ZHydro Seminar 2021

Seminar in Hydrology

Programs and teasers for the presentations

November 3, 2021

GEP Pavillon, MM C78.1, Polyterrasse, ETH Zentrum

Organisation: Simon Loew, Bernard Brixel, Chair of Engineering Geology ETH

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General information

The ZHydro seminar (Seminar in Hydrology) provides a platform to foster exchange and interaction between different research groups in the Zürich area working on hydrology-related topics.

This year's seminar will be held in the GEP Pavillon, MM C78.1, at the Polyterrasse, ETH Zentrum. We invite all researcher, students and other interested people to join. Please register by sending an email to Peter Lehman (peter.lehmann@env.ethz.ch), by Friday noon, October 29. There is no registration fee, but a limited number of seats.

Provided in this booklet is the seminar's schedule and a list of oral presentation abstracts. Oral presentations will either be 10' or 20', followed by 5' discussion.

Many posters will be presented, and presenters will have the opportunity to briefly advertise their posters in a one-minute pitch using one presentation slide. The poster should be a one-page, portrait format up to A0 size.

The event requires a valid Covid-19 certificate and ID.

Schedule

Time	Title	Presenter
	Introduction	
09:00	Welcome!	Simon Loew, Bernard Brixel
	Mountain hydrology and Glaciers	
09:05	On the use of surface deformation to understand groundwater systems: The case of the Great Aletsch Glacier	Nicolas Oestreicher
09:30	The impact of snow melt on groundwater table fluctuations in Switzerland	Raoul Collenteur
09:55	Long-term changes in surface hydrological properties and processes on moraines in the Swiss Alps during the first millennia of landscape evolution	Fabian Maier
10:20	Poster session (one-slide) introduction	
10:30	Coffee break	
	Climate and hydro-geomorphology	
10:50	A Glimpse beneath the Surface: On the Numerics of Richards' Equation as implemented in Weather and Climate Models.	Daniel Regenass
11:15	Uncertainty of small-scale hydrological projections due to climate change	Jorge Sebastián Moraga
11:40	Climate change impacts on Alpine sediment cascades: Insights from the Illgraben basin	Jacob Hirschberg
12:05	Global dominance of tectonics over climate in shaping river longitudinal profiles	Hansjörg Seybold
12:30	Lunch break	
	Hydrological modelling	
13:30	Quantifying the hydrologic response of heterogeneous, nonstationary, and nonlinear systems	James Kirchner
13:55	Behind every robust result is a robust method: Perspectives from a hydrological case study	Fabrizio Fenicia
14:20	Hybrid Hydrological Modeling for Sub-seasonal Droughts Forecasts - A Combination of Traditional Models and Machine Learning Techniques for Streamflow and Lake Level Predictions For the Alpine Aare Basin	Simone Jola
14:35	Poster session (one-slide) introduction	
14:45	Coffee break	
	Catchment hydrochemistry and Soil-plant hydraulics	
15:15	Soil-plant hydraulics as a key to predicting terrestrial water fluxes	Fabian Wankmüller
15:30	Pore-scale engineers – how plants and bacteria alter liquid connectivity	Pascal Benard
15:45	The overlooked pathway: Hydraulic shortcuts and their influence on pesticide transport in agricultural areas.	Urs Schönenberger
16:10	Sensitivity of groundwater recharge and nitrogen leaching to meteorological conditions in irrigated Mediterranean agriculture	Sandra Pool
16:35	Outlook 2022 and Goodbye	Simon Loew, Bernard Brixel

Schedule (posters)

Time	Title	Presenter
Morning poster-session introduction		
10:20	CAMELS-CH - Building a Common Open Database for Catchments in Switzerland	Marvin Höge
10:22	CH-GNet – Swiss Groundwater Network	Christian Moeck
10:24	The Swiss Society for Hydrology and Limnology (SGHL)	Dorothea Hug
Afternoon poster-session introduction		
14:35	Spatial extrapolation of pesticide pollution in agricultural streams and its limits	Clément Fabre
14:37	High-frequency Monitoring of pesticide dynamics reveal the catchment hydrochemistry: Remote sensing and Modelling to explain the unexpected?	Daniele La Cecilia
14:39	Initial investigations into microbial dynamics and biogeochemical cycling in the Bedretto Tunnel	Andrew Acciardo
14:41	A dual-scale fracture network model for computing hydro-mechanical properties of fractured rock	Wang Liang

MOUTAIN HYDROLOGY AND GLACIERS

On the use of surface deformation to understand groundwater systems: the case of the Great Aletsch Glacier valley

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Changes in groundwater level lead to deformation of the aquifer solid squeleton. Such deformation can be observed from the ground surface, and help to understand hydraulic properties of groundwater systems in a non-invasive way. For alpine fractured bedrock slopes aquifers, where other types of investigations are very challenging, surface deformation become a critical tool for hydrogeologists. However, poroelasticity of the rock mass is not the only source of deformation at the ground surface. Other factors such as tectonic forces, gravity, rock thermoelasticity, surface loadings or hygroscopic expansion also influence the ground deformation and need to be disentangled from the signal of interest.
We focus on the case study of the Great Aletsch Glacier tongue valley, where we track surface displacements of fractured crystalline rock slopes for more than six years at unprecedentedly high spatial and temporal resolutions. Centimetric reversible outward displacements are observed after the snowmelt season each year, followed by a seasonal recession to which are superimposed displacements caused by heavy rainfall-recharge events. Fault zones can be key features where most of the hydromechanical deformation occurs, and their geometry can control the direction of deformation. Glacier melting induces long-term trends of deformation. In addition, annual pore-pressure cycles lead to hydromechanical fatigue processes. We discuss the capabilities and limits of surface deformation monitoring systems, and their usefulness for the hydrogeological community.

The impact of snow melt on groundwater table fluctuations in Switzerland

Raoul Collenteur[1,2], Christian Moeck[2], Steffen Birk[1], Mario Schirmer[2,3]

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[2] Eawag, Department Water Resources and Drinking Water, Switzerland
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A prerequisite for sustainable water resource management is a good understanding of groundwater systems and their behavior over time. Time series modeling (TSM) has been shown to be a suitable tool to improve our understanding. TSM using predefined impulse response functions (von Asmuth et al., 2002) has become an increasingly popular method to model groundwater level fluctuations and gain a better understanding of the subsurface system. The method requires limited time and effort from the modeler, and only few assumptions are made about the system under study. This makes the method applicable for a wide range of environmental locations. Recently, it has been shown that these models may also be applied to obtain estimates of groundwater recharge (Collenteur et al., 2021). However, most studies applied the method to monitoring wells located in climate regions where precipitation primarily occurs as rainfall. In cold-temperature regions, where part of the precipitation falls as snow, applications of the aforementioned TSM have been limited. In this exploratory study, we test the use of TSM for selected groundwater monitoring wells in Switzerland. A simple degree-day snow model is added to the TSM to account for snowfall and make the method applicable to cold-temperature regions. Preliminary results show that the use of a snow model routine improves the simulation of groundwater recharge in the winter period, leading to a better prediction of the groundwater levels. The preliminary results from this study can be used to further explore the use of TSM to better understand groundwater systems in cold-temperature regions.

Long-term changes in surface hydrological properties and processes on moraines in the Swiss Alps during the first millennia of landscape evolution

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Overland flow (OF) and subsurface flow (SSF) are key processes that determine the streamflow response to precipitation, as well as water quality, but are affected by the land surface and soil characteristics. They can also modify the shape of our landscape. However, our understanding of the evolution of OF and SSF characteristics and the feedback mechanisms between hydrological, pedological, biological and geormorphological processes that affect OF and SSF during landscape evolution is still limited.
We used a space-for-time approach and studied 3 plots (4m x 6m each) on four different aged moraines (several decades to ~13.500 years) on the Sustenpass near the Steinglacier and in the karstic glacier foreland of the Griessfirn near Klausenpass (total of 24 plots) to determine how OF & SSF change during landscape evolution. We used artificial rainfall experiments with high rainfall intensities to determine runoff ratios, peak flow rates, timing and duration of OF & SSF. The addition of tracers (^{2}H and NaCl) to the sprinkling water and sampling of soil water allowed us to determine the degree of mixing of the applied rainfall with water in the soil. Measurements during natural rainfall events helped to determine the impact of the rainfall volume and intensity on the runoff generation. In addition, the runoff samples and sensor-based turbidity measurements of OF provide an estimate of the erosion rates during extreme events. In order to link the differences in runoff generation with the pedological and biological characteristics of the slopes, vegetation cover, root density, soil texture, soil aggregate stability, and the saturated hydraulic conductivity (Ksat) were measured as well.
The results show that K_{sat} at both study areas decreases with moraine age and soil depth and is mainly driven by the increase in silt and clay content. Despite the high Ksat values, local OF occurs frequently on the youngest moraines due to the large rock and stone cover. Sediment flux and the related erosion rates are largest for the young moraines, since vegetation cover and soil aggregate stability is small. Soil and vegetation development change major OF and SSF characteristics during landscape development, such as the mixing processes and the pre-event water fraction in OF & SSF, which both increase for the older moraines. However, the rate of these changes during landscape evolution is controlled by the parent material. These results can be used to inform landscape evolution models and help us to understand processes within the critical zone during the first millennia of soil development.

CLIMATE AND HYDRO-GEOMORPHOLOGY

A Glimpse beneath the Surface: On the Numerics of Richards' Equation as implemented in Weather and Climate Models.

Daniel Regenass[1], Christoph Schär[1]

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The exchange of water and energy between the land surface and the atmosphere is tightly coupled to the hydrological cycle. On annual and interannual timescales, catchment precipitation is roughly balanced by evapotranspiration and river discharge. The partitioning of incoming rainfall between runoff and infiltration, and thus availability of water for subsequent evapotranspiration, is a key task of the land surface model (LSM). Errors in one component of the hydrological cycle will inevitably propagate to the other components. In climate and numerical weather prediction models, one is mostly concerned with an accurate estimation of precipitation and evapotranspiration, but for the aforementioned reason, an accurate representation of the partitioning between infiltration and runoff is critical for the estimation of evapotranspiration. As LSMs in weather and climate models are often run over continental to global scales and over centennial time periods, computational performance is a critical issue, and the respective LSMs often use low computational resolution and make simplifying assumptions.

Our recent investigations using one particular LSM reveal that runoff formation is tightly linked to the representation of the infiltration process, which is in turn subject to the representation of vertical water transport. In addition to physical processes determining the partitioning between infiltration and surface runoff, one is also faced with numerical challenges. In order to represent the infiltration process properly, the sharp gradients around the propagating wetting front must be resolved. In many LSMs, vertical water transport in the soil is represented by the one-dimensional Richards Equation, which is solved using finite differences on a grid with typically around ten vertical layers. In this work, we use a Python implementation of the 1D Richards equation to examine the infiltration process and the formation of surface runoff with a focus on numerical aspects. The convergence of numerical implementations of the Richards Equation with respect to the spatial and temporal discretization is investigated. It is shown that in order to resolve the sharp gradients around the propagating wetting front -- which determine infiltation capacity -- relatively high resolutions in space and time are required. The propagation velocity of the wetting front decreases systematically with decreasing resolution. The demands in terms of vertical resolution are higher than what is typically implemented in state-of-the-art LSMs. The rather crude numerical implementation of the 1D Richards Equation in state-of-the-art weather and climate models is in stark contrast to developments in the groundwater community, where more advanced numerical methods are commonplace. This also hampers the dialogue between LSM, hydrological and vadose zone communities as advances and developments in soil physics (such as improved pedotransfer functions) may not yield the expected improvements when implemented to LSMs, simply because the 'numerical backbone' of the model is behaving in an unexpected manner.

Uncertainty of small-scale hydrological projections due to climate change

Jorge Sebastián Moraga[1], Nadav Peleg[2], Peter Molnar[1], Simone Fatichi[3], and Paolo Burlando[1]

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Climate change-induced hydrological projections are subject to uncertainty arising from a number of factors along the modelling chain, including climate model uncertainty and the irreducible internal climate variability (ICV). This is particularly true in the case of small-scale hydrological statistics, which are key for assessing risks over complex topographies as is the case of mountainous environments. In this work, a framework to quantify and partition the uncertainty of hydrological projections at the underexplored sub-catchment and sub-daily scales is proposed. A two-dimensional stochastic weather generator, AWE-GEN-2d, was used to obtain ensembles of climate variables at 2-km and hourly resolutions by downscaling outputs of different climate model chains. High-resolution gridded hydrological variables were then simulated until the late 21st century at two study catchments in the Swiss Alps using Topkapi-ETH, a distributed hydrological model. Despite the uncertainty of estimations, the results show that an increase in temperature of around 4°C and a changing precipitation regime will translate into robust elevation-dependent changes in hydrological components, especially during the warm season. Climate models and ICV will both contribute equally to the overall uncertainty. In contrast, the impacts on extreme hydrological events are small in comparison with their uncertainty and are dominated by large ICV values (doubling or even tripling climate model uncertainties), which suggests that the tools we have today will be insufficient for improving their estimation under a warming climate. These results highlight the importance of considering the magnitude of uncertainty when projecting changes to small-scale hydrological processes.

Climate change impacts on Alpine sediments cascades: Insights from the Illgraben basin

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Sediment production and transfer processes shape river basins and networks and are driven by variability in precipitation, runoff and temperature. Changes in these hydrological and geomorphological processes are especially difficult to predict in temperature-sensitive environments such as the Alps. In addition, non-linear relationships between forcing and sediment mobilization may lead to dampening or shredding of environmental signals, further complicating the analysis of sediment flux estimates. We used the SedCas sediment cascade model (Bennett et al., 2014; Hirschberg et al., 2021) and the AWE-GEN stochastic weather generator (Fatichi et al., 2011) (1) to quantify climate change impacts on sediment yield and debris-flow activity in the Illgraben with the CH2018 climate scenarios and (2) to study the effects of the inherently stochastic forcings (climate and sediment recharge) on sediment yield estimates based on only short records.
We show how contrasting predictions can be, dependent on if sediment production (and therefore the sediment availability) is considered or not. Furthermore, we demonstrate the elevation dependency of frost-cracking, a common weathering mechanism, such that increases in the debris-flow activity are predicted in higher basins (>2000 m) and decreases in lower basins such as the Illgraben. We further show how short observation records of sediment fluxes suffer from large uncertainties. One source of this uncertainty is that large hillslope landslides can generate long-term memory effects in the sediment output lasting up ~50 years. Interestingly, details of the actual timing of sediment supply events are shredded and have no discernible impact on sediment yields at the outlet. These findings give insights on geomorphic system functioning and will support the climate change impact assessment on mass movements and sediment yields in Alpine basins, in particular with regard to how to deal with uncertainties.

Global dominance of tectonics over climate in shaping river longitudinal profiles

Hansjörg Seybold

Department of Environmental Systems Science, ETH Zurich, Switzerland

River networks are striking features engraved into the surface of the Earth, shaped by uplift and erosion under the joint influence of climate and tectonics. How a river's gradient changes as it descends along its course—its longitudinal profile concavity—varies greatly from one basin to the next, reflecting the interplay between uplift and erosional processes. A recent global analysis has suggested that climatic aridity should be a first-order control on river profile concavity, but the importance of climate relative to other factors has not been tested at global scale. Here, we show, using recent global datasets of climate, river profiles and tectonic activity, that tectonics is much more strongly expressed than climate in global patterns of river profile concavity. River profiles tend to be more strongly concave in tectonically active regions along plate boundaries, reflecting tectonically induced spatial variations in uplift rates. Rank correlations between river profile concavity and four global tectonic proxies (basin-averaged channel gradients, distance to plate boundaries and two measures of seismic activity) are much stronger than those between river concavity and three climate metrics (precipitation, potential evapotranspiration and aridity). We explain the association between tectonic activity and increased river profile concavity through a simple conceptual model of long-term uplift and river incision. These results show that tectonics, and not climate, exerts dominant control on the shape of river longitudinal profiles globally.

HYDROLOGICAL MODELLING

Quantifying the hydrologic response of heterogeneous, nonstationary, and nonlinear systems

James Kirchner

Department of Environmental Systems Science

For nearly 100 years, catchment hydrologic response has been quantified using unit hydrograph methods. However, these techniques assume that hydrologic response is linear and stationary, whereas many real-world systems exhibit clearly nonlinear and nonstationary behavior. Here I present data-driven, model-independent, nonparametric methods that can efficiently deconvolve the nonlinear, nonstationary, and heterogeneous hydrologic responses of real-world systems, using widely available rainfall and runoff data. These methods will be illustrated using data from several Swiss catchments.

Behind every robust result is a robust method: Perspectives from a hydrological case study

Fabrizio Fenicia

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The degree of confidence we can place in scientific results strongly depends on the methods used to generate them. However, the presentation of scientific research is seeing an ever increasing emphasis on the “results” at the expense of the underlying “methods”. This study tells the story of a scientific article, which went through several rounds of revision before being accepted for publication. The objective of the article was to shed light on the dominant processes in a mesoscale catchment through a distributed modeling application. Each round of review illustrated the value of a given methodological instrument, which is arguably underutilized in the modeling practice. Increasingly stringent and inquisitive verification techniques progressively changed the initial perceptions of dominant processes in the catchment, to the point of overturning the initial results. The intention of this story is to stimulate a reflection on the balance between results and methods in scientific communication, as well as on how to increase the rigor of hydrological and environmental model applications.

Hybrid Hydrological Modeling for Sub-seasonal Droughts Forecasts – A Combination of Traditional Models and Machine Learning Techniques for Streamflow and Lake Level Predictions For the Alpine Aare Basin

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Droughts can occur on a wide spatial and temporal range and are a normal phenomenon in the mid-latitude seasonal climate. However, extreme events, such as that of summer 2003 and 2018, have severe impacts on water resources, water supply, agriculture, energy production and natural ecosystems. To mitigate and reduce such harmful effects, warning systems aiming to the early recognition of droughts are a fundamental tool for public and private water managers. In an integrated risk management perspective, sub-seasonal streamflow and lake levels ensemble forecasts provide useful information for medium-long term. Recently, approaches from machine learning (ML) have shown to outperform traditional hydrometeorological modeling approaches, mainly due to their hyper-flexibility. Nevertheless, purely ML-based modeling depends on large data availability, ignores general knowledge about system functioning, and it does not easily extrapolate to unseen conditions. Combining general knowledge and learning-from-data in hybrid models is therefore currently seen as a promising paradigm for hydrological and earth science modelling. The purpose of this study was to investigate the power of ML as a routing scheme for the discharge output of the PREVAH hydrological model to provide ensemble sub-seasonal streamflow and lake level forecast for the alpine Aare at the outlet of both the 1’200 km2 Brienz basin and 8’000 km2 Biel basin. We implemented an ensemble of linear and non-linear ML algorithms. We accounted for both the hydrologial and the ML uncertainty using the 51-members-hydrological-ensemble and running the ML simulaitons several times with different train-test datasets. The machine was additionally informed with the initial conditions, weather regimes forecasts and an hydropower proxy. Three different meterological forecasts were used: raw forecasts, pre-processed forecasts and a reference simulation.

We are able to demonstrate that hybrid hydrological modeling outperforms traditional approaches to forecast sub-seasonal streamflow and lake level for both Brienz and Biel basin. The results show that informed ML produces better forecasts than those obtained using hydrological model outputs only. In the first half the forecast performance is boosted by the initial conditions and in the second half especially by the hydropower proxy. Lake levels prediction shows for both basins promising skill, wheareas the streamflow performance shows signs of basin-size dependency. Finally, raw meteorological forecasts give better results compared to ones obtained using the pre-processed meteorological forecasts.

CATCHMENT HYDROCHEMISTRY AND SOIL-PLANT HYDRAULICS

Soil-plant hydraulics as a key to predicting terrestrial water fluxes

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Understanding stomatal regulation is essential to predict water exchange between vegetation and atmosphere. Under drought conditions, incomplete knowledge of stomatal behaviour diminishes the predictive value of current stomatal models. For instance, stomatal optimization models are becoming widely accepted, but critical discussion on what mechanism allows stomata to perform optimally is missing. In this presentation, we will introduce a model of stomatal regulation that results in optimal-like stomatal behaviour without presupposing an optimality principle. The proposed model explains stomatal closure based on a well-known mechanism for stomatal regulation, which is abscisic acid (ABA). As a prerequisite, we introduce the hydraulic constraints on plant's gas exchange and discuss the implications of our concept under variable soil and atmospheric conditions. For example, the presented model predicts that stomatal regulation is soil specific. We believe that bringing together soil-plant hydraulics with stomatal physiology is an important step to better understand stomatal responses to drought and to predict water exchange between soil, plant and atmosphere.

Pore-scale engineers – how plants and bacteria alter liquid connectivity

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Plant roots and bacteria alter the soil physical properties by releasing highly polymeric blends into the pore space. Despite considerable alterations attributed to the presence of mucilage exuded from root tips and EPS released by bacteria, and the immense amounts of water that cross the rhizosphere (ca. 40% of all terrestrial precipitation) related mechanisms remain largely unexplored.
The physical properties and implications of mucilage and EPS are surprisingly similar. Both can form a polymeric network that can retain water, they decrease the surface tension and increase the viscosity of the soil solution. This results in the formation of stable filaments and two-dimensional structures that reach across the pore space in drying soil. The modified spatial configuration of soil water affects the retention and transport properties in soil biological hotspots like the rhizosphere.
When soil dries, mucilage and EPS are concentrated, the viscosity of the soil solution increases, and its retreat is eventually impeded when the friction between polymers and solid surfaces becomes too high. The different types of liquid bridges created in this process are explained by the interplay of capillary, viscous and absorptive forces. Resulting increase in liquid connectivity can improve water flow and nutrient diffusion along with other processes. Images of mucilage and EPS structures in soil resolved with synchrotron X-ray computed tomography provided the basis for this concept.

The overlooked pathway: Hydraulic shortcuts and their influence on pesticide transport in agricultural areas

Urs Schönenberger, Janine Simon, Birgit Beck, Anne Dax, Bernadette Vogler, Christian Stamm

Eawag, Environmental Chemistry, Switzerland

Pesticides can enter surface waters through various pathways and impair the water quality. In the past, numerous studies were conducted for certain entry paths such as surface runoff, direct drift into water bodies or preferential flow to drainage systems. Previous studies have shown that so-called hydraulic shortcuts (e.g. inlet or maintenance shafts of agricultural storm drainage systems, but also to roads, farm tracks, channel drains, and ditches) might also play a major role for pesticide inputs into surface waters. However, they have received little scientific attention in the past.

We will present the results of a PhD thesis assessing the relevance of pesticide losses via hydraulic shortcuts to Swiss surface waters. For this, the following four research questions were investigated: 1) How widespread do hydraulic shortcuts occur in Swiss agricultural areas? 2) What is their relevance for surface runoff-related pesticide transport? 3) What is their relevance for spray drift-related pesticide transport? 4) What pesticide concentrations and loads are found in hydraulic shortcuts?

To answer these research questions, shortcuts were mapped in 29 small catchments representing arable land and vineyards in Switzerland. Based on these maps, pesticide transport was modelled using a georeferenced surface runoff connectivity model and a georeferenced spray drift model. In addition, during a full agricultural season, we measured pesticide transport in a small catchment with intensive arable land use. This included the measurement of discharge and pesticide concentrations in four out of 158 storm drainage inlets of a small Swiss catchment. These measurements were accompanied by additional measurements in the stream and by a collection of pesticide application data.

The results of the mapping campaign show that hydraulic shortcuts are a frequent structure in Swiss arable land catchments and that inlet shafts are the most important shortcut type. The results of the surface runoff connectivity model suggest that around half of the surface runoff from arable land reaches surface waters via hydraulic shortcuts. The same holds for the surface runoff-related pesticide load. The results of the spray drift model show that spray drift wash-off from roads that are drained by hydraulic shortcuts may also be a major pesticide transport pathway to surface waters. Finally, the results of the field measurements show that agricultural storm drainage inlets strongly influence surface runoff and related pesticide transport in the studied catchment. High pesticide concentrations (up to 62 µg/L) were found in inlets and, during some rain events, transport through single inlets was responsible for up to 10% to the total load of certain pesticides in the stream.

In conclusion, our results suggest that pesticide transport via hydraulic shortcuts is an important pathway for the pollution of Swiss surface waters that has been overlooked in the past. Current regulations and mitigation measures are not addressing this pathway and – consequently – fall short in preventing pesticide losses through this pathway.

Sensitivity of groundwater recharge and nitrogen leaching to meteorological conditions in irrigated Mediterranean agriculture

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The sustainability of agriculture in the Mediterranean area is challenged by high irrigation water demands and nitrogen fertilizer losses to the environment, causing significant pressure on groundwater resources and groundwater dependent ecosystems. Developing effective water management strategies requires understanding the performance of irrigation-fertilizer practices under the specific agro-meteorological characteristics of the Mediterranean area. Here, we use hydrological simulations over a historical period of fifty years to quantify the magnitude and dynamics of groundwater recharge and nitrogen leaching under five real-case irrigation-fertilizer practices observed in Valencia (eastern Spain). The Valencian Region is the largest citrus producing region of Europe and current irrigation-fertilizer practices are a result of the ongoing transformation of irrigation systems from flood to drip irrigation. We find that a transformation from flood to drip irrigation significantly reduces the recharge fraction and the nitrogen leaching fraction on long term. However, the long-term performance of the two irrigation practices is subject to substantial inter-annual differences controlled by precipitation variability. The sensitivity of recharge and nitrogen leaching to annual meteorological conditions is stronger in drip irrigation, which eventually leads to a similar performance of flood and drip irrigation in wet years if fertilizer inputs are similar. Our simulations further reveal a pronounced year-to-year nitrogen memory in the soil that either improves or worsens the performance of a given irrigation-fertilizer practice after a wet or dry preceding year, respectively. This study demonstrates the highly variable nature of the performance of irrigation-fertilizer practices, and the major findings can guide future efforts in designing sustainable water management strategies for agricultural areas with a Mediterranean climate.