Assessment of contribution of groundwater discharge in delivering nitrogen to Fongafale lagoon, Tuvalu

James Gale and Clare Robinson
Dept. of Civil and Environmental Engineering, The University of Western Ontario, London, ON N6A 5B9 Canada; Email: jgale@uwo.ca

RESTORE: Research for Subsurface Transport and Remediation

1. Introduction

- Small island development states (SIDS) are subject to compounding anthropogenic and climate change stresses including coastal lagoon pollution and deterioration of fisheries.
- Excessive nitrogen inputs into Fongafale Lagoon, Tuvalu, are causing eutrophication and associated macro-algal blooms, nearshore habitat loss, and decreased fish numbers.
- Poorly functioning septic tanks and pig pen effluents may be an important source of nitrogen to the lagoon.
- Groundwater may be an important pathway for delivering land-derived nitrogen to the lagoon but its relative contribution to coastal nutrient loads remains unclear.

*Figure 1. Fongafale Islet, Funafuti Atoll, Tuvalu **[1].***

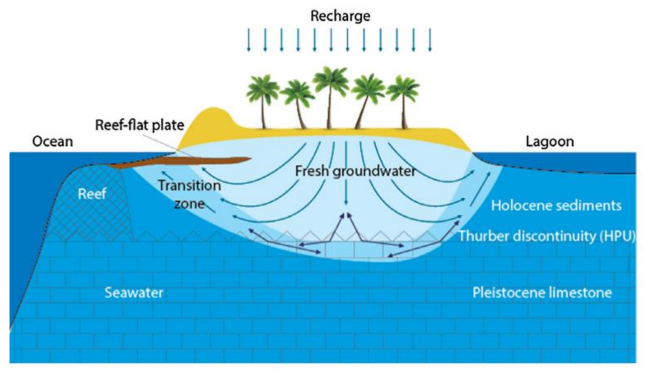

*Figure 2. Atoll island groundwater dynamics **[2].***

- OBJECTIVE: Evaluate subsurface pathways delivering nitrogen from septic systems to Fongafale lagoon, Tuvalu, and potential influence of transient forcing on these pathways.

2. Study area: Fongafale, Tuvalu

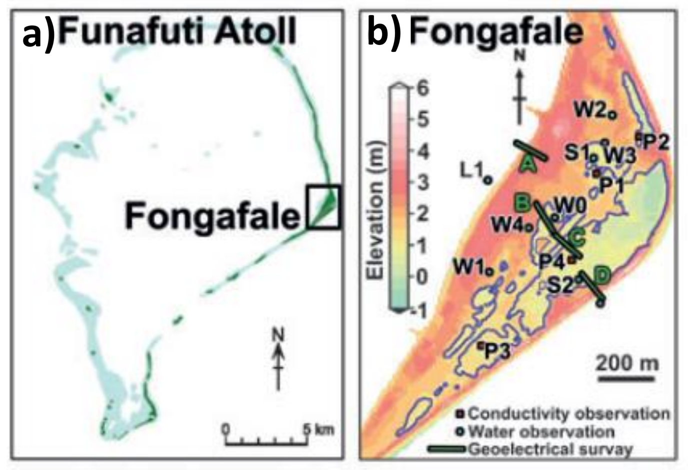

*Figure 3. (a) Fongafale Islet at Funafuti Atoll, and (b) land elevation across Islet and location of geoelectric surveys indicated by green lines **[3]**.*

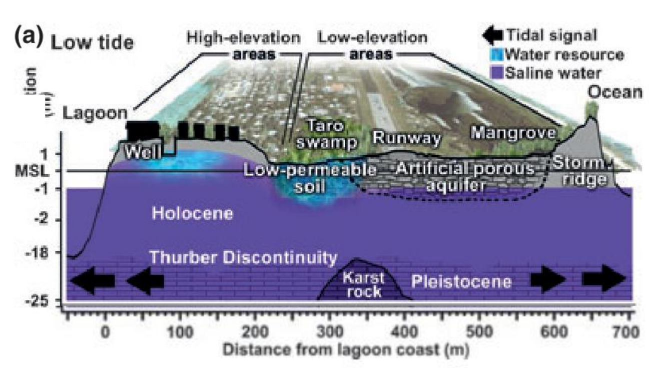

*Figure 4. Conceptual model of the hydrogeology and groundwater flow across Fongafale Islet at low tide **[3].***

- Study focuses on cross-island transect across Fongafale Islet which is densely populated (near green lines B-C-D in Fig. 3b.)
- Hydrogeology is characterized by Holocene and Pleistocene geologic layers, and a low permeability Taro swamp region near the middle of the island (Fig. 4).
- Mean annual rainfall in study area is 3,400 mm but can vary considerably between years **[4]**.
- Tide is predominately semi-diurnal with a tidal range between 0.5 - 1 m (mean range = 0.6 m) **[5]**.

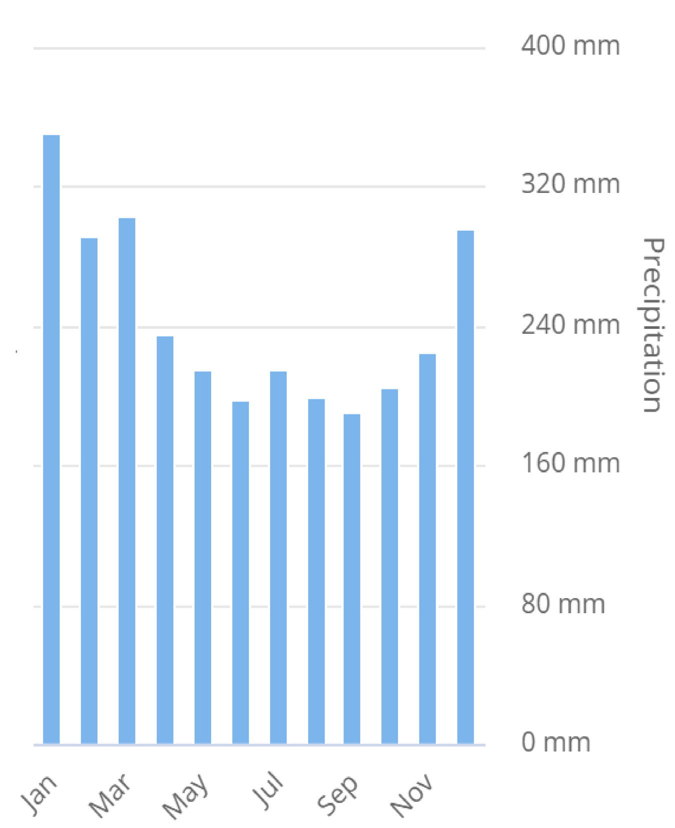

*Figure 5. Monthly mean precipitation (mm) for Fongagale, Tuvalu,1991-2020 **[4].***

3. Groundwater flow and nutrient transport model

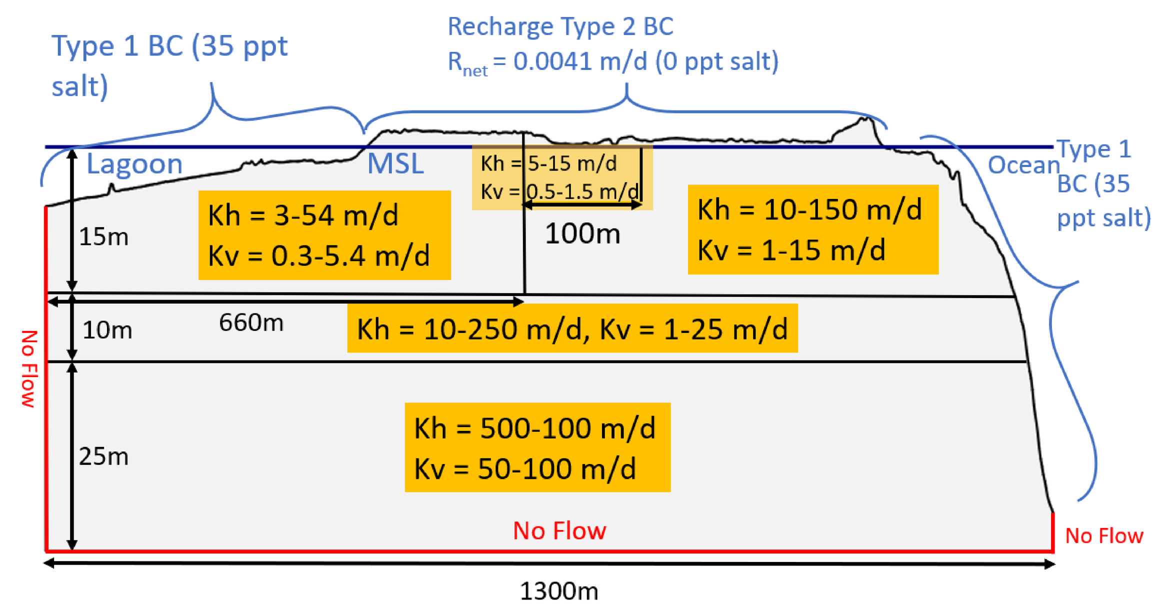

Figure 6. Conceptual model of Fongafale Islet (vertical cross-section) with hydraulic conductivity (K) range, zones and boundary conditions indicated.

- A variable density groundwater and nutrient transport (conservative) model was developed in SEAWAT-2005 and MT3DMS to evaluate subsurface pathways of nitrogen to Fongafale lagoon (Fig. 6).
- Tidal fluctuations acting on sloping coastal boundaries were simulated.
- Sensitivity analyses were conducted using range of hydraulic conductivity (K) and dispersity (α) values from literature to match observed freshwater lens size (Fig. 7) ***[3].***

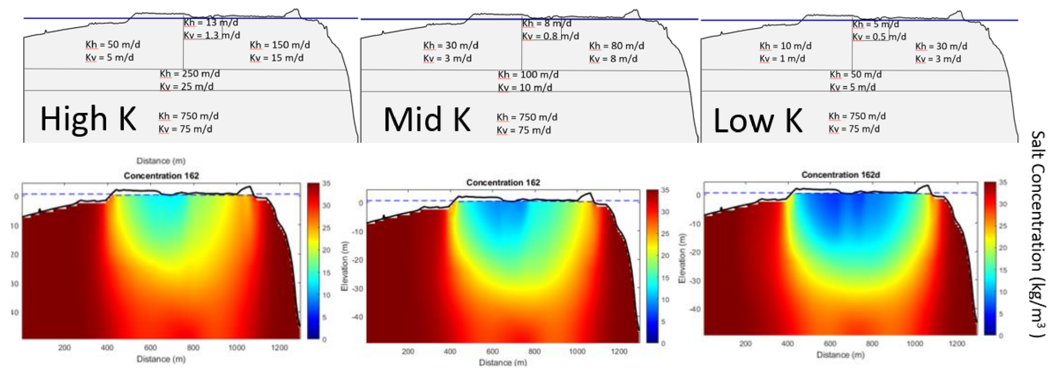

Figure 7. Salt distribution (in kg/m³) for tidal simulations with varying K values.

- Nitrogen transport was simulated using low K model (Fig. 7) with a single continuous (septic system) nitrogen source.

4. Results: Salt-freshwater distribution

- Heterogeneous aquifer layers and tides considerably influence the size of the freshwater lens across Fongafale Islet. The freshwater lens is <5 m thick for the simulation that considers tides and the heterogeneous layers (Fig. 8d)
- The high permeability lower aquifer layers limit the depth of the freshwater lens as they reduce storage of freshwater.
- Tide-induced oscillatory flow decreases the freshwater lens depth due to increase salt-freshwater mixing.

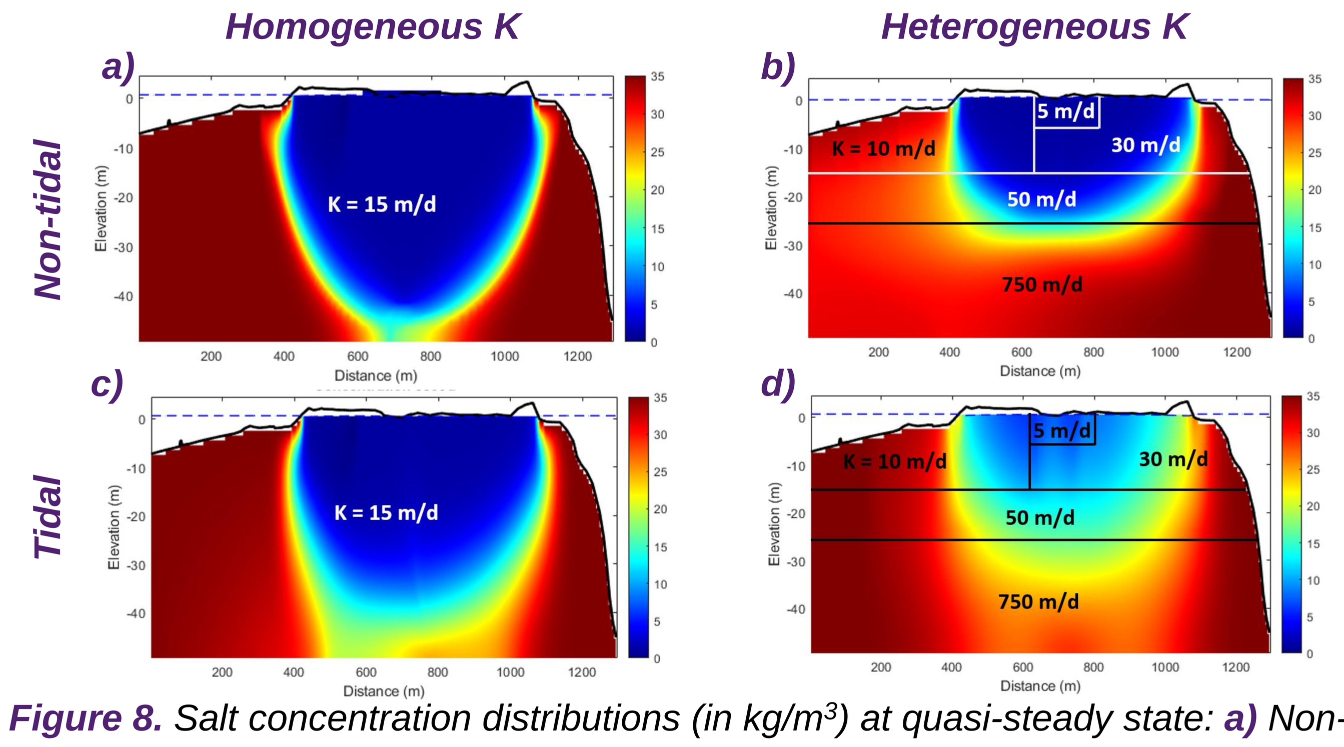

*Figure 8. Salt concentration distributions (in kg/m³) at quasi-steady state: **a)** Non-tidal model with homogeneous K, **b)** Non-tidal model with heterogeneous K, **c)** Tidal model with homogeneous K, and **d)** Tidal model with heterogeneous K.*

5. Results: Nitrogen transport modelling

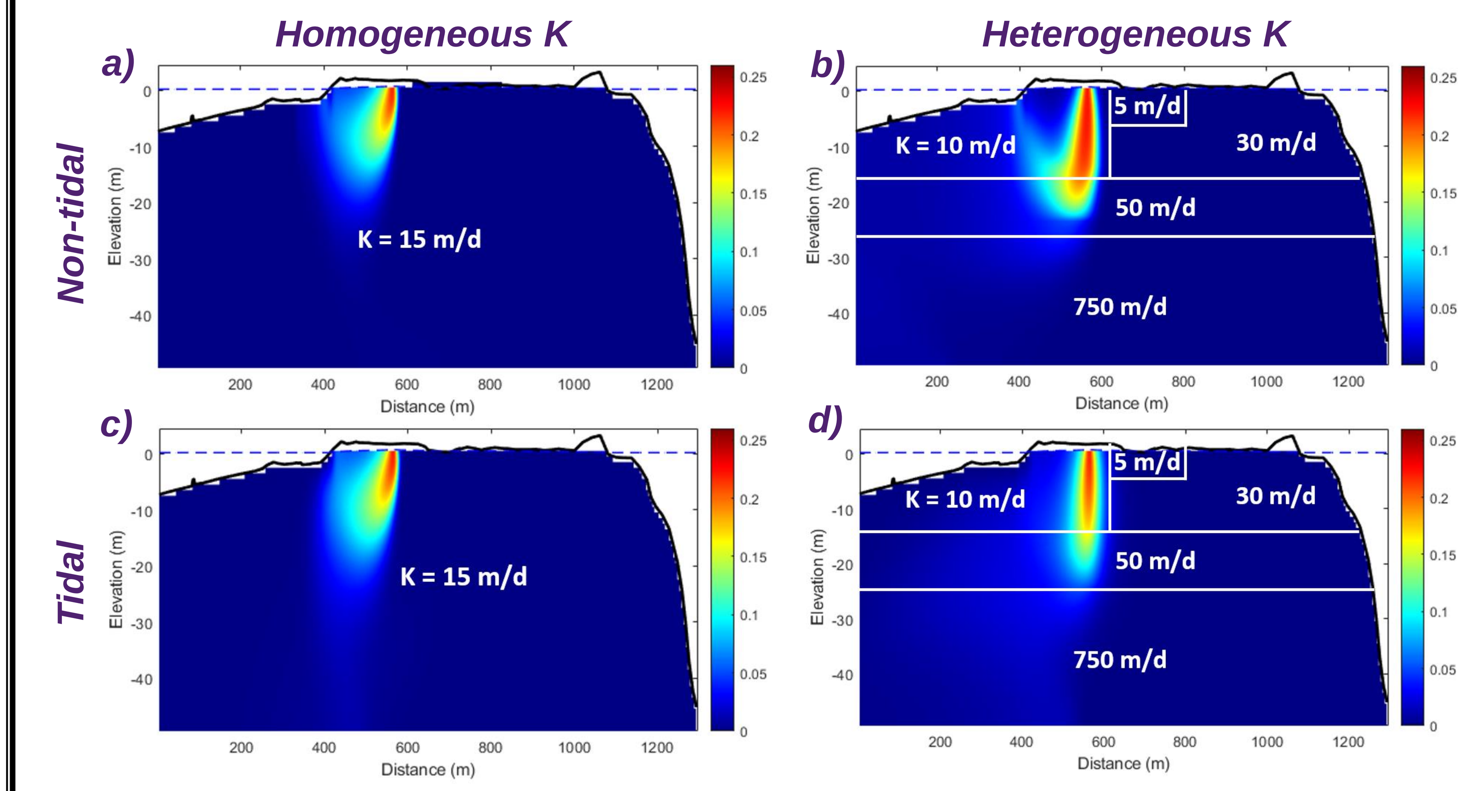

*Figure 9. Nitrogen concentration distributions (in kg/m³) at quasi-steady state: **a)** Non-tidal model with homogeneous K, **b)** Non-tidal model with heterogeneous K, **c)** Tidal model with homogeneous K, **d)** Tidal model with heterogeneous K.*

- For all simulations, nitrogen is transported to the lagoon from a single septic system source (Fig. 9).
- High K layer at depth acts as a preferential pathway causing nitrogen to be transported deeper into the aquifer compared to homogeneous aquifer simulations (Fig. 9).
- Tidal forcing causes greater dispersion of nitrogen and as a result a less defined nitrogen plume (and lower concentrations) reaches the lagoon compared to non-tidal simulations (Fig. 9).

6. Conclusions & Future Work

Conclusions

- Simulation results indicate nitrogen inputs from septic systems may be delivered to the lagoon via groundwater discharge and contribute to nitrogen loads to the lagoon.
- Tidal forcing and heterogeneous aquifer zones considerably reduce the depth of the freshwater lens and alter the subsurface nitrogen transport pathways.

Future Work

- Consider multiple household/septic system locations as nitrogen sources across the simulated transect.
- Determine the pathways and residence times for nitrogen plumes.
- Extend simulations to include seasonal and interannual rainfall variability.

References

1. De Ramon N'Yeurt, A., Iese, V. The proliferating brown alga *Sargassum polycystum* in Tuvalu, South Pacific: assessment of the bloom and applications to local agriculture and sustainable energy. *J Appl Phycol* **27,** 2037–2045 (2015). https://doi.org/10.1007/s10811-014-0435-y
2. Adrian D. Werner, Hannah K. Sharp, Sandra C. Galvis, Vincent E.A. Post, Peter Sinclair, Hydrogeology and management of freshwater lenses on atoll islands: Review of current knowledge and research needs, Journal of Hydrology, Volume 551, 2017, Pages 819-844, ISSN 0022-1694, https://doi.org/10.1016/j.jhydrol.2017.02.047
3. Nakada, S., Umezawa, Y., Taniguchi, M., & Yamano, H. (2012). Groundwater dynamics of Fongafale Islet, Funafuti Atoll, Tuvalu. Ground water, 50(4), 639–644. https://doi.org/10.1111/j.1745-6584.2011.00874.xD
4. World Bank Climate Change Knowledge Portal. (n.d.). World Bank Group. Retrieved September 17, 2021, from https://climateknowledgeportal.worldbank.org/country/tuvalu/climate-data-historical
5. 2013 Tidal Predictions Tuvalu – Funafuti. (2012). [36_TV_Funafuti_TC_IDO60051.2013]. Commonwealth of Australia, Bureau of Meteorology. http://www.pacgeo.org/documents/2529

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Contact
Dr. Clare Robinson
RESTORE Co-Director
crobinson@eng.uwo.ca
www.eng.uwo.ca/research/restore