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ESSAY

Celebrating 50 years of SWIMs (Salt Water Intrusion Meetings)

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Abstract
The Salt Water Intrusion Meetings, or SWIMs, are a series of meetings that focus on seawater intrusion in coastal aquifers and other salinisation processes. 2018 marks the 50th year of the SWIM and the 25th biennial meeting. The SWIM proceedings record half a century of research progress on site characterisation, geophysical and geochemical techniques, variable-density flow, modelling, and water management. The SWIM is positioning itself to remain a viable platform for discussing the coastal aquifer management challenges of the next 50 years.

Keywords Salt-water/fresh-water relations · Salt-water intrusion · Salinisation · History of hydrogeology

Emergence of SWIM

Almost 50 years ago, on 28 and 29 November in 1968, a group of 20 German, Danish and Dutch scientists met in Hanover, Germany, to discuss salinisation of groundwater in coastal areas. They had been invited by the late Prof. Wolfgang Richter (working at the Geological Survey of Lower Saxony), who recognised the need to exchange knowledge with neighbouring countries that faced similar saline groundwater problems. Participant contributions were printed and most were gathered in a proceedings report. Due to the usefulness of the meeting, another meeting was organised in the Netherlands. The conference series, now known as the Salt Water Intrusion Meeting, was born.

The second meeting (13–15 May 1970 in Vogelenzang, the Netherlands) was organised by the Dutch committee of UNESCO's International Hydrological Decade (IHD, 1965–1974). This meeting had a logo, the outline of the organising country visible through the wavy lines of the UNESCO IHD logo—see Fig. S1 of the electronic supplementary material (ESM). The name 'Salt Water Intrusion Meeting' was introduced at the third meeting (1972 in Copenhagen, Denmark). The conference series was maturing with a catchy acronym (SWIM) and a logo style that has been used for almost all following SWIMs.

This article is part of the topical collection "Celebrating 50 years of SWIMs (Salt Water Intrusion Meetings)"

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Topics and trends

The first proceedings describes the early application of techniques that have become commonplace today. While most contributions focussed on describing the fresh–saline groundwater situation using hydrochemical data, contributions about geo-electrical techniques were also prominently represented. Computers were already used to make resistivity models with more than three layers (Flathe 1968). Quite sophisticated chemical tracer techniques were being applied, and the first proceedings contained contributions on the use of isotopes (Stahl 1968; Nielsen 1968; Geyh 1968) to infer origins of different coastal groundwater types.

The current pervasiveness of numerical modelling and software tools was still years away. The first SWIM contribution about using numerical techniques was by Verruijt (1972), who demonstrated the principles of the finite element method and showed two applications regarding theoretical freshwater–saltwater interface problems. Presentations about numerical models of real-world coastal aquifers took another decade to appear.

Case studies describing coastal aquifer systems have been part of SWIMs since the first meeting and constitute an important contribution to the knowledge of coastal areas. As the number of participating countries grew, the geographical diversity of contributions increased (Fig. 1). At the first two meetings, the focus was on unconsolidated sedimentary aquifers prevalent in the three organising countries. The first descriptions of salinisation in chalk aquifers soon followed (e.g. Downing 1972). Karst systems were extensively discussed at the Hannover meeting in 1979, the proceedings of which feature a paper of 68 pages about the coastal aquifer system of Apulia, Italy (Cotecchia 1981). Several case studies in fractured bedrock aquifers were presented at the 1981 Sweden meeting (e.g. Lindewald 1981; Sund and Bergman 1981). A few SWIM contributions deal with the movement of saline groundwater in inland aquifers—for example, the genesis and migration of brines originating from leaching of salt domes or stratiform salt deposits (e.g. Ochmann and Fielitz 1993; Klinge et al. 1999; Zechner et al. 2014), and the existence of brackish and saline groundwater due to aridity (Custodio 1992; Bauer et al. 2002).

In a landmark early SWIM paper, Lebbe (1981) demonstrated the existence of an intruded seawater cell below a wide beach in Belgium surrounded in the subsurface by fresher groundwater. He recognised that the circulatory flow of intruded seawater inside the cell was driven by the tide and used a numerical model to quantitatively interpret flow dynamics. Since then, similar tide-driven circulation cells have been found elsewhere, but Lebbe's (1981) SWIM contribution can be credited as the first description of such a system. More generally, interactions between coastal aquifers and the ocean and submarine groundwater discharge have become a main SWIM theme. Early contributions dealt mainly with submarine springs in karst systems (Schwerdtfeger 1981), while more recently interest has shifted towards the role of submarine groundwater discharge as an important source of nutrients to the marine environment (e.g. Scholten et al. 2014).

Some interesting trends are visible when the contributions to the meetings are aggregated in categories (Fig. S2 of the ESM). The mathematical treatment of sharp interface solutions, frequently discussed at early meetings, has become a rare topic. At the first two meetings, geochemistry comprised a considerable proportion of the contributions, then disappeared during the 1970s, and increased again, reaching a peak (as a percentage) in the mid 1990s. Geophysics, (numerical) modelling, management, sea-level rise, island hydrology, and climate change, have become more prominent topics, although the latter category has been showing a decline since 2010.

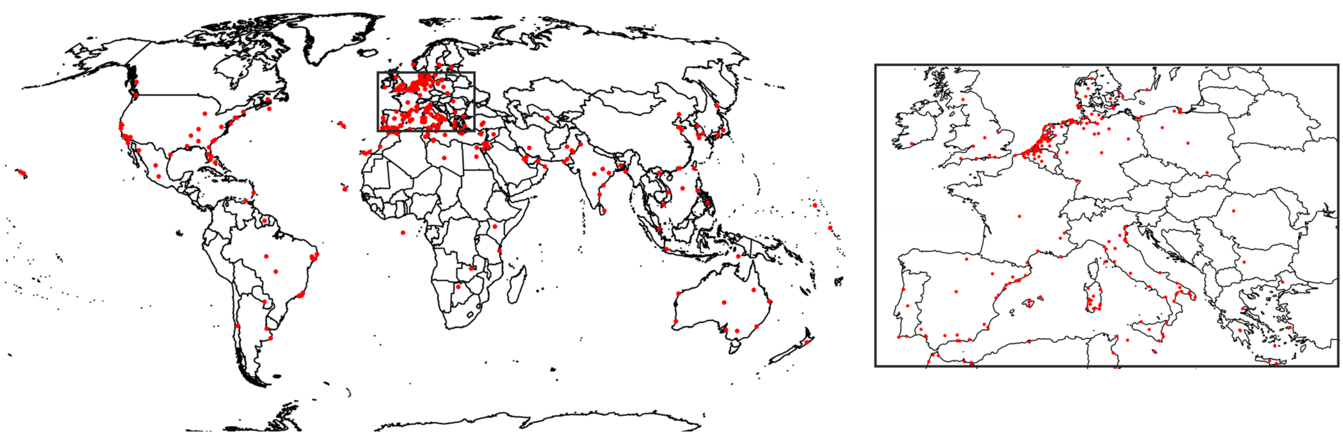

Fig. 1 Maps with dots showing the locations of the case studies of saltwater intrusion presented at SWIMs. The main map covers the entire globe, while the inset map is an enlargement of Europe and the Mediterranean region, which have the highest density of studies. When the precise location of a study could not be determined, the dot was placed in the centre of a country

From European to global

The 1960s world was not yet as globalised as today, so SWIM began as a Western European meeting series and contributions by non-European participants remained rare during the meetings organised before 2000. At the 1986 SWIM in Delft, the Netherlands, Cliff Voss (US Geological Survey) suggested to make SWIM a worldwide conference because of its great importance to all countries, but the European organisers did not wish to make it more difficult for European students, who often gave their first international talk at the SWIMs, to travel to the meetings. This later led to the establishment of the Salt Water Intrusion and Coastal Aquifer (SWICA) conference series that were held in Essaouira, Morocco, in 2001 and in Merida, Mexico, in 2003. Since both SWIM and SWICA meetings attracted the same participants, it was discussed during the 18th SWIM that the biennial meetings be combined, with meeting location alternating between a European country (just as in the original SWIM series) and a non-European country. The first instance of the new combination was in 2006, a joint 19th SWIM and the 3rd SWICA meeting held in Cagliari, Italy, at which the attendees voted to combine the two meeting series under the name SWIM.

Since 2009, Asian countries have been organising a successful series, the Asia-Pacific Coastal Aquifer Management Meeting (APCAMM). The first APCAMM was held in Bangkok, Thailand. The 24th SWIM and the 4th APCAMM were held jointly in Cairns, Australia, in 2016. There are no current plans to merge with SWIM and APCAMM, as APCAMM has a specific geographic focus, but there will be coordination, joint participation, and exchange of ideas between these conference series.

Current status

SWIM has become a conference series with a strong reputation. The format has evolved into a 1-week meeting, always with exclusively plenary sessions, and a mid-week field trip to sites related to saltwater problems. In recent years, it has become customary to organise short courses, for example on seawater intrusion modelling, prior to the meeting. At the 24th SWIM in Cairns, the participants voted to continue the plenary-only format for all future meetings, as this exchange of ideas among all attendees is one of the attributes that makes SWIM so successful.

The informal passing of the responsibility of hosting the next meeting to the next organiser has proven to be a sustainable model that has ensured the SWIM continuity for half a century. The number of participants has risen over the years (peaking at 165 in Husum, Germany, in 2014, see Fig. S3 of the ESM), but the SWIM's primary objective is still the same as the first meeting: the exchange of knowledge on saline groundwater problems.

The 25th SWIM in Gdańsk, Poland, from 17 to 22 June 2018 (see http://www.swim2018.syskonf.pl) is the fifth SWIM organised in a Baltic country. Despite the low salinity of the Baltic Sea relative to ocean water, numerous cases of saltwater intrusion have been investigated in this region, from spits (e.g. Dowgiałło and Frączek 1990) to deltaic areas (e.g. Zuber et al. 1990) to crystalline bedrock islands (e.g. Lindewald 1981). A previous SWIM meeting in Sopot, a locality near Gdańsk, took place in 1990. Great socio-economic changes began at that time in Eastern Europe, which, among many other consequences, led to a significant shift in groundwater usage patterns in the Gdańsk region and Poland. The risk of salinisation of coastal water wells substantially decreased due to reduced water uptake by heavy industry, while contamination by nutrients originating from agricultural practices has become a major concern (e.g. Højberg et al. 2017; Szymczycha and Pempkowiak 2016).

The proceedings of all SWIMs are available online and can be accessed via the website http://www.swim-site.org (SWIM 2018). They archive developments in coastal hydrogeology characterisation, process understanding, and water-supply management over the past half century. The causes of salinisation are now better understood than at the first meeting, and the technologies to measure and model groundwater processes in coastal areas, albeit still in need of improvement, have reached high levels of sophistication. A special volume republishing selected papers from the SWIMs prior to 1990 was published by the International Association of Hydrogeologists (De Breuck 1991). A table with a listing of all SWIM and SWICA conferences is given in Table S1 of the ESM.

The next 50 years

The problems of saltwater intrusion and aquifer salinisation have not been solved. Population growth, urbanisation, land-use change, environmental destruction, globalisation, and tourism are increasing the pressure on coastal freshwater resources (Michael et al. 2017). The possible acceleration of sea-level rise and land subsidence compound the seawater intrusion problems in coastal areas. At the same time, monitoring networks are often inadequate, leading to a paucity of data for numerical model analyses and management decisions. Governance issues such as a lack of adequate legislation and enforcement, as well as poor users' and civil society involvement form other obstacles against effectively combating saltwater intrusion problems, let alone the more general problem of the slowness of the uptake of new science into management and society.

There are many important topics for which better understanding of the physical system is required, as evidenced by recent trends in SWIM contributions. The example of submarine groundwater discharge was already mentioned in the context of the Baltic Sea, but to understand its importance to ocean water quality and ecosystems across the globe is an essential current research challenge. The topic of land-aquifer-ocean connection is likely to see significant advances in the future. Research into better ways of describing mixing in groundwater, and the effects of heterogeneity (as well as tides and wave action) on coastal aquifer water quality, also continues. All these new physical insights, partly based on evolving measurement techniques, will require more sophisticated numerical models that could certainly benefit from quantum computers when they become a reality.

The relevance of the SWIM is thus greater than ever. One future challenge may partly be to transform the meeting from a platform where experts discuss problems to one where solutions are explored and developed. An increasing number of SWIM contributions are already shifting towards providing solutions such as managed aquifer recharge, the control of saline groundwater, the capture of marine water through the aquifer to feed desalination plants, and the use of coastal aquifers for the storage of surplus water. Bridging the gap between science and management is another direction that SWIM will likely take, and in this perspective, SWIMs will likely develop more outreach activities. The recent video that was produced by GEUS in Denmark is a good example in that sense (accessible via SWIM 2018). Thus, apart from celebrating SWIM's 50th anniversary, the 2018 meeting in Gdańsk will also be used to develop ideas about how SWIM can continue its successful tradition and at the same time evolve and innovate to continue its relevance in the coming five decades, which, however scary it may sound, may see even faster and more far-reaching global changes than the past 50 years.

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