Karst SWAT hydrological modeling at large and regional scale: the case study of the island of Crete

Creating tools towards achieving WFD water quantity and quality targets

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Overview

I. Context of the research
II. The karst system
III. How to model the karst system with SWAT?
IV. The case study of Island of Crete
V. Conclusion
Context

• Protection of groundwater for human consumptions:
• Study of karst system characteristics
• Identifications of hydrogeological surfaces
• Hydrogeological running and budget: Recharge, Circulation and Discharge

Groundwater Directive 2006/118/EC

WFD

Water Framework Directive
Karst in numbers

Karst regions represent 7-12% of the Earth's continental area (Hartmann, 2014)

35% of Carbonate rock regions in Europe (Williams and Ford, 2006)

50% of Water supply in Europe (COST, 1995)
The Karst system and features

Karstic features

Conceptual model
(White W.B., 2003)

Recharge

Direct connection to the conduits below
Very fast infiltration
Transfer of water in extended areas, outside the superficial subbasin delineation

Discharge

Circulation
Can we model Karst system with SWAT?

**Baffaut & Benson** (2008)

- Sinkholes ~ Ponds (small Area and large K)
- Loosing stream ~ Tributary channel (with large K)
- New recharge of deep aquifer (rchrg_krst) and consequent return flow/baseflow
- Springs ~ return flow in the same subbasin
- NO: transfer of water from one subbasin to another

**Nikolaidis et al.** (2013)

- Modification of SOIL characteristics and GROUNDWATER parameters
- Introduction of a karst-flow model with the sum of DA_RCHRG (deep aquifer recharge) of different subbasins as input
- Springs ~ point sources
- YES: transfer of water from one subbasin to another
Our hybrid approach

(a) Precipitation

Soil Profile

SEEPAGE

LATQ

Shallow aquifer

GWQ₁: baseflow from shallow aquifer

GWQ₂: baseflow from deep aquifer

SURQ: Surface Runoff

Deep aquifer

DA_RCHRGG

PERC

(b) Precipitation

SURQ

SURQ-TWLWET

SPRING

Adapted SWAT model

Soil Profile

Shallow aquifer

Deep aquifer

DA_RCHRGG

PERC+TLOSS

TWLWET: losses from the bed of wetlands

DA_RCHRGG: amount of direct recharge of deep aquifer from several sub-basins;

Qₖ: deep groundwater flow from deep aquifer to Upper Reservoir

Qₜ: outlet of Upper Reservoir

Q₂: outlet of Lower Reservoir

α₁: fraction of DA_RCHRGG to the Upper Reservoir

α₂: fraction of flow from Upper to Lower Reservoir

PERC: percolation

GW_RCHRGG: the shallow aquifer recharge

DA_RCHRGG: the deep aquifer recharge

SWAT model

KSWAT model
No Karst Subbasins

SWAT MODEL

Watershed/reach delineation, **Landcover and landuse attribution**, soils distribution and types, climate data (pcp, tmp, userwgn)

No Karst Subbasins

Karst Subbasins

SWAT MODEL

Adapted SWAT Model

- Karst Soils/GW par.
- Wetlands
- Stream losses from tributaries

**Water consumption analysis and abstractions in each subbasin**

**ANALYSIS OF PLANT GROWTH**

**CALIBRATION of selected subbasins**

SWAT-CUP SUFI-2

**REGIONALIZATION of calibrated parameters**

**CALIBRATION of SPRINGS**

Karst-flow model

Add SPRINGS as POINT SOURCES in SWAT
The case study: Crete Island

Total area 8336 km$^2$

30% of Carbonate Rocks (~ 3000 km$^2$), 47 monitored Springs

2550 km$^2$ of agricultural land, 1200 km$^2$ irrigated area

~ 360 Mm$^3$/y demand for irrigation
Dry semi-humid Mediterranean climate

Mean annual rainfall decreases from west to east

Mean Annual temperature 18.5° in the West and 20° in the South decreasing with altitude

In the model: 69 stations with daily data for precipitation and 21 stations for temperature (period 1961-2009)
22 gauged streamflow stations
47 gauged springs

STR: 15 for calibration and 7 for validation, monthly calibration, period 1980-2009 (before warm up 10 years)

SP: daily calibration from 1983-2009

SP1, Almiros ~ 240 Mm^3/y
STR31, AlmirosH ~ 240 Mm^3/y

SP20, Votomos-Zaros ~ 3 Mm^3/y
SP21, Gergeri ~ 1.5 Mm^3/y

SP41, Platanos ~ 82 Mm^3/y
STR32, Koiliaris 180 Mm^3/y

SP32, Kourtaliotis ~ 37 Mm^3/y
STR9, Geropotamos ~ 17 Mm^3/y
352 subbasins, 19 km² avg area
502 HRUs
2600 km² total area karst-subbasins
Land cover was derived from a 1 km raster (CAPRI - SAGE - HYDE - GLC2000) for the year 2005.

Land use was obtained from the Agriculture statistics of Greece, 2005 and distributed using an Optimization Tool.

The major water use in Crete is irrigation for agriculture (84.5% of the total consumption) while domestic use is 12% and other uses 3.5%. The monthly abstractions from domestic, industry and other uses were modeled using the file .WUS, instead the abstractions for irrigation were defined in .MGT2.

Chartzoulakis, 2001
Results

Monthly simulated and observed streamflow

Start springs time series in SWAT

NSE=0.68, PBIAS=3.3%  
NSE=0.6, PBIAS=13.5%  
NSE=0.54, PBIAS=-12%  
NSE=0.84, PBIAS=-5%  
NSE=0.24, PBIAS=6.4%
Results

Daily simulated and observed discharge of springs

Overestimation to take into account ungauged springs (Nikolaidis et al., 2013)

NSE=0.77, PBIAS=0.7%

NSE=0.44, PBIAS=-0.8%

NSE=0.42, PBIAS=-0.2%
Discussion
EXTENDED KARST AREAS

The extended karst area of each spring was defined

The main extended karst area drains ∼ 300 km² into Almiros Springs (SP54) that discharges directly ∼240 Mm³/y to the sea.
Discussion
THE SPATIAL and TEMPORAL DISTRIBUTION OF RESOURCES

Long term simulated monthly variation of precipitation, evapotranspiration and water resources in deep aquifer in each subbasin

Direct connection of precipitation and aquifer in karst subbasin

Clear regional and seasonal variation in water availability in the aquifer: surplus in the west, deficit in the east
Discussion

THE WATER BALANCE UNDER DIFFERENT HYDROLOGICAL CONDITIONS

The total available water resources in the deep aquifer changes significantly under different hydrological conditions.

~3500 Mm³/y
Water resources in deep aquifer

~2000 Mm³/y
Water resources in deep aquifer

~500 Mm³/y
Water resources in deep aquifer

GW lost underestimated

Kourtialotis et al. (2013)

GW lost understimated

Precipitation=9600 Mm³/y

Precipitation=6400 Mm³/y

Precipitation=3700 Mm³/y

Soil Profile

Shallow aquifer

Deep aquifer

DA_RCHRIG=97%

LATQ=25%

GWQ1=8%

Qk=9%

Qkout=4%

Qk=13%

LATQ=25%

GWQ1=8%

Qk=9%

Qkout=5%

Qk=13%

Wettest year

Normal year

Driest year

ET= 26%

SURQ=9%

Qk=13%

ET= 40%

SURQ= 5%

Qk=13%

ET= 60%

SURQ= 3%

Qk=13%

K= 0.03

K= 0.05

K= 0.1

K= 0.15

K= 0.2

K= 0.25

K= 0.5

K= 0.75

Qunoff

Qinfiltration
Conclusions

• The hybrid karst model (Adapted SWAT+ karst flow model) has allowed to calibrate 47 springs with good efficiency and adjusting the streamflow predictions.

• The springs contribute significantly to freshwaters with large regional and seasonal variation. This resource should be conserved and preserved in particular in summer months (April-September) when available water resources are at their minimum level and the demand of agricultural and tourism is peaking. In a WATER NEXUS context this work highlighted the importance of addressing trade-off solutions on how to efficiently allocate water in the future.

• The water balance estimated in different hydrological conditions highlighted also the importance of preserving the resources during climate extremes (DROUGHT and FLOOD).
• This study described an operational methodology for the integrated water management in karst areas providing:
  
  • detailed hydrological balances
  • regional and seasonal accurate estimations of water availability
  • a tool for optimizing water allocation of resources and management giving information on potential overexploitation

• We will apply this methodology at large scale, however with some limitations:

  ~180 km² avg area of subbasins

  Lack of information about springs position and time series
Thank you for your attention

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http://ies.jrc.ec.europa.eu/
References for figures in this presentation:

-slide 4:
http://web.env.auckland.ac.nz/our_research/karst/
https://simple.wikipedia.org/wiki/Karst

-slide 5: karst features
http://www.esi.utexas.edu/outreach/caves/karst.php