Karlsruhe Institute of Technology

An integrated GIS and SWAT model approach to assess past, present and future land use changes and related water management impacts in the upper Amazon region of Ecuador.

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Motivation

- The main watersheds of Ecuador are some of the most important ecological areas in the world. However, nowadays many of them are endangered mainly because of land degradation.
- Land use changes (LUC) have potentially large and negative impacts on the hydrology of the basin, which are further enhanced when combined with bad practices of watershed management; such as the establishment of pasture and crops on slopes and natural forests logging.
- The use of modeling tools allows the analysis of the LUC, since they enable the formulation of future scenarios, the understanding of the key processes that explain the changes, and the description of these in quantitative terms. Those analysis and predictions are essential for land policy planners to understand the problems and take action for improvement in soil and water conservation measures.
- The main objective of this study is to assess the LUC and its impact on the water balance of the Coca River basin, located in the upper part of the Amazon region in Ecuador. The study of this catchment in terms of LUC and its impact on the water balance is of high importance for Ecuador, since this basin is the one that provides the necessary flow for the operation of the largest hydroelectric plant in the country (Coca-Codo Sinclair).

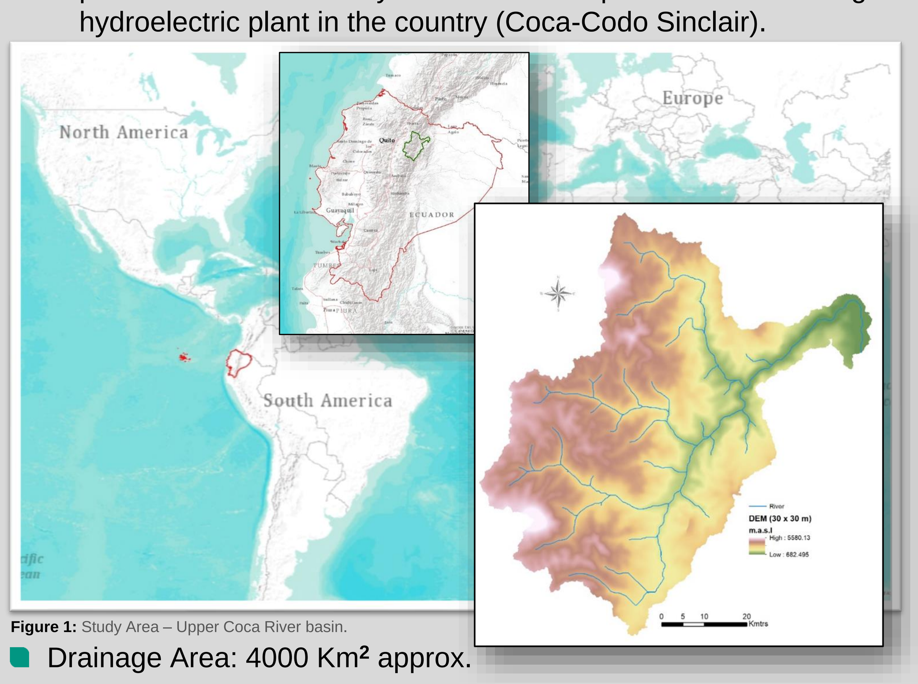
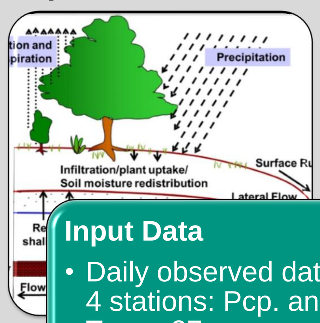


Figure 1: Study Area – Upper Coca River basin.

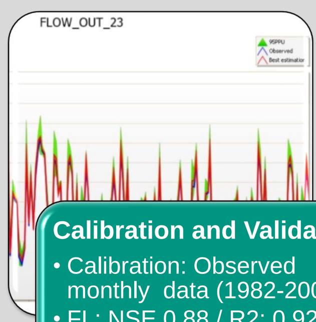
- Drainage Area: 4000 Km² approx.
- Main Ecosystems: Cloud forest and Andean Páramo.
- Main Land Uses: Agriculture, Grass, Natural Forest and Páramo.
- ***Páramo:*** *Neotropical high mountain biome with a vegetation composed mainly of giant rosette plants, shrubs, grasses and lagoons.*

Materials and Methods

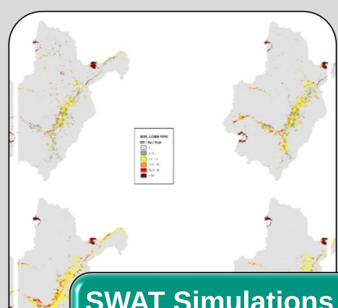
A) SWAT: Calibration, Validation, Past and Present Simulations.



Input Data
- Daily observed data: 4 stations: Pcp. and Temp. 37 years (1980 – 2016).
- LU and Soil maps (1:250.000).
- DEM (30 x 30m).

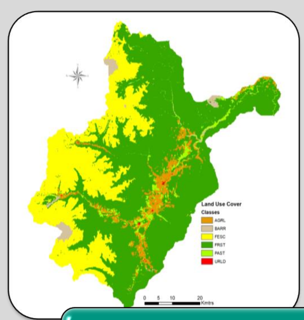


Calibration and Validation
- Calibration: Observed monthly data (1982-2000).
- FL: NSE 0.88 / R2: 0.92
- SL: NSE 0.76 / R2: 0.74
- Validation: Observed Data (2001-2016).
- FL: NSE: 0.91 / R2: 0.95
- SL: NSE 0.82 / R2 0.8



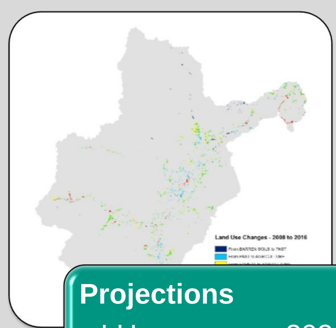
SWAT Simulations
- Year 1990
- Year 2000
- Year 2008
- Year 2016

B) Land Use projection: Markov Chain Method.



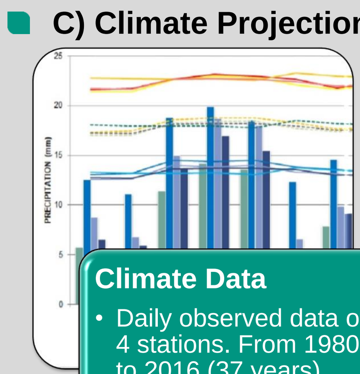
Input Data
- LU map year 2000.
- LU map year 2008.

Validation
- LU map year 2016.
- Accuracy 89%.

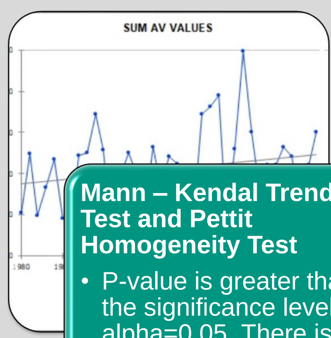


Projections
- LU maps year 2026.
- Trend, Best case and Worst case scenarios.

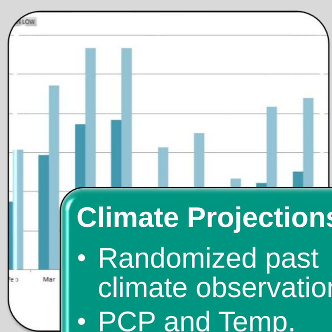
C) Climate Projection (2026): Randomized Past Climate Observations.



Climate Data
- Daily observed data of 4 stations. From 1980 to 2016 (37 years). Precipitation and Temperature.



Mann – Kendal Trend Test and Pettit Homogeneity Test
- P-value is greater than the significance level alpha=0.05. There is no trend.
- Data are homogeneous.



Climate Projections
- Randomized past climate observations.
- PCP and Temp. projection (2017/2026).

General Information of the Watershed.

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- Average PcP: 3500 -6000 mm / year.
- Average Temp: 19°C.
- Temperate – humid climate
- Average ET: 1200 mm / year.
- Minimum Average daily discharge: 350m³/s.
- Inhabitants (Year 2010): 23500 ihab.
- Economic Activities: Agriculture and livestock, commerce, industry, government and tourism.
- Problems: Agricultural areas increased; Natural cover reduction; migration and immigration processes; Mining activities (stone and sand) increases.
- Management initiatives: Environmental services payments; Reforestation and natural regeneration.

SWAT: Simulations year 2026.

Input A
- DEM (30x30m); Soil Information.
- Calibration Values.

Input B
- LU maps year 2026: Trend, Best and Worst case scenarios.
- Land management practices incorporated into the Best case scenario.

Input C
- Climate data projections: PcP. and Temp. (2017 – 2026).

Simulation
- Simulations year 2026: Trend, Best and Worst case scenarios.

Results

SWAT Simulations 1990 - 2016: Flow (m³/s).

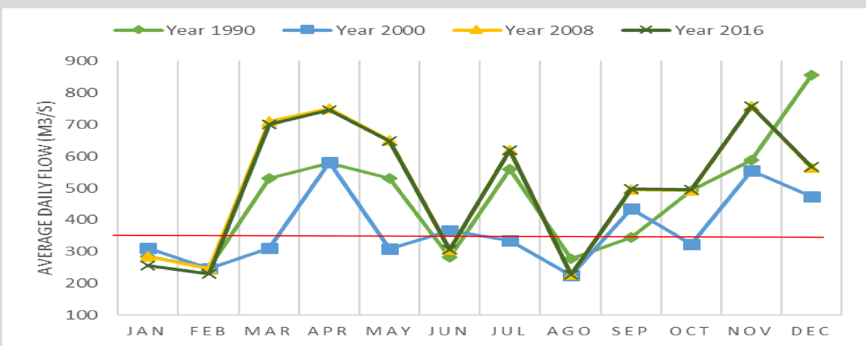

Figure 2: Average daily Flow (m3/s) by month in the watershed 1990 – 2016.

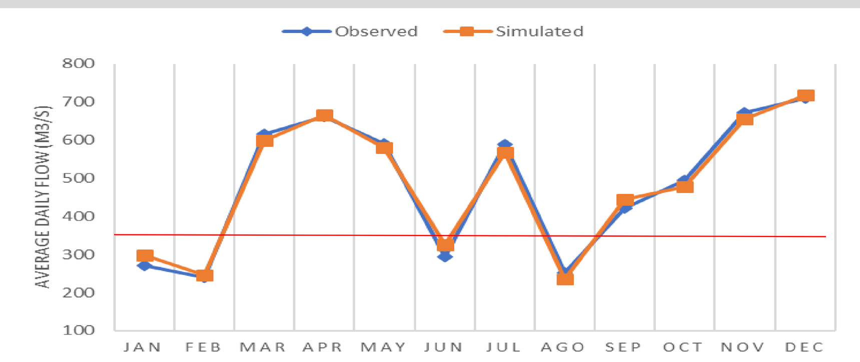

Figure 3: Average daily Flow (m3/s) by month in the watershed 1990 - 2016. Observed vs. Simulated.

- Over the years (1990 – 2016), the average daily flow that leaves the catchment and nowadays enters the Coca-codo Sinclair Hydro Power Plant did not changed significantly, and the necessary flow for the operation of the HPP (350 m³/s) has been maintained.

SWAT Simulations 2026: Flow (m³/s).

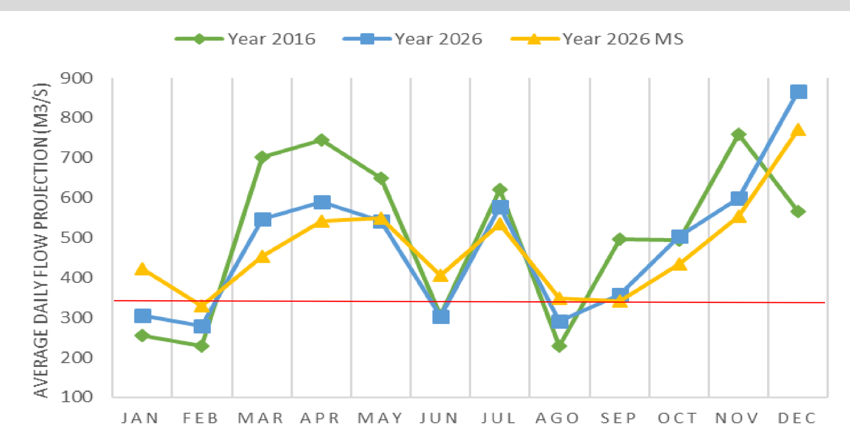

Figure 4: Average daily Flow projection (m3/s) by month in the watershed 2026. Trend and Management Practices Scenario

- According to the simulated scenarios in the catchment, in 2026 the average flows that reach the HPP will vary with respect to the year 2016, depending on the seasonality inside the watershed.
- Reduction in the average flow during the period between the months of March, April, May and September, October and November, with respect to the year 2016.
- The minimum necessary flow (350 m³/s) will be maintained.

SWAT Simulations and LU projections 1990 – 2026: Soil Loss (MT/Ha/Y).

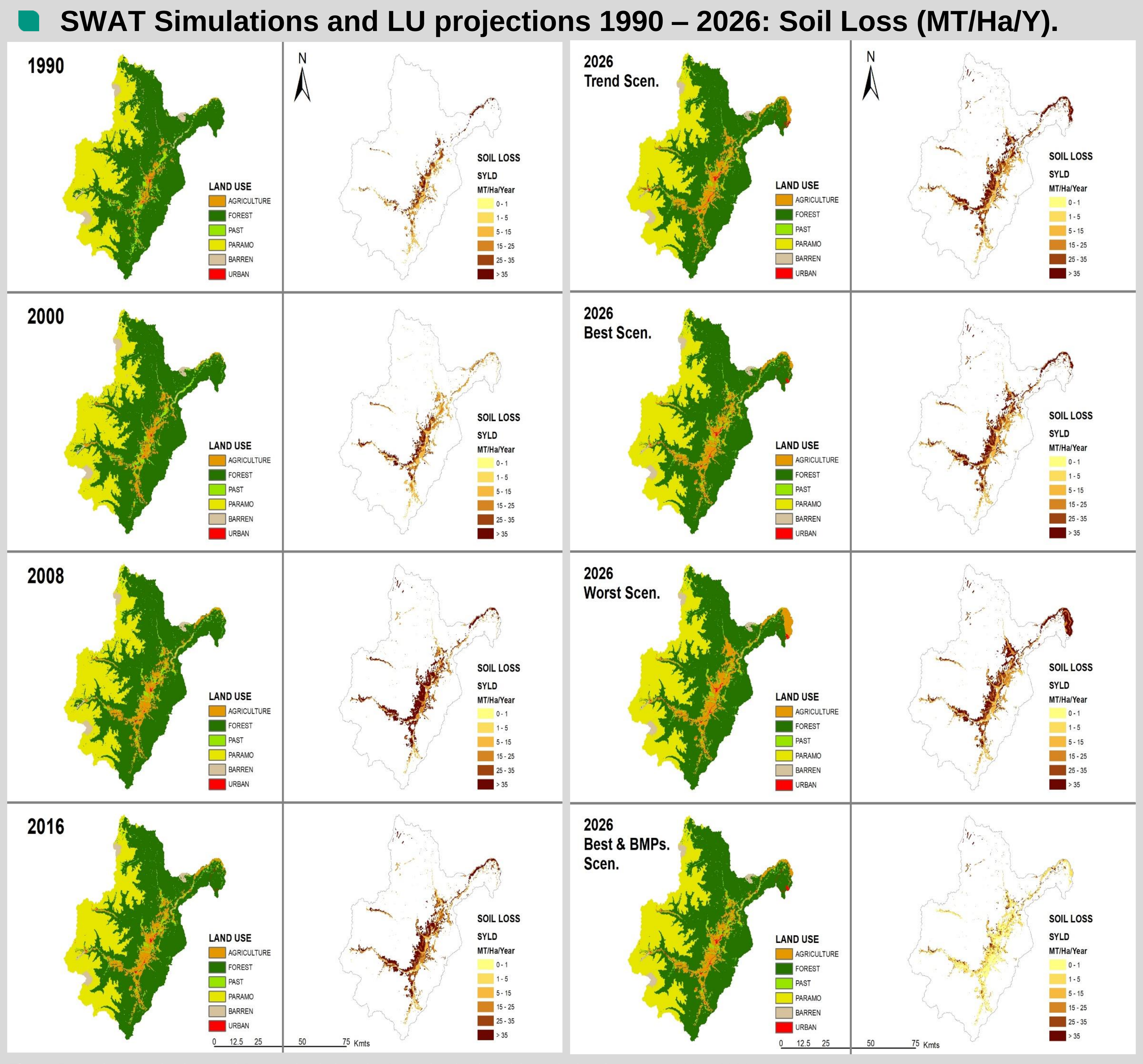

Figure 5: Land Use projections and SWAT simulations for SYLD (MT/Ha/Year) in Agricultural Areas – 1990 to 2026.
BMPs (Best Management Practices) Land Management Practices at HRU Level: a) Buffer strips, b) Terraces (Steep AGRL Areas), c) Contour tillage.

LUC and Soil Loss inside the Catchment. Past, Present and Future scenarios.

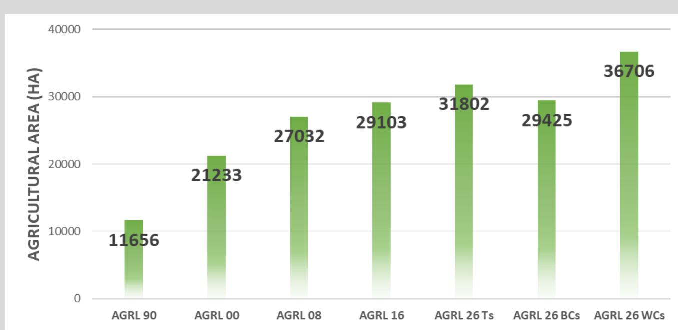

Figure 6: Total agricultural areas (Ha) according to the LUC and their projections.

- **LU Trend Scenario (Ts):** Maintains the probabilities of change in land use that the Markov Chain Model (after having been validated for 2016) predicts for the year 2026.
- **LU Best Case Scenario (BCs):** Addresses the probabilities of change in land use, within the Markov Chain Model, towards a balanced scenario between conservation of natural ecosystems and productive activities within the basin, by the year 2026.
- **LU Worst Case Scenario (WCs):** Scenario where extractive activities prevail and the productive areas in the basin increase by the year 2026.
- **LU Best C. Sc. BMPs (BCs BMPs):** BCs Land use map with land management practices incorporated at HRU level during the SWAT simulation for the year 2026. *Buffer strips, Terraces (Steep AGRL Areas) and Contour tillage*.

Soil Loss (MT/Ha/Year) in Agricultural Areas vs. Slope Ranges in the Catchment.

SLOPE	AGRL 90	AGRL 00	AGRL 08	AGRL 16	AGRL 26Ts	AGRL 26BCs	AGRL 26WCs	AGRL 26BMPs
0 - 10	405	464	817	702	670	665	677	220
10 - 20	921	1075	1807	1539	1473	1469	1491	551
20 - 35	1312	1478	2577	2177	2142	2103	2187	776
> 35	760	1019	2171	2000	1962	1936	2013	860
TOTAL	3398	4035	7372	6418	6248	6173	6368	2407

Figure 7: Soil Loss in Agricultural Lands: Past, Present and Future Scenarios.
With the BMPs (Best Management Practices), Soil Loss rates in agricultural areas can be reduced up to 60% approx.

SYLD (MT/Ha/Year) Agricultural Areas – Future Scenarios

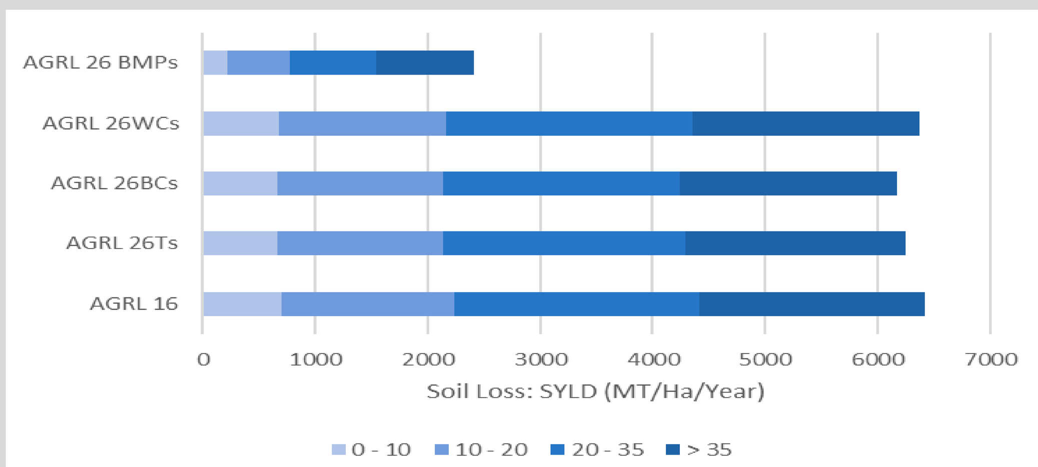

Figure 8: Soil Loss (MT/Ha/Year) by Slope Range in AGRL Areas with the Future Scenarios - year 2026.

- According with the SWAT Model simulation results, Best Management Practices (BMPs) are necesary inside the watershed for the future.
- With BMPs incorporated at HRU level in the Agricultural areas (Farming) during the simulation with the Best Case Scenario Land Use Map 2026; Results show that Soil Loss rates can be reduced up to 60% approx.
- BMPs: a) Buffer strips, b) Terraces (Steep AGRL Areas), c) Contour tillage.

Conclusions / Future work

Conclusions

- The simulation results show that the annual average discharge in the catchment did not change significantly over the past years and the necessary flow for the operation of the HPP (350 m³/s) has been maintained. The simulated scenarios for the year 2026 show that the average flows that reach the HPP will vary with respect to the year 2016, but the minimum necessary flow will be maintained.
- Different land uses in the catchment contribute differently in the annual amount of soil loss, however, the highest annual rate of soil loss within the catchment is found in the agricultural areas and specifically in zones with a slope percentage between 20% and 30%.
- Integrated watershed management procedures and BMPs are necessary in order to reduce Soil Losses inside the Basin. Results show that Soil Loss rates can be reduced up to 60% approx. in Farming areas.
- LUC and crop management resulting from different factors may cause more considerable effects on soil erosion than the changes in rainfall or temperature themselves.

Future work

- In the future, more simulations incorporating climate change models - like GCMs and downscaling methods - could be done in order to assess and analize Soil Losses inside the watershed with another approach.