Water Cycle and Hydrology
Ecohydrology & surface and groundwater Hydrology

Water Forum Suriname & GCCA+

Water Training

Integrated Water Resources Management

July, 17th-18th 2023

M.A.Amatali, M.Sc. (Hydrology)

Introduction

Ecohydrology is an integrative science that focuses on the interaction between hydrology and biota (UNESCO-IHP).

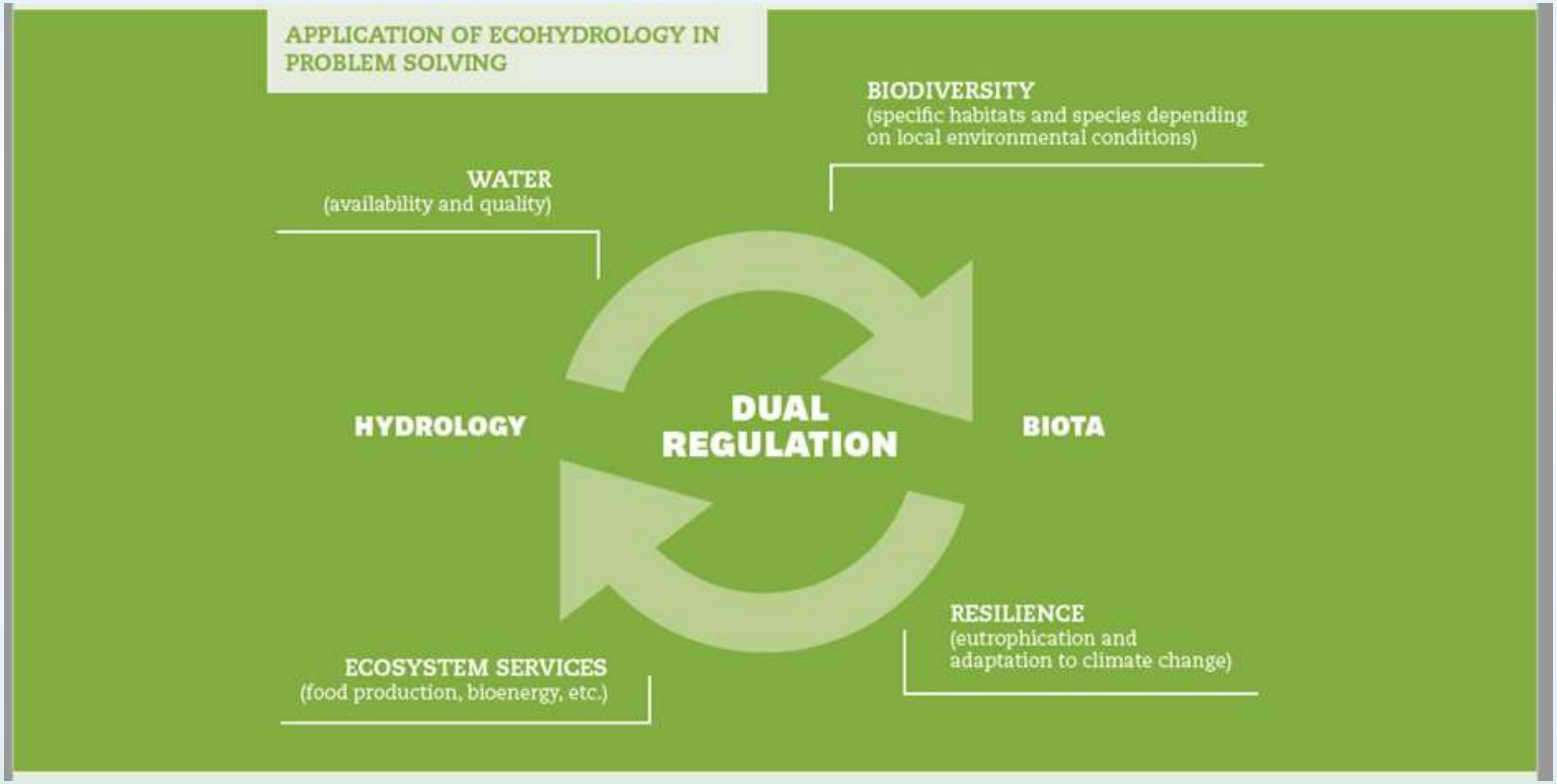
- Transdisciplinary approach in finding solution-oriented methods for reduction of anthropogenic impacts on ecosystems.
- Achievement of sustainability in both ecosystems and human populations

Introduction

Ecohydrology is an integrative science that focuses on the interaction between hydrology and biota (UNESCO-IHP).

- **Improve Integrated Water Resources Management**
- **Consideration of four multi-dimensional parameters within river basins (WBSR).:**
  1. **Water**
  2. **Biodiversity**
  3. **Ecosystem Services for Society**
  4. **Resilience to climatic changes (WBSR)**

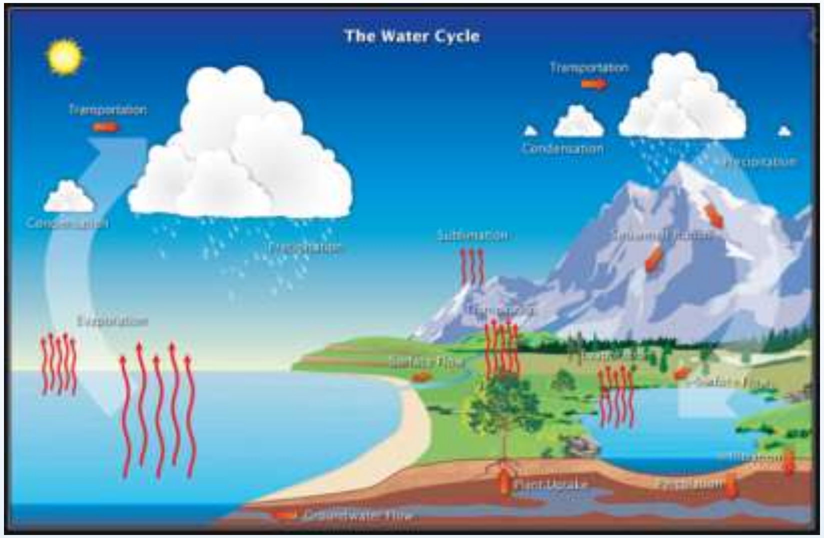
Application of Eco-Hydrology in Problem Solving



Source: UNESCO/IHP 2016

Necessary prior knowledge

- **The Hydrological Cycle**
- **Components and processes of the hydrological cycle**
- **Precipitation**
- **Interception**
- **Infiltration**
- **Percolation**
- **Soil moisture and soil moisture dynamics**
- **Groundwater and groundwater dynamics**
- **Potential/Actual Evaporation/Transpiration/Evapotranspiration**
- **Field capacity of soil**
- **Permanent wilting point**
- **Water Balance**



How Trees Influence the Hydrological Cycle in Forest Ecosystems

Emphasize

- Some aspects of the interactions between forest trees and water/moist and hydrology, especially transpiration, over others, such as moisture interception by forest canopies.

Forest

- Occupy approximately one-third of the Earth's land area,
- accounting for over two-thirds of the leaf area of land plants,
- play a very important role in terrestrial hydrology

How Trees Influence the Hydrological Cycle in Forest Ecosystems

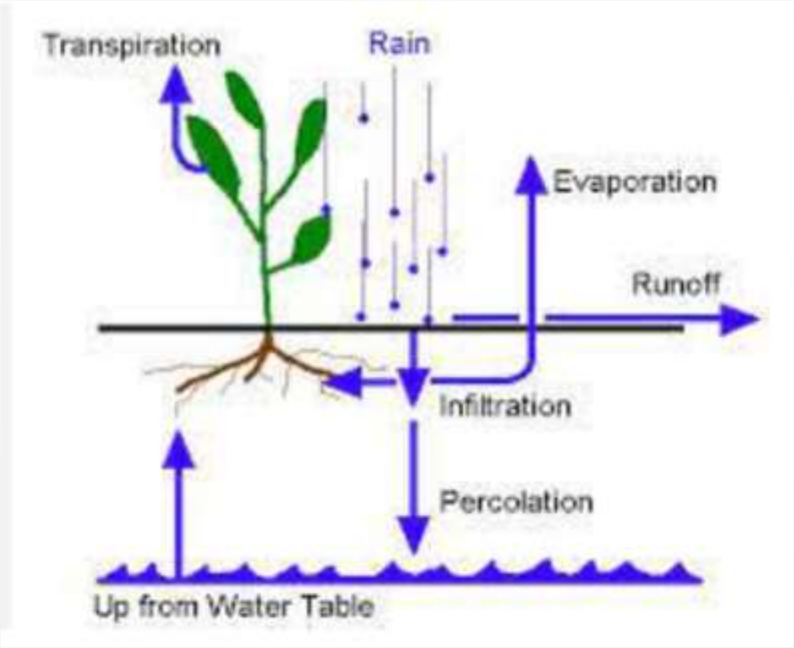
Processes generally applicable to all forest trees

- Transpiration from top (leaves) to bottom (roots), emphasizing the importance of tree hydraulic architecture to transpiration
- Evapotranspiration from trees to forest ecosystems
- How hydrological processes in forests change as they age

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

- Key concept in studies of plant water use
- Emerging from the cohesion-tension (CT) theory of water movement through plants
- Water moves from soil into roots, through plants and into the atmosphere along thermodynamic gradients in water potential

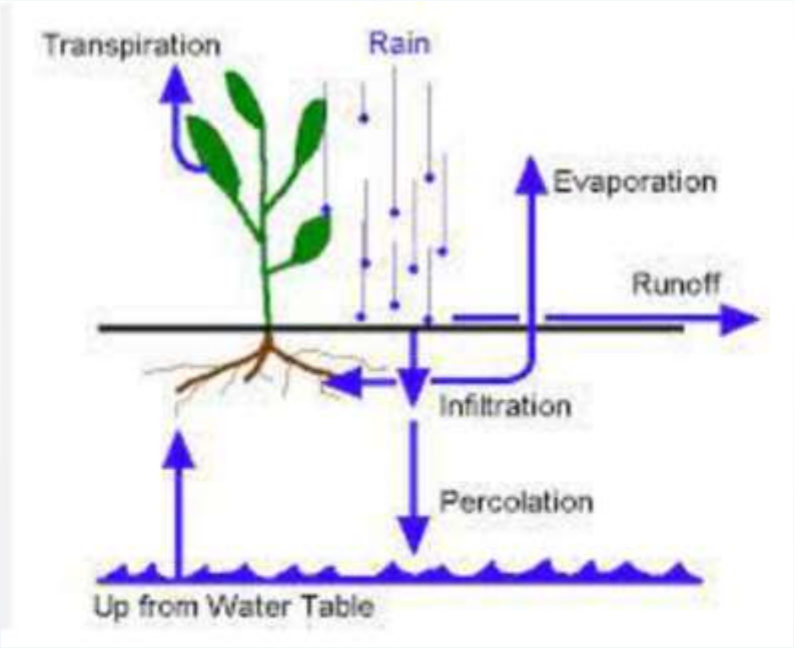


Source: https://forestrypedia.com/infiltration-and-percolation/

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

- **CT theory has been disputed, nowadays widely accepted**
- **Visualized as chain of conected resistances for water movement**

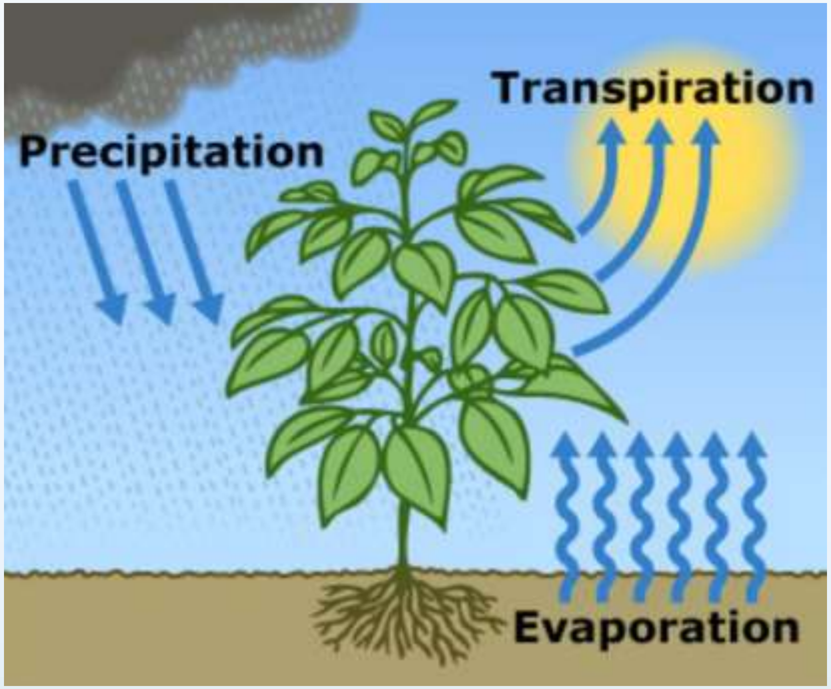


Source: https://forestrypedia.com/infiltration-and-percolation/

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

- Total hydraulic resistance sum of individual ressistances
  - aerodynamic boundary layer resistances associated with canopy elements
  - the boundary layer at the leaf surface
  - stomatal pores

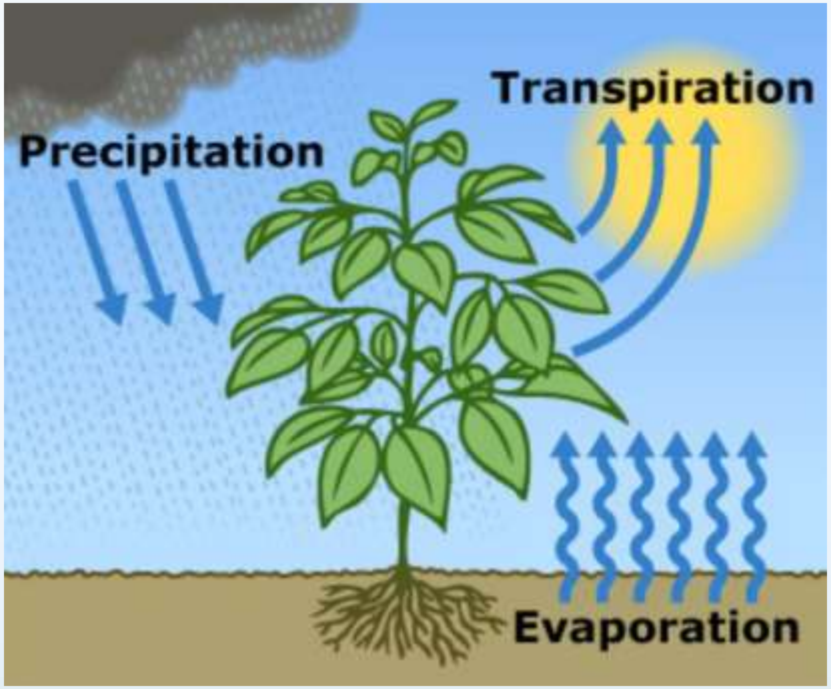


Evapotranspiration Source picture: USGS

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

- **Total hydraulic resistance sum of individual ressistances**
  - Through **the xylem pathway** of the plant,
  - Across **root membranes** to the soil
  - Through **the soil.**
  - Analog to electricity:
    - V = I.R   I = V/R = k.V
  - Darcy's law in groundwater flow: v = k.S



Evapotranspiration Source picture: USGS

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

- Application in ecology
  - powerful conceptual basis for understanding plant–water relations
  - constrains SPAC with ecological concepts:
    - models hydrological cycle 1-dimensional, ecological liquid waterflow 3-dimensional
    - Merging ecologist and hydrologist:

      1-dimentional model with 3-dimentional hydrological models

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

$$\lambda ET = \frac{\Delta (R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma \left(1 + \frac{r_s}{r_a}\right)}$$

(Source FAO)

Penman-Monteith formula

ET = Evapotranspiration

rs = (Bulk) Surface ressistance

ra = Aerodynamic ressistance

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

Transpiration

- Ratio transpiration to biomass accumulation: forest trees 170 to 340 kg of water vapor for every kg of biomass
- Air saturation deficit (D) and net radiation (Rn) are the principal drivers of transpiration
  - Air saturation deficit directly affects transpiration by establishing the vapor pressure gradient between the vapor-saturated leaf interior and the surrounding air.
  - Net radiation indirectly affects transpiration through heating of the canopy

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

Transpiration

- Nearly all transpirational vapor loss occurs through the stomatal pores
- Over short time periods transpiration controlled by regulating the size of stomatal pores, over longer time periods water balance regulated largely by changes in the amount of leaf area and species composition

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

Liquid Water Transport through Trees and the Role of Hydraulic Architecture

- Canopy conductance controls transpiration, strongly influenced by hydraulic architecture of trees
- Atmospheric conditions create a demand for water, and hydraulic architecture influences the supply of water from the soil.
- Ultimately, stomata regulate transpiration to ensure that losses do not exceed the supply capacity.
- it is necessary to understand how hydraulic properties of trees influence their use of water.

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

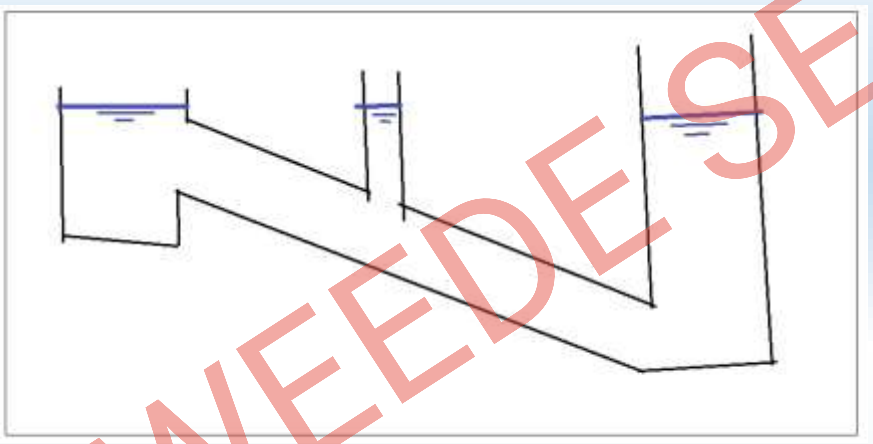
Tree Hydraulics

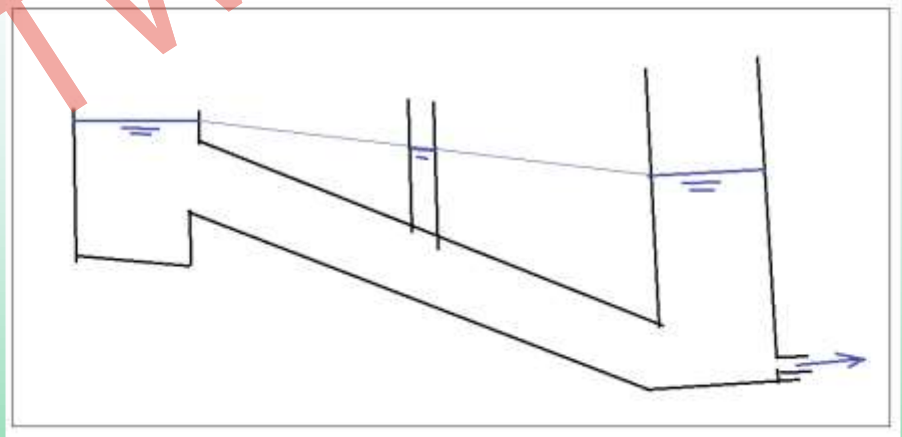
- According to the CT theory:
- Volume flow per unit time (Q) of liquid water through plants (the 'supply' for transpiration) is directly proportional to difference in water potential between leaves and soil

Analogy with electricity

- V = I.R
- I = V/R
- I = Electrical current
- V = difference in electrical potential
- R = ressistant
- I/R = conductiviyty (= k)

Flow through pipes





How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

Tree Hydraulics

- $Q = \Delta\Psi * K$
- $Q = \Delta\Psi / R$

- ($\Delta\Psi$; or Ψleaf − Ψsoil)
- K = whole-tree hydraulic conductance
- R = whole-tree hydraulic resistance (inversely proportional to K)

- When available water is limited water is limited for transpiration, partial stomatal closure occurs,limiting transpiration.

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

Water Uptake by Roots

- In woody plants, resistance to water flow in the root system can be equal or greater than resistance aboveground
- Constraints in root water intake also important
- Ability of roots to supply water for plant transpiration depends on the hydraulic conductance of the root system

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

Evapotranspiration in Forest Ecosystems

- Micrometeorologists hydrologists often combine evaporation and transpiration into one measurement for a watershed,
- Difficult to measure sepately Stable isotopic techniques have become available for helping to separate these two fluxes, transpired from leaves is more enriched isotopically than is water evaporated from soil.

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

Evapotranspiration in Forest Ecosystems

- Trees have the potential to greatly increase evaporative losses from an ecosystem because of the increase in evaporative surface and the greater access to soil water through roots.

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

Evapotranspiration in Forest Ecosystems

- Evaporation from soils is generally restricted to the upper few centimeters;
- In forests, transpiration generally accounts for most of ET.

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Soil-Plant-Atmosphere Continuum (SPAC) concept

Evapotranspiration in Forest Ecosystems

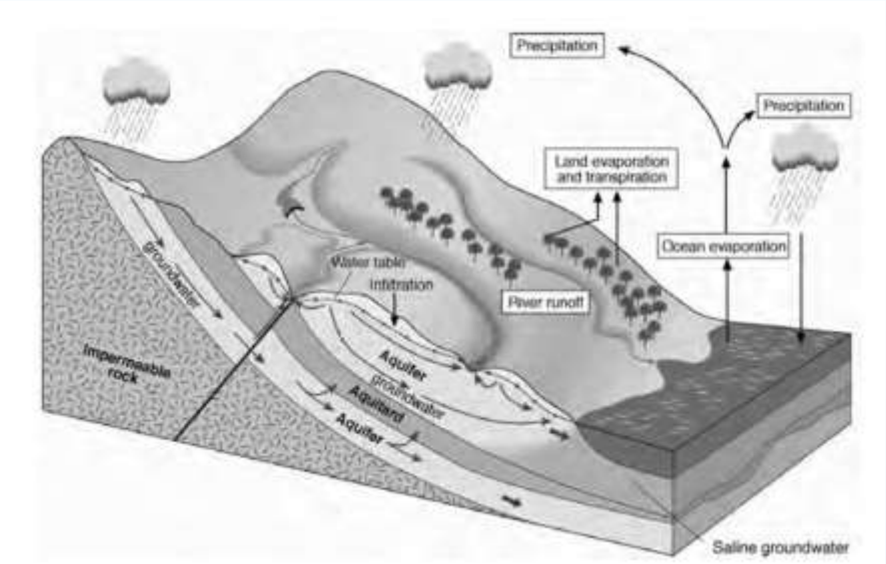
- In Amazon forest, transpiration responsible for nearly all of the loss in water vapor found. Soil evaporation only few % of the evapotranspiration flux from crops in a desert environment.
- Surinamese tropical forrest: about 2/3 of the rainfall is evapotranspirated, and circulating above the forest (Amatali, 1993)

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Data collection, analyses and modelling

Collecting the components of the hydrological cycle

- Precipitation (Rainfall, dew, snow, hail)
- Evaporation and Evapotranspiration
- Interception
- Infiltration
- Percolation
- Storage
- Soil moisture
- Discharge
- Groundwater



Picture: WHO 2006

How Trees Influence the Hydrological Cycle in Forest Ecosystems

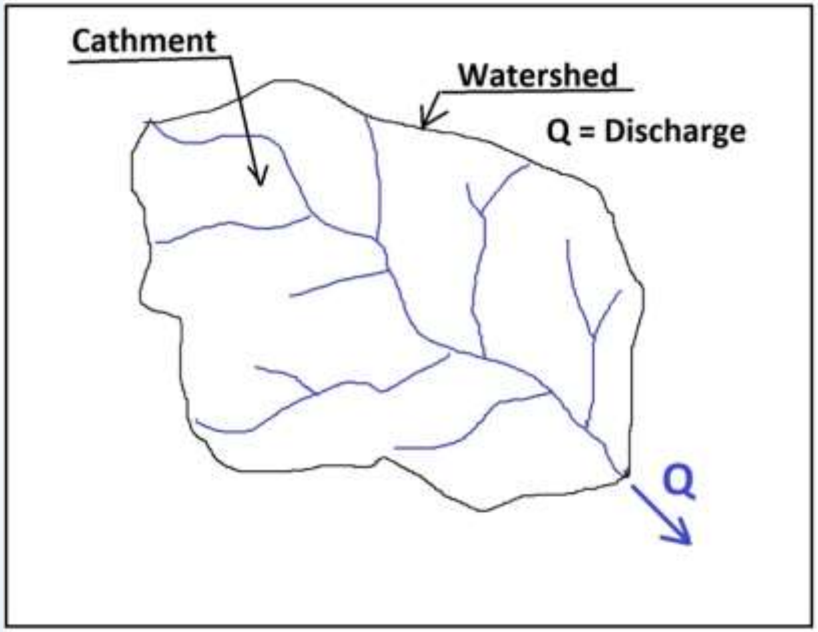
Consequences of deforestation

- Less vegetation
  - Less interception
  - Less infiltration
  - Less evapotranspiration => less rainfall
- Less storage
  - Less baseflow (groundwater flow)
    - More surface waterflow, direct/storm
    - Increase of peak surface water flow and floods (dischage and water level), during the wet period
    - Decrease in low water (discharge abd water level), during the dry period
- Less protection of the soil
  - Less ressistant to the surface waterflow
  - Increase of surface water flow
  - Flushing away the topsoil and fertile soil and vegitation
  - Infertile soil, vegetation disappear
  - Higher sedimentation concentration in the surface water cources

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Water balance:

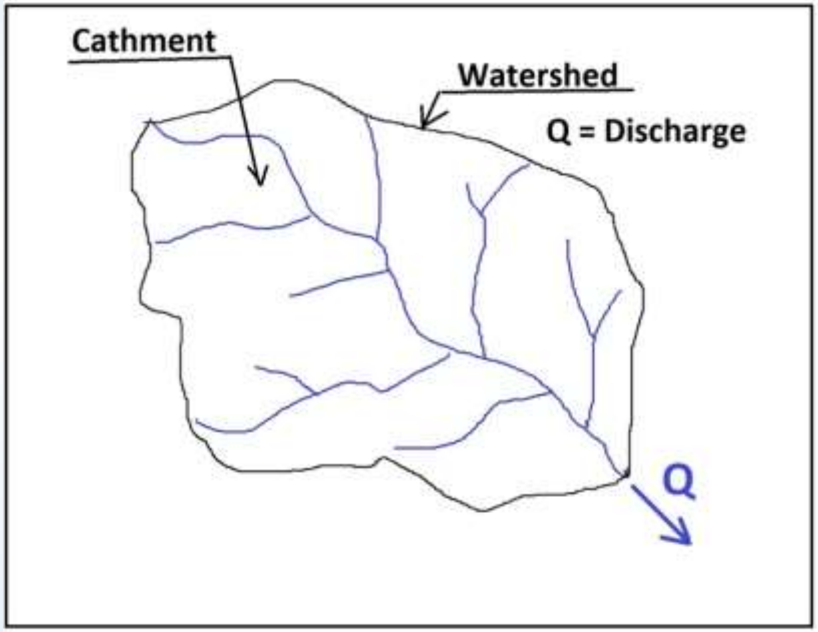
- Consider a catchment bordered by a watershed
- Be aware that topographical watershed is static. When the area near the watershed is inundated, the actual watershed is mobile, depending upon the water level. The same with groundwater, it depends on the groundwater level and will not always coincide with the geographical watershed, which is the watershed of surface water.



How Trees Influence the Hydrological Cycle in Forest Ecosystems

Water balance:

- Take a hydrological year into account, which generally does not coincide with the calendar years. The hydrological year ends when the storage throughout the year is minimum. In Suriname that is at the end of the Long Dry Season (End of November).
- Water balance equation (based on continuity)



How Trees Influence the Hydrological Cycle in Forest Ecosystems

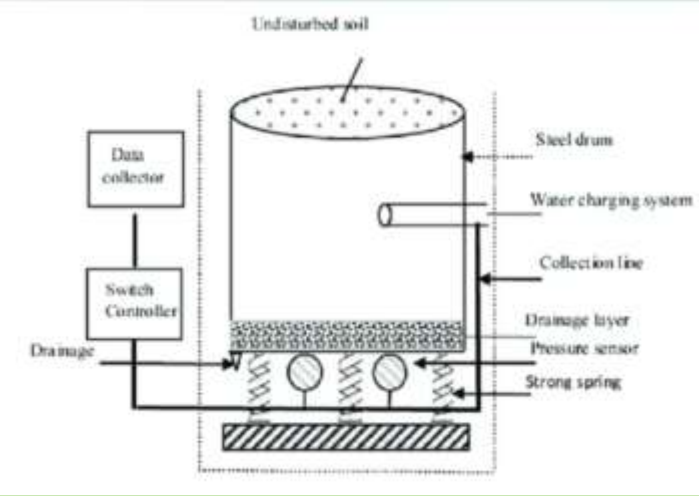
Water balance:

- In = Out + ΔS
- $P + Q_{in} + L_{in} = Q_{out} + L_{out} + ET + \Delta S$
- P = (Areal) Precipitation
- Q_{in} = Recharge, inflowing water rate
- L_{in} = Water leaking into the catchment, including seapage
- Q_{out} = Discharge, outflowing water rate
- L_{in} = Water leaking from the catchment, including seapage
- ET = (Areal) Evapotranspiration
- ΔS = Change in storage
- The water balance is used to estimate the magnitute of the components of the hydrological cycle which is unknown.
- When the time period of the water balance calculation is long, the change in storage is negiglible.

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Methods of modelling an hydrological/ecosystem

- A lysimeter can used to measure to estimate the evapotranspiration and inflitration.
  - It is a container installed in the field. The top of the container is open, the bottom and the side-walls are closed. The evelation of the top of the container is identiacally as the adjecent soil level. The container is filled with soil identical as the adjacent soil and planted with the same type vegitation. The rainfall, the surface water flow, the soil moisture and the groundwater level are measured. The evapotranspiration, interception and infiltration can be estimate by means of a water balance.

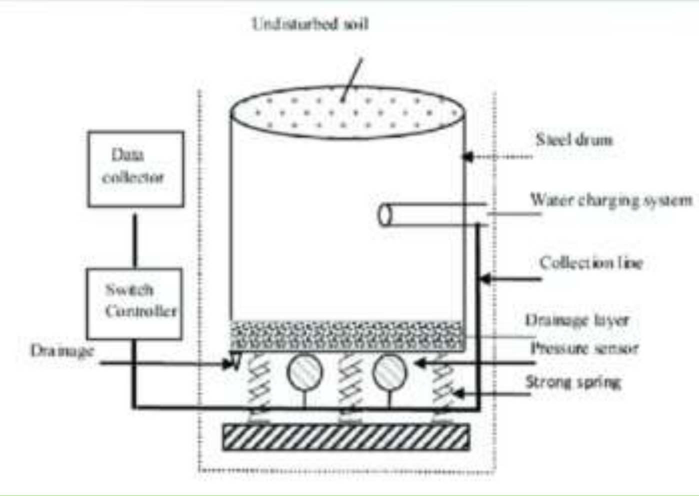


Lysimeter

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Methods of modelling an hydrological/ecosystem

- An experimental catchment can be established, of which the watershed has been identified. The different components of the hydrological cycle can measured, among others the precipitation, the river discharge, the waterlevel in the river, the groundwater level and the soil moisture content. The water balance principle can be used to estimate the magnitute of the unmeasured component of the hydrological cycle.



Lysimeter

Establishment of demonstration sites (experimetal sites)

UNESCO promotes the establishment of demonstration sites (experimental catchments)

- Displaying an application of ecohydrology in its objective of dealing with issues such as nutrient concentrations, water purification, etc
- Studying Hydrological and ecological processes in diverse aquatic habitats like wetlands, marshes, mangroves, cyanobacterial blooms in order to find long-term solutions, that integrate social components.
- Including the concept of enhanced ecosystem potential through
  - the application of ecohydrological strategies to achieve sustainability of ecosystems
  - closely related to water so as to improve IWRM
- Taking the WBSR (W-water,B-biodiversity, S-ecosystem services, and R-resilience) in consideration capacity).

How Trees Influence the Hydrological Cycle in Forest Ecosystems

methods of

Modelling a hydrological/ecosystem

An eco-hydrological (water balance) model can be established for the aforentioned experimental catchment.

- With modelling the following obstacles to overcome :
  - Limitations of hydrological measurements techniques
  - Not able to measure everything about hydrological systems in space and time
  - Possibility for extrapolation of the available measurements in space and time
    - ungauged catchments
    - to assess impact of future and possible changes in the catchment on the hydrological
- Results can be applied for other similar catchments and water-ecological systems

How Trees Influence the Hydrological Cycle in Forest Ecosystems

Methods of modelling an hydrological/ecosystem

- Means of quantative extrapolation or prediction
  - helpful in decision making
- Can be carried out within purely analytical framework based on observations of inputs to outputs of a catchment area (a hydrological system)
- Understanding nature of catchments and its responses.
- Complicated processes simplified in models described
- Unknown parameters can be estimated by means of optimizing the unknown parameters, using observed input and output data. An example is the estimation of parameters of the Nanni Swamp in Nickerie by Sevenhuysen in 1969 (see list)

Optimized Paramers of the Nani swamp by Sevenhuysen (1977)

Table 20. Summary optimized parameters (Sevenhuijsen, 1977)

	Start-waarde	Onder grens	Boven grens	Definitieve waarde
Bergingscapaciteit in het droge profiel van drooggevallen zwampgedeelten (mm)	100	150	30	57,9
Afvoercoëfficiënt zuidelijk zwamp ($m^3\ s^{-1}\ m^{-1}$)	50	10	100	71,7
Correctie van de verdampings-factoren van de begroeiing	1,00	0,80	1,20	0,95
Coëfficiënt van de lek ($m^3\ s^{-1} m^{-2,8}$)	150	100	200	145
Oppervlakte Nannizwamp bij peil NP + 10,00 m ($m^2.10^7$)	26	17	37	17,1
Oppervlakte Nannizwamp bij peil NP + 10,50 m ($m^2.10^7$)	48	40	56	55,8
Totale oppervlakte Nannizwamp ($m^2.10^7$)	54	48	56	55,9
Oppervlakte zuidelijk zwamp bij peil NP + 10,50 ($m^2.10^7$)	16	10	22	21,2
Totaal oppervlakte zuidelijk zwamp ($m^2.10^7$)	36	32	42	39,5
Standaardafwijking	0,067			0,044

Eco-hydrological study of the Nanni Swamp ecosystem

Background

- Rice is cultivate in Nickerie, with two crops a year
- During the second crop water from rainfall is not sufficient to satisfy the water needs for the rice cultivation and irrigaion is necessarry
- Irrigation is applied during the second crop, of which the water is from the Nickerie river, Nanni swamp and the Corantijn River. The avalability of irrigation water is generally not sufficient.
- Ministry of Agriculture has the intention to take measuese to increase the availability of irrigation water and to increase the efficiency in the water use.
- There a plans build new structures in the Nanni swamp and take additional measures.
- ESS (Environmental Survices and Support) was assigned to conduct and Eco-Hydrological study for the Nani Swamp
- Aim of the study was better understanding the biodiversity values, hydrological function, and potential sensitivity to changes in hydrological regime that could result from the proposed Program

Public Presentation

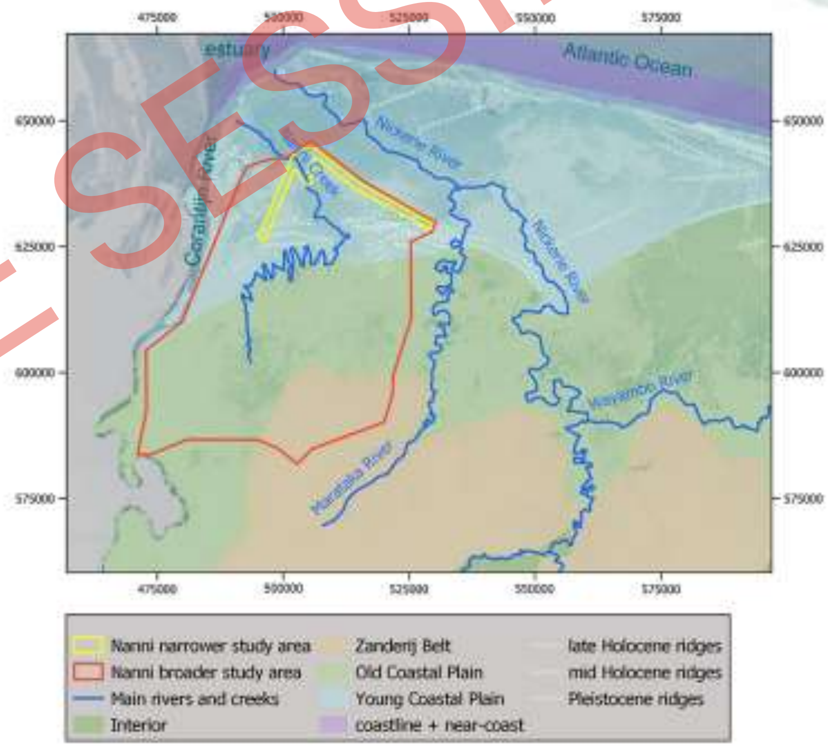
Eco-hydrological study of the Nanni Swamp ecosystem

Presentation by Chantal Landburg

Q&A by ESS team of experts

ESS environment

Study area

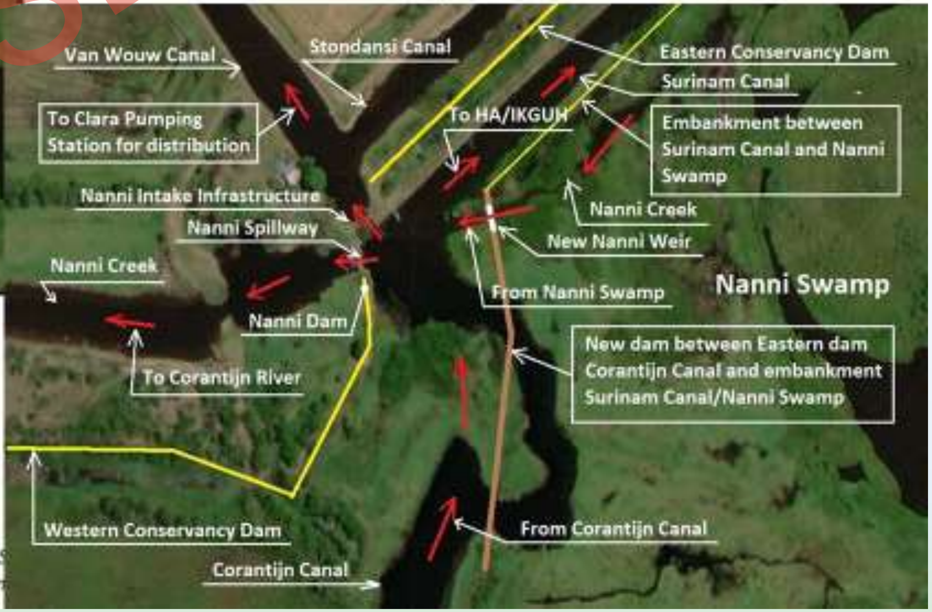


Ecohydrological Study Nanni Swamp - RFP No. IDB LVV 1052/01/2021
Public Presentation Final Report 20 March 2023

Proposed works – Nanni Weir

Option 1

Option 2



Proposed works – Maratakka Spillway

Overview Surinam Canal- Creek to Maratakka

Conclusions

Overall

- Study limitations:
  - Time: hydrology data not continuous, short ecological field trips in one year
  - Space: recent hydrology data only at one point, ecological study limited to the Suriname and Corantijn Canal and Nanni Creek Downstream
- The large, once biodiverse swamp is changing into an (unproductive) ombrogenous bog
- DOL is yet another example of an old-fashioned, engineer-planned, single-objective mega project that destroyed an important ecosystem and biodiversity (see Brokopondo Reservoir). Resulting in many unforeseen problems
- Hydrology study presented several scenario's, resulting in three options for management of the Nanni Swamp water level:
  1. Level of 3.65 m NSP (elevation of the crest of the projected Maratakka Weir) → a more or less constant high water level
  2. More or less coinciding with the seasonal patterns
  3. Depletion of the water from the Nanni swamp during the dry season

Scenario 1

1. Level of 3.65 m NSP → a more or less constant high water level

- **Maintained high water levels will highly impact vegetation and fish. Impacts on other wildlife may vary. Impacts potentially lower if water maintained between 3-3.5m NSP**
- Increased tree mortality expected except for more elevated areas. Vegetation will change to more herbaceous swamps, watrabebe and Kofimama swamps
- Large impact expected on fish as nutrients will become locked and the absence of seasonal fluctuation will disrupt migration patterns and reproduction cycles
- No impacts expected on manatees. Giant Otter reproduction may be limited due to lack of higher ground for den establishment and decreased food availability
- May benefit some aquatic species but would have negative impacts on terrestrial and wading species

Scenario 2

2. More or less coinciding with the seasonal patterns

- **Expected impacts generally lowest if seasonal fluctuations mimic natural patterns and prolonged (deep) flooding is avoided**
- Intermediate impacts expected compared to other scenario's. Sufficiently low water levels to enable (limited) burning will enable release of essential nutrients from peat
- Decrease negative impacts on vegetation, but tree mortality will occur if water levels exceed 3.65m NSP or >3m NSP for long periods
- No negative impacts expected on manatees, Giant Otters might be impacted if levels are not low enough for den establishment
- Minimal impacts on bird diversity and abundance expected

Scenario 3

3. Depletion of the water from the Nanni swamp during the dry season

- **Repeated drying of the swamp will easily lead to repeated burning and therefore impacting vegetation and wildlife**
- **Localized controlled burning may be beneficial, but burning should be avoided during El Niño years to avoid catastrophic impacts**
- Increase of herbaceous swamps in case of repeated burns
- No negative impacts expected for fishes
- No negative impacts expected for Giant Otters. Manatees may not be able to flee drying swamps
- Increase of generalist bird species and reduced bird diversity in case of repeated burns

Recommendations

Overall

- More efficient use of water resources and implement innovative solutions to decrease or eliminate need for increased capacity of Nanni Swamp

Hydrology

- Develop and apply a swamp water management scheme
- Avoid prolonged inundation
- Develop hydrological model for entire system for planning purposes and operational management existing water balance model can be used as a basis
- Develop seasonal weather predictions
- Assess water recycling options (e.g. wadoeks)
- Take climate change impacts into account

Ecology

- Preference for infrastructural adaptations such as underground pumping of water from the upper Corantijn River straight to the irrigation system, therefore avoiding impact on the Nanni Swamp
- Increase capacity of water management bodies to enable improved operational management
- Protect lower Nanni Creek

Follow-up

- Hydrological assessment and monitoring:
  - actual watershed and discharge of Nanni Creek
  - water level @ Nanni creek from the Southern area
  - periodical discharge @ Nanni Intake Infrastructure and upstream stations Frazer, Kaaiman and Bigi Draai
  - rainfall and evapo-transpiration
  - establish I&D database
- Ecological assessments and monitoring:
  - Central swamp area: obtain lidar images (topography), satellite images of vegetation changes, aerial and ecological surveys
  - Night surveys to assess presence and abundance megafauna
- Continuous monitoring for adaptive management → based on ecohydological management and monitoring plan (to be developed)

END
Thank You