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WATER FLOW REGULATION AND INCENTIVES FOR CONSERVATION: COCA RIVER - ECUADORIAN AMAZON

REGULACIÓN HÍDRICA E INCENTIVOS DE CONSERVACIÓN: RÍO COCA – AMAZONÍA ECUATORIANA

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Water flow regulation and incentives for conservation: Coca river - ecuadorian Amazon

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ABSTRACT

Conservation and land use policies are key to regulating water in watersheds, influencing water quantity, quality and storage, and mitigating risks such as erosion and flooding. In Ecuador, the Socio Bosque Program (SBP), part of the Good Living Development Plan (2013-2017), focused on conservation without fully considering water benefits. To optimize its implementation, the upper basin of the Coca River, relevant for its hydroelectric potential, was evaluated by analyzing the inclusion of water criteria in the SBP. Four scenarios of land cover and land use change were developed using the Delphi method: Business as Usual (BAU), Strengthening of SPB (SBPS), National Incentive Plan (NIP), and Degradation (DEG). Runoff rates were estimated for each scenario using a land cover and land use model (TerrSet) and a hydrological model (SWAT). The results show that BAU and DEG cause a decrease in lateral and base flow and an increase in surface runoff, while NIP is the only scenario that maintains water regulation. This highlights the need for future incentives to prioritize strategic areas for water regulation in line with watershed management objectives.

Keywords: land use/land cover change, conservation incentives, Socio Bosque Program, water ecosystem services, water regulation

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Regulación hídrica e incentivos de conservación: río Coca - Amazonía ecuatoriana

RESUMEN

Las políticas de conservación y uso de suelo son clave para la regulación hídrica de las cuencas, influyendo en la cantidad, calidad y almacenamiento del agua, además de mitigar riesgos como la erosión y las inundaciones. En Ecuador, el Programa Socio Bosque (PSB), en vigencia desde 2008, se ha enfocado en la conservación sin considerar sus repercusiones en términos hídricos. Con el objetivo de proponer mecanismos que optimicen la aplicación del PSB, se seleccionó la cuenca alta del río Coca, relevante por su potencial hidroeléctrico, para evaluar la incidencia de incluir criterios hídricos en la aplicación del PSB. Mediante el método Delphi se desarrollaron cuatro escenarios de cambio de cobertura y uso de suelo: Business as Usual (BAU), Fortalecimiento del PSB (FSB), Plan Nacional de Incentivos (PNI) y Degradación (DEG). A través de modelos de cobertura y uso de suelo (TerrSet) e hidrológicos (SWAT), se estimaron caudales para cada escenario. Los resultados muestran que BAU y DEG provocan disminución en la escorrentía subterránea y aumento de la superficial, mientras que el PNI es el único escenario que preserva la regulación hídrica. Esto resalta la necesidad de que futuros incentivos prioricen áreas estratégicas para la regulación hídrica, alineados con los objetivos de manejo de cuencas.

Palabras clave: cambios de uso de suelo/cobertura de suelo, incentivos de conservación, Programa Socio Bosque, servicios ecosistémicos, regulación hídrica

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INTRODUCTION

Integrated Water Resources Management (IWRM) ensures the coordinated development and management of water in interaction with other natural, social and cultural systems, maximizing economic well-being without compromising vital ecosystems (Tortajada, 2016). The watershed approach is the most appropriate territorial unit for its application (Forero & Mosquera, 2014).

Land use and its degree of exploitation modify the hydrological functions of a watershed (Can et al., 2015); thus, Land Use/Land Cover (LULC) changes affect the ecosystem service of water flow regulation (Bonnesoeur et al., 2019; Brath et al., 2006; Costa et al., 2003; Crooks & Davies, 2001; Wang et al., 2006). Inadequate soil management can lead to the loss of ecosystem services and biodiversity (Can et al., 2015; Fernández & Prados, 2010; Li et al., 2009); therefore, to counteract these effects, public policy instruments in the form of environmental incentives have been proposed in recent decades to stimulate sustainable land use processes and actions (S. Ortega, 2008; Ramírez, 2006).

In 2008, following the ratification of the United Nations Framework Convention on Climate Change (UNFCCC) and in line with the National Development Plan in force at the time, Ecuador established the Socio Bosque Program (SBP), with the main objectives of conserving native vegetation, reducing greenhouse gas emissions from deforestation and contributing to the improvement of the living conditions of the rural population (MAE, 2008). In 2013, the National Incentive Program for the Conservation and Sustainable Use of Natural Heritage (NIP) was established with the aim of integrating all incentive initiatives (conservation, restoration, forest management, biotrade and financial sustainability) into a single program (Acuerdo Ministerial 131, 2013; De Koning et al., 2011). With this amendment, the SBP becomes part of the conservation and restoration chapters of this program.

According to the operating rules and internal procedures of the SBP, the applicant property must be located within the areas identified as priority areas according to the criteria of deforestation risk, provision of environmental services (water regulation, biodiversity habitat and climate change mitigation) and poverty level (unsatisfied basic needs) (Manual Operativo Del Proyecto Socio Bosque, 2014).

The SBP has been consolidated as a valid strategy to promote the conservation of native vegetation (Zurita & Cotacahi, 2019). This program works by providing annual financial incentives of USD$30.00

per hectare to individual or collective landowners who voluntarily commit not to intervene in areas of native vegetation (primary forest or páramo) for a period of 20 years (Granda & Yánez, 2017; Perafán & Pabón, 2019). Although participation in the program is voluntary, membership is conditional on the property being located within the areas identified as priority areas. In addition, each property that joins the program must undergo a monitoring and control process to periodically verify that no changes in land cover or land use are occurring (Braulete, 2012), but it is not necessary to measure the environmental benefits generated (Farley & Bremer, 2017; Hansen et al., 2015; McAfee, 2016; Ponette-González et al., 2015; Vanacker et al., 2018).

The Coca watershed, located in the northeastern Ecuadorian Amazon, is one of the most mega-diverse regions in the world (Mittermeier et al., 2011), which is why 76% of its area is part of the National System of Protected Areas (SNAP) (Torres et al., 2018). Due to its abundant river system and special orography, it has a hydroelectric potential of 4640 MW, making it the second most important watershed in the country (CONELEC, 2013), with 22 hydroelectric plants (five in operation, one under construction and 16 in planning). Currently, the watershed produces 30% of the energy consumed by the entire country, thanks to the NSPA operation of the Coca Codo Sinclair Hydropower Plant (CCSHP), with 1,500 MW, according to the Ministry of Energy and Non-Renewable Natural Resources (MERNNR, 2020). It also plays a key role in the current and future provision of water for the consumption of around 40% of the population of the Metropolitan District of Quito (Jiménez & Temeus, 2019).

Although most of the watershed area belongs to the SNAP, according to the Ministry of the Environment (MAE, 2015), since 2014 it has not been possible to stop the advance of pasture and arable land (5.7% per year). In this context, the SBP is implemented as the only National Incentive Program for the Conservation and Sustainable Use of Natural Heritage incentive present in the area, with a total of 24,897 ha of private and communal forests and peatlands, distributed inside and outside the SNAP. Despite the importance of this basin in terms of hydroelectric production and as indicated in the SBP regulations, no studies were found on the relevance of focusing the incentives provided by the current SPB regulations on areas whose conservation or restoration will have a positive impact on the hydrological functions of the basin (Torres et al., 2018). In addition, the watershed presents a complex nature in terms of soils, geology, vegetation, which has recently been reflected in the process of regressive erosion downstream, which became evident in 2020 with the loss of the iconic San Rafael waterfall (Barrera Crespo et al., 2024). While water regulation is not explicitly identified as an objective of the SBP, the selection of priority areas for its application does include water regulation criteria (Acuerdo Ministerial 066, 2022; Consulado del Ecuador, 2012). Furthermore, the environmental policy that supports the program recognizes the state's obligations in relation to aspects such as: a) guaranteeing the conservation, recovery and integrated management of water resources and watersheds; b) regulating changes in land use, ensuring the minimum impact and restoration of ecosystems in water protection areas; and c) implementing environmental incentives that promote the conservation, sustainable use and management, and restoration of ecosystems (A. Martínez, 2019).

This study focused on identifying and analyzing how the implementation of different conservation and land-use policies, provided in current national legislation, would affect water flow regulation in the upper Coca river watershed. To this end, the Delphi method was used to generate four land use scenarios with a horizon of 2030 (J. Martínez et al., 2016; F. Ortega, 2008); then, the scenario approach was applied as input to the hydrological modelling of the watershed (Marhaento et al., 2017; Mckenzie et al., 2012), to obtain indicators to assess the impact of the scenarios on the water flow regulation. The results of this study are expected to be an input for decision makers to consider mechanisms to optimize the application of existing conservation incentives.

METHODOLOGY

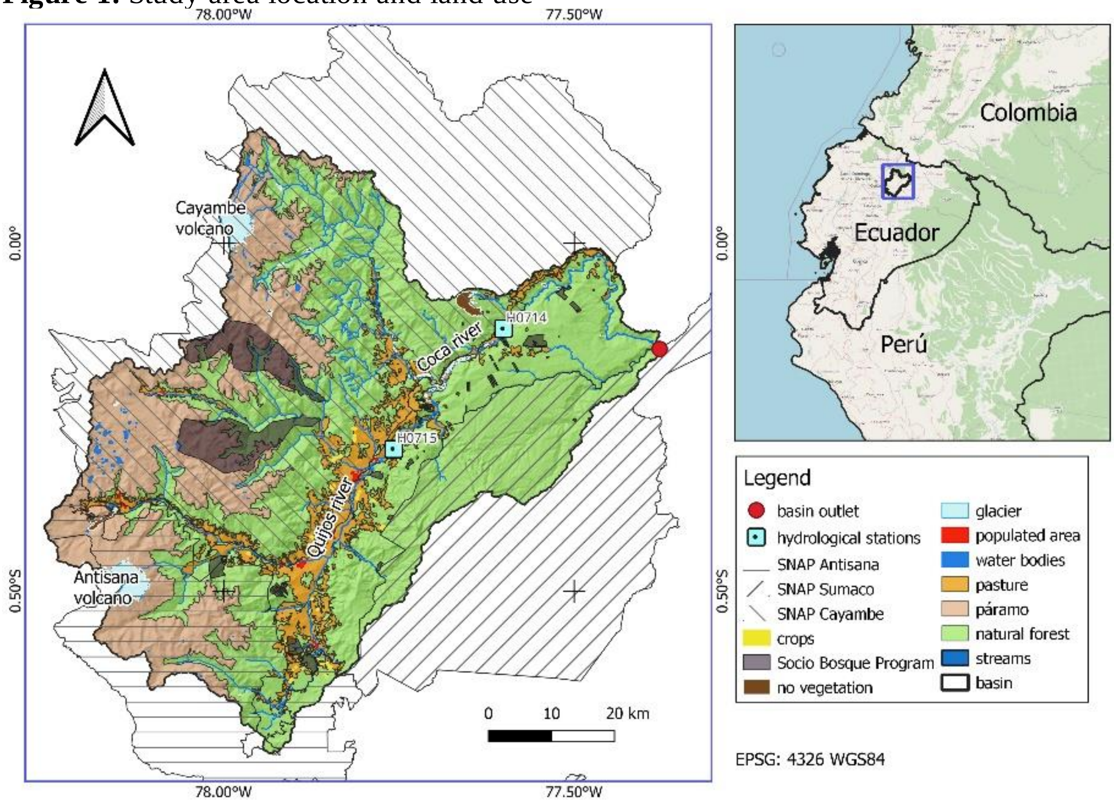
Study area

The upper zone of the Coca river watershed (with outlet point at the confluence with Machacuyacu river) is located in the northwest of the Ecuadorian Amazon, between the eastern Cordillera of the Andes and the Amazon forest. Its altitude varies between 5,790 and 533 masl, and it has an approximate drainage area of 4,597 km2, which includes part of three protected areas (Cayambe-Coca, Antisana and Napo-Sumaco-Galeras) (López, 2016) (Figure 1). Its rivers originate in the foothills of the Antisana and Cayambe volcanoes. The average rainfall is 2,950 mm/year, with the wettest period corresponding to the months of May to July; the average annual temperature is 15.4°C, and relative humidity varies between 84% and 93% (Horna, 2016). The soils are mainly Andisols (81%) and Inceptisols (8.2%)

(Tamayo, 2017). Land use is distributed between natural forest (61%), páramo (27%) and pasture (10%) (Figure 1) (Torres et al., 2018).

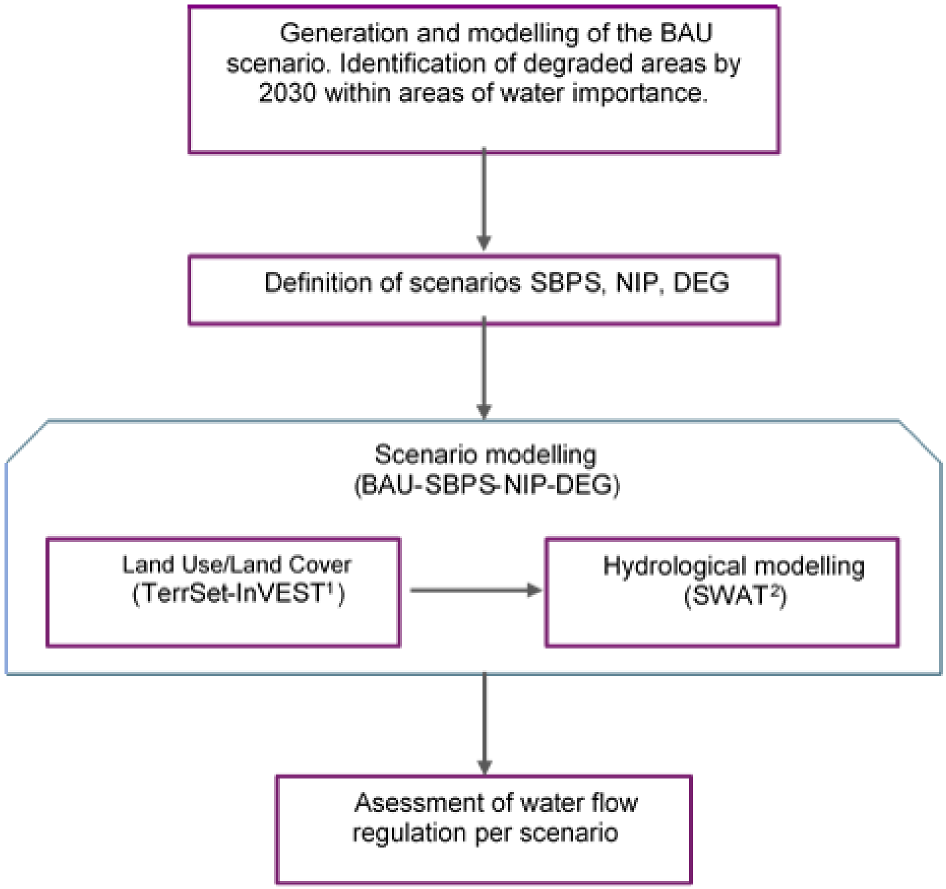
The soils in the watershed are fragile, with a shallow arable layer that is highly sensitive to leaching due to high precipitation (Sánchez et al., 2018; Vargas et al., 2018). The conversion of natural forests to pasture in this watershed results in reduced soil fertility and low crop productivity (Mainville et al., 2006). Consequently, agriculture is a marginal activity, with most crops corresponding to pastures for livestock maintenance.

Figure 1. Study area location and land use



In alignment with the objective of this research, we considered the areas of water importance identified by Torres et al. (2018). On this basis the LULC was projected, assuming that the trend associated with the conservation policies currently applied will remain constant over time. This analysis was used to construct four land use scenarios based on the current legal framework and the Delphi method. These scenarios were created to support the estimation of potential changes in vegetation cover and to assess the impact of such changes on water flow regulation in the watershed. The study was conducted in accordance with the steps presented in Figure 2.

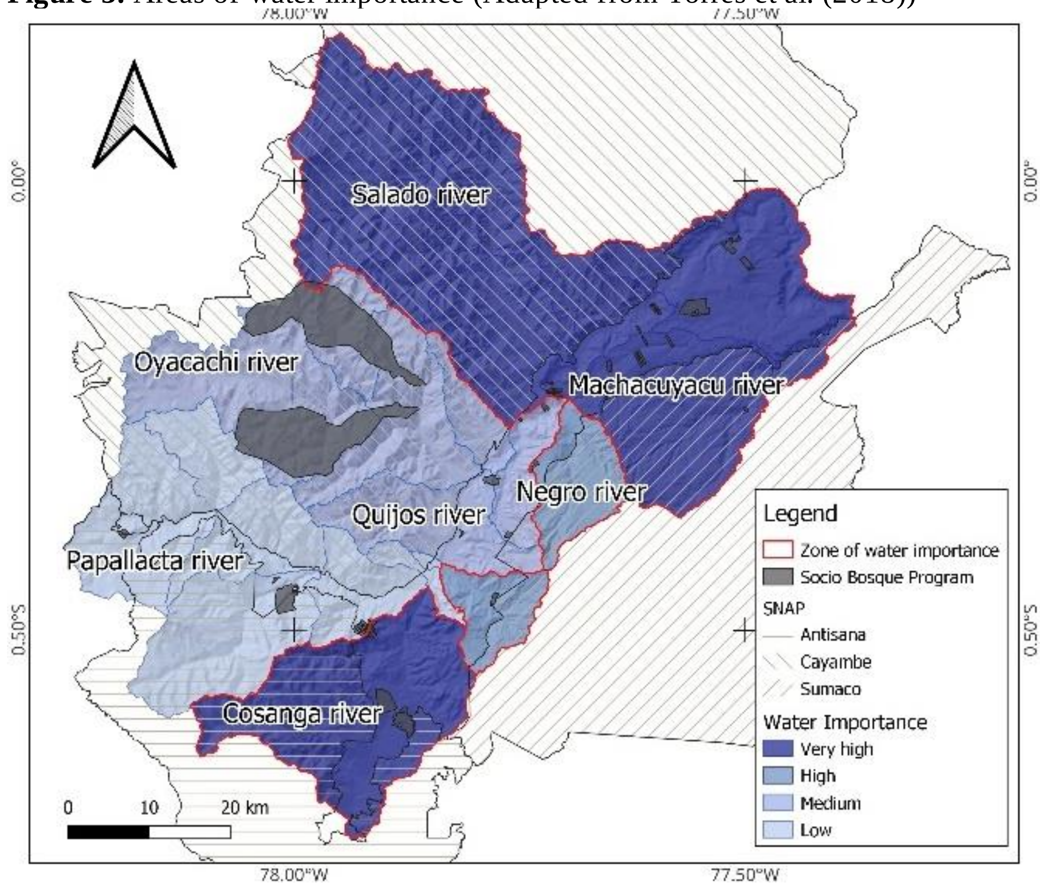
Figure 2. Study methodological framework. Notes: 1 Integrated Valuation of Ecosystem Services and Trade-offs, 2 Soil & Water Assessment Tool



Scenario generation

The areas of water importance were established by identifying the sub-watersheds with the highest water and sediment production (Torres et al., 2018). The water production was obtained by modelling with the Soil and Water Assessment Tool (SWAT) model, represented by the total annual runoff. The sediment production was obtained from sediment discharge of nine stations within the study area. A qualitative assessment of water and sediment production was conducted using a scale ranging from low to very high. Low corresponds to the lowest production, while very high corresponds to the highest. Map algebra was then employed to sum the values assigned to each sub-watershed, identifying the areas that met the characteristic of highest water and sediment production simultaneously (Figure 3). Further details regarding the areas of water importance can be found in Torres et al. (2018).

Figure 3. Areas of water importance (Adapted from Torres et al. (2018))



LULC scenarios describe possible situations of an uncertain future (Alpizar & Bovarnick, 2013). This study developed four scenarios of LULC change under the current environmental legal framework and defined using the approach of McKenzie et al. (2012). The scenarios were defined following the Delphi method, with the aim of including the criteria of different actors and disciplinary fields (García, 2013). To achieve this, the collaboration of seven experts in legal, economic, social, environmental, hydraulic and hydrological issues was sought, with extensive knowledge of the socio-environmental dynamics of the study area. These experts were consulted on the interaction of the variables that drive land use change and the ideal conservation criteria for this watershed (Velázquez & Sánchez, 2021). The outcome of this process was the identification of the underlying assumptions that inform the scenarios and the set of variables that define the projected LULC.

The cartographic information available was aligned with the SBP assessment horizon (Torres et al., 2018) and the Sustainable Development Goals 2015-2030 assessment period promoted by the United Nations (ONU-CEPAL, 2016), with the year 2030 defined as the horizon for the land cover projections for each scenario. Given that the populated area and crops represent only 0.20% of the watershed area, only the transformation of native forest, páramo and pasture cover was considered for the quantification of LULC. Table 1 provides a summary of the assumptions and methods employed in the projection of the four scenarios generated.

The starting scenario was the BAU, which was projected considering both the SBP coverage and the loss of native vegetation for the period 2009-2014 as invariant. To project land use in this scenario, we used the Land Change Modeler (LCM), a software tool integrated with the TerrSet framework (Eastman, 2016). This incorporated explanatory variables and historical land cover data (1991, 2000, 2009 and 2014) provided by the MAE. The result of the projection of this scenario made it possible to identify the areas that, due to their characteristics, should be incorporated into the different incentive proposals of the SBPS and NIP scenarios.

Table 1. Scenario generation (assumptions and projection methodology

Scenario		Assumptions	Methodology for Generating the Land Use/Land Cover Use Map to 2030
1	Business As Usual (BAU)	• The annual loss of native forest and *páramo* throughout the watershed is presented by the historical trend between 2009-2014 (Torres et al. 2018): - Decrease of 0.7% in native forest per year - Decrease of 0.05% in *páramo* per year - Increase of 1.1% in pasture per year • The same SBP coverage as in 2014 (24,987 ha) is maintained in 2030.	Mathematical model (quantitative) SIG – TerrSet
2	Strengthening of SBP (SBPS)	• It foresees the optimization of the **conservation** incentive in terms of water regulation, by including 6250 ha defined as water significant outside the SNAP that are under threat of degradation. Totaling 31147 ha under contract in the SBP. • The annual loss of forest and *páramo*, as well as the increase of pasture areas continues in the rest of the watershed with the historical trend.	Expert judgement (qualitative)
3	National Incentive Program (NIP)	• Extends the **conservation** of the areas defined in the SBPS to areas that in the BAU scenario (2030) were identified as areas of transition from native forest to pasture, which are within protective forests, correspond to areas of water importance and are located outside the SNAP.	Expert judgement (qualitative)

		• **Restoration** of areas identified as degraded under the following scheme: - Degraded river slopes throughout the watershed. - Degraded areas from 2009-2014, which are outside the Salado River sub-watershed and outside the river slopes. - Degraded areas within the Salado River sub-watershed (identified as being of high water importance). • **Sustainable production** by replacing pasture with silvopastoral systems in degraded areas not under other incentives.	
4	Degradation (DEG)	• Disappearance of the SBP • Uncontrolled loss of natural vegetation due to road growth and extensive expansion of livestock activities is expected with the following annual trend: • 1.1% decrease in native forest. • 0.3% decrease in *páramo* • 7% increase in grassland	Mathematical model (quantitative) InVEST ((Sharp et al. 2018)

The SBPS scenario proposes the strengthening of the current SBP, with its application extended to areas of water importance located outside protected areas and showing degradation in the BAU scenario. The scenario is conceived as an intermediate situation between the current trend (BAU) and the ideal situation represented by the NIP scenario. To check the projected land use for this scenario, the Delphi methodology was once again employed.

The NIP scenario responds to the vision of an ideal situation of conservation and management of the watershed, which includes the simultaneous application of three incentives contemplated in the National Program of Incentives for the Conservation and Sustainable Use of Natural Heritage. In this study, these incentives are grouped into three categories: conservation, restoration and sustainable production. The latter category is represented by silvopastoral systems, which combine secondary forest, pasture and livestock. The land use projection for this scenario was generated using the Delphi methodology. The inclusion of silvopastoral systems is of great importance, as traditional livestock production systems in the Ecuadorian Amazon region are based on pastures and monocultures that are extensively grazed. This contributes significantly to the loss of fertility of naturally poor soils and has also become one of the main drivers of landscape transformation and the loss of ecosystem services (Congo et al., 2018). Faced with this situation, silvopastoral systems are a viable alternative for the area, as they are more respectful of biodiversity, make it possible to exploit the great diversity of tree species, increase soil fertility and reduce the negative impact of a fundamental activity of the local economy (Fajardo et al., 2012).

Finally, the DEG scenario simulates a critical situation in terms of conservation where the NIP is not applied and the SBP disappears, thereby weakening the restrictions on anthropic activities within protected areas. This, in turn, facilitates the advance of the agricultural frontier, which has the effect of reducing the extent of natural vegetation cover. A mathematical model, InVEST (Sharp et al., 2018), was employed to project land use to 2030.

Water Flow Regulation

- Hydrological modelling

The SWAT model was employed, which simulates the rainfall-runoff relationship over extended periods of time, based on the biophysical characteristics of a river basin in a semi-distributed framework according to Hydrological Response Units (HRU). This model is one of the most popular tools to assess water related ecosystem services (Nedkov et al., 2022). It performs the analysis in a deterministic and continuous manner, using a daily climate information base (Arnold et al., 1998). The selected modelling period was 1976 to 1988, which corresponds to the time interval with the longest continuity of data available at station H0714 – Coca in San Rafael (Figure 1). Station H0714 was employed as a calibration point for the SWAT model. Three sub-periods were selected for each of the modelling stages. The data were divided into three sub-periods: 1976-1978 (warm-up), 1979-1983 (calibration) and 1984-1986 (validation). The vegetation cover and land use applied to this modelling were those of 1990, as the available information was closest in time to the period of the hydrological data used. Consequently, the results obtained from this modelling are referred to as the 'base model (1990)'. Further details on the hydrological modelling can be found in the work of Tamayo (2017).

To perform the calibration, the SWAT-CUP (Calibration and Uncertainty Program) was employed. This involved a sensitivity analysis that required 1000 iterations, which enabled the optimal parameterization values to be determined. The model results were obtained at the daily level for the calibration-validation periods (1979-1986) for stations H0714 and H0715 – Quijos AJ Bombón. The latter station was employed to validate the spatial representation of the model, as it corresponds to the upper part of the study area (Figure 1). The statistical performance of the model was evaluated at a monthly scale by calculating the Nash-Sutcliffe (NSE), Percent Bias (PBIAS) and coefficient of determination (R2), using the criteria proposed by Moriasi et al. (Moriasi et al., 2007).

- Estimation of water flow by scenario

The representative water flows for each scenario were obtained by running the hydrological model, calibrated and validated, using the land covers corresponding to each scenario projected to 2030 (López, 2016; Torres et al., 2018). In each run, the land cover of the scenarios was modified while all other parameters were kept constant. To illustrate the impact of land use change on water flow regulation, the mean annual flows, as well as the monthly surface runoff, lateral flow and base (return) flow of each scenario were compared with those of their respective counterparts in the base model (Birkel et al., 2012; Can et al., 2015; Marhaento et al., 2017; Zhang et al., 2020). The application of land covers in hydrological modelling is detailed in the studies by López (2016) and Torres et al. (2018).

- Water flow regulation indices

The water flow regulation indices were obtained at an annual scale based on the hydrological simulations of each scenario for the entire simulation period (calibration and validation) (Marhaento et al., 2017). The following components of the SWAT model were used at the annual scale for the calculation of the hydrological indices: surface runoff (Qs), lateral flow (Ql), base flow (Qb) and total stream flow (Q).

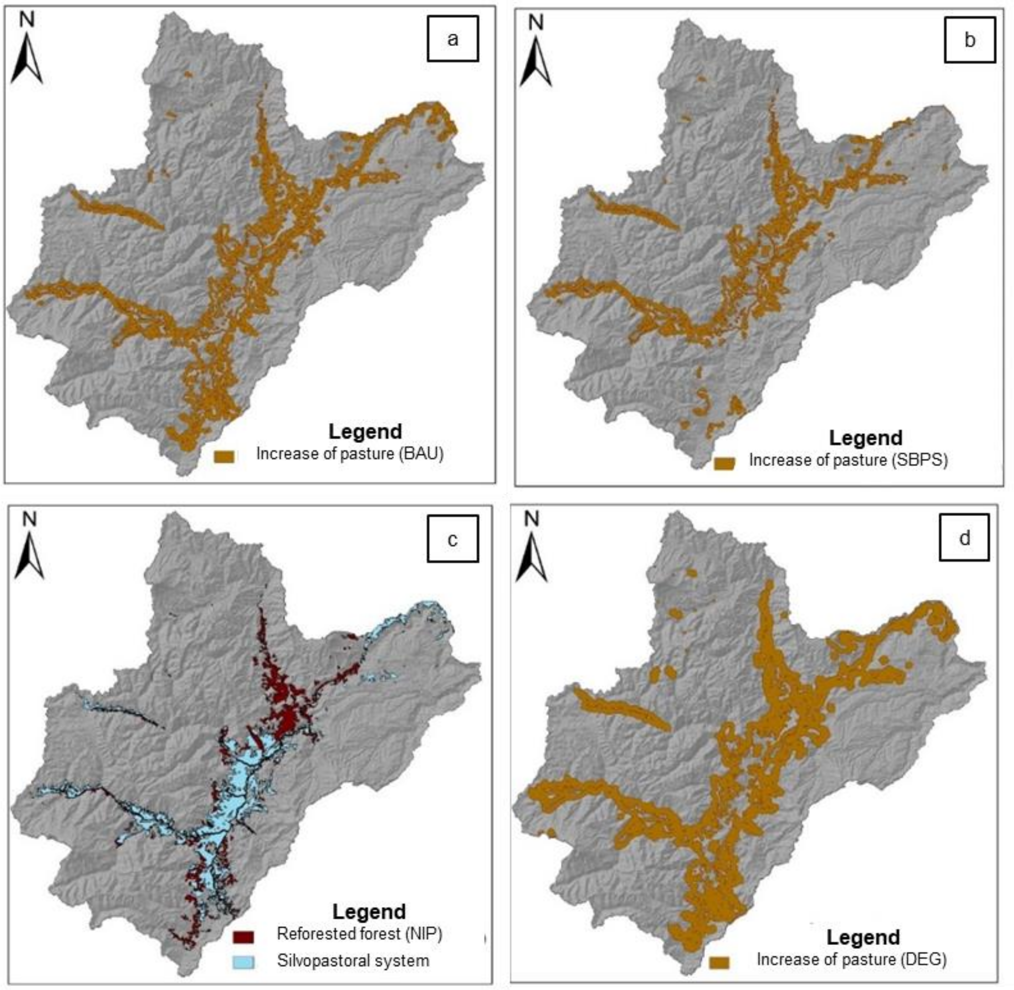
Firstly, three water flow regulation indices were calculated for the base scenario (1990 cover) and for the four land cover scenarios: the base flow index (BFI) = Qb/Q, lateral flow index (LFI) = Ql/Q and surface runoff index (SRI) = Qs/Q. This was done following the procedure described by Marhaento et al. (2017). Secondly, to analyze the effect of land cover change with respect to the base scenario, the hydrological indices (BFI, LFI, SRI) of each scenario were divided by corresponding indices of the base scenario. According to the data normalization criteria, a value close to 1 indicates a similarity of the water flow regulation indices between the scenarios and the baseline scenario; a value less than 1 indicates a decrease of the water flow regulation indices of the scenarios with respect to the baseline scenario, while a value greater than 1 indicates an increase of the hydrological indices of the scenarios with respect to the baseline scenario.

RESULTS AND DISCUSSION

Scenario projection

After obtaining the 2030 land cover projections, these were classified into three categories: páramo, native forest and pasture. Figure 4 depicts the land cover and land use change maps generated for each scenario, which served as the foundation for the hydrological modelling.

Figure 4. Projection of pasture, silvopastoril system and reforested forest by scenario a) BAU, b) SBPS, c) NIP, d) DEG



It can be observed that three of the four scenarios demonstrate an increase in grassland in comparison to the 2014 coverage, which was selected as a reference point due to its status as the most recent cartographic information provided by the MAE at the time of the study.

Regarding native forest, the NIP scenario is the only one that maintains the same area of cover as in 2014. The BAU and SBPS scenarios indicate a loss of 10.7% and 7.5% respectively, while the greatest loss corresponds to the DEG scenario, with a decrease of 16.9%.

In comparison to the total increase in pasture that would occur in the BAU scenario, the SBPS scenario projects a 29% smaller increase. However, it is important to note that this scenario alone is insufficient to halt the advance of the agricultural frontier. The DEG scenario indicates an increase of approximately 127%. The combined application of the measures considered in the NIP scenario is the only one that projects the total disappearance of the grassland identified in 2014. This is because a percentage is transformed into reforested forest (sub-watersheds and banks of Cosanga and Salado rivers), while the remainder is converted into silvopastoral systems (pasture combined with secondary forest). This configuration is deemed appropriate for the area in question, given the limited suitability of the existing soils for agricultural purposes. Consequently, an opportunity is created for farmers to explore other possible sustainable alternatives (Congo et al., 2018; Murgueitio, 2009; Pattanayak et al., 2003; Sotelo et al., 2017). It is crucial to emphasize that any policy designed to restore ecosystems in the region must consider the dynamics of the human populations that have settled there. These populations must be acknowledged as significant factors in the determination of land use and in the variability of anthropogenic pressure (Rodríguez, 2021). This aligns with findings in other Andean basins, where the importance of considering the participatory and social approach to solve anthropogenic effects and socioeconomic disparities in IWRM has been highlighted (Mera-Parra et al., 2022).

The identified dynamics demonstrate that the páramo is highly susceptible to the removal of the forest conservation incentive, with greater forest loss resulting in greater páramo loss (Espinosa & Rivera, 2016). In the DEG scenario, characterized by the greatest forest loss, the retreat of the páramo is estimated to reach 20.3%. In contrast, in the BAU and SBPS scenarios, the retreat is less than 1%. Once more, the NIP scenario shows no variation with respect to the 2014 coverage. These findings indicate that the forest plays a protective role in this region, acting as a barrier against the loss of the páramo. It is crucial to highlight that, based on existing knowledge, the loss of the páramo vegetation results in the modification of the soil structure and associated hydrological functions (Patiño et al., 2021; Podwojewski et al., 2002). Consequently, depending on the level of degradation achieved, it will be necessary to allow the soil to rest for decades to achieve its recovery and the subsequent spontaneous sprouting of vegetation (Hofstede et al., 2014; Torres et al., 2024).

Water Flow Regulation

The performance evaluation criteria presented in Table 2 indicate that the SWAT hydrological model at the monthly scale for the 1990 baseline scenario is within the established ranges of good to very good, as defined by the classification of Moriasi et al. (2007). These results show that the model represent adequately the hydrological variables for the vegetation cover considered within the watershed at a monthly scale.

Table 2. Performance evaluation criteria at monthly scale at stations H0714 and H0715 for the base model (1990)

	H0714			H0715		
Period	**NSE[a]**	**PBIAS[b]**	**R^{2c}**	**NSE**	**PBIAS**	**R^2**
Calibration	0.74	-5.11	0.51	0.81	1.83	0.43
Validation	0.62	-9.71	0.28	0.67	8.57	0.37

NSE[a] = Nash Sutcliffe Efficiency, PBIAS b = Percent Bias, R2 c = Coefficient of Determination

Table 3 presents the values of the hydrological variables simulated in SWAT at a mean annual scale for the period 1979-1986 in the watershed of station H0714, both for the 1990 base model and for the scenarios with projected coverage to 2030. Furthermore, Table 3 illustrates the variation in percentage of each variable with respect to the corresponding values generated from the base model.

Table 3. Annual mean hydrological variables for each scenario

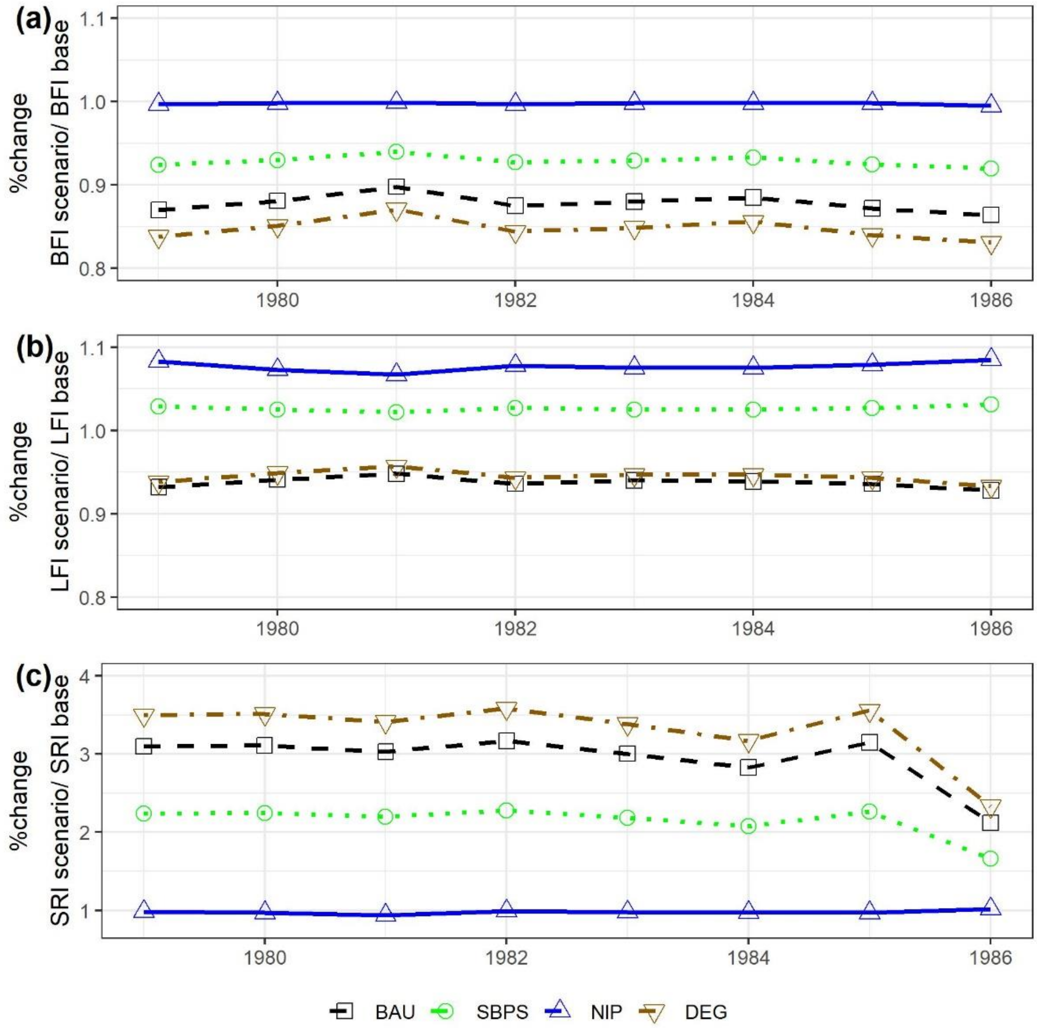
Hydrological Variable	Unit	BAU	SBPS	NIP	DEG	Base model (1990)
Mean annual discharge	m^3/s	403.08	403.01	402.52	403.20	402.79
Surface runoff (Qs)	mm	863.85	838.73	715.63	911.27	734.84
Lateral flow (Ql)	mm	559.23	563.89	589.11	548.57	588.01
Base flow (Qb)	mm	1342.36	1362.35	1456.81	1306.41	1440.59
Changes to the base model (1990)						
Mean annual discharge	%	0.07	0.06	-0.07	0.10	-
Surface runoff (Qs)	%	17.56	14.14	-2.61	24.01	-
Lateral flow (Ql)	%	-4.89	-4.10	0.19	-6.71	-
Base flow (Qb)	%	-6.82	-5.43	1.13	-9.31	-

The results presented in Table 3 demonstrate that, considering the projected land use changes, the mean annual discharge of the scenarios remains largely unchanged in comparison to its reference in the base model, with a difference of less than 0.1%. In contrast, the mean annual surface runoff, lateral and base flow values exhibit a notable variation between the scenarios and the 1990 base model. The hydrological simulations demonstrate that the land use policy applied in the BAU, SBPS and DEG scenarios results in lower lateral and base flow (< -4%) and higher surface runoff (> +14%) in comparison to the 1990 base model. Conversely, NIP scenario results in higher lateral and base flows as well as lower surface runoff compared to the 1990 base model.

Figure 5 illustrates the percentage change in the water flow regulation indices of base flow (BFI), lateral flow (LFI) and surface runoff (SRI) over the annual period (1979 to 1986) for the four scenarios of land cover change in comparison to the base model (1990 coverage). It is observed that the NIP scenario projects a lower percentage change (close to 1) for all water flow regulation indices over the modelling period. The similarity between the behavior of the projected runoff indices in the BAU and DEG scenarios is remarkable. The percentage change in lateral and base flow is less than 1, with the greatest reduction observed in base flow (between 0.84 and 0.90). This evidence suggests a reduction in this type of flow with respect to the base model. Conversely, the percentage change in surface runoff for the BAU and DEG scenarios show values greater than 1 (between 2.1 and 3.6), indicating that surface runoff increases with respect to the 1990 model.

The results presented in Table 3 can be interpreted as indicative of water flow deregulation at the mean annual level for scenarios BAU, SBP and DEG (Bonnesoeur et al., 2019; Francesconi et al., 2016; Logsdon & Chaubey, 2013; Oliveira et al., 2018; Zhao et al., 2024). The DEG scenario presents the most severe alterations to the hydrological response. In contrast, in the NIP scenario, water flows exhibit a behavior that improves regulation in comparison to the base model. This is evidenced by the maintenance of lateral and base flow (between +0.19% and +1.13%) and a decrease in surface runoff (-2.61%). Likewise, in Figure 5 the same behavior is evidenced at annual scale.

Figure 5. Percentage change scenario indices vs. 1990 base indices a) Base flow index (BFI) b) Lateral flow index (LFI). c) Surface runoff index (SRI).



The results presented in Table 3 and Figure 5 provide evidence that the current conservation policy (BAU) is not effective in maintaining the provision of the ecosystem service of water regulation. Conversely, the SBPS scenario performs better than BAU; however, it does not reach the regulation levels obtained in the NIP.

It can be seen that maintaining current conservation policies (BAU) does not guarantee the maintenance of water regulation in this watershed. Indeed, conservation initiatives (BAU) applied in isolation from restoration processes (SBPS) contribute to the maintenance of water regulation, but do not ensure it. This is evidenced by similar watersheds (Konetter and Galmez 2017). This illustrates the necessity for the creation of technical studies that align with the specific characteristics, potential, and objectives of each watershed (Coral et al., 2021). As noted in similar studies, monitoring should include ways to transfer knowledge to decision makers to ensure effective watershed management (Mera-Parra et al., 2022).

The findings of this study highlight the need for establishing a watershed management organization for the Coca river watershed, as previously identified by Fierro (2017), who emphasized that the fundamental issue in water resource management for this watershed is the absence of an articulating entity with decision-making capacity. This aligns with successful experiences in Ecuador, such as the Paute River Basin Council, which has demonstrated the effectiveness of watershed-based management organizations in coordinating conservation efforts, water regulation, and hydroelectric production (Molina, 2008). The creation of such an organization for the Coca watershed would be particularly relevant given our results regarding water flow regulation under different scenarios, as it could facilitate the coordinated implementation of conservation and restoration policies, while ensuring the participation of multiple stakeholders in watershed management decisions.

In light of the findings from the NIP, it can be posited that the simultaneous implementation of restoration, conservation, and sustainable production strategies represents the sole policy avenue that exhibits the potential to positively impact the water infiltration and storage processes, which ultimately regulate the water balance of a watershed (Guo et al., 2000; Núñez et al., 2006).

In a watershed with 22 hydropower plants, the projected deregulation in the BAU, SBPS and DEG scenarios is a factor that should be considered, as the base and lateral flows could be significantly lower than the design flows; whereas higher surface flows are associated to high sediment transport. This water flow deregulation could represent the greatest impact for hydropower plants (Lin et al., 2022; Nguyen et al., 2013; Vogl et al., 2016).

The primary limitation of the study pertains to the representativeness of the hydrological parameters of the land covers provided by default in the SWAT model, which were assigned to the land covers of the study watershed. A further significant limitation is the scarcity of data, which results in the hydrometeorological series being discontinuous. It is also important to note that there is a lack of socioeconomic data for the area, which limits the ability to fully assess the impact of the research criteria. Moreover, the people who live in this watershed play a crucial role in the stewardship of natural resources that benefit the entire country, yet there is a dearth of information on their socioeconomic status and circumstances.

CONCLUSIONS

The conservation policies currently in place in the Coca river watershed (NSPA and SBP) are insufficient to halt the loss of native vegetation and the subsequent increase in pasture. However, despite its limitations, the SBP plays a crucial role in the conservation of the watershed, as the area of pasture would double by 2030 if this program were to disappear. The joint application of conservation, restoration and sustainable production policies as outlined in the national environmental regulations (NIP) and applied in areas of water importance is the only mean of ensuring the conservation of the vegetation cover.

The results of this study have established the relationship between the application of conservation and restoration policies and water flow regulation. This is expressed as the change in the flow components of the watershed in each scenario with respect to the 1990 base model. The BAU and DEG coverage scenarios result in a reduction in lateral and base flows and an increase in surface runoff. In contrast, the NIP scenario is the only one that guarantees the permanence of water flow regulation in the watershed. Furthermore, it was identified that the mean annual discharge is not affected by the implementation of these policies.

The incentive foreseen in the BAU scenario have been applied without considering hydrological analysis, which generates, in terms of water flow regulation, similar results to not applying any incentive (DEG). Understanding that the SBP was not designed with water objectives in mind, it remains to recommend that the creation and application of future conservation-oriented incentives prioritize the a priori analysis of water flow regulation as the basis for ecosystem conservation and be based on the identification of priority areas according to the specific objectives of each basin. For this purpose, the methodology proposed in this study can be used as a starting point, and then be complemented with socioeconomic studies to establish the viability of the planned incentives, both in terms of the openness of landowners to join the programs, and in terms of their economic sustainability.

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