Assessing the Impacts of Climate Change and Landuse Practices on Water Quality and Quantity in Rwanda

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Introduction

Water is an important resource for humans and wildlife, and the sustainable management of this resource is essential to ensuring it is availability for all species. Nyungwe National Park is an important water source for the country of Rwanda as it receives approximately 2,000 mm of rain per year and has the potential to convert up to 40% of that rain into surface runoff. Surface runoff is water that comes from rain and flows overland into streams. Nyungwe overlies the Nile and Congo River Basins and is the source for the Nile River. Land management decisions in and around Nyungwe can adversely affect the quality and quantity of water originating from the park. Some environmental challenges impacting water quality and quantity within Rwanda are soil erosion, deforestation, and forest degradation. Deforestation is the cutting and removal of forests, and replacing the forest with another land use type like crops. Forest degradation is the reduction in forest growth, structure, or composition.

In 2011, the Wildlife Conservation Society (WCS) partnered with the US Agency for International Development (USAID), the USDA Forest Service International Programs (USFS IP), and the USDA Forest Service Eastern Forest Environmental Threat Assessment Center (EFETAC) to conduct a regional watershed assessment across conservation projects in east and southern Africa including Nyungwe National Park, Rwanda. The objectives of this project were:

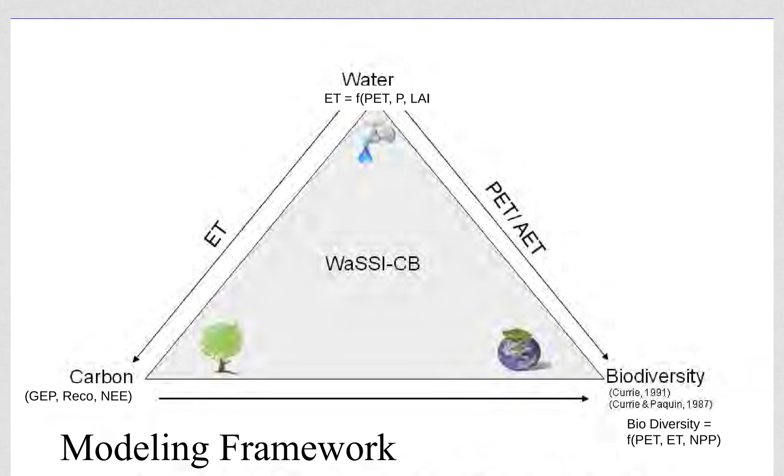
- Model water quantity and sedimentation within Rwanda using current landcover conditions
- Simulate land use change and climate change within a modeling framework and quantify the potential impact on water quantity and sedimentation
- Validate modeled water quantity to field data
- Conduct technical training workshops on the use of project models
- Communicate results to key stakeholders and the public by developing policy briefs, technical papers, and educational materials

The project is currently on going specifically in the communication phase.

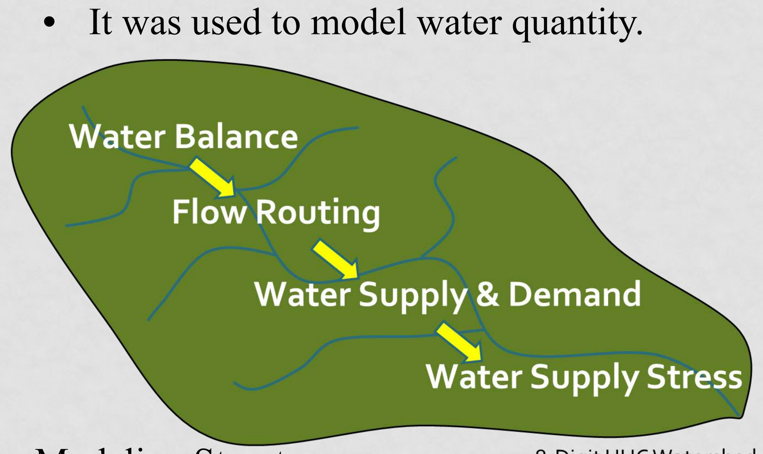
Methodology

1)Water Supply Stress Index Model-Carbon and Biodiversity(WaSSI-CB)

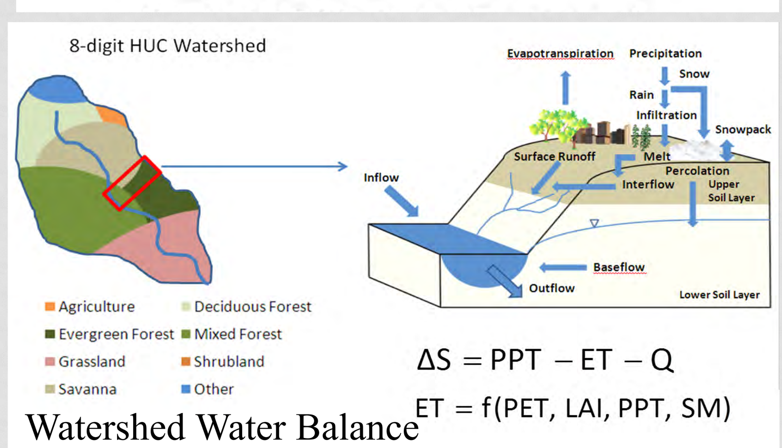
- WaSSI-CB assesses the impacts of land management and climate change on water availability and ecosystem productivity.
- It was used to model water quantity.



Modeling Framework



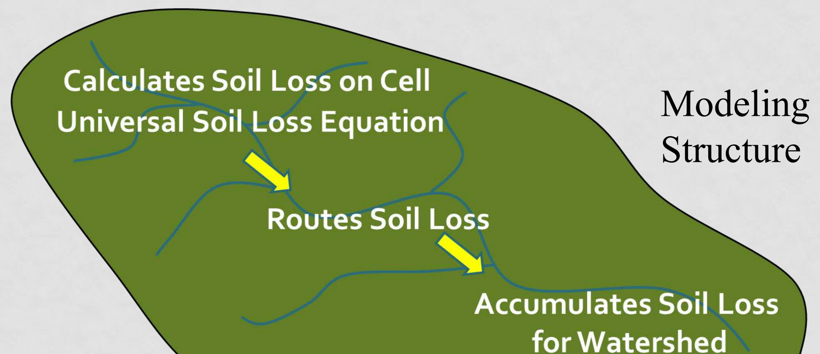
Modeling Structure



Watershed Water Balance

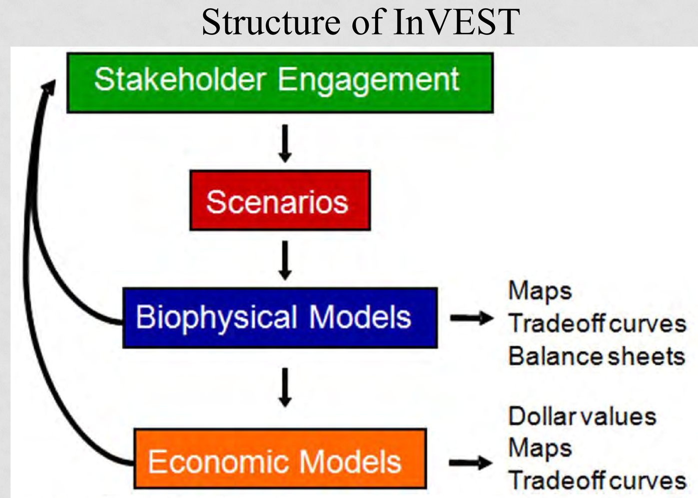
2)Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)

- InVEST is a suite of tools that model natural processes and some of the economics associated with those processes to give a complete picture of management options.
- Our project used the Sediment Retention Model.



Modeling Structure

Decision Making Process
Structure of InVEST

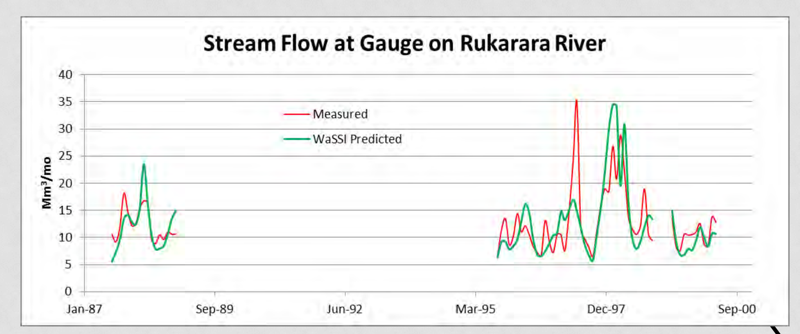


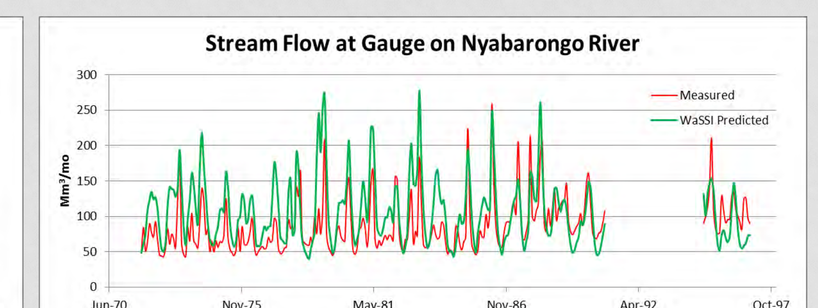
Data

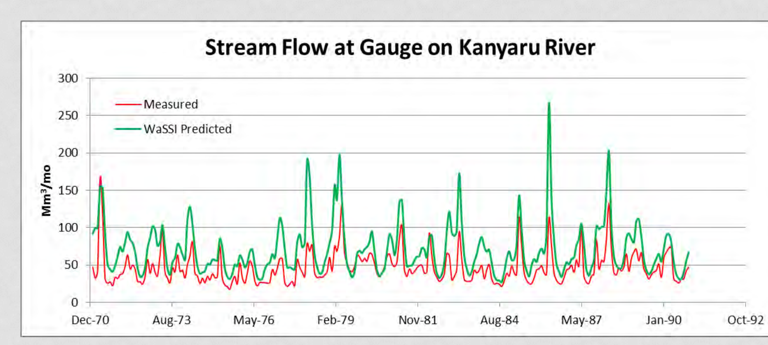
Dataset	Source	Time Period	Resolution
Climate: Historic	University of East Anglia Climatic Research Unit (CRU) Monthly Time Series Data, Version 3.1	1960-2009	0.5° x 0.5°
Climate: Future	Global climate model output, from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007)	1960-2099	0.5° x 0.5°
Landcover	European Space Agency (ESA) Globcover	2009	300m x 300m
Leaf Area Index	Zhao et al.,2005; Numerical Terradynamic Simulation Group (NTSG) at the University of Montana Missoula Moderate Resolution Imaging Spectroradiometer (MODIS) Imagery, MOD15(FPAR/LAI)	2000-2006	1km x 1km
Digital Elevation Model	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) GDEM2	Published 2011	30m x 30m
Soils (Local Rwanda)	Personal communication with Leon Nabahungu	Static	
Soils (World)	Harmonized World Soils Database Version 1.2	Published 2012	1km x1km
Observed Stream flow (Model Validation)	Minitere/Sher, 2005. Assistance Technique A La Preparation Du Project De Gestion Nationale Des Ressources En Eau. Revue des données des Stations limnimétriques. Kigali, Rwanda	Various years between 1971-2000	
	Personal communication with Antoine Niragire; Nile Basin Initiative Decision Support System Unit	1971-1990	

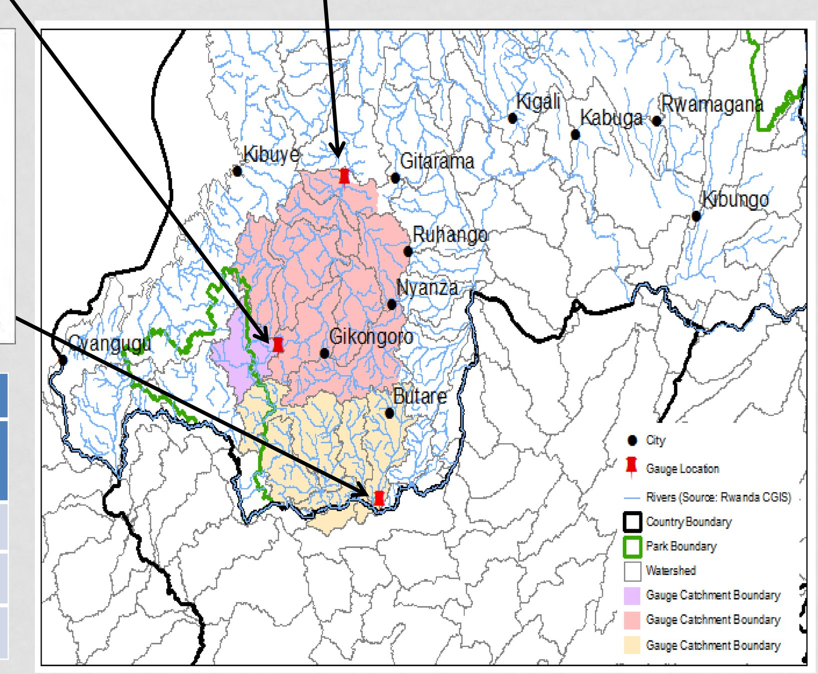
Water Balance Validation

Validation of model results to field data is important, because it can indicate how well the model is capturing the real world processes. Nine stream stations were compared in the water validation. The stations drained catchment areas of varying sizes and were located throughout the country of Rwanda. Three of the WaSSI model predictions to field data comparisons are listed below.









Statistics			
Gauge Location	N	R^2	Nash and Sutcliffe Coefficient of Efficiency
Kanyaru River	240	0.65	-0.77
Nyabarongo River	253	0.42	-0.19
Rukarara River	68	0.47	0.95

Multiple statistics were calculated for each station to assess how well WaSSI predicted the stream flows. Several of those statistics are listed above.

- R^2 reflects how much variance in the measured data can be explained by the regression equation.
  - Range 0 to 1; closer to 1 means the linear regression equation accurately estimates the stream flow.
- Nash and Sutcliffe Coefficient of Efficiency evaluate the predictive power of hydrology models.
  - Range -∞ to 1; closer to 1 implies the predictive model is a good match to measured data; closer to 0 implies the predictive model is as accurate as the mean of the measured data; and less than 0 implies the measured data mean fits the data better than the predictive model.

The statistics indicate WaSSI modeled the gauge on Rukarara River the best. The land cover in that watershed has been dominated by forest for decades, and the stream channel has few changes imposed by engineering structures. WaSSI predictions are improved when the land cover used in the model matches the land cover on the ground for the time period being modeled, and when streams don't have engineering structures like dams or diversions on them.

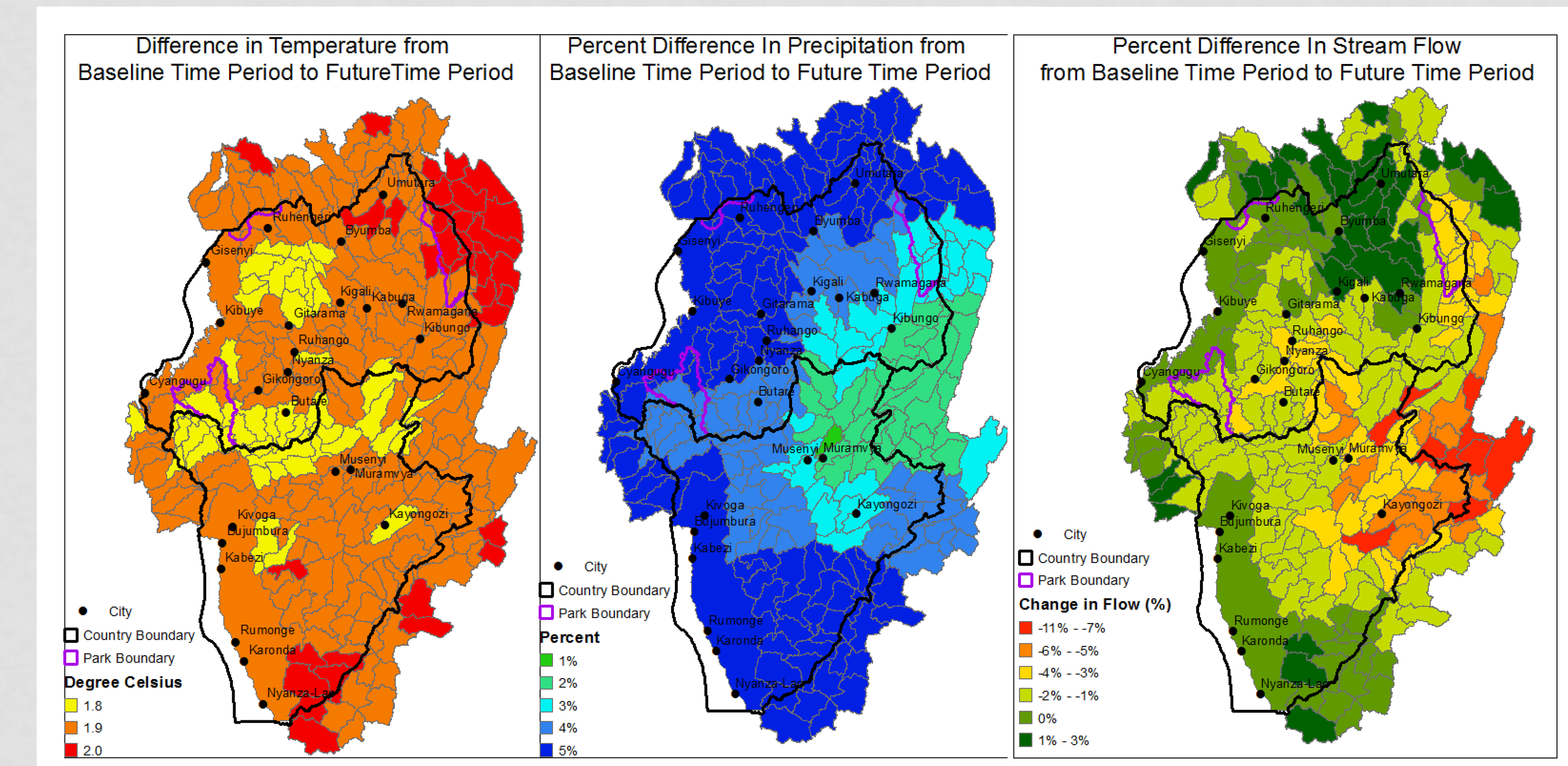
Results

Impacts of Future Climate Change on Stream Flows

- Downscaled future climate data from the 4th Assessment of Intergovernmental Panel on Climate Change (IPCC) was input into the WaSSI Model

Climate Model: UKMO-HadCM3 | Emission Scenario: A2
Baseline Time Period: 1981-2000 | Future Time Period: 2040-2060

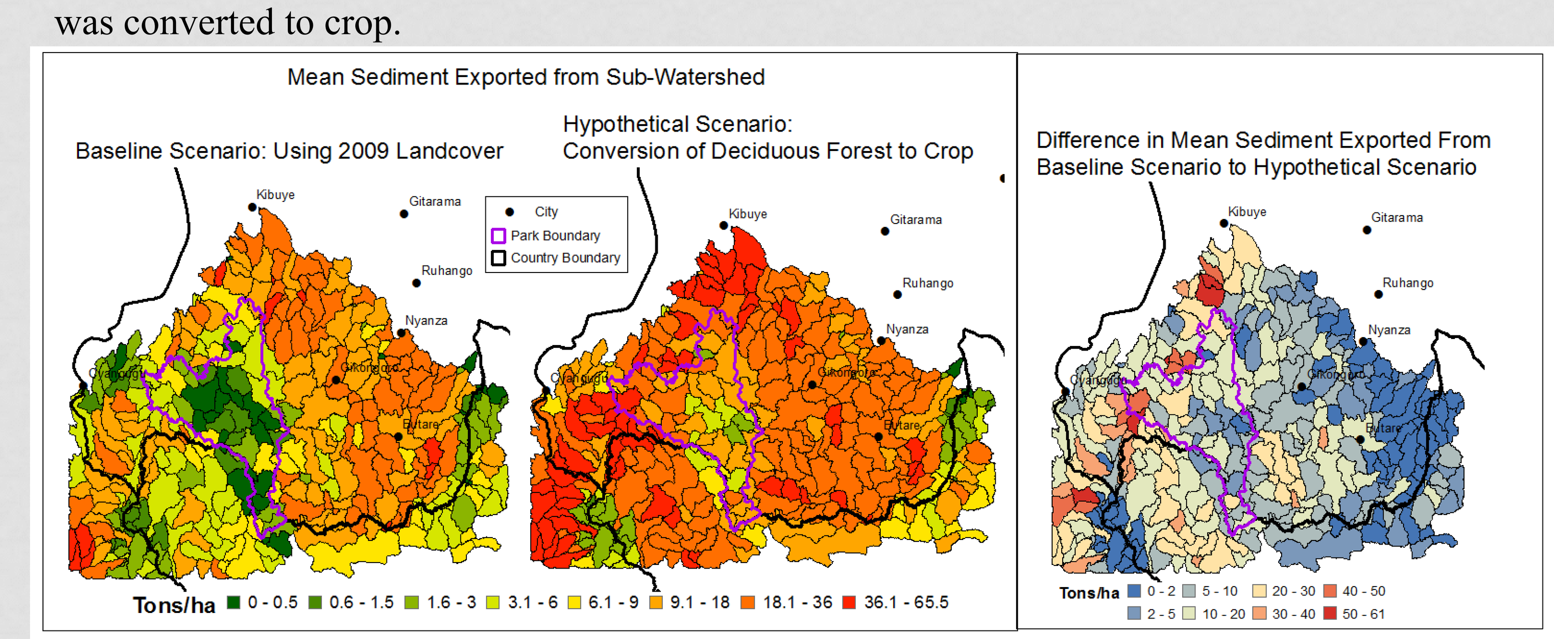
- The UKMO-HadCM3 climate data was used for the baseline and future time periods.



- The mean annual precipitation averaged across the study area increased from 1140mm in 1981-2000 to 1182mm (4% increase) in 2040-2060, and the mean annual temperature averaged across the study area increased from 20°C in 1981-2000 to 22°C (+2°C) in 2041-2060.
- Increase in temperature and precipitation resulted in 39 watersheds having no change, 35 watersheds increasing stream flow ranging from a 1% to 3% increase, and 157 watersheds decreasing stream flow ranging from a 1% to 11% decrease.
- The mean annual stream flow averaged across the study area decreased by 2% in 2041-2060.

Impacts of Land use Change on Sedimentation

- At the core of the InVEST Sediment Retention Model is the Universal Soil Loss Equation (USLE) which estimates the potential for sediment to move when accounting for rainfall intensity, soil erodibility ,land management practices such as terracing, and the relationship between the slope of the landscape and the potential length sediment could move when motion occurs.
- This sediment retention model was run for the entire extent of Nyungwe National Park, Rwanda and Kibira National Park, Burundi and the area surrounding the parks on sub-watersheds of the watersheds used in the WaSSI model.
- To simulate land use change, a hypothetical scenario was used where only deciduous land cover was converted to crop.



- The mean sediment exported averaged across all sub-watersheds increased from 12 Tons/ha in the baseline scenario to 24 Tons/ha in the hypothetical scenario.
- All sub-watersheds saw an increase in sediment exported, and each sub-watershed was composed of a different percent of deciduous forest.

Implications

The WaSSI model and InVEST sediment retention model were run to assess the potential impacts of climate change and land use change on water quantity and sedimentation. The Nyungwe National Park region of Rwanda is water rich and on average the WaSSI model estimated that this region has the potential to convert 39%(~500mm) of the precipitation falling in the area into surface runoff. This volume of surface runoff is important for water users downstream of the park. Land management practices within and surrounding Nyungwe can impact water users downstream. The results of the sediment retention models runs were an increase in sedimentation in all watersheds (some watersheds saw up to 60 tons/ha) due to converting deciduous forest to crops, and the results of the WaSSI model runs was on average a decrease in stream flow across the study region due to future climate conditions. Downstream water users will see the impacts from land conversion quicker than impacts from climate change, however if both actions individually are resulting in decreases in water flow the combined affect would have greater negative implications for water users. As Nyungwe is water rich, land management practices here and surrounding the park should continue to conserve the forested land cover.

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Run WaSSI Online:
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