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COMPARATIVE COMPUTATION OF SOIL EROSION AND RESERVOIR SEDIMENTATION ON A MONTHLY AND ON A DAILY TIME BASIS

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INTRODUCTION

- Computation of sedimentation in Yermasoyia Reservoir in terms of soil erosion in the corresponding basin

- Yermasoyia Reservoir is located northeast of the town of Limassol, Cyprus

- Storage capacity of the reservoir: 13 600 000 m^3
- Basin area of the reservoir: 122.5 km^2
- Main stream of the basin: Yermasoyia River

- Two versions of a mathematical model are used for the computation of the mean annual reservoir sedimentation

FIRST VERSION OF THE MATHEMATICAL MODEL

Three submodels:

- **Hydrological submodel**
- **Soil erosion submodel (Poesen, 1985)**
- **Stream sediment transport submodel (Yang, 1973)**
- **The calculations are performed on a monthly time basis**

SECOND VERSION OF THE MATHEMATICAL MODEL

<u>Three submodels</u>:

- **Hydrological submodel**
- **Soil erosion submodel (Poesen, 1985)**
- **Empirical concept of sediment delivery ratio**
- **The calculations are performed on a daily time basis**

HYDROLOGICAL SUBMODEL

Simplified water balance model for the root zone of the soil:

$$S_n' = S_{n-1} + N_n - E_{pn}$$

S: available soil moisture [mm]

N: rainfall amount [mm]

E_p: potential evapotranspiration [mm]

n: index for the time step

HYDROLOGICAL SUBMODEL

If $S_n' < 0$, then $S_n = 0$, $h_{on} = 0$, $IN_n = 0$

If $0 \leq S_n' \leq S_{max}$, then $S_n = S_n'$, $h_{on} = 0$, $IN_n = 0$

If $S_n' > S_{max}$, then $S_n = S_{max}$, $h_{on} = K(S_n' - S_{max})$, $IN_n = K'(S_n' - S_{max})$
where $K' = 1 - K$

h_o: direct runoff [mm]
IN: deep percolation [mm]
S_{max}: maximum available soil moisture [mm]
K, K′: proportionality coefficients

SOIL EROSION SUBMODEL

(Poesen, 1985)

$$q_{rs} = C(KE)r_s^{-1}\cos a$$

$$q_r = q_{rs}[0.301\sin a + 0.019 D_{50}^{-0.22}(1-e^{-2.42\sin a})]$$

q_{rs}: mass of detached particles per unit area [kg/m^2]

C: soil cover factor

KE: rainfall kinetic energy [J/m^2]

r_s: soil resistance to drop detachment [J/kg]

a: slope gradient [^{o}]

q_r: downslope splash transport per unit width [kg/m]

D_{50}: median particle diameter [m]

SOIL EROSION SUBMODEL

$q_f = rq_t$ (Nielsen et al., 1986)

q_f: sediment transport by runoff per unit width [m^3/(s m)]

r: entrainment ratio ($r=1$ for noncohesive soils, $r<1$ for cohesive soils)

q_t: sediment transport capacity by overland flow per unit width [m^3/(s m)]

SOIL EROSION SUBMODEL

$$q_t = [0.04(2g/f)^{1/6} q^{5/3} s^{5/3}] / [(\rho_s/\rho - 1)^2 g^{1/2} D_{50}]$$

(Engelund and Hansen, 1967)

g: gravity acceleration [m/s^2]

f: friction factor

q: runoff rate per unit width [m^3/(s m)]

s: energy slope

ρ_s: sediment density [kg/m^3]

ρ: water density [kg/m^3]

SOIL EROSION SUBMODEL

Available sediment on the soil surface of a sub-basin (q_{rf}) = downslope splash transport (q_r) + sediment transport by runoff (q_f)

<u>Estimation of sediment ES reaching the main stream from the respective sub-basin area</u>

$$\text{If } q_{rf} > q_t, \text{ then } ES = q_t$$

$$\text{If } q_{rf} < q_t, \text{ then } ES = q_{rf}$$

q_t: sediment transport capacity by overland flow

STREAM SEDIMENT TRANSPORT SUBMODEL

Estimation of sediment load FLO at the outlet of the main stream of a sub-basin

$$\text{If } ESI > q_{ts}, \text{ then } FLO = q_{ts}$$

$$\text{If } ESI < q_{ts}, \text{ then } FLO = ESI$$

ESI: available sediment load in the main stream considered

q_{ts}: sediment transport capacity by streamflow

STREAM SEDIMENT TRANSPORT SUBMODEL

$$\log c_t = 5.435 - 0.286\log(wD_{50}/\nu) - 0.457\log(u_*/w) +$$
$$+[1.799 - 0.409\log(wD_{50}/\nu) - 0.314\log(u_*/w)]\log(us/w - u_{cr}s/w)$$

(Yang, 1973)

c_t: total sediment concentration by weight [ppm]

w: terminal fall velocity of suspended particles [m/s]

D_{50}: median particle diameter of bed material [m]

ν: kinematic viscosity of the water [m^2/s]

u: mean flow velocity [m/s]

u_{cr}: critical mean flow velocity [m/s]

u_*: shear velocity [m/s]

s: energy slope

SEDIMENT DELIVERY RATIO
(Williams, 1977)

$$DR = 1.366 \times 10^{-11} F^{-0.0998} s^{0.3629} CN^{5.444}$$

DR: sediment delivery ratio

F: basin area [km²]

s: average slope gradient of the main stream of the basin [m/km]

CN: curve number

APPLICATION OF THE MATHEMATICAL MODEL

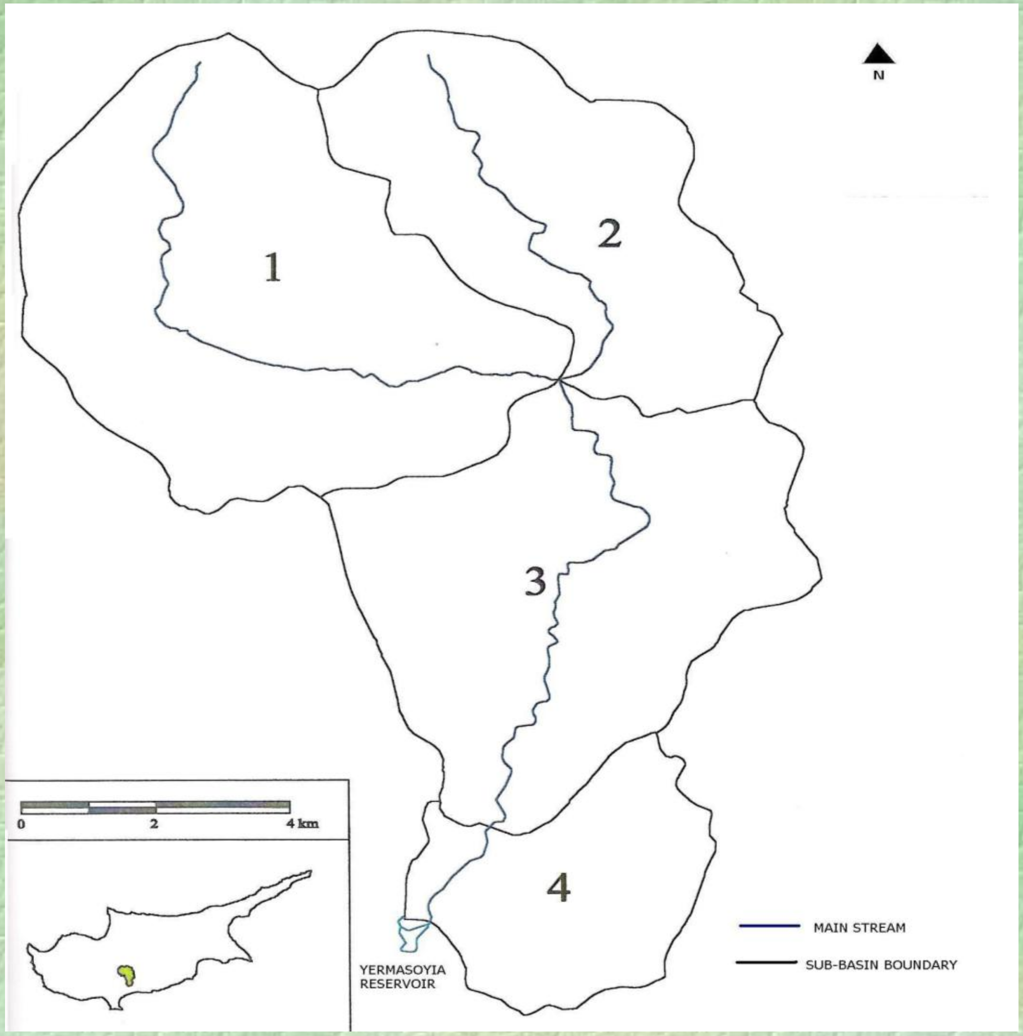
Yermasoyia Reservoir:

- **northeast of the town of Limassol, Cyprus**
- **Storage capacity: 13 600 000 m^3**

Basin of Yermasoyia Reservoir:

- **Area: 122.5 km^2**
- **Main stream length: 25 km**
- **Soil cover: forest (57.7%), bush (33.7%), urban area (1.8%), cultivated land (5.8%), no significant vegetation (1%)**
- **Highest altitude: 1400 m**

Division of Yermasoyia Reservoir basin into 4 natural sub-basins



AVAILABLE DATA

- **Daily rainfall data for 3 years (1987 – 1989) from 3 rainfall stations**
- **Mean daily values of air temperature, relative air humidity and wind velocity for 3 years (1987 – 1989) from 1 meteorological station**
- **Daily values of sunlight hours for 3 years from 1 meteorological station**

Symbols:

- **yd: annual erosion amount in the basin [t]**
- **ya: annual sediment yield at the basin outlet [t]**
- **dr: sediment delivery ratio (ya/yd)**

APPLICATION OF THE FIRST MODEL VERSION

Arithmetic results

Year	yd [t]	ya [t]	dr [%]
1987	681 000	229 000	34
1988	533 000	255 000	48
1989	72 000	59 000	82
Mean value	429 000	181 000	55

APPLICATION OF THE FIRST MODEL VERSION

- **Mean annual erosion rate: 1.32 mm (calculations)**
  0.70 mm (measurements)
  1.32/0.70=1.9
- **Mean annual deposition volume in the reservoir: 97 600 m^3**
- **Useful life of the reservoir: 139 years**

APPLICATION OF THE SECOND MODEL VERSION

Arithmetic results

Year	yd [t]	ya [t]	dr [%]
1987	807 000	234 000	29
1988	43 000	12 500	29
1989	474 000	138 000	29
Mean value	441 000	128 000	29

APPLICATION OF THE SECOND MODEL VERSION

- **Mean annual erosion rate: 1.36 mm (calculations)**
  0.70 mm (measurements)
  1.36/0.70=1.9
- **Mean annual deposition volume in the reservoir: 69 000 m^3**
- **Useful life of the reservoir: 197 years**

CONCLUSIONS

- Both model versions overestimate the mean annual erosion rate.
- The deviation between the two calculated mean annual erosion rates is negligible (1.32 / 1.36 = 0.97).
- The deviation between the two calculated values of the sediment delivery ratio is considerable (0.55 / 0.29 = 1.9).
- The deviation between the two calculated mean annual deposition volumes in the reservoir is not considerable (97 600 / 69 000 = 1.4).
- The small number of years considered does not allow to draw widely representative conclusions.