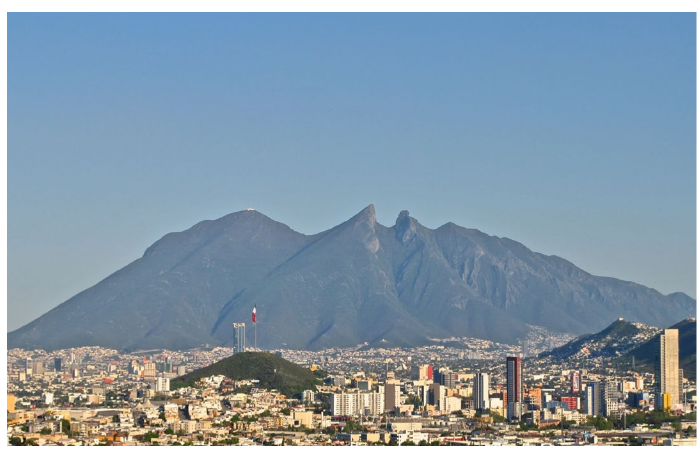
To engage these beneficiaries in the MMWF, a robust business case for investing in natural infrastructure is needed. As a hypothetical benchmark, TNC has posited that the fund should aim to increase the amount of water available for aquifer recharge by 20 percent, which would improve groundwater supply and reduce the costs associated with managing and treating more expensive surface water systems. If these benefits could be achieved (either partially or fully), the SADM, CONAGUA, and the state government all stand to benefit from reduced operation costs and improved system resilience.

## STUDY AREA

The metropolitan area of Monterrey sources its water from the San Juan River Basin. The region's hot, dry climate faces seasonal periods of intense rainfall and prolonged dry periods (Sisto et al. 2016). The water supply system includes three major surface reservoirs (El Cuchillo, Cerro Prieto, and La Boca) and four principal underground systems (Campo Buenos Aires, Cañón del Huajuco, Área Metropolitana de Monterrey, and Campo Mina). According to official government data from the Diario Oficial de la Federación (DOF), all four of these aquifers are overextracted (DOF 2018a).

Known as "the City of Mountains," Monterrey is surrounded by tall, green mountains jutting out of an otherwise flat, dry, and brown landscape (see Figure 1). These unique topographic and ecological features greatly impact water resources. Part of the Sierra Madre Oriental range, these mountains are mostly protected as national parks or belong to a legally declared natural protected area of federal or state jurisdiction. Cerro de la Silla, Cañón del Huajuco, Cerro del Obispo, Cerro del Topo Chico, and Cerro de las Mitras are located on territory that also includes Cumbres de Monterrey National Park. The MMWF considers this a priority area for natural infrastructure management.

Figure 1 | **Cerro de la Silla and the Monterrey Metropolitan Area**



*Source:* Alejandro Galindo/Flickr

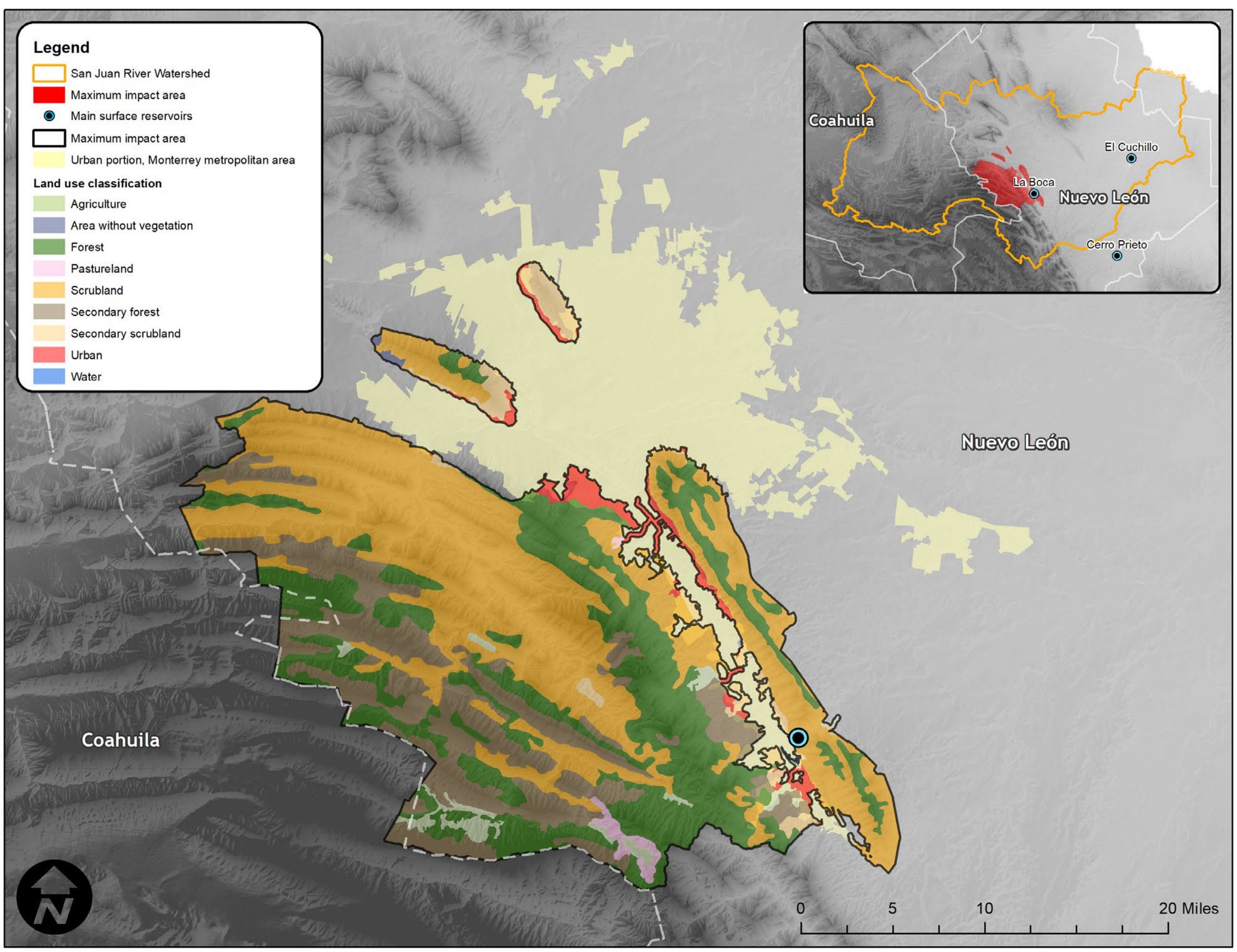
Reaching as high as 3,400 meters above sea level, these mountainous areas are typically pine-oak and scrub forests representative of the Sierra Madre Oriental ecoregion. The mountains possess fractures and permeable geologic structures that are known to recharge aquifers, although these recharge zones are neither well mapped nor studied.

Many communities reside in these natural areas and the national park. For example, more than half of Cumbres de Monterrey National Park legally belongs to *ejidos* and *comunidades* that manage their lands communally as productive pastures for cattle, goats, and subsistence agriculture. These communities must follow government conservation rules (Clifton et al. 2016).

The MMWF has defined a maximum impact area (MIA) within the San Juan River Watershed where it focuses its natural infrastructure interventions. This is 151,958 hectares (ha) of territory that covers part of the Santa Catarina River catchment area. Hesselbach et al. (2016) point out that at least 60 percent of the water that goes to the Monterrey metropolitan area comes from this territory. In alignment with the MMWF's efforts, this research adopted the MMWF's MIA as the core territory for its target area and pilot analysis.

Officially classified land covers within the San Juan River Basin are shrubland or scrubland (50 percent), agriculture (16 percent), forest (primary and secondary forest types, 15 percent), and pasture (14 percent) (CONABIO n.d.), whereas the MIA is primarily composed of forestland and scrubland in the mountains (see Figure 2).

Figure 2 | **Land Use within the MIA of the MMWF's Intervention Strategy in the San Juan River Watershed**




*Sources:* Adapted from Hesselbach et al. 2016 and CONABIO n.d.

Remote sensing data and national databases show that, for the most part, these areas are in good ecological health and conservation status. However, local stakeholders and experts cite encroachment, fires, invasive species, pests, and climate variability as drivers of ecosystem degradation. Hesselbach et al. (2016) also point to soil erosion as a major threat, and report that at least 53 percent of the MIA has either high or very high levels of erosion. Stakeholders suggest further conservation actions could boost ecosystem health and resilience, whereas TNC has identified degraded areas within their MIA that could be restored.

It is still unknown how the conservation and forest restoration agendas could impact groundwater supply, but these groups believe the impact could be positive. Their main arguments relate to the notion that improving vegetation conditions and soil health could reduce the peak runoff and enhance the land's ability to retain water and promote greater infiltration.

## CALCULATOR OVERVIEW

To support the MMWF's strategic planning and selection of interventions, WRI has produced a flexible tool—the Natural Infrastructure for Aquifer Recharge Financial Calculator—to evaluate the potential financial performance of the fund's natural infrastructure intervention strategies. This calculator draws on the Green Gray Assessment methodological framework developed by WRI (Gray et al. forthcoming).

A variety of calculators, guides, and models already exist for evaluating sustainable and cost-effective water resource management solutions in the face of increasing water risks worldwide.[2] Unlike other tools, however, the Natural Infrastructure for Aquifer Recharge Financial Calculator translates the impacts of natural infrastructure interventions on groundwater supply into critical financial performance metrics for water supply system actors, such as ROI and net present value (NPV). The tool's strengths lie in its scenario-planning capabilities. Rather than only providing a financial analysis for a fixed set of data, this tool can model various hypothetical scenarios and easily assimilate new or better data as it becomes available. This calculator can be used in tandem with some of these other tools to characterize in greater detail the various environmental, political, and economic implications of different natural infrastructure strategies.

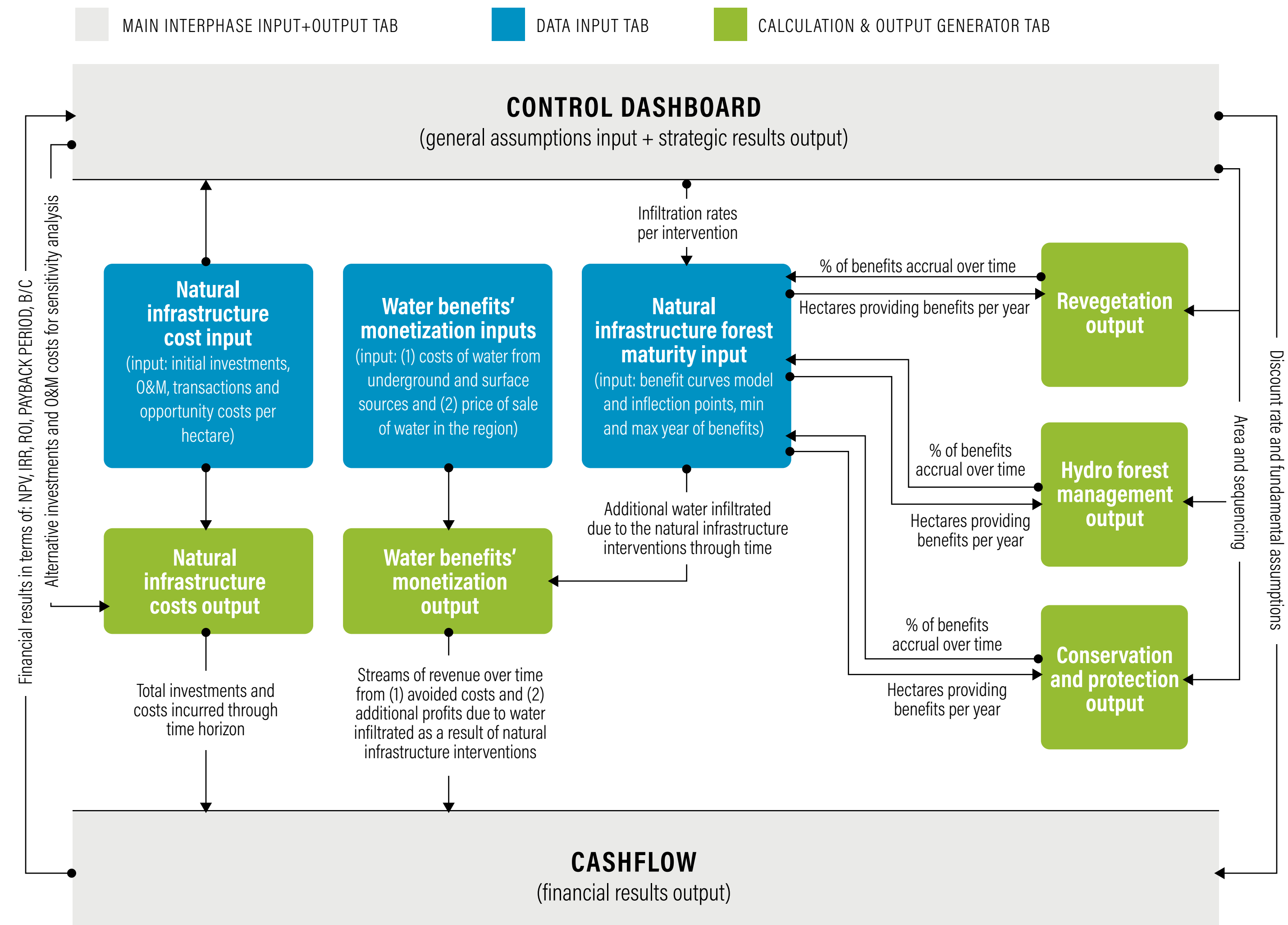
The current prototype version estimates two main sources of direct benefits. It focuses on monetizing the avoided costs of supplying water from alternative existing sources (surface reservoirs and dams) and the potential profit gains that the water utility may capture as a result of the additional water in situ, available for market distribution.

Other direct benefits of aquifer recharge that are not currently considered in the tool but might apply to other contexts include avoided costs of installing new infrastructure, avoided costs associated with groundwater overexploitation (e.g., the costs of subsidence, saltwater intrusion, or the decommissioning of an aquifer), avoided costs of water transfers from distant watersheds, and avoided costs related to drought or meeting emergency supply, among others. These additional benefits, as well as those related to other natural infrastructure environmental services, could be incorporated in the future if the relevant information is available.

The Natural Infrastructure for Aquifer Recharge Financial Calculator is an Excel-based tool built over 10 interconnected tabs (see Figure 3). It combines fixed and variable inputs.

Across the tool, users can only adjust the values on cells marked in yellow. Each of the adjustable cells relates to an input or assumption that sets boundaries of the scenario being evaluated (see Table 1). All other cells pertain to either fixed assumptions, automated calculations, or results.

Figure 3 | **The Calculator's General Outline: Tab Interconnections**




*Source:* WRI.

The required inputs for the tool's performance are discussed in three sections in this document:

- General assumptions, which refer to elements that constrain the analysis to a specific case. They include concepts like the time horizon, discount rate, and green infrastructure implementation sequencing plan. These general assumptions will be an input to the Control Dashboard tab and will have a direct or indirect effect on all the other tabs.
- Biophysical assumptions, which pertain to the assumed characteristics of the territory, including climatic and biological conditions. Concepts like precipitation and infiltration rates, the growth speed of vegetative species, and the timeline to accrue infiltration benefits all belong to this category. The majority of these assumptions would be entered either into the Control Dashboard or the Forest Maturity Input tab. Their impact and results are automatically computed on the Revegetation (RV), Hydro Forest (HF) Management, and Conservation and Protection (CP) Output tabs and then automatically transferred to the Cashflow tab.

Table 1 | **The Calculator's Adjustable Assumptions (Dynamic Inputs)**

| GENERAL ASSUMPTIONS | TOLL TAB | CELL |
|---|---|---|
| Discount rate (%) | CTRL Dashboard | B7 |
| Target area (ha) | CTRL Dashboard | B8 |
| Sequencing (yrs) | CTRL Dashboard | B9 |
| Investment portfolios—RV | CTRL Dashboard | F6 |
| Investment portfolios—HF management | CTRL Dashboard | F7 |
| Investment portfolios—CP | CTRL Dashboard | F8 |
| **BIOPHYSICAL ASSUMPTIONS** | **TOLL TAB** | **CELL** |
| Infiltration baseline and kept through CP | CTRL Dashboard | B10 |
| Precipitation (mm) | CTRL Dashboard | B11 |
| Infiltration gained by RV | CTRL Dashboard | L6 |
| Infiltration gained by HF management | CTRL Dashboard | L7 |
| RV forest maturity model | 2.0 ForestMat Input | B6, B7, B9 |
| HF management forest maturity model | 2.0 ForestMat Input | C6 |
| CP forest maturity model | 2.0 ForestMat Input | D6, D7, D9 |
| Year of max benefits for RV strategies | 2.0 ForestMat Input | B8 |
| Year of max benefits for HF management strategies | 2.0 ForestMat Input | C8 |
| Year of max benefits for CP strategies | 2.0 ForestMat Input | D8 |
| **ECONOMIC ASSUMPTIONS** | **TOLL TAB** | **CELL** |
| Natural infrastructure costs—RV cost per hectare ($/ha) | 1.0 Costs Input | C6:K13 |
| | CTRL Dashboard *(for cost sensitivity analysis)* | H6:I6 |
| Natural infrastructure costs—HF cost per hectare ($/ha) | 1.0 Costs Input | C18:K25 |
| | CTRL Dashboard *(for cost sensitivity analysis)* | H7:I7 |
| Natural infrastructure costs—CP cost per hectare ($/ha) | 1.0 Costs Input | C30:K37 |
| | CTRL Dashboard *(for cost sensitivity analysis)* | H8:I8 |
| Natural infrastructure opportunity cost | 1.0 Costs Input | C44:K46 |
| Natural infrastructure transaction costs | 1.0 Costs Input | C51:K53 |
| Water from underground sources—cost of provision | 3.0 BenefitsMonetiz Input | C8:C19 or C22 |
| Water from surface sources—cost of provision | 3.0 BenefitsMonetiz Input | D8:D19 or D22 |
| Water provision—cost increase per year | 3.0 BenefitsMonetiz Input | D26 |
| Domestic water consumption and market structure | 3.0 BenefitsMonetiz Input | A31:D31 |
| Public water consumption and market structure | 3.0 BenefitsMonetiz Input | A32:D32 |
| Commercial water consumption and market structure | 3.0 BenefitsMonetiz Input | A33:D33 |
| Industrial water consumption and market structure | 3.0 BenefitsMonetiz Input | A34:D34 |

*Source:* WRI.

- Economic assumptions, which establish the customized cost and benefit conditions for the financial analysis, include:
  - Natural infrastructure cost assumptions, which refer to the local costs to be incurred to implement the natural infrastructure strategies. These are required on the Costs Input tab, and their consequent results are automatically computed on the Costs Output tab and transferred to the Cashflow tab.
  - Water benefit assumptions, which refer to market assumptions to monetize the water benefits obtained through interventions. These assumptions would be inserted on the Benefits Input tab and computed on the Benefits Output and Cashflow tabs.

We expect users to make changes mainly to the general analysis assumptions (Control Dashboard) and the customizable financial data (Costs Input and Benefit Input tabs). However, most of the inputs associated with the biophysical assumptions and models can also be changed (Forest Maturity Input tab).

## CALCULATOR COMPONENTS, METHODS, AND ASSUMPTIONS

### General Assumptions

This section describes the contextual variables for the evaluation. It outlines the foundational assumptions that confine the study to the territory and aspects of interest, such as the target area, time horizon, and restoration types, among others (see Figure 4).

All general assumptions are entered into the Control Dashboard tab, which connects user inputs to all other processing tabs and computes the financial impacts of the established scenario. As the main user interface, the Control Dashboard will also display the most strategic results from the financial analysis. These assumptions and inputs would ideally be defined by project stakeholders and local research.

#### Land use

*(Fixed assumption, cannot be manipulated by the user)*

Our study assumes that land use remains constant into the future, which means the target area will not change over time. Land cover data from Hansen et al. (2103) shows that this area has not experienced significant land use change in recent years. There are no known studies projecting future land cover in this region.

Figure 4 | **General Assumption Variables in the Calculator**

| General assumptions | Value |
|---|---|
| Land use | Constant |
| Time horizon | 30 years |
| Discount rate (%) | 10.0% |
| Target area (ha) | 29,172 |
| Sequencing (yrs) | 30 |

| Natural infrastructure investment portfolios | % of total |
|---|---|
| | |
| ✓ Revegetation (RV) | 0.06% |
| ✓ Hydro Forest management (thining & pruning) (HF) | 42.03% |
| ✓ Conservation and protection (CP) | 57.91% |
| Totals | 100% |

*Note:* Included values are hypothetical references.
*Source:* WRI.

## Time horizon

*(Fixed assumption, cannot be manipulated by the user)*

Time horizon defines the amount of time in which costs and benefits will be accounted. The time horizon for this financial model is 30 years, which is what public sector decision-makers in Mexico use. This assumption aligns with guidance from the DOF (2013), Meixuerio Garmendia et al. (2017), and Hernández Pérez et al. (2015).

## Discount rate

*(Dynamic input, cell B7 on the Control Dashboard tab)*

The discount rate is used to determine the present value of future cashflows and to reflect the cost of financing the project. The selection of the discount rate largely depends on whether the project is evaluated from a private or social perspective, and on the cost of the capital granted by financing institutions. The lower the discount rate, the higher the chances of getting a favorable result. However, the discount rate selection must always be a direct reflection of the financial reality in the territory where the project is evaluated, considering the risk of the investment and the cost of capital granted by financiers. For the Monterrey case study, it could be between 6 and 22 percent, depending on the source of funding (see Table 2).

A conservative 10 percent rate shall be used for any public investment analysis, as recommended by DOF (2013).

## Target area

*(Dynamic input, cell B8 on the Control Dashboard tab)*

This represents the total area (in ha) where the natural infrastructure strategy would be implemented. It is a variable input so that users can compare the results of different intervention scales. For our case study and financial pilot, we selected a target area of 29,172 ha. This territory presents adequate conditions for aquifer recharge (due to its topography and geologic features such as permeable soils and fractured bedrock) and is a prime area for forest conservation, management, or restoration strategies (based on Hesselbach et al. 2016 and 2018).[3] Figure 5 shows the areas where the potential recharge zones overlap with the MMWF's potential intervention strategies zones.

## Sequencing of the natural infrastructure implementation plan

*(Dynamic input, cell B9 on the Control Dashboard tab)*

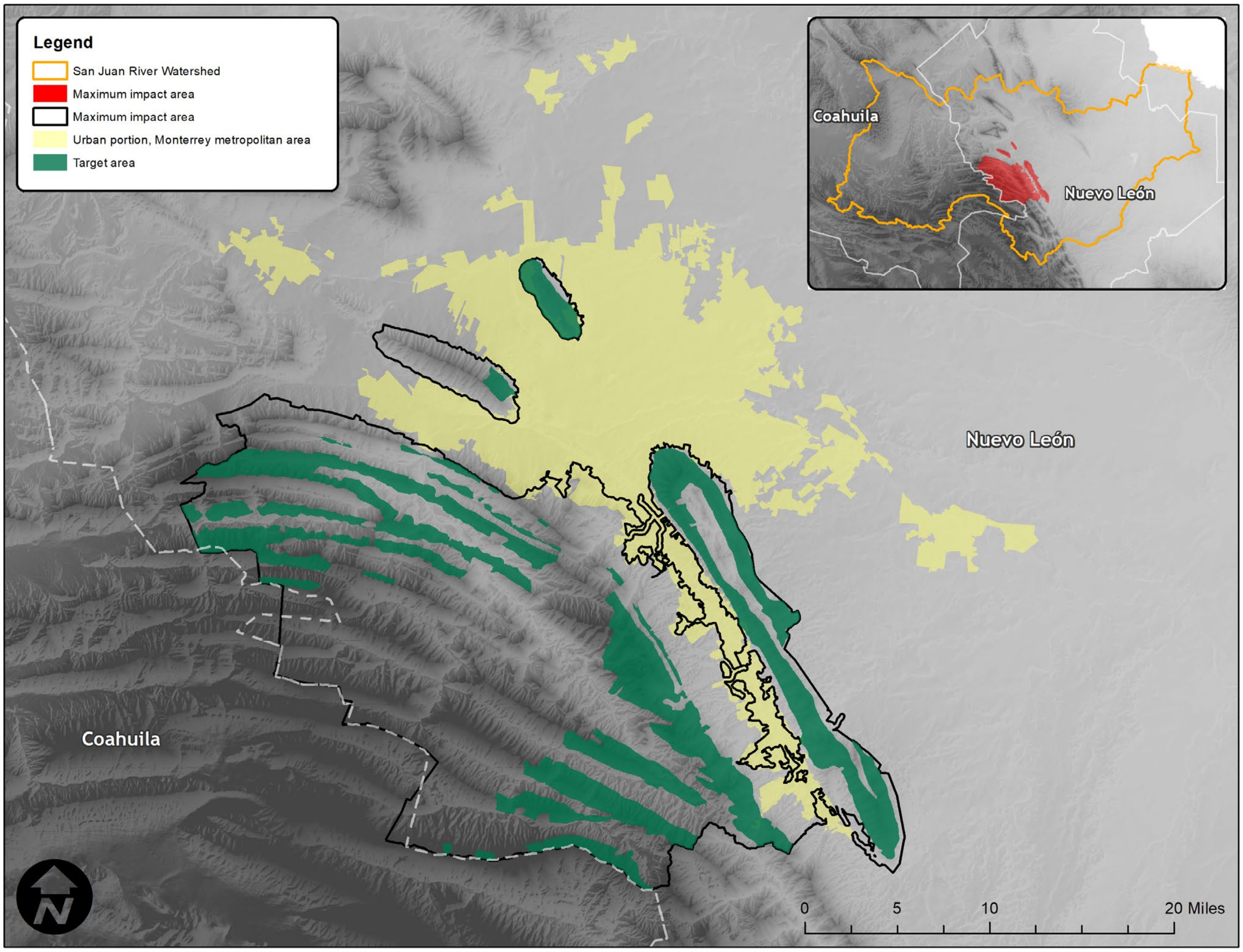
Because natural infrastructure interventions could be implemented within one year or over several, the tool lets users select the timeline. The sequencing plan specifies how many years are needed to implement the natural infrastructure intervention plan. This value should align with the implementers' financial, technical, and operational capacity to roll out the intervention strategies over time. It will help represent the progression of expenses over the cashflow. All interventions will be tied to the same sequencing plan selected by the user. We assume that the interventions will be conducted at a constant rate over the duration of the selected time frame (e.g., on a targeted area of 1,000 ha with a 10-year sequencing, 100 ha will be implemented per year).

Table 2 | **Discount Rate Reference Guide**

| SOURCE | DISCOUNT RATE |
|---|---|
| Conservative (low-end) rate. Equivalent to the interest rate extended by the Infrastructure and Public Services National Bank (Banco Nacional de Obras y Servicios Públicos; BANOBRAS) on strategic public investment credit loans, also aligned with the current interbank equilibrium rate from the Mexican national bank (Banco de México; BANXICO). | 6–8% |
| Discount rate recommended by the Mexican Ministry of Finance (Secretaría de Hacienda y Crédito Público; SHCP) for social cost-benefit investment analyses. | 10% |
| Discount rate recommended by Inter-American Development Bank (IDB) on Latin American cases. | 12% |
| Cost of capital for private investments in Mexico. Conservative scenario, may vary according to specific conditions such as risk and guarantees related to the investor and the project. | 18–22% or more |

*Sources:* Banco de México 2018; DOF 2013; Meixueiro Garmendia et al. 2017; Campos et al. 2015.

Figure 5 | **Natural Infrastructure Target Area Defined for the Calculator Pilot Analysis**




*Source:* Hesselbach et al. 2016; Hesselbach et al. 2018; CONABIO n.d.

## Natural infrastructure investment portfolios

*(Dynamic inputs, cells E6:F8 on the Control Dashboard tab)*

The natural infrastructure investment portfolios are bundles of potential natural infrastructure interventions designed to target specific land cover conditions to enhance hydrologic functions. The portfolios highlighted in this tool are adapted from the MMWF's Conservation Plan[4] and were selected on the basis of their relevance to current land cover and condition as well as cost-data availability.

- **Revegetation (RV):** Treeless or degraded hectares that could be restored to forest. In our target area, the hectares that could be revegetated would most likely require tree or shrub planting. This intervention requires high up-front costs and takes several years to accrue benefits. Typically, more mature forests provide more ecosystem services than young forests. This is the case with aquifer recharge, where younger forests typically use more water than they recharge, and older forests have lower evapotranspiration rates.

  *Suggested inputs to the calculator for Monterrey:* Between 0 and 1 percent from the 29,172 ha target area (those that hold potential for revegetation, are currently under agriculture, or are pasture or bare land).

- **Hydro forest (HF) management:** Forest areas that could be improved through hydroecological restoration practices such as clearing, pruning, thinning, and erosion control. The benefits of this improved management accrue immediately. Although these practices may not increase the forest's recharge capacity per se, they do reduce evapotranspiration.

  *Suggested inputs to the calculator for Monterrey:* Between 0 and 42 percent from the 29,172 ha target area (which represents Monterrey's forest and vegetated areas in poor or fair condition and thus suitable for this type of intervention).[5]

- **Conservation and protection (CP) of existing vegetative cover:** Healthy forest hectares in need of additional protection. Forests can be protected through fencing or by making agreements with communities to restrict their activity to compatible uses. The benefits of conservation begin to accrue instantly and must be measured by avoided costs of inaction.[6]

  *Suggested inputs to the calculator for Monterrey:* Between 0 and 57 percent from the 29,172 ha target area (related to hectares of forest in good condition, according to MMWF Conservation Plan maps provided by TNC). To maximize aquifer recharge benefits in this territory, conservation of existing vegetative cover should target scrub and oak forests.

Box 2 provides a series of recommendations and rationale to select the investment portfolio for the Monterrey case.

### Box 2 | Selecting a Green Infrastructure Investment Portfolio for Aquifer Recharge in Monterrey

Designing natural infrastructure interventions requires careful consideration of biophysical relationships and thresholds and on-the-ground realities.

Although some studies have shown that healthy forests can help improve aquifer recharge, contrary to conventional wisdom, a forest in good biological condition may or may not be compatible with aquifer recharge goals (see Box 3). Many studies have also found the converse to be true. The mixed results of scientific studies suggest that using forests to achieve aquifer recharge goals must be carefully planned and informed by the best available science. A paucity of local studies about these links in the Monterrey region presents challenges to selecting the right mix of green infrastructure to achieve water management objectives.

Based on the best available literature to date, to achieve optimal aquifer recharge in Monterrey's dry, hot climate, a natural infrastructure strategy must include these objectives:

- **Target high impact areas:** Areas that provide greater impact in terms of aquifer recharge should be targeted for restoration or conservation. Even if a large area is available for forest restoration, an optimal aquifer recharge may be achieved by restoring only a portion of that area.
- **Aim for intermediate tree cover density:** Planting trees at low to moderate density allows sufficient groundwater percolation while controlling evapotranspiration rates.[a] Under this principle, forests are able to grow and communities can continue cultivation activities, making it compatible with rural food security and economic opportunities. Due to a lack of local studies on this topic, the optimal tree cover density to promote groundwater infiltration in this region is unknown. The calculator's default settings optimistically assume that the correct density is applied.
- **Identify the optimal tree species for the region:** Elevation, climate, and other biophysical elements impact the recharge rates for a given species. For example, conifer trees can have lower recharge rates than deciduous trees in hot, dry climates due to their higher evapotranspiration rates. However, at high elevations, some conifer species capture fog and deliver it to the ground, generating water supply that would otherwise remain in the atmosphere. In Monterrey's hot, arid climate, deciduous trees likely have the higher recharge rate, though no local studies are available to corroborate this.
- **Utilize improved forest management practices (hydro forest management strategies):** These practices include pruning and thinning vegetation to control evapotranspiration rates, or erosion control and fire control practices to maintain healthy soil and reduce runoff in appropriate areas.[b] In addition, wood collected from thinning and pruning can have a positive financial impact on communities in need of building materials or firewood. Exceptions are that forest thinning on steep slopes could increase runoff and reduce slope stability. Evapotranspiration can lead to more moisture in the atmosphere and more rainfall in nearby areas—so management practices to control evapotranspiration may be less suitable if a broader scope of assessment is adopted.

For these reasons, one interpretation of the literature would be that assisted forest restoration (revegetation or hydro forest management) could best enhance aquifer recharge for this biome and climate, where the density, species, and location of forests can be controlled better than through natural regeneration or by conserving existing forest.

As additional research linking forests to aquifer recharge becomes available in the future, it will be easier to design interventions. Ideally, users will have designed a green infrastructure portfolio using a biophysical model and by working with local experts and stakeholders prior to using this tool.

*Notes:* a. Ilstedt et al. 2016; b. Smith et al. 1997.

## Biophysical Assumptions

This analysis assumes that a change in the study area's land cover condition and management (through natural infrastructure interventions) impacts the volume of the underground water supply. This section provides guidance and recommendations for selecting values related to aquifer recharge and the other biophysical variables. A number of variables related to forest condition and type can impact aquifer recharge rates, including forest age and maturity, tree species, and tree density and spacing. The impact these variables have on aquifer recharge is not well understood globally and is not well researched locally, at our study site or similar sites. Due to these important data gaps, our calculation aims to be flexible, customizable, and comprehensible, rather than detailed. The calculator's purpose is not to output a single predictive value to represent the impact of land cover change on groundwater availability; rather it is to identify a possible range of impacts by characterizing some probable linkages among precipitation, forest cover, and aquifer recharge on the basis of the best available data.

### Precipitation

*(Dynamic input, cell B11 on the Control Dashboard tab)*

Precipitation levels directly impact the amount of groundwater recharge, because a portion of the water from precipitation ultimately makes its way to underground water reserves. On the basis of consultation with experts in watershed science and hydrology, the tool applies a yearly average precipitation volume[7] (in mm) to the entire testing area.[8,9] This value is held constant over time during the analysis, although users can change it to simulate higher or lower rainfall averages.

Consulted literature about the case study region (the Monterrey metropolitan area) reported average annual precipitations of 616 mm and 622 mm (Sisto et al. 2016; Aguilar-Barajas et al. 2015) These sources also reported inter-annual variability and prolonged periods of water scarcity. Observed data was available from two sources: the MMWF (2001–2015), and the National Meteorological Service (SMN) (1957–2016). Annualizing these data sets and organizing them into frequency charts produced an average of 636 mm/year, with standard deviations of +/- 216 mm/year. It is important to understand the limitations when using average rainfall in a territory like Nuevo León, which is prone to cyclonic activities and has pronounced seasonal and inter-annual variability. The most important limitations are described later in this document. We strongly recommend users to become familiar with these limitations to ensure they correctly interpret the calculator's results.

### Forest maturity and ecosystem services dynamics over time

*(Dynamic variables, tab 2.0 Forest Maturity Input, yellow cells on B6:D9, underlying calculations on tabs 2.1, 2.2, 2.3)*

Forest type, condition, density, maturity, and other features can impact the portion of rainwater that ultimately infiltrates groundwater systems. Of these, forest maturity has a particularly unique and powerful impact on infiltration and is an important factor for all natural infrastructure interventions. Generally, studies show that younger forests consume more water as they grow, which can reduce infiltration rates; in turn, older forests are more likely to have a positive impact on water infiltration because they consume less water, provide shade that inhibits evapotranspiration, and have deep, complex root systems that can slow water runoff and promote soil absorption.

It is important to account for these trends over time when analyzing the benefits of forest restoration and conservation, especially when conducting a financial analysis. Revenues derived from aquifer recharge may not be immediate and may change over time through the cashflow.

This calculator roughly assumes that the level of aquifer recharge services correlates to the rate of forest recovery and that forests provide their maximum possible aquifer recharge services when they reach full maturity (potentially after 30–40 years of growth, adapted from findings from Poorter et al. 2016). Prior to maturity, forests provide only a portion of maximum potential aquifer recharge. No study has estimated the flux of aquifer recharge rates in a restored natural forest over a 30-year period for the forests in this study area. Still, forest recovery rates have been observed for the neotropics and other nearby regions.

Given the lack of specific data to precisely determine the benefit progression of the interventions, our model uses a transformation of a logistic curve to characterize the groundwater infiltration rates over time. This mathematical function is commonly known as an S-shaped curve and is used to represent growth models with increasing and then decreasing rates of growth in an established time horizon. The formula used is defined by the equation $X_i\,(t)$.

EQUATION 1

$$X_i(t) = Min_i + \frac{K_i}{1 + e^{b_i - r_i t}}$$

Where

$X_i(t)$ Rate of benefit accrual from the intervention (*i*) for each time period (*t*)

$Min_i$ Minimum value of benefits that intervention *i* could provide (%)

$K_i$ Maximum percentage of benefits that the intervention can produce (curve range of the intervention *i*)

$b_i - r_i$ Rate of change of the intervention *i*, where *r* and *b* define the curve's slope and its amplitude of growth. In our model, this results from the combination of the following two parameters:
($b_i$) The year when the maximum benefits of the intervention *i* are met
($r_i$) The moments when the marginal rate of benefits of intervention start to (1) increase and (2) decrease

*t* Time in years, where (for our analysis, m is limited to the 30 years of the time horizon)

*i* The intervention (revegetation, hydroforest, and conservation and protection)

This function allows for additional parametric adjustments to characterize different benefit progression curves. Specifically, users can manipulate the following four simplified parameters on tab 2.0 Forest Maturity Input to change the shape of the S-curve:

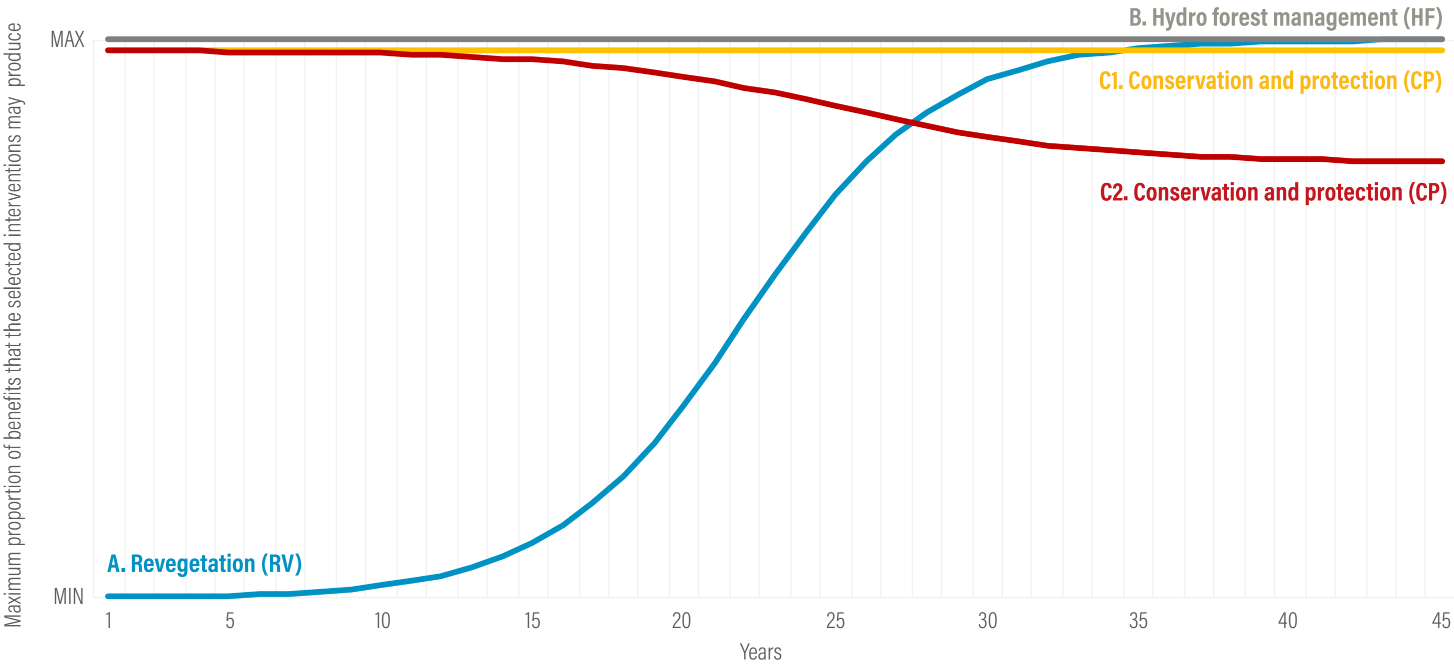
- **The maximum percentage of benefits that the action can produce** (cells B6:D6). We recommend this be kept at 100 percent, which means achieving the maximum intended benefits by the time this limit is met.
- **The minimum percentage of benefits that the action can produce** (cells B7:D7). We recommend this be kept at 0 percent unless there is reason to believe a different minimum value would better represent reality. Zero percent means achieving "no benefits" by the time this limit is met.
- **The year when maximum benefits are achieved** (cells B8:D8). We recommend keeping this value between 30 and 40 years, unless there is expert advice or literature that suggests the maximum maturity and maximum benefits (100 percent) are achieved at a different year.[10]
- **The inflection points for commencement and conclusion of benefits** (cells B9,D9). This functionality allows the user to test different years when the rate of benefits start to become apparent (initial years) and start to disappear (final years). This is not an accurate value like the years of maximum benefits. Instead, it is an intuitive range of years that can be adjusted by a dynamic scroll, which tests different "b values" that automatically adjust the slope of the curve (r) while not affecting the maximum year of benefits (also related to the slope).

As a result of these customizations, the benefits of each intervention are shaped by a different benefits progression curve,[11] one that properly represents the lag time required to accrue the intervention's benefits, as presented in Figure 6.

### A. REVEGETATION, FOREST MATURITY AND BENEFIT PROGRESSION MODEL

Benefits derived from revegetation strategies are assumed to follow a traditional logistic curve. The S-curve pattern describes the expected progression of potential aquifer recharge associated with forest growth. During the first years, the young trees and forests may consume more water than they allow for infiltration. Once a certain maturity level is reached, the forest will require less water for growth and promote less evapotranspiration (displayed graphically by an inflection point in the S-curve). The exact year of this occurrence will vary by region and species. In our model, this situation translates into a benefit behavior change, going from a more accelerated accrual of benefits to slower accrual, until it reaches its maximum potential of benefits at full maturity (curve A in Figure 6 ).

Figure 6 | **Benefit Progression Characterization Curves (Forest Maturity Time Lag Representation)**




*Note:* For illustrative purposes, not based on observed data for the region.
*Source:* WRI.

**Suggested time frame for revegetation benefits to accrue in the Monterrey case:** Impacts increase to 100 percent in 30 to 45 years, once the trees have grown and the forest structure has fully matured.

### B. HYDRO FOREST MANAGEMENT, FOREST MATURITY AND BENEFIT PROGRESSION MODEL

Under the HF portfolio, benefits are assumed to follow a horizontal line trend. We expect recharge benefits from reduced evapotranspiration and improved infiltration to be fully realized immediately after the HF intervention is completed. Assuming that the interventions are maintained throughout the 30-year period, benefits are expected to remain constant. To represent this dynamic, we relied on the transformation of the logistic function, with a slope of 0 to represent a flat line with a constant state through the time horizon (curve B in Figure 6).[12]

**Suggested time frame for HF management benefits to accrue in the Monterrey case:** 100 percent of impacts are reached in year one and remain constant over time.

### C. CONSERVATION AND PROTECTION, FOREST MATURITY AND BENEFIT PROGRESSION MODEL

Two benefit trends are possible under the CP portfolio.[13] In the first trend, we assume that the progression of benefits can be represented using a horizontal line because the interventions maintain a consistent recharge rate over time (curve C1 in Figure 6). Here, we assume the impacts of avoided deforestation are immediate because deforestation would cause an immediate shift from one land cover to another. If the baseline land cover is providing a service, that service would be immediately lost following conversion. We assume conservation is successful at maintaining a healthy forest, and therefore the benefits persist as a constant into the future. In the second trend, we assume there are reasons to believe that conservation and natural regeneration could potentially lead to a decrease in aquifer recharge (see Box 3 for information on and examples of this occurrence). Here, the transformed S-curve is used to represent a decrease in benefits over time (curve C2 in Figure 6).

**Suggested time frame for conservation benefits to accrue in the Monterrey case:** 100 percent of impacts are immediate (start in year one) and endure throughout the 30-year time horizon.

## Estimated aquifer recharge—infiltration rates obtained per intervention

*(Dynamic inputs, cells L6:L8 on the Control Dashboard tab; underlying calculations in tab 2.3)*

The exact rates of current groundwater infiltration are unknown in the study area. Cedillo de Lucas (2012) estimates an infiltration coefficient of 17 percent and an 82 percent conversion into runoff in the Santa Catarina Basin, which includes our study area. However, this coefficient must be used with caution in our pilot analysis. Infiltration coefficients depend on several variables and the specific conditions under which they were calculated. Thus, they can vary significantly across the territory. Further details about this and other limitations associated with the methods utilized in the tool for infiltration rates are discussed in the limitations section of this document. We highly recommend that users familiarize themselves with these limitations to ensure they accurately interpret the calculator's results.

In any case, the intervention strategies aim to enhance this baseline rate or, at the very least, maintain it over time. Each intervention will relate to different recharge impacts (in terms of rate changes relative to the baseline). The user can create scenarios for those impacts using the following parameters as referential examples:

- **Aquifer recharge, impacts of revegetation:** While no data exist for this study site, we can draw on literature from similar areas to determine that the impact of reforestation on aquifer recharge could fall between -10 percent and +10 percent, depending on the forest type and density. Whereas low-density native deciduous vegetation is likely to have a positive impact, high-density coniferous vegetation and non-native species are likely to have high evapotranspiration rates and therefore negatively impact aquifer recharge.
- **Aquifer recharge, impacts of HF management (clearing, thinning, and pruning):** While no data exist for this study site, one could imagine a 0 to 5 percent improvement in aquifer recharge in this area.
- **Aquifer recharge, impacts of conservation and protection:** While no data exist for this study site, we can draw on literature from similar areas to determine that the impact of conservation on aquifer recharge could be between -10 percent and +10 percent, assuming conserved areas are in good condition and avoid deforestation.

The above parameters are assumptions and should not be interpreted as validated ranges. They conservatively represent the order of magnitude of potential benefits assumed for this region on the basis of literature reviewed (see sources in Box 3) and corroborated by expert opinion.[14,15] Values may vary by territory depending on forest type, density, and other biophysical characteristics. Although this calculator uses them as referential parameters, we recommend users validate and refine them with local research. No local studies were available to help better approximate this important reference during our research.

## Biophysical assumptions, underlying calculations

The biophysical parameters (precipitation, forest maturity, benefit curves, and aquifer recharge impacts) must be translated into volume of water made available.

The total yearly maximum aquifer recharge is a function of the restored area per year, the age of the forest, the percentage of the maximum aquifer recharge per type of intervention per year, and the yearly precipitation per ha. To estimate the annual amount of water recharged to aquifers, we built a matrix function, as presented in Equation 2:

EQUATION 2

$$GI_y = \begin{bmatrix} a_{1,1} & 0 & 0 \\ \cdots & a_{i,j}^{*} & 0 \\ a_{n,1} & \cdots & a_{n,m} \end{bmatrix}_{n\times m} \times \begin{bmatrix} X(t)_1 \\ \cdots \\ X(t)_m \end{bmatrix}_{m\times 1} \times IR \times P$$

Where

$GI_y$ Groundwater infiltration due to restoration placed in the year $y$

$a_{i,j}$ Area restored (ha) in the sequencing year $i = 1, \ldots, n$ and with age $j = 1, \ldots, m$

$a_{i,j}^{*}$ Area restored (ha)

$X(t)_j$ Benefit rate (%) of the intervention with age $j$

## Box 3 | Using Literature to Link Natural Infrastructure Interventions to Aquifer Recharge Potential in Monterrey

Although no local data exist to directly inform the biophysical inputs of this calculator, several global meta-analyses, as well as relevant studies conducted at sites that also have dry, subtropical seasonal climates and mountain areas, help to inform the calculator's defaults. Findings from these studies may differ from our study site on the basis of geographic, climatic, topographic, hydrologic, biotic, and management factors, but are still useful because they help explain relevant processes.

**Global studies**
The global scientific information regarding the impacts of forest loss and gain on aquifer recharge show unclear results and highlight the need for more research. For example, Filoso et al. found that, among 15 relevant studies from around the world, 67 percent concluded that reforestation reduced groundwater supply, and 33 percent found that reforestation increased groundwater supply.[a]

Therefore, it is more useful to look at specific intervention factors when linking restoration to recharge. Owuor et al. reviewed 27 studies in semiarid environments and found that restoring bare land decreases groundwater recharge by 6 to 42 percent.[b] Although tree cover has a beneficial effect on soil infiltrability,[c] trees have a higher evapotranspiration rate than other land covers. Ellison et al. point out that tree cover loss from agriculture or pastures leads to an impoverished soil structure, which in turn reduces groundwater infiltration. Some studies have shown that agroforestry systems with low tree density have higher infiltration capacity than nonforest areas or forestland.[d]

**Relevant studies from Nuevo León, Mexico**
Maqueda et al. applied the Soil and Water Assessment Tool (SWAT) model to the San Juan watershed in Nuevo León, covering our study area. The model estimated that on average, 40 percent of water flow was base flow, and 60 percent was surface runoff. They also found that a 20 percent increase in the urban area of Cañón del Huajuco caused an 18 percent increase in surface runoff, indicating a lower base flow and higher risk of flood. Forested mountain regions showed a high percolation capacity.[e]

Návar studied northeastern pine-oak forests in the Sierra Madre Oriental, the same climate and ecoregion as our study site. Návar found that areas influenced by stem flow (e.g., forest areas) receive two to seven times more water than open soils; however, some of this water will be used by trees, and some will evaporate from the soil. Even so, stem flow along deep root systems can be a source of groundwater recharge by promoting water flow pathways through soil and bedrock.[f]

**Studies from similar sites outside this study area**
Studies from outside our study site that share relatively similar climatic and topographic characteristics also provide useful insights. Though from another Mexican biome, López Báez et al. and Castro Mendoza et al. found that in a forested biosphere in Chiapas, 24 percent of water infiltrates into the groundwater and subsoil system, providing an infiltration capacity two and a half times higher than areas outside the biosphere that were otherwise similar.[g,h]

In India's Western Ghats, Krishnaswamy et al. estimated that 50–61 percent of water on native forest plots is recharged. Native evergreen forests recharged 4–6 percent more water than degraded savanna forests, depending on the location, and significantly more than nonnative plantation.[i] In northern Ethiopia, Descheemaeker et al. concluded that increased vegetation (i.e., conversion of pasture to forest) on hillsides created source-sink systems that increased deep percolation tenfold.[j]

*Note:* a. Filoso et al. 2017; b. Owuor et al. 2016; c. Ilstedt et al. 2007; d. Ellison et al. 2017; e. Maqueda et al. 2008; f. Návar 2011; g. López Báez et al. 2014; h. Castro Mendoza et al. 2016; i. Krishnaswamy et al. 2013; j. Descheemaeker et al. 2009.

resultant from Equation 1

| | |
|---|---|
| *IR* | Infiltration rate (%) established at the end of m years |
| *P* | Precipitation yearly average ($m^3$/ha)[16] |

The results from the biophysical assumptions and methods are computed by the application of Equation 1 and 2 described earlier. Those results are displayed on the 2.0 Forest Maturity Input tab over cells A21:AE36 as the total volume of water gained because of natural infrastructure interventions (A36:AE36). Water gained is then transformed into monetary terms, which will be further explained in the next section.

## Economic Assumptions

This section provides information about the economic assumptions and methods used to quantify the total costs of implementing the natural infrastructure portfolios, as well as the economic benefits from the water gained through the interventions.

The three cost categories considered here are natural infrastructure implementation and operation and maintenance (O&M) costs, opportunity costs, and transaction costs. Further details about these cost categories and how to integrate them can be found in Gray et al. (forthcoming). The benefits accounted for include avoided costs from alternative sources and profit gains from additional water sales.

## Natural infrastructure costs

*(Dynamic inputs, 1.0 Costs Input tab, cells A1:K38)*

Tab 1.0 Costs Output corresponds to the capital investments and natural infrastructure establishment costs, as well as to the O&M costs that must be incurred through the time horizon. These costs are classified as follows:

- **Costs associated with revegetation** (cells A4:K14 of the 1.0 Costs Input tab): Labor (planting costs), technical assistance, per diem expenses, and input materials and expenses (e.g., either the cost of seeds, seedlings, and nurseries or grown plant acquisition and transportation).
- **Costs associated with hydro forest management** (cells A16:K26 of the 1.0 Costs Input tab): Labor, per diem expenses, and input materials required for clearing, thinning, and pruning activities.
- **Costs associated with conserving and protecting existing forest** (cells A28:K38 of the 1.0 Costs Input tab): Labor, per diem expenses, and surveillance and required materials to protect the territory and promote its natural generation (e.g., materials needed to establish protective fences and signs).

The costs of restoring or conserving a habitat depend on many variables, such as the type of habitat, the severity of degradation, the characteristics of the terrain, and the extent of restoration or conservation intended (King and Bohlen 1995). Specific studies to define site- and ecosystem-specific costs may be needed if accurate values are expected (FAO and GM 2015). International sources confirmed the pronounced cost variability, ranging from US$300 to $9,800 (Appanah et al. 2015) or $675 to $2,700 (Vergara et al. 2016) per ha. National sources (DOF 2013) and Saldívar et al. (2016) reported costs ranging from MXN$6,000 to $19,000 per ha, depending on the type of intervention and specific terrain characteristics. Additional interviews conducted with TNC local specialists and MMWF staff confirmed the variability on the basis of the nuances of the terrain (level of degradation and accessibility to the area). They reported ranges from MXN$19,000 to $26,000 per hectare. The duration and periodicity needed to guarantee optimal results of these interventions would be equally variable.

The 1.0 Costs Inputs tab will serve as a template for the user to insert the local cost assumptions associated with each portfolio. Columns C:F must reflect the investment and establishment (I&E) expenses generally associated with either the initial purchase of fixed assets, or the one-time expenses required to achieve the objective. Columns H:K are reserved for the O&M costs as well as any other periodical expense required to preserve the intervened area in optimal conditions. The O&M costs will require the user to input either periodicity[17] or duration[18] restrictions for each portfolio.

Natural infrastructure costs must be inputted in "cost per hectare" units. If the user encounters a situation where a cost is provided in a different unit (e.g., cost per linear kilometer, cost per lot, or other), then the costs should be converted to hectares before being entered into the calculator. At the bottom of the Costs Input tab, the user will find a unit converter aid section to help convert the original unit's value into cost per hectare values. The user must then manually transfer the results to the applicable Costs Input section.

Figures 7 and 8 contain hypothetical cost scenarios constructed with data obtained from sources consulted. Further characterization of the microsites and validation from local stakeholders would be required for actual investment projects.

## Opportunity costs

*(Dynamic inputs, 1.0 Costs Input tab, cells A43:K47)*

Opportunity costs are the benefits one could have received had an alternative action been taken. In the case of land, it could be revenues that would have been obtained if the property had been sold or rented, or the value of goods and services that would have been obtained if the land had been cultivated to produce commercial goods (e.g., crop yield per ha) (Maliva 2014).

Another type of opportunity cost can relate to incentives paid for conservation, such as a payment for ecosystem services (PES) program. A PES is a governmental or private program that incentivizes preservation of a territory, generally in the form of a payment to the landowner per hectare preserved. In this analysis, PESs are consid-

## Figure 7 | 1.0 Costs Input Tab: Cost Structure Scenario

**Investments and Establishment Costs (I&E)** (Occur at the beginning of the project, refer to initial establishment expenses or capital investments)

**Revegetation (RV)**

| I&E costs concepts (RV) | Average/ha | Max/ha | Min/ha |
|---|---|---|---|
| Plant production | $ 5,661.50 | $ 7,000.00 | $ 4,323.00 |
| Plant transportation | $ 866.50 | $ 1,200.00 | $ 533.00 |
| Gasoline | $ 1,000.00 | $ 1,200.00 | $ 800.00 |
| Labor reforestation/planting | $ 1,752.00 | $ 2,000.00 | $ 1,504.00 |
| Labor establishement trenches or terraces | $ 10,393.50 | $ 11,000.00 | $ 9,787.00 |
| Technical assistance | $ 1,836.50 | $ 2,000.00 | $ 1,673.00 |
| Per diem allowance for technical leader | $ 500.00 | $ 700.00 | $ 300.00 |
| Food for staff | $ 950.00 | $ 1,200.00 | $ 700.00 |
| REVEGETATION Investments Total | $ 22,960.00 | $ 26,300.00 | $ 19,620.00 |

**Hydro Forest Management (HF)**

| I&E costs concepts (HF) | Average/ha | Max/ha | Min/ha |
|---|---|---|---|
| Labor trimming and prunning | $ 1,000.00 | $ 1,000.00 | $ 1,000.00 |
| Gasoline / transportation | $ 800.00 | $ 800.00 | $ 800.00 |
| Technical assistance | $ 1,000.00 | $ 1,000.00 | $ 1,000.00 |
| Food for staff | $ 700.00 | $ 700.00 | $ 700.00 |
| Supervision | $ 1,150.00 | $ 1,200.00 | $ 1,100.00 |
| Inputs and labor operative staff | $ 5,000.00 | $ 5,000.00 | $ 5,000.00 |
| | $ 9,650.00 | $ 9,700.00 | $ 9,600.00 |

**Conservation and Protection (CP)**

| I&E costs concepts (CP) | Average/ha | Max/ha | Min/ha |
|---|---|---|---|
| Fencing | $ 1,235.00 | $ 1,235.00 | $ 1,235.00 |
| Signs | $ 142.50 | $ 142.50 | $ 142.50 |
| Supervision | $ 1,150.00 | $ 1,200.00 | $ 1,100.00 |
| | $ - | $ - | $ - |
| | $ 2,527.50 | $ 2,577.50 | $ 2,477.50 |

**Operation and Maintenance Costs and Recurrent Expenses (O&M)** (Occur over a series of years or periodically through the time horizon)

**Revegetation (RV)**

| DURATION (During how many years will you supervise revegetation?) | 5 | | |
|---|---|---|---|
| O&M costs concepts (RV) | Average/ha | Max/ha | Min/ha |
| Plant production for replanting | $ 1,044.50 | $ 1,729.00 | $ 360.00 |
| Plant transportation for replanting | $ 102.00 | $ 150.00 | $ 54.00 |
| Gasoline | $ 800.00 | $ 800.00 | $ 800.00 |
| Labor reforestation/replanting | $ 488.00 | $ 616.00 | $ 360.00 |
| Technical assistance | $ 750.00 | $ 1,000.00 | $ 500.00 |
| Per diem allowance and food | $ 300.00 | $ 500.00 | $ 100.00 |
| Maintenance (herbs, fertilization, protection and others) | $ 1,297.00 | $ 2,100.00 | $ 494.00 |
| | $ - | $ - | $ - |
| REVEGETATION O&M Total | $ 4,781.50 | $ 6,895.00 | $ 2,668.00 |

**Hydro Forest Management (HF)**

| PERIODICITY (Occurs every "X" Years) | 5 | | |
|---|---|---|---|
| O&M costs concepts (HF) | Average/ha | Max/ha | Min/ha |
| Labor trimming and prunning | $ 1,000.00 | $ 1,000.00 | $ 1,000.00 |
| Gasoline / transportation | $ 800.00 | $ 800.00 | $ 800.00 |
| Technical assistance | $ 1,000.00 | $ 1,000.00 | $ 1,000.00 |
| Food for staff | $ 700.00 | $ 700.00 | $ 700.00 |
| Supervision | $ 1,150.00 | $ 1,200.00 | $ 1,100.00 |
| Inputs and labor operative staff | $ 5,000.00 | $ 5,000.00 | $ 5,000.00 |
| HYDRO FORESTRY Total | $ 9,650.00 | $ 9,700.00 | $ 9,600.00 |

**Conservation and Protection (CP)**

| PERIODICITY (Occurs every "X" years) | 5 | % OF TC | 100% |
|---|---|---|---|
| O&M costs concepts (CP) | Average/ha | Max/ha | Min/ha |
| Fencing | $ 1,235.00 | $ 1,235.00 | $ 1,235.00 |
| Signs | $ 142.50 | $ 142.50 | $ 142.50 |
| Supervision | $ 1,150.00 | $ 1,200.00 | $ 1,100.00 |
| | $ - | $ 1,250.00 | $ 1,250.00 |
| | $ 2,527.50 | $ 3,827.50 | $ 3,727.50 |

*Note:* This is a hypothetical case for illustration purposes. Results have been transferred to the conservation and protection costs input section.
*Source:* WRI.

## Figure 8 | Units Converter Aid, Monterrey Conservation Actions

**Units Converter Aid**

| Concept | Cost Per Unit | U/M | Number Of Units | Cost Subtotal | Total Hectares Where These Costs Apply | Cost Per Hectare Reference |
|---|---|---|---|---|---|---|
| Fencing | $ 13,000.00 | KM | 190.00 | $ 2,470,000.00 | 2000.00 | $ 1,235.00 |
| Signs | $ 15,000.00 | LOT | 19.00 | $ 285,000.00 | 2000.00 | $ 142.50 |
| Capacity building | $ 25,000.00 | workshop | 5.00 | $ 125,000.00 | 100.00 | $ 1,250.00 |

*Note:* This is a hypothetical case for illustration purposes. Results have been transferred to the conservation and protection costs input section.
*Source:* WRI.

ered opportunity costs because they represent a value per hectare that investors may need to pay to motivate landowners to avoid converting the land. This type of PES must not be confused for a payment that covers the cost of the environmental outcome, but rather understood as an incentive to preserve it.

The tool allows users to list three opportunity costs in the analysis. To insert the opportunity costs, the following information must be previously defined:

- Name of opportunity costs to consider (e.g., land acquisition, land rent, annual crop yield, payment for ecosystem service, etc.)
- Cost per hectare per opportunity cost considered
- Percentage of the target area subject to the opportunity costs considered
- Duration of the opportunity costs considered (e.g., how many years will this cost be accounted for?)
- Definition of whether the opportunity cost will be prorated[19] or repeated[20] through the established duration

In the MMWF case study, most of the target area (91 percent) is located within a natural protected area. Cerro de la Silla and Cumbres de Monterrey National Park make up almost 85 percent of the MIA (Hesselbach et al. 2016). Due to regulations over these jurisdictions (DOF 2018b), natural protected areas must abide by the rules and prohibitions laid out in their official management plans (CONANP 2016). The Cerro de la Silla management plan (DOF 2014) and the Cumbres de Monterrey National Park published decree (DOF 1969) both prohibit land use change and alternative activities. We can then assume that the cost of opportunity related to alternative income (crop yield) and land rental in this case study would be zero, as there is no legal permission to do so. Despite these restrictions, existing PES systems have set a precedent for compensating landowners in this area. Thus, the PES mechanism is a necessary cost of opportunity to guarantee restoration success. For our pilot analysis, it was set between MXN$300 and $600 per ha per year.

It is recommended that users apply the PES opportunity costs in cases similar to our case study (where there is a precedent of the community expecting conservation incentives) and include other opportunity costs (land rental, yearly crop yield), where market incentives require it to increase the probability that the natural infrastructure actions will be successful.

### Transaction costs

*(Dynamic input, 1.0 Costs Input tab, cells A49:K54)*

Transaction costs are the indirect costs incurred, and generally reflect the "time, effort, and resources needed to search out, initiate, negotiate, and complete a deal" (Gray et al. forthcoming; Lile et al. 1998). The transaction costs will vary across projects depending on social, physical, political, and financial conditions (see Figure 9 for examples). The inputs required to account for transaction costs in the calculator would be a maximum and minimum cost parameter for each transaction cost concept, and the respective periodicity restrictions would be as follows:

- Cost parameter: The total cost of transaction-related expenses in a given year (cost per year). The cost parameter is in "costs per year" because logistics required to sustain meetings and negotiations are unrelated to the number of hectares. Hence, the total transaction cost will be the costs incurred during a year to reach consensus or contracts, regardless of how many hectares are being negotiated.

- Periodicity: This establishes how often these transaction costs would be incurred. The figure should account for the optimal relations between stakeholders, ensure proper operations, and fulfill regulations.

If the user does not have accurate estimates of transaction costs, a global percentage and global periodicity can be entered into cell K49.[21] When doing this, the percentage in cell K49 will be applied over the I&E costs as a proxy for the transaction costs in the financial calculation. The suggested global transaction cost of natural infrastructure implementations is 10–25 percent, using estimations from Vergara et al. (2016).

### Estimation of water benefits in economic terms

*(Dynamic input, 3.0 Benefits Monetization Input tab, underlying calculations, 3.1 Benefits Monetization Output tab)*

The benefits represent the income to be gained by investing in natural infrastructure. Beneficiaries would be those who have access to the benefits. The water utility is the main beneficiary of our financial evaluation. However, as

Figure 9 | **Examples of Transaction Cost Concepts**

TRANSACTION COSTS — INVESTMENTS AND ESTABLISHMENT COSTS (Occur at the beginning of the project, refer to initial establishment expenses or capital investments)

| Transaction Costs concepts | AVG $/YR | MAX $/YR | MIN $/YR |
|---|---|---|---|
| Licencing | $ - | $ - | $ - |
| On the ground communications and as: | $ - | $ - | $ - |
| Contracts | $ - | $ - | $ - |

O&M COSTS AND RECURRENT EXPENSES (Occur over a series of years or periodically through the time horizon)

| | | % Over I&E | 25% |
|---|---|---|---|
| Transaction Costs characteristics | Periodicity (Occurs every X years) | % from total cost to be repeated on subsequent years | Type of expense |
| License from authority | | 100% | Periodical |
| coordination with land owners and authorities | | 100% | Periodical |
| legal agreements with stakeholders | | 100% | Periodical |
| | 0.00 | | |

*Source:* WRI.

noted earlier, there are other indirect beneficiaries, such as CONAGUA and the state government, which also stand to gain from reduced operation costs and an improved, more resilient system in the region.

In the tool, the benefits section translates the intervention's biophysical results (the aquifer recharge volume gained or maintained) into potential streams of revenue for the beneficiary's cashflow.

## Benefits$_1$ avoided costs

*(Dynamic inputs, 3.0 Benefits Monetization Input tab, cells A3:D26)*

The analysis of local data and stakeholder interviews in Monterrey led to the assumption that the total cost of managing underground sources is cheaper than managing surface sources (with differences ranging from 8 to 26 percent, depending on the year),[22] largely due to a differential in conduction costs. While those assumptions could not be further refined or validated by the water utility, it was deemed as the first potential "benefit" from natural infrastructure interventions. To value it, we used an alternative cost approach,[23] assuming that if the additional water volume gained from natural infrastructure interventions can be drawn from underground instead of surface water sources, it would result in an accumulation of avoided costs.

The total income of this first benefit's monetization method is a function of the underground volume variation (gain or loss) and the management cost difference between the water sources (underground and surface):

EQUATION 3

$$B_1 = GI_y \times (TC_{sf,y} - TC_{ug,y})$$

Where

$B_1$ Benefits obtained on year $y$ as a result of avoided costs

$GI_y$ Groundwater infiltration due to restoration placed in the year $y$ (resultant from Equation 2)

$TC_{sf}$ Total cost of managing surface sources on year $y$ ($/m$^3$)

*TCug* Total cost of managing underground sources on year $y$ ($/m$^3$)

$y$ The year being analyzed (1, 2, 3 . . . *m*) for our case study; the maximum valid year is 30

Including this type of benefit must only be considered if the following three criteria are met:

1. There is a management cost difference between surface and underground sources.
2. It is cheaper to manage underground sources.
3. The management cost difference between the sources is due to the watershed factors such as favorable topography, or smaller distances, and not to operational or administrative inefficiencies.

If those three principles are not fully met, the Benefits$_1$ section must be left blank in the calculator. The rationale for this recommendation is included in the limitations section of this document.

Information about local benefits must be entered into the 3.0 Benefits Monetization Input tab. The template allows the user to input either disaggregated cost structure per source or bottom-line cost values per source. The decision regarding which to use depends on data availability. If the user has access to the detailed cost structures of the water distribution system, this information can be inserted into cells A6:D24. Having detailed and disaggregated data would lead to a more informed analysis and allow the user to locate inefficiencies and improvement opportunities in a more precise manner. However, when this is not possible, a bottom-line value would suffice (cells C22:D22).[24] The user can also include a rate of yearly cost increase in cell D26. If this cell is left blank, the avoided cost estimation would remain constant over time.

## Benefits$_2$ profit of water sale

*(Dynamic inputs, 3.0 Benefits Monetization Input tab, cells A28:D35)*

The second stream of revenue incorporated into the tool results from estimating the potential profit of selling the extra volume of water accrued or conserved through natural infrastructure interventions. Note that the water volume used to calculate both the profit from sales and avoided costs is the same, as there is no overlap in water allocation.

The profit would be a function of underground water volume variation (gain or loss) and the profit obtained from selling that water. The profit itself results from the difference between the costs from the underground system and the selling price correspondent to the consumer to whom it is sold.

EQUATION 4

$$B_2 = \sum_{i=1}^{4} GI_y \times VC_{i,y} \times (PS_{i,y} - TC_{ug,y})$$

Where

$B_2$ Benefits obtained on year $y$ through the additional profit method

$VC_{i,y}$ Total volume sold to a consumer type $i$ on the year $y$ ($m^3$)

$GI_y$ Groundwater infiltration due to restoration placed in the year $y$ resultant from Equation 2

$PS_{i,y}$ Selling tariff applicable to a consumer type $i$ on the year $y$ (\$/$m^3$)

$TC_{ug}$ Total cost of underground sources on the year $y$ (\$/$m^3$)

$i$ Consumer categories established by the calculator user (e.g., industrial, domestic, public, etc.)

$y$ The year being analyzed (1, 2, 3 . . . $m$); for our case study, the maximum valid year is 30

To compute Benefits$_2$ (profit from water sale) the calculator calls for the following local information:

- **Water consumer categories:** In Mexico, most water utilities classify their demand by type of consumer. Such classifications allow them to set differentiated tariffs based on the social, political, or environmental standards. The calculator allows four different types of consumer categories, which in our pilot analysis are represented by household consumers, public consumers, industrial consumers, and commercial consumers.
- **Consumption share per consumer:** The user must indicate or assume the estimated consumption share over the total volume distributed for each consumer type.
- **Selling tariffs:** the user must insert the estimated tariff per cubic meter paid per each of the consumer types listed.
- **Price increase:** The user must input the yearly price increase per consumer category to be used in the financial exercise. If no price increase is expected, these parameters must be marked as 0 percent.

Table 3 | **Estimated Unit Cost of Providing Water from Underground and Surface Sources**

| COSTS AND EXPENSES CONCEPTS | UNDERGROUND SOURCES (MXN\$/M$^3$) | SURFACE SOURCES (MXN\$/M$^3$) |
|---|---|---|
| Catchment and purification | \$0.58 | \$0.39 |
| Conduction | \$0.40 | \$1.42 |
| Storage and distribution | \$0.83 | \$0.83 |
| General expenses for potable water | \$0.34 | \$0.34 |
| Drainage and treatment | \$1.31 | \$1.31 |
| Commercial expenses | \$0.64 | \$0.64 |
| Administrative expenses | \$6.37 | \$6.37 |
| Engineering expenses | \$0.18 | \$0.18 |
| Financial expenses | \$0.58 | \$0.58 |
| CONAGUA extraction rights | \$0.44 | \$0.44 |
| Depreciation | \$2.29 | \$2.29 |
| **Totals costs and expenses per source** | **\$13.96** | **\$14.79** |

*Source:* WRI based on and adapted from SADM 2011

Table 4 | **Hypothetical "Intermediate Level" Price Scenarios for Monterrey**

| CONSUMER CATEGORY | CONSUMPTION SHARE | YEARLY AVERAGE INCREASE (%) | 2010 | TREND 2011 | TREND 2012 | TREND 2013 | TREND 2014 | TREND 2015 | TREND 2016 | TREND 2017 | TREND 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Domestic users | 73% | 6.29% | $9.19 | $9.77 | 10.38 | $11.04 | 11.73 | $12.47 | $13.25 | $14.08 | $14.97 |
| Public users | 14% | 3.05% | $8.40 | $8.66 | $8.92 | $9.19 | $9.47 | $9.76 | $10.06 | $10.37 | $10.68 |
| Commercial users | 10% | 7.57% | $26.89 | $28.93 | $31.12 | $33.47 | 36.01 | $38.73 | $41.67 | $44.82 | $48.22 |
| Industrial users | 3% | 6.90% | $32.48 | $34.72 | $37.11 | $39.67 | $42.41 | $45.33 | $48.46 | $51.80 | $55.37 |

*Note:* Price scenarios reflect yearly increases based on historical linear averages, 2004–10. All amounts in MXN$.
*Source:* WRI, based on SADM 2011.

## Monterrey case study parameters

To establish the benefit's parameters for the Monterrey case, the cost data, pricing data, user types, and consumption rates had to be averaged and generalized. Historical data from an old water utility report (SADM 2011) was used to create the key assumptions for both categories of benefits (avoided costs and water selling profit) (see Tables 3 and 4).

## Economic assumptions, underlying calculations

Once all the economic assumptions have been made, the output generator tabs will be able to evaluate the investment portfolio under the selected scenario.

- Tab 1.1 Costs Output will use the data provided on tab 1.0 to estimate the annual costs through the set timeline. Then, the 4.0 Cashflow tab will automatically take those results to construct the cost section of the cashflow.
- Tab 3.1 Benefits Monetization Output will take the data from tab 3.0 to compute the benefits of the interventions and display them over three sections:
  - Cells A3:AH7: Display the water volume in cubic meters per year accrued as a result of the natural infrastructure portfolio implementation (the yearly results of Equation 1).
  - Cells A9:AH14: Display the yearly income from the water benefits (applying Equation 2).
  - Cells A16:AH30: Compute the expected profit from selling the water accrued each year (applying Equation 3).

All results from these calculations are then automatically sent to the Cashflow tab to perform the financial analysis.

## Cashflow

*(4.0 Cashflow tab, cells A1:AG31, and main functionalities and graphics included on the Control Dashboard tab)*

To finalize the analysis, the input data and models produced through the sections previously described are used to create a cashflow. The cashflow summarizes the annual "ins and outs" (benefits and costs) through the time horizon. These results are displayed on the 4.0 Cashflow tab, an output spreadsheet that connects the model results as seen in Table 5.

The Cashflow tab also estimates the NPV, the internal rate of return (IRR), the payback period, the ROI, and the benefit-cost ratio using standard accepted formulas. Gray et al. (forthcoming) include the formulas in a detailed manner. The quantitative and graphic results of these calculations are also displayed on the Control Dashboard tab.

## Sensitivity analysis

The last piece of the tool is a dynamic sensitivity analysis. This functionality shows how changes in the independent variables impact the project's financial outcome.

Table 5 | **Sources of Information Tabs to Construct the Final Cashflow**

| CASHFLOW COMPONENT ON TAB 4.0 | SOURCE TAB | SOURCE CELLS AND PRECEDING SOURCE TABS |
|---|---|---|
| Investments in green infrastructure | 1.1. Costs Output | **Source cells:** (RV) C13:C42 (HF) C54:C83 (CP) C95:C124<br>**Preceding tabs:** 1.0 Costs Input, Control Dashboard |
| O&M in green infrastructure | 1.1. Costs Output | **Source cells:** (RV) D44:AG44 (HF) D85:AG85 (CP) D126:AG126<br>**Preceding tabs:** 1.0 Costs Input, Control Dashboard |
| Opportunity costs in green infrastructure | 1.1. Costs Output | **Source cells:** C139:AG142<br>**Preceding tabs:** 1.0 Costs Input, Control Dashboard |
| Transaction costs in green infrastructure | 1.1. Costs Output | **Source cells:** C149:AG152<br>Preceding tabs: 1.0 Costs Input, Control Dashboard |
| Benefits$_1$, alternative costs | 3.1 Benefits Monetization Output | **Source cells:** E14:AH14<br>**Preceding tabs:** 3.0 Benefits Monetization Input, 2.0 Forest Maturity Input (2.1 RV Output, 2.2 HF Output, 2.3 CP Output), Control Dashboard |
| Benefits$_2$, selling profit | 3.1 Benefits Monetization Output | **Source cells:** E30:AH30<br>**Preceding tabs:** 3.0 Benefits Monetization Input, 2.0 Forest Maturity Input (2.1 RV Output, 2.2 HF Output, 2.3 CP Output), Control Dashboard |

Source: WRI.

This section is located on the lower part of the Control Dashboard tab (cells A33:M57). The calculator is preset to run a robust sensitivity analysis (100 iterations) of one of seven independent variables: discount rate, yearly precipitation, sequencing plan time frame, the target area's total number of ha, and the maximum infiltration rate variation expected from each of the three portfolios (RV, HF, CP).

To conduct the analysis, the user must select the independent variable to test from the drop-down menu on cell F33 of the Control Dashboard and set the variable's maximum and minimum bounds. The calculator will then test 100 different values between the limits and gauge their financial impact over the evaluated portfolio.

The results will be displayed on three graphs that represent the NPV, ROI, and IRR from each of the iterations. The graphic results allow the decision-maker to see a snapshot of the thresholds of sensitivity and influence of a given independent variable. Users can check the underlying quantitative results of a run on the hidden (back-end) tab titled "_sheet."

## LIMITATIONS

This section summarizes the generalizations and assumptions made to simplify the model across this analysis. It also describes opportunities to improve the methods. We expect those improvements to be pursued progressively through the feedback and information that users and decision-makers provide to us, as they are in a good position to offer information about the usability and strategic adjustments that may add value to this prototype.

### General Limitations

Given the acknowledged limitations of this tool, its outputs should not be used to make detailed financial decisions. Indeed, this calculator must not be considered a predictive tool that can substitute for the lack of science or transparency in the region; rather, it should help users to better understand natural infrastructure opportunities, define the limits of risk and uncertainty, and constrain these to lower extent on the basis of informed assumptions. Its financial results should not be assumed as results of a full cost-benefit analysis of natural infrastructure interventions but as an approximation to the private costs and potential gains that beneficiaries can incur by investing in natural infrastructure. The tool's calculations are expected to serve as informative arguments for better planning and decision-making.

## Limitations of Biophysical Assumptions

### Forest characteristics (baseline and interventions)

- We assume any restoration would occur at a sufficiently low density to optimize aquifer recharge, although this optimum density is unknown.
- We do not account for cloud forest benefits, which typically capture and promote infiltration of water from fog.

Further analysis is needed to test these assumptions, determine which forest types are most suitable for given areas of the MIA, identify the optimum density needed, and confirm that none of these forests is a cloud forest.

### Forest maturity

- Our assumptions regarding establishing ecosystem services at rates related to forest structure are based on a well-regarded paper (Poorter et al. 2016) and expert advice (Filoso et al. 2017). However, we have not been able to find a paper on which to base the curve progression assumptions used to define accurate rates of progression over time for this region.
- Similarly, we have described and represented the continuity of benefits for hydro forest management and conservation and protection on the basis of the assumption of flat line behaviors; however, we have yet to find literature to support these assumptions.

Further research should be conducted to refine the aquifer recharge limit assumptions and their link to forest maturity progression so that the curves used can be further refined. Similarly, additional research is needed to refine the recharge benefit limits of various sustainable management practices and to improve how to represent the way in which this intervention's benefits persist or change over time.

### Precipitation

Additional research must also be conducted to incorporate the dynamic roles of precipitation variability and soil saturation limits into the model and constrain the current uncertainty levels of this variable in the tool. Currently, as detailed in previous sections, only annual average precipitation is accounted for, which entails the following:

- We assume the yearly average precipitation adequately captures any seasonal or spatial variability.
- We assume the soil saturation is not met at any point of the analysis; therefore, all precipitation is properly infiltrated under the established maximum infiltration rates.

Precipitation dynamics tend to be much more complex than the former assumptions. Therefore, these may not accurately represent Nuevo León's reality. To curtail this uncertainty, we recommend using conservative approaches when setting precipitation values, assuming that not all net precipitation will become "effective precipitation" for the established recharge rate. We recommend testing a minimum of three different precipitation values with volumes of at least 10–20 percent below the known regional averages. In addition, the sensitivity of the precipitation variable should be evaluated using at least two more scenarios with more radical values—representative of very low precipitation and very high precipitation—to examine the overall impact that such changes have on the financial analysis.

### Infiltration

- We assume that the entire land area designated for the intervention activities offers the ideal topographic conditions needed to achieve the impact expected on aquifer recharge.
- We assume that areas defined as aquifer recharge zones have geology that potentially delivers as much as 100 percent of water infiltrated to the aquifers from which Monterrey draws its municipal water supply.
- We assume the aquifer recharge impacts (maximum infiltration rates per type of intervention), are steady regardless of the vegetative species being targeted.

In reality, geology, topography, and vegetative species often have a more complicated relationship with aquifer recharge. Concerning geology, it is true that the fractured cell geology of this region is likely to facilitate higher levels of aquifer recharge compared to other geologic formations; however, experts have indicated that fractured cells sometimes indicate deep aquifer recharge or recharge of nonlocal aquifers.[25] Similarly, regarding topography, research by Schilling (2009) claims that groundwater recharge quantity is highly dependent on the topography, with the greatest quantities of recharge observed in alluvial zones along rivers (not in mountains, where water quickly flows downhill). We can expect that forestland on moderately steep slopes is likely to slow runoff, enhancing water infiltration in less steep areas. Thus, further analysis is needed to determine how the topography of the priority areas impacts aquifer recharge at different rates, and to map the groundwater pathways for the MMWF site. Likewise, additional research should be conducted to define how the aquifer recharge impacts could vary in this area depending on which forest type is targeted.

## Limitations of Economic Assumptions

- This prototype only accounts for private costs and benefits potentially attributable to a single direct beneficiary: the water utility.
- The current version of this calculator was developed under a restricted analysis to exclusively capture and monetize the environmental benefit of aquifer recharge.

Several potential cost impacts and benefit valuations had to be disregarded to focus only on calculating in situ groundwater value (the benefit of additional groundwater in an aquifer). Similarly, there are several potential impacts on gray infrastructure capital investments and O&M costs that could not be estimated due to data constraints (see Table 6). Additional research is needed to incorporate new sets of avoided costs and streams of revenue to strengthen this analysis or to expand this tool to a version able to account for the social benefits of the natural infrastructure portfolios.

## Benefits$_1$ (Avoided Costs) Additional Rationale

As mentioned in the Benefits$_1$ section, this benefit's component must be considered in the analysis only when groundwater sources are cheaper than those for surface water, and only when this difference is produced by the groundwater's proximity to the end user and favorable topographic conditions (which turns gravity into an advantage for groundwater distribution). The Benefits$_1$ section must be left blank under the following circumstances to avoid drawing erroneous conclusions or obtaining negative results:

- If the cost difference (between underground and surface sources) was the result of inefficiencies (e.g., pipes, leaks, pumps) in known operational, administrative, or mechanical-electrical systems, it should be left blank to avoid accounting for a benefit that is completely unrelated to the natural infrastructure interventions.
- If managing surface sources was cheaper than managing underground sources, it should be left blank to avoid getting a negative value result, which would imply that it was detrimental to promote aquifer recharge.

Table 6 | **Additional Water System Impacts and Benefit Valuation Methods**

| WATER SYSTEM IMPACT | VALUATION METHODS | |
|---|---|---|
| | AVOIDED COSTS | ALTERNATIVE COSTS |
| Increased groundwater supply (i.e., abstraction benefits; water is easier to access and will not evaporate as it would from a reservoir) | Avoided costs of installing new/additional infrastructure (e.g., avoidance of groundwater pumping costs; wells; artificial infiltration) | Cost of alternatives for this additional water supply (e.g., from surface water sources or transfers from distant watersheds) |
| Reduction in overexploitation of aquifers | Avoided costs associated with groundwater overexploitation (e.g., related to land subsidence or saltwater intrusion; decommissioning of aquifer, among others) | N/A |
| Water supply reliability (increased access to water during times of high demand) | Potentially, avoided costs related to drought and meeting emergency supply needs | Alternative costs of providing same water supply from these sources, guaranteed through alternative methods such as artificial water injection |

*Source:* WRI.

## Benefits$_1$ and Benefits$_2$

The benefits valued by the tool are potential, and their effective realization is constrained by additional elements of the territorial, political, legal, and economic reality. For instance:

- If the utility is just meeting current water demand and does not require utilizing additional groundwater resultant from the natural infrastructure interventions, then there would be no additional profit from sales, nor from avoided costs from distribution.
- If current usage of groundwater is equal to the legal concessions and allowances, having more groundwater in situ will not automatically translate into the ability to utilize it for distribution, and therefore into achieving the potential gains.

# PILOT TEST ANALYSIS

To demonstrate how this tool operates and the interpretations one can make from it, a pilot analysis was conducted using some of the locally collected data for the Monterrey case study. For this analysis, we created a portfolio based on the three categories of potential interventions (RV, HF management, and CP), and followed all the recommended parameters included in this technical note (see Table 7).

## Results

The results from the pilot analysis signal that natural infrastructure is a promising option for water management in Monterrey. The NPV is over MXN$238 million, the IRR is 23 percent, and the ROI is a bit over 118 percent. Under this scenario, the investment would be paid back by year 14, resulting in a benefit-cost ratio of MXN$2.18 to $1.00. From quantitative and graphical results, it is easy to see that the "conservation" strategy provides the greatest benefits to this portfolio. Its initial costs are low, yet end up accounting for 76 percent of all benefits. Part of the reason is that CP interventions claim a guaranteed conserved infiltration of 9 percent, which results in significantly positive financial yields when turned into water volume sold (see Figure 10).

### Sensitivity Analysis

As results are based on hypothetical scenarios, a strong sensitivity analysis is highly recommended. Running the calculator's sensitivity analysis module allows the user to understand the breaking points of strategic variables. We recommend this type of analysis, especially for highly uncertain variables where no validated data can be found (in this case study, almost all biophysical elements meet this criterion). A sensitivity analysis run for the infiltration baseline (maintained through CP interventions) found that it only takes having a little more than 2.5 percent of the infiltration baseline to achieve a positive NPV for this investment portfolio and keep conservation investments at a profitable level in the pilot (see Figure 11). Doing a similar exercise to capture the sensitivity of the precipitation variable shows that as little as 202 mm/yr of precipitation through the time horizon is required to keep the investment portfolio profitable (assuming the rest of the original variables remain the same).

Table 8 depicts the sensitivity of a few other strategic variables from the general and economic assumptions. The original selection of these inputs did rely on validated sources. However, it is advisable to understand how sensitive they might be to changes in market conditions and gauge their influence over the general results.

These results show that keeping revenue streams stable is a highly strategic way for the beneficiary to secure their investment. The slightest change in some of those economic variables—such as the cost of managing the water sources (only by MXN$2/$m^3$ going from MXN$16/$m^3$ to MXN$18/$m^3$)—can turn a portfolio from MXN$88 million of positive NPV to a negative NPV of MXN$37 million. This underlines the importance of stable, affordable, underground source management costs.

Similar results are observed regarding selling prices. For example, when the selling price was raised just 1 percent (going from 5 to 6 percent of yearly increase), the value of the investment went from unprofitable to very profitable (from MXN$45 million of negative NPV up to MXN$132 million of positive NPV). This confirms the idea that the sale price per year should increase at least at the same rate as the costs per year.

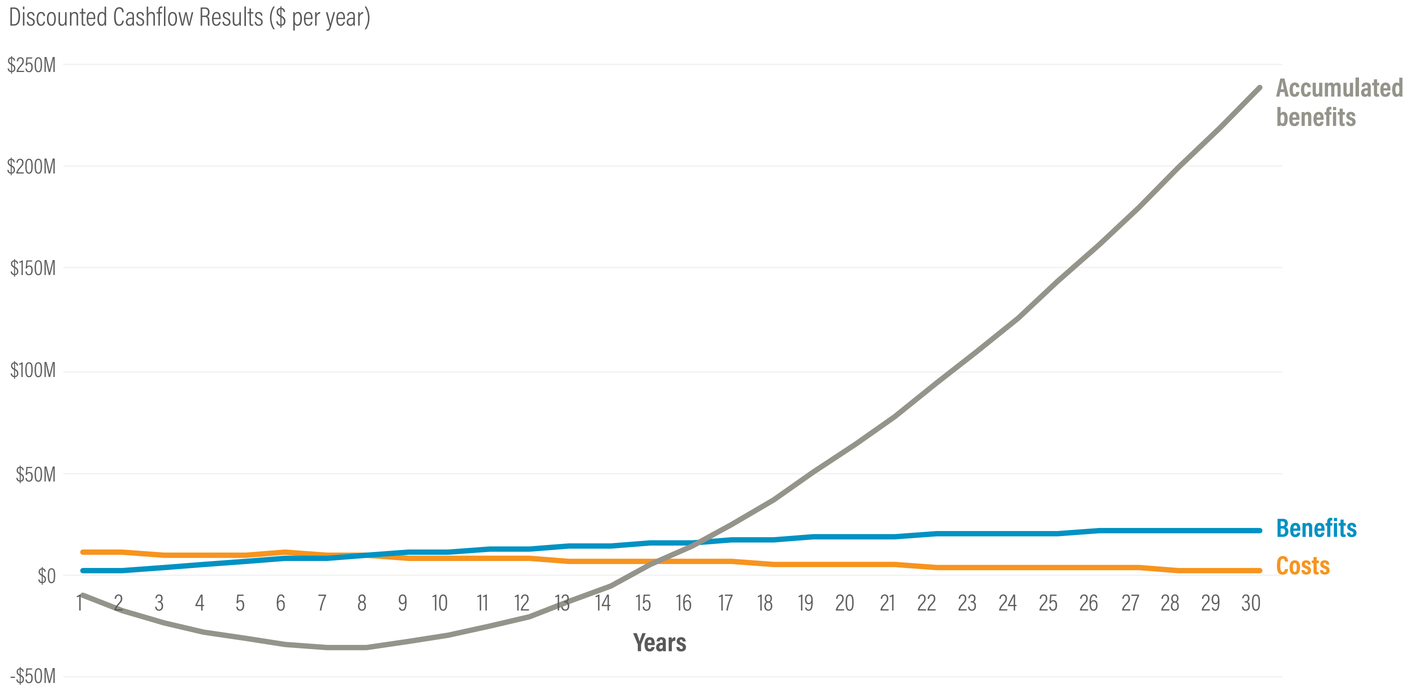
Table 7 | **Assumptions Used for Monterrey Case Pilot Test Analysis**

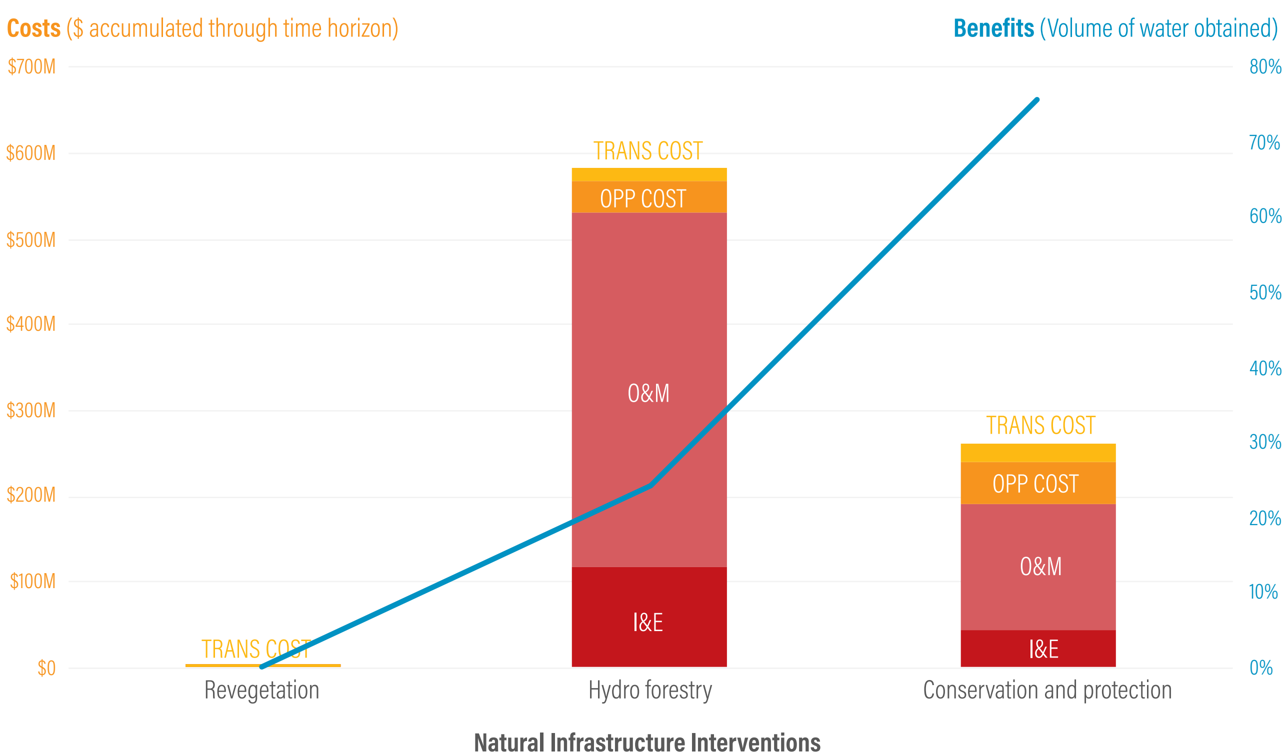
| | |
|---|---|
| **GENERAL ASSUMPTIONS** | |
| Discount rate (%) | 10 |
| Target area (ha) | 29,172 |
| Sequencing (yrs) | 30 |
| RV investment portfolios | 18 (0.06%) |
| HF investment portfolios | 12,260 (42.03%) |
| CP investment portfolios | 16,894 (57.91%) |
| **BIOPHYSICAL ASSUMPTIONS** | |
| Precipitation (mm) | 440 mm/yr (30% below yearly average as a conservative assumption) |
| Infiltration gained through RV | 6% |
| Infiltration gained through HF management | 4% |
| Infiltration baseline and kept through CP | 9% |
| Revegetation forest maturity model | S logistic curve |
| HF management maturity model | Flat line |
| Conservation forest maturity model | Flat line |
| Year of max benefits | 44 for RV, 1 for HF, and 1 for CP |
| **ECONOMIC ASSUMPTIONS (MXN$)** | |
| Natural infrastructure costs—RV cost per hectare ($/ha) | $22,960 (I&E) + $4,781.50 (O&M) during 5 years |
| Natural infrastructure costs—HF management cost per hectare ($/ha) | $9,650.00 (I&E) + $9,650.00 (O&M) every 5 years |
| Natural infrastructure costs—CP cost per hectare ($/ha) | $2,527.50 (I&E) + 2,527.50 (O&M) every 5 years |
| Natural infrastructure opportunity cost | $600/ha during 5 years to 100% of target area |
| Natural infrastructure transaction costs | 25% of I&E costs |
| Water from underground sources—cost of provision | $13.96/m$^3$ |
| Water from surface sources—cost of provision | $14.78/m$^3$ |
| Water provision—cost increase per year | 6% |
| Domestic water consumption and market structure | 73% of consumption at $14.97/m$^3$ with a 6.29% of yearly price increase |
| Public water consumption and market structure | 14% of consumption at $10.68/m$^3$ with a 3.05% of yearly price increase |
| Commercial water consumption and market structure | 10% of consumption at $48.22/m$^3$ with a 7.57% of yearly price increase |
| Industrial water consumption and market structure | 3% of consumption at $55.37/m$^3$ with a 6.90% of yearly price increase |

*Note:* I&E represents investments and establishment costs, O&M represents operation and maintenance costs

*Source:* WRI.

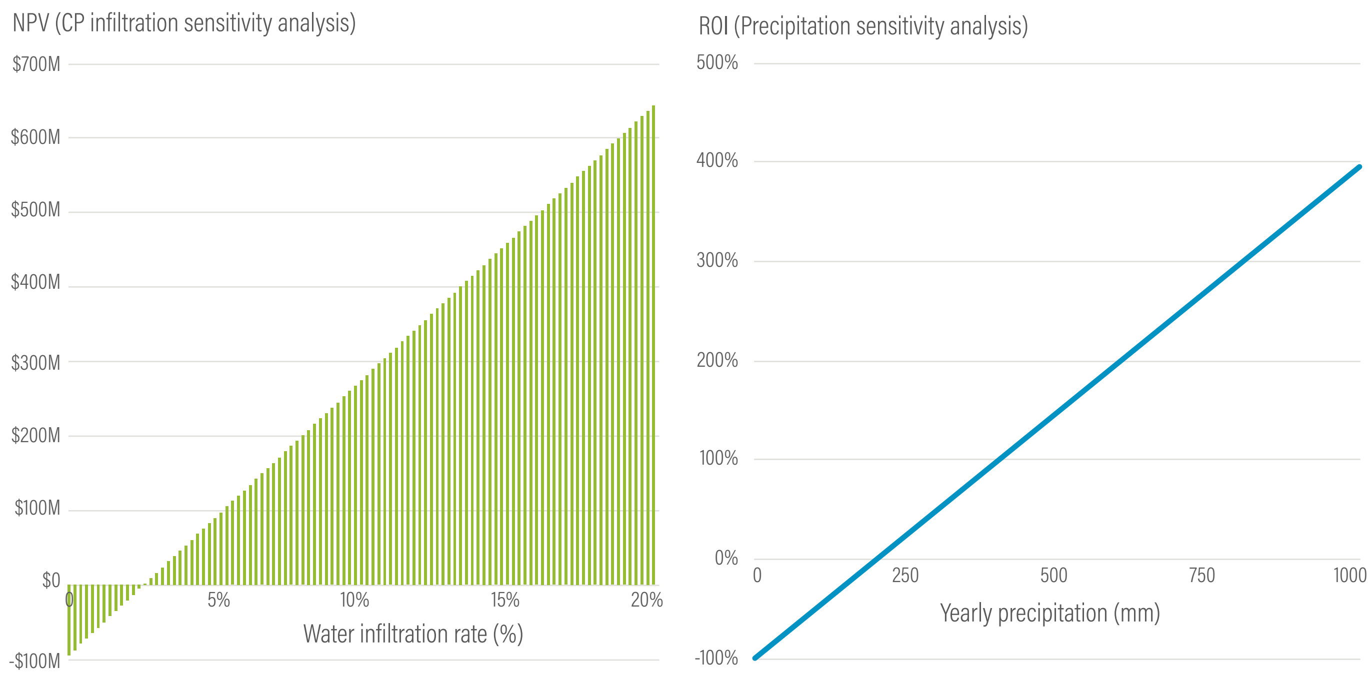
Figure 10 | **Financial Analysis Graphic Results**




*Note:* I&E: investments and establishment costs; O&M: operation and maintenance costs; Opp costs: opportunity costs; Trans costs: transaction costs. All amounts in MXN$.
*Source:* WRI.

### Figure 11 | Sensitivity Analysis Graphic Results




*Note:* The calculator presents these values in nominal figures. All amounts in MXN$.
*Source:* WRI.

### Table 8 | Sensitivity Analysis Quantitative Results

| DISCOUNT RATE (%) | | | | | |
|---|---|---|---|---|---|
| | **12%** | **15%** | **18%** | **21%** | **24%** |
| NPV (MXN $, million) | 150.6 | 73.8 | 33.0 | 10.8 | -$1.5 |
| ROI (%) | 92 | 59 | 33 | 13 | -2 |
| **COST OF WATER PROVISION*** | | | | | |
| | **$14** | **$16** | **$18** | **$20** | **$22** |
| NPV (MXN $, million) | 214.9 | 88.5 | 37.9 | -164.4 | -290.8 |
| ROI (%) | 107 | 44 | -19 | -82 | -145 |
| **ANNUAL WATER PRICE INCREASE**** | | | | | |
| | **3%** | **4%** | **5%** | **6%** | **7%** |
| NPV (MXN $, million) | -317.7 | -194 | -45.8 | 132.3 | 346.6 |
| ROI (%) | -158 | -96 | -23 | 66 | 172 |

*Notes:*
*This assumes that both types of water sources (underground and surface) have equal costs.
**This assumes the same price increase is applied to all types of water users (domestic, public, commercial, and industrial).
*Source:* WRI.

## FUTURE DEVELOPMENT

Global experiences have made it clear that protecting and restoring nature's hydrologic benefits can constitute a cost-effective, resilient water security strategy. However, such efforts must be based on local assessment and design. Very few regions of the world have sufficient biophysical data to predict the hydrologic outcomes of land cover change; likewise, most lack transparent data on water management strategies and costs. To date, this lack of sufficient data has been a barrier to integrating natural infrastructure strategies into water-sector decision-making.

The calculator demonstrates one approach to addressing this important challenge. It aims to balance scientific integrity with practicality to integrate natural infrastructure into water management plans, even in data-scarce situations. Future work should be undertaken to develop other decision-relevant calculators to help decision-makers more efficiently and easily integrate natural infrastructure into water investment objectives and to help guide future local research to overcome important data gaps and be as relevant as possible.

Currently, the Natural Infrastructure for Aquifer Recharge Financial Calculator contains approximated data and formulas, and allows users to enter their own data and assumptions. While the tool contributes a hypothetical approximation of the financial impacts of land cover change, it has numerous sources of uncertainty and limitations that can only be solved through additional research and local validation. Looking ahead, the tool may be enhanced by integrating additional and better locally collected data and formulas. Once water managers and other relevant stakeholders are able to test the tool and provide feedback, we will be able to refine the tool's utility, the quality of its outputs, and identify the most critical areas for further development.

We encourage users of this prototype to contact the authors and convey their impressions and recommendations so as to continue improving this calculator and its underlying methods.

## ENDNOTES

1. Comprehensive information about the MMWF's strategy, structure, and operation can be found at http://famm.mx/.

2. Platforms reviewed include WEAP (Water Evaluation and Planning system); Liquid Assets: Investing for Impact in the Colorado River Basin; Water Risk Monetizer; InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs); WaterWorld; Co$ting Nature, i-Tree Eco/i-Tree Hydro; L-THIA (Long-Term Hydrological Impact Assessment); AQUATOOL; Global Water Tool; Green Values (National Stormwater Management Calculator); WRI Aqueduct; ARIES; and TESSA (Toolkit for Ecosystem Service Site-based Assessment).

3. The MMWF's Conservation Plan covers an MIA of 151,958 ha located on the forested mountains around Monterrey. From that entire area, we selected only the territory that met four criteria: (1) it was part of the "local catchment and potential recharge" priority area within the MIA (per Hesselbach et al. 2018); (2) it was located directly on areas with geological aquifer recharge facilitation characteristics; (3) it had assigned intervention strategies in the MMWF Conservation Plan; and (4) its condition (good, fair, or poor) had already been evaluated and characterized by Hesselbach et al. (2016).

4. They were determined by overlaying the "local catchment and potential recharge" priority map with "intervention strategies" map provided by TNC (Hesselbach et al. 2016; Hesselbach et al. 2018).

5. Due to the legal status and the prohibitions from the Natural Protected Areas National Commission (Comisión Nacional de Áreas Naturales Protegidas; CONANP), HF management practices cannot be promoted in Nuevo León. Nonetheless, the HF management interventions were kept as an option in the tool, acknowledging the relevance of these practices for aquifer recharge and allowing for the possibility to test the tool in other contexts where those actions are legally plausible.

6. For hypothetical purposes to demonstrate the potential ROI of conservation, we suggest running the model twice: once with the preset baseline infiltration rate associated with some hectares for conservation, and again with a scenario in which the same number of hectares are designated for forest loss and therefore the infiltration capacity is also lost (infiltration baseline and conservation investments both change to 0 percent). The difference between the two scenarios would show the benefits of conservation and the cost of inaction.

7. We assume the mean from a set of historical values has a higher probability to be closer to the "true" value of what can be expected in future events than any other typical value from the historical observations.

8. Personal communication between the authors and Dr. Zablon Adane, associate researcher for the Water Program at the World Resources Institute, Washington, DC. November 21, 2017.

9. Online conversation between the authors and Dr. Solange Filoso, World Resources Institute, Washington, DC. November 21, 2017.

10. In our financial pilot analysis, we used an even more conservative assumption—of 44 years—to achieve maximum revegetation benefits, delaying revenue accrual even further and limiting what can be captured during the time horizon.

11. Reality manifests more dynamic behaviors than those represented in Figure 6 (e.g., in reality, the benefits of HF would not be a perfect flat line). These curves, however, can be reasonably assumed as average trends of real dynamics.

12. This transformation is achieved by shifting the "minimum rate of benefits to model" to 100 percent (cell C7 on the Forest Maturity Input tab). Having a minimum rate of benefits (100 percent) equal to the maximum rate of benefits (also 100 percent) produces a flat line with no slope at the rate of 100 percent of benefits constant over time.

13. In the Excel-based calculator the user will only be able to model one of the two possible benefit progression curves for CP. The user must previously decide which of the two (C1 flat line or C2 decreasing line) better represents the target area. We strongly recommend using C1 benefit's progression model, unless there is sufficiently robust data to prove otherwise, and is detailed enough to properly adjust the decreasing curve (C2).

14. Personal communication between the authors and Dr. Zablon Adane, associate researcher for the Water Program at the World Resources Institute, Washington, DC. November 21, 2017.

15. Online conversation between the authors and Dr. Solange Filoso, World Resources Institute, Washington, DC. November 21, 2017.

16. Precipitation volume will be inputted by the user on cell B9 of the Control Dashboard, as a yearly average in mm, which is the common way to express precipitation. Considering that 1 mm is equivalent to 1 liter per square meter (1 $l/m^2$), the volume inputted by the user is automatically converted by the tool into cubic meters per ha ($m^3/ha$). This conversion is done by dividing the millimeters by 1,000 (to convert them to cubic meters) and multiplying the square meters by 10,000 (to obtain the volume per ha).

17. Periodicity: How often does this O&M cost occur? For example, every three years.

18. Duration: During how many years does this O&M cost occur? For example, during three continuous years.

19. Prorated: If the opportunity cost needs to be divided through the years of duration (e.g., a land purchase, where the investor might want to divide this capital investment over several years). Row 45 of the 1.0 Costs Input tab is reserved for prorated opportunity costs.

20. Repeated: If the opportunity cost must be paid in full for several years. Land rental and crop yield are examples of repeated opportunity costs, as, for instance, the rent of land would have to be paid in full through all the years agreed. Rows 51 and 53 are reserved for the user to input repeated opportunity costs.

21. To activate cell K49 functionalities, cells H51:J54 must be switched to blank.

22. The cost components considered to establish this comparison were catchment and purification, conduction, storage and distribution, general expenses for potable water, drainage and treatment, commercial expenses, administrative expenses, engineering expenses, financial expenses, CONAGUA extraction rights, and depreciation.

23. According to Maliva (2014), "The alternative cost method is based on the notion that the maximum amount that people would be willing to pay for a good or service will not be greater than the cost of providing that good or service through a different process." Hence, we assume that the avoided cost-benefit's potential for this case study would be limited by the difference in the cost of the underground water and the cost of the alternative source (in this case, surface water).

24. Note that If both sections are fulfilled (disaggregated costs as well as total bottom-line costs), the tool would prioritize the values on cells C22:D22 (the broad assumptions). If the user's desire is to prioritize the disaggregated values, then the global value's section must remain blank.

25. Personal communication between the authors and Dr. Zablon Adane, associate researcher for the Water Program at the World Resources Institute, Washington, DC. November 21, 2017.

# REFERENCES

Aguilar-Barajas, I., N.P. Sisto, and A.I. Ramírez Orozco. 2015. *Agua para Monterrey: Logros, retos y oportunidades para Nuevo León y México*. Monterrey: Servicios de Agua y Drenaje de Monterrey. https://www.sadm.gob.mx/PortalSadm/Docs/aguaparamonterrey-media.pdf.

Appanah, S., K. Shono, and P.B. Durst. 2015. "Restauración de tierras y bosques degradados en Asia sudoriental." *Unasylva: revista internacional sobre bosques y actividades e industrias forestales* 66 (3): 52–63. http://www.fao.org/3/a-i5212s.pdf.

Banco de México. 2018. "Mercado de valores (tasas de interés)." http://www.banxico.org.mx/portal-mercado-valores/.

Campos, J., T. Serebrisky, and A. Suárez Aleman. 2015. *Time Goes By: Recent Developments on the Theory and Practice of the Discount Rate.* New York: Inter-American Development Bank. https://publications.iadb.org/bitstream/handle/11319/7206/Time_Goes_By_Recent_Developments_on_the_Theory_and_Practice_of_the_Discount_Rate.pdf?sequence=2&isAllowed=y.

Castro Mendoza, I., et al. 2016. "Balance hídrico de la cuenca Pijijiapan en Chiapas, México." *Ingeniería Hidráulica y Ambiental* 37 (2): 18–28.

Cedillo de Lucas, L.L. 2012. *Evaluación de las fuentes abastecimiento de agua para la zona metropolitana de Monterrey*. Monterrey, Mexico: Instituto Tecnológico y de Estudios Superiores de Monterrey. http://hdl.handle.net/11285/571550.

Clifton, K.M., J. Gan, and H. Ibarra Gil. 2016. "User's Perception on Conservation on Communal Lands in Cumbres de Monterrey National Park, Mexico." *Range Management and Agroforestry* 37 (2): 133–41. https://www.researchgate.net/publication/313851267_User's_perception_on_conservation_on_communal_lands_in_Cumbres_de_Monterrey_National_Park_Mexico.

CONABIO (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad). n.d. (Database.) *Portal de información geográfica*. Accessed July 24, 2018. http://www.conabio.gob.mx/informacion/gis/?vns=gis_root/dipol/dpotras/manzmge15gw.

CONANP (Comisión Nacional de Áreas Naturales Protegidas). 2016. "Programas de Manejo." http://www.conanp.gob.mx/que_hacemos/programa_manejo.php.

Descheemaeker, K., D. Raes, J. Nyssen, J. Poesen, M. Haile, and J. Deckers. 2009. "Changes in Water Flows and Water Productivity upon Vegetation Regeneration on Degraded Hillslopes in Northern Ethiopia: A Water Balance Modelling Exercise." *Rangeland Journal* 31 (2): 237–49. http://doi.org/10.1071/RJ09010.

DOF (Diario Oficial de la Federación). 1969. "Decreto por el que se declara área natural protegida, con el carácter de parque nacional, la región conocida con el nombre de Cumbres de Monterrey, ubicada en los municipios de Allende, García, Montemorelos, Monterrey, Rayones, Santa Catarina, Santiago y San Pedro Garza García, Estado de Nuevo León," December 31. http://www.dof.gob.mx/nota_detalle.php?codigo=2063788&fecha=31/12/1969.

DOF. 2013. "Lineamientos para la elaboración y presentación de los análisis costo y beneficio de los programas y proyectos de inversión," December 13. http://www.dof.gob.mx/nota_detalle.php?codigo=5328458&fecha=30/12/2013.

DOF. 2014. "Acuerdo por el que se da a conocer el resumen del Programa de Manejo del Área Natural Protegida con la categoría de Monumento Natural El Cerro de La Silla," June 1. http://www.dof.gob.mx/nota_detalle.php?codigo=5328874&fecha=06/01/2014.

DOF. 2018a. "Acuerdo por el que se actualiza la disponibilidad media anual de agua subterránea de los 653 acuíferos de los Estados Unidos Mexicanos, mismos que forman parte de las Regiones Hidrológico-Administrativas que se indican," January 4. http://www.dof.gob.mx/nota_detalle.php?codigo=5510042&fecha=04/01/2018.

DOF. 2018b. *Ley general del equilibrio ecológico y la protección al ambiente,* June 5. http://www.diputados.gob.mx/LeyesBiblio/ref/lgeepa/LGEEPA_ref41_05jun18.pdf.

Ellison, D., C.E. Morris, B. Locatelli, D. Sheil, J. Cohen, D. Murdiyarso, V. Gutierrez, et al. 2017. "Trees, Forests and Water: Cool Insights for a Hot World." *Global Environmental Change* 43 (March): 51–61. http://doi.org/10.1016/j.gloenvcha.2017.01.002.

FAO (Food and Agriculture Organization of the United Nations) and GM (Global Mechanism of the United Nations Convention to Combat Desertification). 2015. "Sustainable Financing for Forest and Landscape Restoration: Opportunities, Challenges and the Way Forward." Discussion paper. Rome: FAO and United Nations Convention to Combat Desertification. http://www.fao.org/publications/card/en/c/274a1d5d-868a-4c70-9700-590615875184/.

Filoso, S., M. Ometto Bezerra, K.C.B. Weiss, and M.A. Palmer. 2017. "Impacts of Forest Restoration on Water Yield: A Systematic Review." *PLOS One* 12 (8): e0183210. http://doi.org/10.1371/journal.pone.0183210.

Gray, E., S. Ozment, J.C. Altamirano, R. Feltran-Barbieri, and G. Morales. Forthcoming. *Green Gray Assessment: How to Assess the Costs and Benefits of Green Investments for Water Supply Systems*. Washington, DC: World Resources Institute.

Hansen, M.C., P.V. Potapov, R. Moore, M. Hancher, S.A. Turubanova, A. Tyukavina, D. Thau, et al. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." *Science* 342 (6160): 850–53. https://doi.org/10.1126/science.1244693.

Hernández Pérez, M.L., M.S. Guridi Cabrera, and O.O. Sotoby. 2015. *Guía general para la presentación de estudios de evaluación socioeconómica de programas y proyectos de inversión: Análisis costo-beneficio; Actualización 2015.* Mexico City: Banco Nacional de Obras y Servicios Públicos and Centro de Estudios para la Preparación y Evaluación Socioeconómica del Proyectos. http://www.cepep.gob.mx/work/models/CEPEP/metodologias/documentos/Guia_General_FINAL.pdf.

Hesselbach, H., J.Á. Sánchez de Llanos, F. Reyna-Sáenz, F.J. García Moral, A. Gondor, J. León Sarmiento, and J.F. Torres-Origel. 2016. "Plan de conservación del fondo de agua metropolitano de Monterrey, A.C. primera parte." Internal Document. Arlington, VA: The Nature Conservancy.

Hesselbach, H., J.Á. Sánchez de Llanos, F. Reyna-Sáenz, F.J. García Moral, S.J. León, F. Torres-Origel, and A. Gondor. 2018. "Plan de Conservación del Fondo de Agua Metropolitano de Monterrey—Versión Resúmen 2018." Internal Document. Arlington, VA: The Nature Conservancy.

Ilstedt, U., A. Bargués Tobella, H.R. Bazié, J. Bayala, E. Verbeeten, G. Nyberg, J. Sanou, et al. 2016. "Intermediate Tree Cover Can Maximize Groundwater Recharge in the Seasonally Dry Tropics." *Scientific Reports* 6 (February): 21930. https://doi:.org/10.1038/srep21930.

Ilstedt, U., A. Malmer, E. Verbeeten, and D. Murdiyarso. 2007. "The Effect of Afforestation on Water Infiltration in the Tropics: A Systematic Review and Meta-Analysis." *Forest Ecology and Management* 251 (1–2): 45–51. https://doi.org/10.1016/j.foreco.2007.06.014.

King, D., and C. Bohlen. 1995. *The Cost of Wetland Creation and Restoration: Final Report.* Washington, DC: Office of Scientific and Technical Information, U.S. Department of Energy. https://doi.org/10.2172/91931.

Krishnaswamy, J., M. Bonell, B. Venkatesh, B.K. Purandara, K.N. Rakesh, S. Lele, M.C. Kiran, V. Reddy, and S. Badiger. 2013. "The Groundwater Recharge Response and Hydrologic Services of Tropical Humid Forest Ecosystems to Use and Reforestation: Support for the 'Infiltration-Evapotranspiration Trade-off Hypothesis.'" *Journal of Hydrology* 498 (August): 191–209. https://doi.org/10.1016/j.jhydrol.2013.06.034.

Latin America Water Funds Partnership. 2017. "Monterrey Water Fund," May 1. http://waterfunds.org/esp/monterrey-water-fund/.

Lile, R., M. Powell, and M. Toman. 1998. "Implementing the Clean Development Mechanism: Lessons from U.S. Private-Sector Participation in Activities Implemented Jointly." Working Paper. Washington, DC: Resources for the Future.

López Báez, W., R. Camas Gómez, R. Reynoso Santos, P. Cadena Íñiguez, and I. Castro Mendoza. 2014. "Conectividad hídrica entre cuencas, municipios y reserva de la biósfera El Triunfo, Chiapas, México." *Revista Mexicana de Ciencias Agrícolas* 8 (May/June): 1417–23. https://www.redalyc.org/articulo.oa?id=263131168006.

Maliva, Robert G. 2014. "Economics of Managed Aquifer Recharge." *Water* 6 (May): 1257–79. https://doi.org/10.3390/w6051257.

Maqueda, A, J. Ren, and F. Lozano. 2008. "Assessment of Land Cover Change Effect on the Hydrology of the San Juan River Watershed, Nuevo León, Mexico." *Journal of Environmental Hydrology* 16 (paper 33). http://www.hydroweb.com/protect/pubs/jeh/jeh2008/maqueda.pdf.

Meixueiro Garmendia, J., M. Pérez Cruz, and A.L. Mascle Allemand. 2017. *Metodología para la evaluación socieoeconómica de proyectos de construcción de plantas de tratamiento de aguas residuales (PTAR).* Mexico City: Banco Nacional de Obras y Servicios Públicos and Centro de Estudios para la Preparación y Evaluación Socioeconómica del Proyectos. http://www.cepep.gob.mx/work/models/CEPEP/metodologias/documentos/metodologia_ptar.pdf.

Návar, J. 2011. "Stemflow Variation in Mexico's Northeastern Forest Communities: Its Contribution to Soil Moisture Content and Aquifer Recharge." *Journal of Hydrology* 408 (1–2): 35–42. https://doi.org/10.1016/j.jhydrol.2011.07.006.

Owuor, S.O., K. Butterbach-Bahl, A.C. Guzha, M.C. Rufino, D.E. Pelster, E. Díaz-Pinés, and L. Breuer. 2016. "Groundwater Recharge Rates and Surface Runoff Response to Land Use and Land Cover Changes in Semi-arid Environments." *Ecological Processes* 5 (16). https://doi.org/10. 0.1186/s13717-016-0060-6.

Poorter, L., F. Bongers, T.M. Aide, A.M. Almeyda Zambrano, P. Balvanera, J.M. Becknell, V. Boukili, et al. 2016. "Biomass Resilience of Neotropical Secondary Forests." *Nature* 530 (7589): 211–14. https://doi.org/10.1038/nature16512.

SADM (Servicios de Agua y Drenaje de Monterrey). 2011. "Estudio de Diagnóstico y Planeación Integral de los Sistemas de Agua Potable, Alcantarillado y Saneamiento del Estado de Nuevo León." Internal Report. Monterrey: SADM.

Saldívar, Américo, M. Oliveira, and A. Isidro. 2016. "Valoración y demanda del servicio ambiental hidrológico en el Parque Nacional Cumbres de Monterrey." *Natura@economía* 1 (2): 9–28. http://revistas.lamolina.edu.pe/index.php/neu/article/view/41.

Schilling, K.E. 2009. "Investigating Local Variation in Groundwater Recharge along a Topographic Gradient, Walnut Creek, Iowa, USA." *Hydrogeology Journal* 17 (2): 397–407. https://doi.org/10.1007/s10040-008-0347-5.

Sisto, N.P., A.I. Ramírez, I. Aguilar-Barajas, and V. Magaña-Rueda. 2016. "Climate Threats, Water Supply Vulnerability and the Risk of a Water Crisis in the Monterrey Metropolitan Area (Northeastern Mexico)." *Physics and Chemistry of the Earth, Parts A/B/C* 91 (February): 2–9. https://doi.org/10.1016/j.pce.2015.08.015.

Smith, D.M., B.C. Larson, M.J. Kelty, and M.S. Ashton. 1997. *The Practice of Silviculture: Applied Forest Ecology.* Hoboken, NJ: John Wiley & Sons.

Vergara, W., L. Gallardo Lomeli, A.R. Rios, P. Isbell, S. Prager, and R. de Camino. 2016. *The Economic Case for Landscape Restoration in Latin America.* Washington, DC: World Resources Institute. http://wriorg.s3.amazonaws.com/s3fs-public/The_Economic_Case_for_Landscape_Restoration_in_Latin_America.pdf.

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## ABOUT THE AUTHORS

**Ana Gabriela Morales** is the Urban Water and Resilience Manager in the World Resources Institute in Mexico.

Contact: gabriela.morales@wri.org

**Suzanne Ozment** is a Senior Associate with the World Resources Institute's Natural Infrastructure Initiative.

Contact: sozment@wri.org

**Erin Gray** is an Economist with the World Resources Institute's Economics Center.

Contact: egray@wri.org

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