Exploring controls on transit times and storage properties in mesoscale catchments in Switzerland

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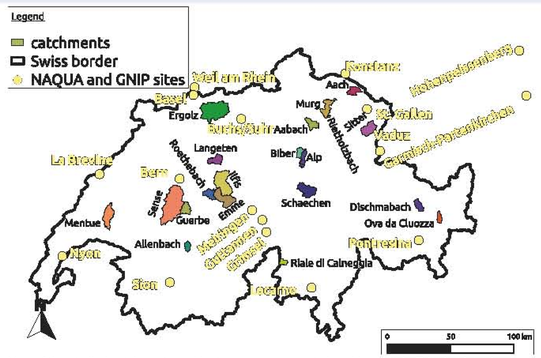
HYDROLOGY

Introduction and Objective

To asses a catchment's vulnerability to drought or contamination, it is essential to predict its storage properties. The **dynamic storage** of a catchment is related to the **mean response time (MRT)**, whereas the **total storage** of water in a catchment can be determined by transit or residence time analysis using stable water isotopes and is related to the **mean transit times (MTT)**.

The objective of this study was to determine MRTs and MTTs and the respective storages for 24 catchments in Switzerland, varying in geology and elevation range, spreading from the Jura to the Alps, and to investigate the relationships between dynamic and total water storages and their relationships to physiographic controls.

Catchments and Data

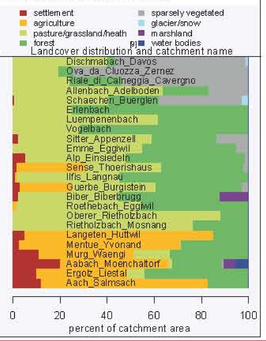


Map of the studied catchments and Isotope measurement sites. Vogelbach, Erlenbach and Luempenenbach are subcatchments of the Alp catchment

- Daily runoff data for an average of over 20 years (24 catchments)[1,2,3]
- Fortnightly stable water isotopes in runoff data from mid of 2010 to end of 2011 (23 catchments)[4]
- Additional runoff isotope data from 1993 to 2010 for the catchment *Rietholzbach Mosnang* and its subcatchment *Oberer Rietholzbach*[5]
- Monthly stable water isotopes in precipitation (17 sites)[6,7]
- Climate data for 100-m elevation ranges for each catchment including air temperature, relative humidity, precipitation, global radiation and wind speed[8]

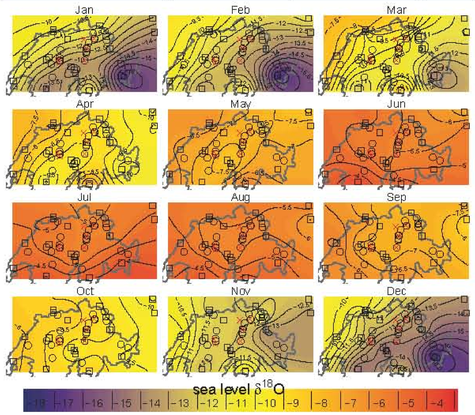
Characteristics of the 24 studied catchments

Mean Height [m]	Min Height [m]	Max Height [m]	Area [km^2]	Catchment
2369	1663	3139	43.2	Dischmabach_Davos
2364	1519	3160	26.9	Ova_da_Cluozza_Zernez
1986	881	2908	23.9	Riale_di_Calneggia_Cavergno
1852	1293	2742	28.8	Allenbach_Adelboden
1719	487	3260	107.9	Schaechen_Buerglen
1359	1117	1650	0.7	Erlenbach
1336	1092	1508	0.9	Luempenenbach
1335	1038	1540	1.6	Vogelbach
1301	768	2500	88.2	Sitter_Appenzell
1295	743	2216	1.27	Emme_Eggiwil
1154	845	1894	46.5	Alp_Einsiedeln
1068	554	2184	351.2	Sense_Thoerishaus
1037	681	2087	167.9	Ilfis_Langnau
1037	566	2152	55.4	Guerbe_Burgistein
999	627	1495	31.6	Biber_Biberbrugg
991	731	1542	54.1	Roethebach_Eggiwil
815	748	938	0.9	Oberer_Rietholzbach
794	671	938	3.2	Rietholzbach_Mosnang
760	598	1100	60.3	Langeten_Huttwil
679	447	926	105	Menthue_Yvonand
648	467	1036	76.8	Murg_Waengi
635	519	1092	55.6	Aabach_Moenchaltorf
584	305	1165	261.2	Ergolz_Liestal
472	408	560	50	Aach_Salmsach



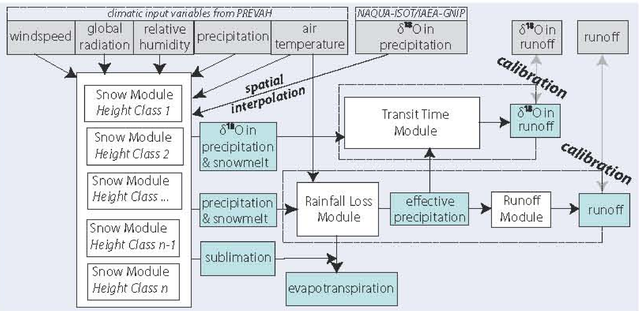
METHODS

Spatial Interpolation of precipitation isotopes



1. Average monthly $\delta^{18}O$ elevation gradients are computed along three sites aligned along an elevation gradient
2. Average monthly elevation gradients are used for an elevation correction of all sites' monthly values
3. Average monthly sea level $\delta^{18}O$ values are spatially interpolated [1] (see Figure to the left)
4. Sea level $\delta^{18}O$ values for a catchment are computed by correcting the catchments' average monthly sea level $\delta^{18}O$ value by the current month's deviation of the closest measurement site's sea level value to its average value
5. Monthly catchment $\delta^{18}O$ values are obtained by an inverse elevation correction of the monthly sea level catchment $\delta^{18}O$ values.

Model Structure



Snow Module

- Uncalibrated
- Energy balance [2]
- Elevation distributed
- Simulating $\delta^{18}O$ values in snow pack and melt water

Rainfall Loss Module [3]

- Implicitly accounts for effects of evapotranspiration
- Effective precipitation is computed by reducing the available amount of precipitation and meltwater according to the antecedent conditions

Runoff Module[4]

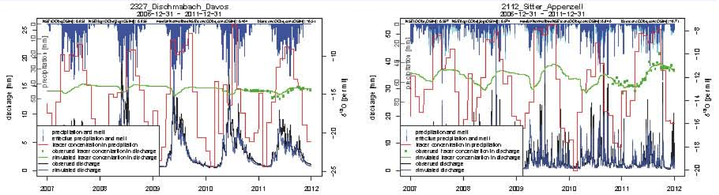
- Lumped convolution model
- Two parallel linear reservoirs (TPLR) model as transfer function
- Mean response time (MRT) can be derived from the calibrated TPLR transfer function.

Transit Time Module[4]

- Lumped convolution model.
- Tracer concentrations ($\delta^{18}O$ values) of the water released by the snow module or from precipitation are weighted by their respective masses.
- TPLR, exponential model (EM) or gamma distribution model (GM) are used as transfer functions.
- Mean tracer transit time (MTT) is derived from the calibrated tracer transfer function.

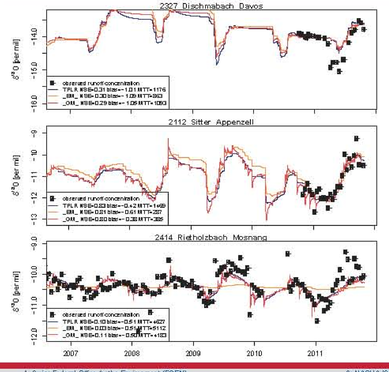
MODEL RESULTS

Runoff and Isotope Concentration Simulations



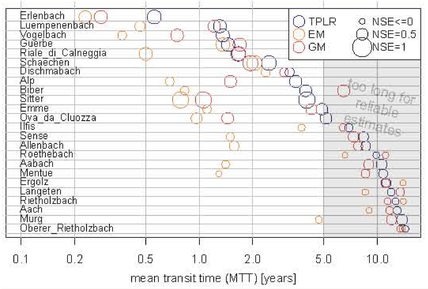
For most catchments runoff simulations reach NSE values of 0.6 and higher. Simulated $\delta^{18}O$ values show a negative bias compared to the observations. With bias correction, simulated $\delta^{18}O$ values reach NSEs around 0.4

Comparison of Transit Time Distributions



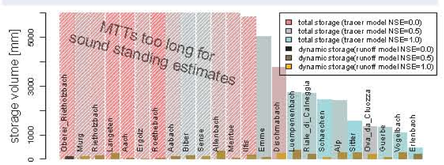
- Gamma distribution (GM) and two parallel linear reservoirs (TPLR) reach similar NSE values for predicting $\delta^{18}O$ in runoff.
- Especially for catchments with longer MTTs, the exponential model (EM) transfer function performs less satisfactory.
- Short runoff $\delta^{18}O$ observation time series are less adequate to identify the "best" transfer function, as clearly different transfer functions may partly overlap.
- Long runoff $\delta^{18}O$ observation time series show that a static transfer function can be adequate for a certain period while it is less adequate for another.

MTT Estimates



Storage Estimates

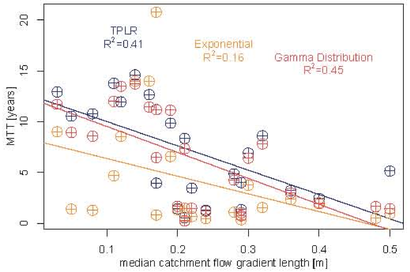
for the Gamma Distribution Transfer Function



- Apparently no clear relationship between dynamic and total catchment water storage.
- Total storage ranges from 450 mm to far over 5000.
- MTTs of more than half of the studied catchments exceed the range were sound estimates with stable isotopes are possible.

Relationship between Topography and MTT

- Low correlation (R^2 < 0.5) between MTT and catchment elevation and other topographic characteristics or controls.
- Nearly no correlations when catchments with estimated MTTs over 5 years are omitted.



CONCLUSIONS

The lumped convolution model approach including a suitable snow model with a distributed elevation input provides good MRT and MTT estimates for alpine catchments.

If the hypothesized influence of topographic controls on MTT exists, it is strongly superimposed by other controls, such as the underlying geology and soil cover. Predicting the MRT of catchments may require detailed knowledge about geology in addition to physiographic controls.

OUTLOOK

The reliability of the MTT estimates will increase with the extension of the runoff isotope time series from 18 to 36 months finalized in summer 2013.

Instead of examining the controls of the MRT of 24 catchments simultaneously, it may be more appropriate to focus on subsets of more geological similar catchments to predict the controls of the mean transit times.

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Data Sources
1: Swiss Federal Office for the Environment (FOEN)
2: Swiss Federal Institute for Forest, Snow and Landscape (WSL)
3: Amt für Abwasser und Umwelt (AWU) Bern
4: Chair of Hydrology, Albert-Ludwigs-University of Freiburg
5: Institute for Atmospheric and Climate Science (IACI), Swiss Federal Institute of Technology Zürich
6: NAQUA SOT, FOEN
7: Global Network of Isotopes in Precipitation (GNIP), International Atomic Energy Agency (IAEA)
8: Input data for PREVAH, by courtesy of Dr. Massimiliano Zappa
9: Corine Land Cover 2006 (reclassified), European Environment Agency (EEA)

Methods
1: Edzer J Pebesma. Multivariate geostatistics in S: the gstat package - *[doi: 10.1016/j.cageo.2004.03.012]*
2: U. Strasser and T. Marke. ESCIMO.spread - *[doi:10.5194/gmd-3-843-2010]*
3: A.J. Jakeman and GM Hornberger. How much complexity is warranted in a rainfall-runoff model? *Water Resources Research*, 1993
4: Markus Weiler. How does rainfall become runoff? Acombined tracer and runoff transfer function approach - *[doi: 10.1029/2003WR002301]*

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