Proposal for a SCOR Working Group

Global Assessment of Nutrient Export Through Submarine Groundwater Discharge (NExT SGD)

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Summary
We propose to establish a new working group that will initiate and develop a new global model for assessing nutrient and constituent export through submarine groundwater discharge (SGD) to nearshore coastal areas and offshore SGD fluxes from artesian aquifers - **the NExT SGD model**. The proposed multi-national NExT SGD working group would consist of scientists whose research crosses disciplinary boundaries (hydrogeologists, geochemists, oceanographers, and global water cycle modelers). This collaboration will provide the mechanistic understanding of controls on groundwater-derived water and constituent fluxes to the ocean necessary for global extrapolations and predictions with this novel NExT SGD model. The currently available data on SGD and nutrient fluxes is extensive and has increased exponentially during the last years (e.g., more SGD data is available now than what previously existed for initiating the NEWS global river flux model 10 years ago) and it is representative of a broad array of aquifer, coastal zone and climate regimes. To ensure the success of this working group we will interact with other working groups and programs (e.g., GEOTRACES, GlobalNEWS and LOICZ) as well as with members of former SCOR working groups (e.g., SCOR 112 "*Magnitude of Submarine Groundwater Discharge and its Influence on Coastal Oceanographic Processes*") and learn from their experiences in compiling large databases, identifying and filling potential data gaps and developing and distributing protocols for best practices.

Rationale

The overarching goal of this proposed SCOR working group is to develop a global model for assessing water and constituent (nutrients, gases, carbon, metals) fluxes to the ocean via groundwater (NExT SGD). Current data availability (**Fig 1**) and conceptual understanding of the processes controlling groundwater discharge to near-shore coastal regions and the associated nutrient and other constituent fluxes is sufficient for formulating a numerical global model for assessing land–ocean material transport fluxes, similar to the river flux global model (GlobalNEWS) constructed about a decade ago (*Seitzinger and Harrison*, 2005). Indeed, the first global models of river constituent fluxes were developed based on a far smaller database than available for SGD today (e.g., *Gibbs and Kump, 1994).*

Figure 1 Snap-shot of the newly created web site by the working group for compiling the available data (>100 locations worldwide presented as red dots). More data are available but not plotted on the map yet. (*from http://sgd.snu.ac.kr/home/gis_main.jsp*).

The global NExT SGD model, will not only enable prediction of SGD and constituent fluxes for any location worldwide for present, past and future climate conditions, but provide the tools to *test potential feedbacks* in the ocean-land-atmosphere earth system. Such a global model will transform our predictive abilities of this important, yet poorly constrained part of the hydrological cycle. Indeed, one of the pioneers in the SGD field advised, "*The **oceanographic and hydrogeologic** communities should recognize the **local and global** importance of SGD and **work together** to achieve a better understanding of the processes that control SGD and its constituents*" (*Moore*, 2010).

Because the model will be capable of capturing nutrient and flow changes triggered by short and long-term anthropogenic activities and climate, it will allow the examination of various scenarios and their *ecological effects on ecosystems and economic effects on societies*. For example, excess nutrient loading due to SGD can initiate and sustain harmful algal blooms (HABs) in coastal areas (*Lee et al*., 2010, *Lecher et al.*, 2015). The predictive power of a large-scale model will allow the identification of locations susceptible to HABs triggered by SGD. Thus, the NExT SGD model will not only significantly improve our understanding of the magnitude of groundwater-derived nutrients and other constituent budgets for the global ocean, but will be extremely useful as a tool to highlight the need for water management assessments in some areas where no data are available.

The global NExT SGD model will enable us to *improve Earth System Models (EMS)*, which at this stage neglect groundwater as a transport pathway from land to sea. For example, alkalinity supplied by groundwater may change the modeled pH response to increased atmospheric CO_2 concentrations (*Cyronak* et al. 2013). Given the potential importance of SGD for material fluxes into the ocean, its inclusion in the EMS will be important for allowing accurate predictions of the effect of global change, including changes in sea-level on the oceans, and a global SGD model is a necessity to enable that inclusion. EMS, like the ORCHIDEE model (http://orchidee.ipsl.jussieu.fr/) could easily be extended to include subsurface material fluxes by forcing existing parameters with outputs from the NExT SGD model.

The NExT SGD model will include coastal aquifer systematics and related controls on SGD (**Fig. 2*b***) and will *aid in determining fluxes from the little explored offshore freshwater seepages* on the continental shelf (**Fig. 2a**) which could have future value as a fresh water source in densely populated coastal regions (*Post et al*., 2013).

Scientific Background

What is SGD and where does it occur? Submarine groundwater discharge (SGD) "*includes any and all flow of water on continental margins from the seabed to the coastal ocean, regardless of fluid composition or driving force*" (*Burnett et al.* 2003, *Moore,* 2010) (**Fig. 2*a*,*b***).

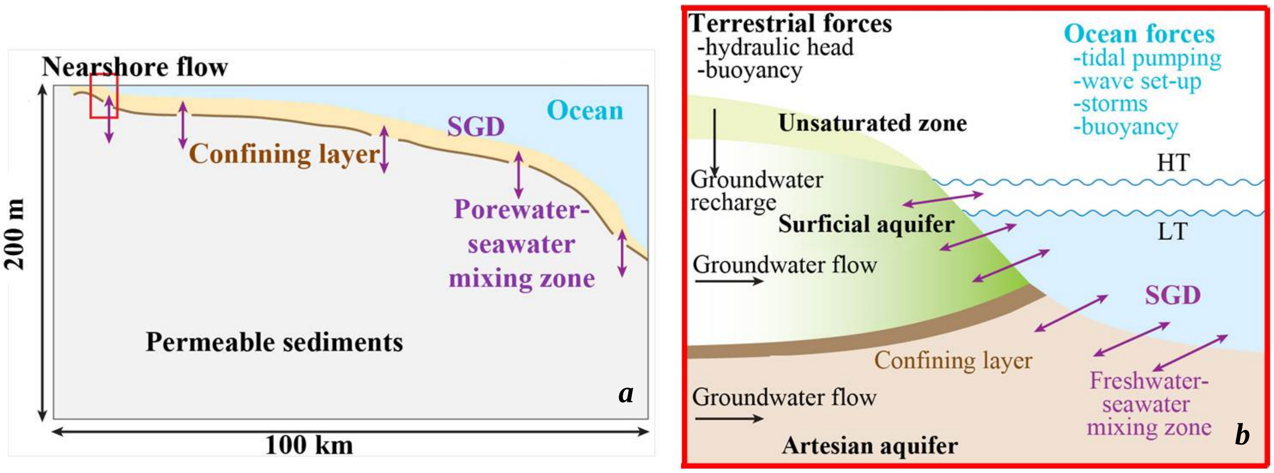

Figure 2 (***a***) SGD extends from the red box labeled "*Nearshore flow*" throughout the continental shelf. The offshore flow on the continual shelf is driven by interactions of ocean forces with geothermal heating and over-pressurized zones beneath discontinuous confining layers. ***(b)*** Near the shoreline SGD (red box) is driven by a combination of terrestrial and ocean physical forces operating in a complex geological environment (*modified from Moore,* 2010).

The NExT SGD model will capture nearshore fluxes (**Fig. 2b**) that include (*i*) fresh and (*ii*) recirculated seawater where most of the SGD data were collected and where most of the terrestrial groundwater-derived constituents are discharged (**Fig. 1**). However, the NExT SGD model can be expanded to include offshore fluxes on the continental shelf once sufficient data from these areas are available. This will be possible because the offshore flows on the continental shelf are channeled through artesian aquifers that have the same hydrogeological properties as nearshore shallower aquifers and will be already embedded in the global model. Moreover, knowing the near-shore fluxes will enable general estimates of the offshore component to be calculated based on ocean-scale radium (Ra) mass-balance models (*Moore,* 2010, *Kwon et al*., 2014).

Despite the rich body of literature characterizing the transport of material fluxes via SGD to the nearshore environments (**Fig. 1**), to date attempts to upscale and evaluate water fluxes on regional or global scales are limited. However, in a recent study of global upscaling, *Kwon et al*. (2014) estimated SGD to amount to 3-4 times the river flux. Nevertheless, the radium mass-balance approach used in this and other studies is not based on a mechanistic understanding of driving forces; hence its predictive and exploratory abilities are limited. The lack of a process-oriented model is a very substantial knowledge gap, especially considering the links between ***SGD, the global carbon cycle, and climate change***. For example, in a key study, *Cole et al*. (2007) showed that SGD could contribute a similar amount of DIC to the coastal ocean as rivers. *Beusen et al*. (2013) established a global model on SGD-derived nitrogen fluxes, but neglected the marine recirculated SGD component, which often has a much larger volume than freshwater SGD (e.g., *Burnett et al.*, 2003; *Waska and Kim,* 2011).

The proposed multifaceted modeling approach will allow connecting ***hydrogeological and marine factors*** (e.g., net precipitation, surface runoff, recharge, groundwater pumping rates, hydraulic heads, aquifer size and aquifer characteristics, topography, lithology, beach morphology, the presence and level of development of stream systems, waves, and tides) affecting SGD to ***nutrient and other constituents loading controls*** (e.g., land use, sewage and agriculture influxes, population growth, groundwater redox state and residence time) in coastal areas on a global scale. For most of the above-listed controls, spatial data are available at very high resolution. For example, a similar approach was used by *Seitzinger and Harrison* (2005) to estimate export from ~6,000 watersheds globally. Results from these modeling efforts demonstrated the power of numerical models, which can be used not only <u>*to create geospatial databases*</u> of the magnitude of water fluxes but also <u>*to reveal relationships*</u> between controlling factors and drivers, which in turn, transform our understanding about the coupled nature of these export fluxes at larger scales. Physical measurements from field-based studies are crucial for calibrating models and performing sensitivity analyses. Sufficient data are now available through the abundant SGD tracer-based coastal oceanographic studies of the last 20 years (**Fig. 1**) and the some assimilation of many local studies in large databases is done (e.g., *Moosdorf et al.*, 2015). The model will help identify data gaps if any exist.

The available spatial SGD data is <u>*highly heterogeneous*</u>; it was produced by many different research groups and government agencies employing different measurement techniques and reporting standards. Hence, the planned NExT SGD model will require a sophisticated data compilation process. The international scientific network of the proposed SCOR working group will set guidelines for compilation of available data in a unified manner and suggest best practices for future data collection. In addition, the parameters needed for the NExt SGD model development will be identified and assessed and model feasibility tested in a cutting-edge *proof-of-concept* study.

Terms of Reference

Disciplinary boundaries in the scientific community working at the land-ocean interface (i.e., oceanography community, hydrogeologists, and experts in global water flux modeling) have hindered the advancement of the mechanistic understanding of the significance of groundwater-derived water and constituent fluxes to the ocean on a global scale. The NExT SGD WG recognizes SCOR as the perfect platform to encourage and stimulate the unique and timely needed collaboration between these disciplines, an issue that was previously also recognized by the SCOR 112 WG.

The group's work will focus on the following terms of reference:

1. Set up a database of available SGD data and initiate the global NExT SGD model (<u>*deliverable 1*</u>, **Table 1**).
2. Collaborate with other working groups and projects (GEOTRACES, Global NEWS, LOICZ, members of former SCOR working groups) to inform the NExT SGD model and connect it to ESM (e.g. ORCHIDEE) (<u>*deliverable 2*</u>, **Table 1**).
3. Produce a "*best practices*" handbook recommending sampling strategies, parameter measurements, and guidelines for sample processing, and handling and sharing of acquired data (<u>*deliverable 3*</u>, **Table 1**).

We foresee the initiation and development of this unique collaboration proceeding in several stages (**Table 1**) which will be centered on in-person meetings, held in conjunction with international conferences or hosted by the National Water Center (NWC) of the University of Alabama. We will organize a virtual seminar series (Webinar) to be delivered quarterly, by different members of the SCOR WG with focus on the progress of the NExT SGD modeling.

Working Plan and Deliverables

Constructing a global model to assess constituent fluxes via SGD is a pressing task. Our in-person meetings (as shown in **Table 1**) will be structured to address specific stages of model development necessary to establish the foundation for successful model outcomes. The groundwork for the NExT SGD model will be achieved through the following specific goals:

***Deliverable 1:* Set up a database and initiate global NExT SGD model**

The NExT SGD SCOR working group will develop specific technical guidelines in the form of *metadata forms* that will be embedded in an existing Global SGD webpage (see URL) and will be filled out for each site. Aquifer-specific regions will be assigned to research groups based on their involvement in data collection. Previously, a SCOR WG (112), which had mainly focused on the detection and quantification of SGD, had come to the conclusion that six major types of aquifers determine SGD dynamics. These types of aquifers will now be used for our NExT SGD model. Scientific sub-groups will be assigned to aquifer types and collaborate to ensure that all available data are compiled and correctly inserted. After filling out the available information, each form will be saved in the SGD database. This will ensure (*i*) *quality control* of the data to be used for the model; and (*ii*) the creation of a *uniform record* that will be independent of the field data collection and techniques. For areas without published data on a specific type of aquifer, high-resolution lithological data from *Hartmann and Moosdorf* (2012) will be used in combination with hydrogeological interpretation (e.g. Gleeson et al., 2014). To adjust the model in terms of constituent fluxes, conceptual understanding of weathering influences on water chemistry will be used until data become available (**Fig.3**). The result will be used as input data into the Next SGD model, which will be developed as process-oriented empirical model by the workgroup members.

***Deliverable 2:* Set up a global network of scientists and "ecosystem task force" through collaboration with other working groups to advance the NExT SGD model (NEWS Model and GEOTRACES)**

The working group will discuss with developers of earth system models to implement SGD water and constituent fluxes into their terms. This should be done based on the controls and structure of the NExT SGD model. The group thus ensures information transfer both from the ESM community into the NExT SGD model development and in the other direction. In particular, potential ecosystem feedbacks of SGD will be focused. Relevant factors for inclusion in the NExT SGD model will be identified by adding field knowledge of the submarine groundwater discharge community to factor setups of existing models (e.g., Global NEWS by *Seitzinger and Harrison*, 2005). The unique combination of terrestrial and marine factors and their interplay is a special challenge to this working group. This will be reflected in the model input data (e.g. land cover and population density, as well as tidal range and wave intensity). This part of the work ensures the compatibility of the NExT SGD model with other global scale nutrient flux models and Earth System models, and the necessary simplification. While at the same time the group will safeguard a realistic representation of the complex processes associated with the subterranean estuary.

***Deliverable 3* Establish a handbook of best practices for sampling strategies, sample processing, and data handling and reporting for SGD data collection to be used in the NExT SGD model**

Constructing a model that has the ability to be improved and updated by including future data is important. The NExT SGD model *will capture nearshore fluxes* that include fresh and recirculating seawater where most of the SGD data was collected in the last two decades (**Fig. 1b**). We will seize the opportunity of this international network of hydrogeologists and biogeochemists to compare, assess, and optimize *in situ* investigations of SGD magnitudes and associated constituent fluxes from local to regional scales. Furthermore, our working group will collaborate with the GEOTRACES community to plan for the collection of offshore SGD data and make sure it is compatible with the model requirements (http://www.geotraces.org/science/science-highlight/1019-submarine-groundwater-discharge-as-a-major-source-of-nutrients-in-the-mediterranean-sea). This will enable an expansion of the model to include offshore fluxes from the continental shelf. Based on these recommendations and model needs a best practices handbook will be composed and disseminated broadly.

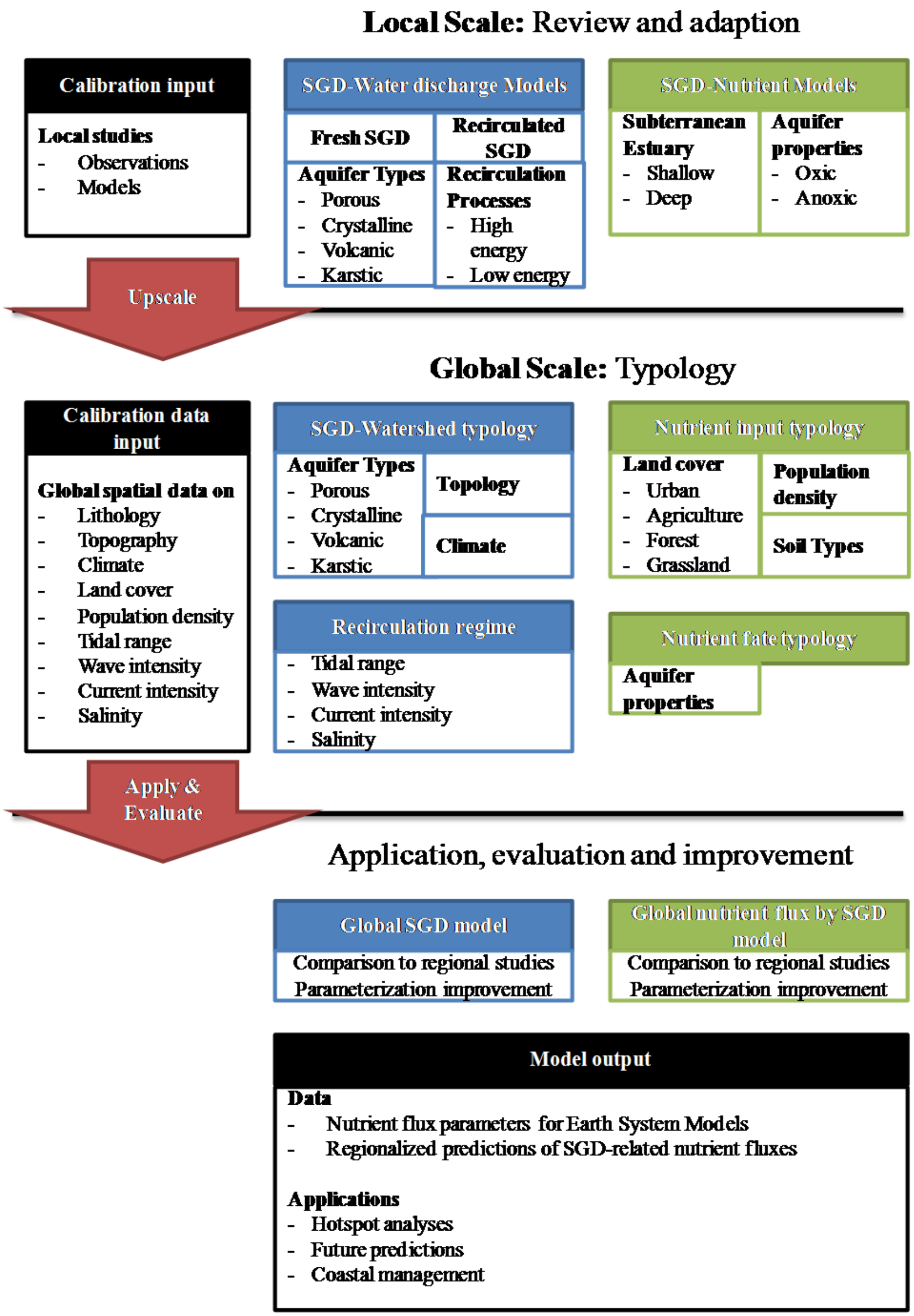

Figure 3 Flowchart presenting the logical step-wise procedure in developing the NExT SGD model

Table 1 Detailed timetable of the scientific activities, and expected deliverables of the working group

	Group activities and deliverables	Deadlines/meeting reports
Initial coordination and data management	1. Classifying sites into the 6 major domains based on aquifer type. 2. Developing specific technical guidelines for building a uniform metadata base of hydrogeological and nutrient parameters and topology. 3. Making initial decisions on governing parameters and boundary conditions for groundwater flow model 4. Extending participation on regional level to facilitate compilation process and disseminate future results.	SPRING: 2016 Ocean Sciences Meeting (proposed special session), 21-26 February, New Orleans, USA followed by first meeting at NWC Tuscaloosa, UA campus. FALL 2016: 26th Goldschmidt Conference, Yokohama, Japan
Global Model Development	1. Performing real-time simulations of flow models in different domains at the NWC University of Alabama; discussing model parameters and sensitivity. 2. Making decisions on constituents adjustments and data gaps: a) Land coverage and use b) Identifying sources and sinks of nutrients: natural (non-point-) versus anthropogenic (point-) sources c) Climate and climate change effects via sea level change and glacial melting.	SPRING 2017: European Geosciences Union (EGU) 17-22 April, Vienna, Austria FALL 2017: Second meeting at NWC Tuscaloosa, UA campus; USA
Model Calibration	1. Performing real-time simulations of constituents flux models in different domains at the NWC University of Alabama; discussing model parameters and sensitivity. 2. Working on model parameterization and refinement 3. Obtaining first assessments of significance of nutrient fluxes (fresh and recirculated) versus river fluxes. 4. Working on dissemination of results in publications (G3) and meetings. 5. Writing and dissemination of the best practices handbook.	SPRING 2018: Third meeting at NWC Tuscaloosa, UA campus, USA FALL 2018: Final meeting December 2018 AGU Special session, San Francisco, USA

Capacity Building

Within the proposed group, we bring together global modeling experts from the riverine and groundwater ***modeling communities*** (e.g., Cohen, Harrison, Michael, Slomp) with specialists in ***large database*** creation and management and holders of large SGD datasets (e.g., Kim, Moosdorf, Michael) as well as field scientists for SGD from the ***terrestrial*** (Cable, Dimova, Santos) ***and marine*** (Burnett, Dimova, Paytan, Waska) realm. In addition to the broad scientific backgrounds, the proposed working group was assembled on the principle of geographical, economical (developed and countries in transition), gender and career stage diversity. The NExT SGD WG includes members from 15 countries spanning four continents with 30% female representation, and 30% members from developing and transition countries (**Tables 2 and 3**). Opportunity for broader involvement of the scientific community will be made possible through open thematic sessions in large meetings and via open Webinars.

The uniqueness of this working group is its initiation largely by early-career young scientists, which has helped crossing traditional boundaries between the research fields of coastal oceanography, hydrology, and global numerical modeling. We will expand on traditional approaches for outreach and funding by actively including social media via Facebook, Twitter, NExT SGD webpage Blogs, virtual seminars (Webinars) and crowdsourcing as part of our portfolio. Establishing the SCOR NExT SGD working group will foster further interdisciplinary collaboration and may catalyze new studies in areas where data gaps are identified during the compilation process. Developing this network will facilitate information exchange between scientists from developed countries and countries in transition. In most developing countries, nutrient enrichment of coastal waters due to SGD is unknown phenomenon. Interactions among group members will aim to create opportunities for student exchange and contribute to the enhancement of graduate programs in these counties which in turn, will promote wider public understanding of the effects of groundwater discharge to the ocean.

Working group meetings (as shown in **Table 1**) will be organized at least twice a year. We plan to meet each year at the NWC on University of Alabama campus, for which most of the funding from SCOR (US$15,000) will be utilized (e.g., to support travel and meeting expenses). The use of the building, audio-visual and computer facilities will be provided at no cost for this project. To allow for broader participation and more frequent interactions we plan to also meet during large international meetings (through town halls and special sessions) in which most WG members participate. The location of these meetings will rotate between the USA, Europe and Asia to distribute the cost of participation among group members.

We will seek funding from additional sources such as UNESCO, IAEA, LOIZ, as well as national and bi-national organizations (NSF, NERC, etc.). We will also establish a donation link on our web page to create an opportunity for private organizations to support our group. Funding through these alternative sources will be independent of that provided by SCOR.

Table 2 Full Members of the SCOR Working Group on Global Groundwater Fluxes to the Ocean

	Member	Gender	Place of work	Expertise relevant to proposal
1	Natasha Dimova (co-chair)	female	University of Alabama, USA	Radionuclides, coastal and freshwater hydrology
2	Nils Moosdorf (co-chair)	male	Leibniz Center for Tropical Marine Ecology (ZMT), Bremen, Germany	Global empirical modeling
3	Guebuem Kim	male	Seoul National University, Korea	Radionuclides and nutrient cycling
4	Isaac Santos	male	Southern Cross University, Australia	Carbon cycling
5	Holly Michael	female	University of Delaware, USA	Numerical & field modeling of coastal groundwater dynamics
6	Caroline Slomp	female	Utrecht University, The Netherlands	Geochemical modeling
7	Makoto Taniguchi	male	Research Institute for Humanity and Nature, Japan	Regional and global groundwater hydrology
8	Bo Chao Xu	male	Ocean University of China	Coastal hydrology, geochemistry
9	Gopal Krishan	male	National Inst. of Hydrology, Uttarakhand, India	Hydrology
10.	Robert Delinom	male	Indonesian Institute of Sciences, Indonesia	Hydrogeology of tropical islands

Table 3 Associate Members* of the SCOR Working Group on Global Groundwater Fluxes to the Ocean

	Member	Gender	Place of work	Expertise relevant to proposal
1	Hannelore Waska#	female	University of Oldenburg, Germany	Groundwater hydrology and geochemistry
2.	Adina Paytan#	female	UC Santa Cruz, USA	Biogeochemistry and nutrient cycling
3.	Jaye Cable	female	University of North Carolina, USA	Groundwater hydrogeology
4	Sagy Cohen	male	University of Alabama, USA	GIS, global numerical modeling, geomorphology
5	Kazi Matin Uddin Ahmed	male	University of Dhaka, Bangladesh	Groundwater contamination
6	Howard Waldron	male	University of Cape Town South Africa	Coastal zone water quality
7	Thomas Stieglitz	male	Institut Universitaire Européen de la Mer, France	Geophysics and SGD
8	Yishai Weinstein	male	Bar-Ilan University, Israel	Hydrogelogy
9	Felipe Luis Niencheski	male	Fundação Universidade Federal do Rio Grande, Brazil	Environmental Chemistry
10	John Harrison	male	Washington State University, Vancouver, USA	River-derived nutrient fluxes

**We realize that there are 4 associate members from the USA in the team, however we emphasize that the members represent distinct strengths and areas of expertise needed for a successful WG, (Cable – Hydrology and SGD; Paytan – Biogeochemistry; Cohen – Modeling; Harrison – River fluxes and GlobalNEWS. These are key areas instrumental for the WG and involvement of world experts is needed regardless of nationality*.

[#]*We would like to acknowledge specially HW and AP whose insightful comments were critical in preparation of this proposal.*

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Appendix

Natasha Dimova (co-chair): Dr. Dimova is a coastal oceanographer and hydrogeologist with expertise in the radon-based tracer techniques in marine and freshwater systems. Dimova initiated the SCOR NExT SGD working group proposal and has been ***working on compilation of SGD data*** with Sagy Cohen (associate member) for establishing a global SGD model. She is an early-career female scientist who has been collaborating with scientists worldwide, including Asia, USA and Europe.

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Nils Moosdorf (co-chair): Dr. Moosdorf is a hydrogeologist, specialized in estimating large scale geochemical material fluxes via statistical methods based on large datasets. His experience lays in ***large scale river constituent flux modeling.*** Since August 2014 Dr. Moosdorf leads a junior research group on ecological impacts of SGD at different scales. He also specialized on global scale datasets based on lithological information. He is involved in several cooperative projects with scientists primarily in the USA, but also in Europe and Asia.

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Guebuem Kim: Dr. Kim's expertise is in radionuclides (Rn and Ra), organic matter, REE and ***nutrient cycling in subterranean estuaries on a regional and global scale***. Dr. Kim established a webpage for SGD data compilation for initiating the NExT SGD working group.

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3) Kim, I, and G. Kim, 2014. Submarine groundwater discharge as a main source of rare earth elements in coastal waters, *Marine Chemistry*, 160 (20): 11-17.

4) Kim, T-H., and G. Kim, 2013. Changes in seawater N:P ratios in the northwestern Pacific Ocean in response to increasing atmospheric N deposition: Results from the East (Japan) Sea, *Limnology and Oceanography*; 58(6): 1907-1914.

5) Kim, T-H., H. Waska, E. Kwon, I. Gusti Ngurah Suryaputra, G. Kim, 2012. Production, degradation, and flux of dissolved organic matter in the subterranean estuary of a large tidal flat, *Marine Chemistry* 142-144: 1-10.

Isaac Santos: Dr. Santos was invited to be part of the NExT SGD working group because of the wide spectrum of research topics he has been involved with and his knowledge of the ***carbon and nutrient cycling in subterranean estuaries,*** specifically in carbonate sandy aquifers and coral reef environments.

1) Santos, IR, S Ruiz-Halpern, DT Maher, 2013. Carbon dioxide dynamics driven by groundwater discharge in a coastal floodplain creek ML Atkins, *Journal of Hydrology* 493: 30-42

2) Santos, IR., B.D Eyre, and M. Huettel, 2012. The driving forces of porewater and groundwater flow in permeable coastal sediments: A review, *Estuarine, Coastal and Shelf Science* 98: 1-15

3) Santos, IR, R.N. Glud, D. Maher, D. Erler, B.D Eyre, 2011. Diel coral reef acidification driven by porewater advection in permeable carbonate sands, Heron Island, Great Barrier Reef, *Geophysical Research Letters* 38 (3), doi: 10.1029/2010GL046053.

4) Santos, IR, D Erler, D Tait, B.D Eyre, 2010. Breathing of a coral cay: Tracing tidally driven seawater recirculation in permeable coral reef sediments, *Journal of Geophysical Research*: *Oceans*, 115, C12, doi: 10.1029/2010JC006510

5) Santos, IR, W. C Burnett, J. P. Chanton, B. Mwashote, and IGNA Suryaputra, 2008. Nutrient biogeochemistry in a Gulf of Mexico subterranean estuary and groundwater-derived fluxes to the coastal ocean, *Limnology and Oceanography* 53 (2): 705-718

Holly Michael: Dr. Michael was invited to this working group because of her unique expertise in both ***numerical modeling and radio tracer field techniques***. Holly has established a connection between the two fields and plays an important role in breaking the boundaries between hydrogeology and coastal oceanography.

1) Sawyer, AH, O Lazareva, KD Kroeger, K Crespo, CS Chan, T Stieglitz, and HA Michael, 2014. Stratigraphic controls on fluid and solute fluxes across the sediment-water interface of an estuary, *Limnology & Oceanography,* 59(3):997–1010.

2) Michael, HA, CJ Russoniello, and LA Byron, 2013. Global assessment of vulnerability to sea-level rise in topography-limited and recharge-limited coastal groundwater systems, *Water Resources Research*, 49 (4): 2228-2240.

3) Michael, HA, MA Charette, and CF Harvey, 2011. Patterns and variability of groundwater flow and radium activity at the coast: a case study from Waquoit Bay, Massachusetts, *Marine Chemistry,* 127: 100-114.

4) Michael, HA, AE Mulligan, and CF Harvey, 2005. Seasonal oscillations in water exchange between aquifers and the coastal ocean, *Nature*, 436: 1145-1148.

5) Michael, HA, JS Lubetsky, and CF Harvey, 2003. Characterizing submarine groundwater discharge: a seepage meter study in Waquoit Bay, Massachusetts, *Geophysical Research Letters*, 30 (6): doi: 10.1029/2002GL016000, 6.

Caroline Slomp: We invited Dr. Slomp as a full member because of her in-depth quantitative understanding of the cycling of elements in marine environments that will be essential in the mechanistic understanding of nutrient fluxes via SGD in nearshore coastal areas. Additionally, Dr. Slomp's research is broad in scope and involves field and laboratory work that is typically ***integrated with large scale ocean and river modeling*.**

1) Beusen, A.H.W., Slomp, C.P. and Bouwman, A.F., 2013. Global land-ocean linkage: direct inputs of nitrogen to coastal waters via submarine groundwater discharge, *Environmental Research Letters,* 8 (3), doi:10.1088/1748-9326/8/3/034035.

2) Dürr, H.H., Laruelle, G.G., van Kempen, C.M., Slomp, C.P., Meybeck, M., Middelkoop, H., 2011. Worldwide Typology of Nearshore Coastal Systems: Defining the Estuarine Filter of River Inputs to the Oceans. *Estuaries and Coasts*, 34(3): 441-458.

3) Spiteri, C., Slomp, C.P., Tuncay, K. and Meile, C., 2008. Modeling biogeochemical processes in subterranean estuaries: Effect of flow dynamics and redox conditions on

submarine groundwater discharge of nutrients, *Water Resources Research*, *44*, W02430, doi:10.1029/2007WR006071.

4) Slomp, C.P. and Van Cappellen, P., 2007. The global marine phosphorus cycle: sensitivity to oceanic circulation, *Biogeosciences*, 4: 155-171.

5) Slomp, C.P. and Van Cappellen, P.S.J., 2004. Nutrient inputs to the coastal ocean through submarine groundwater discharge: controls and potential impact, *Journal of Hydrology*, 295: 64-86.

Makoto Taniguchi: Dr. Taniguchi has long-term experience in working on different aspects of groundwater and its significance for the global hydrological cycle. His contribution will be specifically in ***connection between societies - water resources-climate change***. Dr. Taniguchi is also a former member of the SCOR 112 WG *Magnitude of Submarine Groundwater Discharge and its Influence on Coastal Oceanographic Processes*

1) Taniguchi, M., 2015. The basic act on the water cycle with groundwater, *Journal of Groundwater Hydrology* 57(1):83-90.

2) Taylor, RG, B. Scanlon, P. Döll, M. Rodell, R. van Beek, Y. Wada, L. Longuevergne, M. Leblanc, J. S. Famiglietti, M. Edmunds, L. Konikow, T.R. Green, J. Chen, M. Taniguchi, M. F. P. Bierkens, A. MacDonald, Y. Fan, R. M. Maxwell, Y. Yechieli, J. J. Gurdak, D. M. Allen, M. Shamsudduha, K. Hiscock, P. J.-F. Yeh, I. Holman & H. Treidel, 2013. Groundwater and climate change, *Nature Climate Change*. DOI:10.1038/nclimate1744.

3) Taniguchi, M., Yamamoto, K., and Aarukkalige, P. R. 2011, Groundwater resources assessment based on satellite GRACE and hydrogeology in Western Australia, *GRACE, Remote Sensing and Ground-based Methods in Multi-Scale Hydrology (Proceedings of Symposium J-H01 held during IUGG2011 in Melbourne, Australia, July 2011)* 343 :3-8.

4) Taniguchi, M, 2011. What are the Subsurface Environmental Problems? Groundwater and Subsurface Environmental Assessments Under the Pressures of Climate Variability and Human Activities in Asia, *Groundwater and Subsurface Environments: Human Impacts in Asia Coastal Cities* :3-18. DOI:10.1007/978-4-431-53904-9_1.

5) Taniguchi, M., A. Aureli, and J.L. Martin, 2009. Groundwater resources assessment under the pressures of humanities and climate change. *IAHS Publication* 334.

Bo-chao Xu: The contribution of Dr. Xu for this working group will be primarily in his understanding of ***SGD impacts on large estuaries*** and the geochemical transformations of nutrients at the sediment-water interface.

1) Meng, J., P. Yao, T. S. Bianchi, D. Li, B. Zhao, B. Xu, Z. Yu, 2015. Detrital phosphorus as a proxy of flooding events in the Changjiang River Basin, *Science of the Total Environment*, 517: 22-30.

2) J. Sui, Z. Yu, X. Jiang, B. Xu, 2015. Behavior and budget of dissolved uranium in the lower reaches of the Yellow (Huanghe) River: Impact of Water-Sediment Regulation Scheme, *Applied Geochemistry*, 61: 1-9.

3) Xu, Bo-Chao, W. C. Burnett, N. T. Dimova, H. Wang, L. Zhang, M. Gao, X. Jiang, Z. Yu, 2014. Natural ^{222}Rn and ^{220}Rn Indicate the Impact of the Water-Sediment Regulation Scheme (WSRS) on Submarine Groundwater Discharge in the Yellow River Estuary, China, *Applied Geochemistry*,http://dx.doi.org/10.1016/j.apgeochem.2014.09.018

4) Xu, Bo-Chao, W. C. Burnett, N. T. Dimova, G. Liu, T. Mi, Z. Yu, 2013. Hydrodynamics in the Yellow River Estuary via radium isotopes: ecological perspectives, *Continental Shelf Research*, doi.org/10.1016/j.csr.2013.06.018.

5) Xu, Bo-Chao, N. T. Dimova, L. Zhao, X-Y. Jiang, and Z.-G. Yu, 2013. Determination of water ages and flushing rates using short-lived radium isotopes in large estuarine system, the Yangtze River Estuary, China, *Estuarine, Coastal and Shelf Science*, 121-122: 61–68.

Gopal Krishan: Dr. Krishan's research is in the field of natural resource management, isotope hydrology, RS and GIS applications. His extensive work in ***groundwater systems in India*** and coastal areas on Bengal Bay is extremely valuable for the NExT SGD working group because of the relatively sparse data available in this part of the world.

1) Krishan, G., M. S. Rao, C.P. Kumar, S. Kumar, and M. R. A. Rao, 2015. A study on identification of submarine groundwater discharge in northern east coast of India, *Aquatic Procedia*, 4: 3 – 10.

2) Lohani AK and Krishan G, 2015. Application of Artificial Neural Network for Groundwater Level Simulation in Amritsar and Gurdaspur Districts of Punjab, India, *Earth Science and Climate Change*, 6 (4), doi: 10.4172/2157-7617.1000274.

3) Krishan, G., Rao, M.S. and Kumar C.P., 2014a. Estimation of Radon concentration in groundwater of coastal area in Baleshwar district of Odisha, India. *Indoor Built Environ*. doi:10.1177/1420326X14549979.

4) Krishan, G., Rao, M.S. and Kumar C.P., 2014b. Radon Concentration in Groundwater of East Coast of West Bengal, India. *Journal of Radioanalytical and Nuclear Chemistry*. doi: 10.1007/s10967-014-3808-4.

5) Krishan, G., M.S. Rao, R.S. Loyal, A.K. Lohani, N.K. Tuli, K.S. Takshi, C.P. Kumar, P. Semwal, and S. Kumar, 2014. Groundwater level analyses of Punjab, India: a quantative approach, *Octa Journal of Environmental Research*, 2(3): 221-226.

Robert Delinom: Prof. Delinom is ***hydrogeologist*** who leads a working group which researched submarine groundwater discharge on different Indonesian islands. His perspective will highlight the ***tropical regions***, where particularly tropical islands can contribute significantly to global fluxes and show strong local impacts of SGD.

1) Bakti, H., Naily, W., Lubis, R.F., Delinom, R., Sudaryanto, S., 2014. PENJEJAK KELUARAN AIRTANAH DI LEPAS PANTAI (KALP) DI PANTAI UTARA SEMARANG DAN SEKITARNYA DENGAN ^{222}RADON. Riset Geologi dan Pertambangan, 24(1): 43-51. (In Indonesian)

2) Bakti, H., Lubis, R.F., Delinom, R., Naily, d.W., 2012. Identifikasi keluaran air tanah lepas pantai (KALP) di pesisir aluvial Pantai Lombok Utara, Nusa Tenggara Barat (Identify on submarine ground water discharge (SGD) on the alluvial coast of North Lombok, West Nusa Tenggara), *Jurnal lingkungan dan bencana geologi*, 3(2): 133-149.

3) Umezawa, Y., Onodera, S., Ishitobi, T., Hosono, T., Delinom, R., Burnett, W.C., Taniguchi, M., 2009, Effects of urbanization on groundwater discharge into Jakarta Bay, Trends and Sustainability of Groundwater in Highly Stressed Aquifer. IAHS Publication 329, IAHS Press, Vamsi Art Printers Pvt. Ltd. Hyderabad.

4) Lubis, R., Sakura, Y., Delinom, R., 2008. Groundwater recharge and discharge processes in the Jakarta groundwater basin, Indonesia. *Hydrogeology Journal*, 16(5): 927-938.

5) Umezawa, Y., Hosono, T., Onodera, S., Siringan, F., Buapeng, S., Delinom, R., Yoshimizu, C., Tayasu, I., Nagata, T., Taniguchi, M., 2008. Sources of nitrate and ammonium contamination in groundwater under developing Asian megacities. *Science of the Total Environment*, 404(2-3): 361-376.