Unstable flow patterns during submarine groundwater discharge: Changing the way we look at the freshwater-seawater interface

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ABSTRACT

The importance of submarine groundwater discharge as a material transport pathway to the ocean was already investigated by numerous studies around the world. As groundwater fluxes often contain significantly higher nutrient, metal and organic compound loads than rivers, groundwater discharge to the ocean may have crucial implications for coastal ecosystems. Moreover, discharging groundwater and recirculating seawater interact within the subterranean estuary and generate reactive zones that may alter the geochemical conditions of the water and sediment. Consequences like e.g., the eutrophication of coastal waters or the change of interstitial fauna of sandy beaches were previously reported.

However, the flow patterns in the intertidal region are still not completely understood. Contrary to today's common view of hydraulic conditions in the intertidal region, i.e., the formation of a stable upper saline plume (USP) concurrent with the existence of a so-called "freshwater discharge tube" below, which pinches out at the beach surface close to the low tide mark, this system can be extremely instable under certain conditions.

We conducted laboratory experiments supported by numerical modeling to investigate the instability of submarine groundwater discharge patterns during tidal forcing. For a gentle beach slope of 1:12, our study shows the development of a transient freshwater-seawater interface that is characterized by several migrating saltwater fingers which intrude into the aquifer. Groundwater discharge occurs in between these saltwater fingers at various locations in the intertidal region and is not limited to the low tide mark.

We suggest that a stable USP is limited to a certain range of hydrological and hydrogeological parameter values in nature and does not generally apply to all coastal environments. Especially when the beach slope falls below a critical value, the likelihood of fingering flow and an associated rather chaotic discharge pattern arise. Local sediment heterogeneities or changing recharge patterns will increase the discharge variability.

These new insights have important implications for the biogeochemistry of subterranean estuaries. If the input of nutrients, metals and organic compound is extended from the low water line to the entire intertidal area, this may lead to significant changes in species diversity and abundance of the benthic fauna as well as algae and seagrasses. Moreover, the freshwater discharge under instable conditions is likely to be highly variable over larger time periods, which must be considered when quantifying discharge rates. In case of spatially and temporally variable discharge conditions, local measurements by e.g., a seepage-meter, may lead to an underestimation of the discharge rate. It is a challenge for the future to detect and measure these flow patterns in the field.

REFERENCES

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