

Identification of Prospective Areas in Water-Stressed Regions for Low-Enthalpy Geothermal Desalination

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Keywords: geothermal desalination, direct use, low-enthalpy systems

ABSTRACT

Water scarcity is the lack of fresh water resources to meet water demand. It affects every continent and was listed in 2015 by the World Economic Forum as the largest global risk in terms of potential impact over the next decade. By 2025, an estimated 1.8 billion people will live in areas plagued by water scarcity, with two-thirds of the world's population living in water-stressed regions and approximately 780 million people without clean drinking water. Many solutions have been proposed to help combat this issue. One such solution is the use of desalination plants or systems to convert sea water or brackish water into fresh, usable water. Geothermal can help.

The most effective method for geothermal desalination is to provide a low-enthalpy (70-90°C) geothermal heat source directly into a MED (multiple effect distillation) desalination plant avoiding the need for thermal storage. The geothermal heat source can be obtained using different methods such as: (1) drilling new wells in a proven resource area, (2) using existing geothermal wells that are actively used by the operators and not suitable for electricity generation, (3) using outlet brine from existing geothermal power plants, (4) utilizing waste heat from oil/gas wells.

This paper summarizes the feasibility of implementing geothermal desalination units into various areas of the world effected by water scarcity. As an initial step, JRG Energy has developed a set of criteria for identifying locations within a country that are prospective to low-enthalpy geothermal desalination. The criteria include parameters for geothermal prospectivity (such as temperature, permeability, and fluid (groundwater), direct and indirect sources of heat, potential alternative heat sources such as abandoned oil and gas wells, and global areas of water need.

We have prepared probability maps using spatial datasets and a GIS platform for 3 countries (Egypt, Saudi Arabia, and Vanuatu) that incorporate publicly-available data and existing maps of geothermal potential, source water, demand, and geo-political factors. The probability maps will be used to identify areas within the target countries that pose high likelihood of successfully implementing geothermal desalination plants and justify further site-specific feasibility studies. These maps and corresponding case studies will be presented at the conference.

1. INTRODUCTION

Geothermal energy can be thought of as any portion of the earth's internal heat that can be extracted and put to use for the good of mankind, and has long been exploited in regions with obvious surface thermal manifestations (Harvey et al., 2016). An increasing global focus on sustainable energy sources, however, means that geothermal energy is now being recognized as a valuable and cost-effective source of both direct heat and electricity in many other parts of the world.

Historically, geothermal energy is used in one of two ways: power generation where thermal fluid is converted to electricity, or direct use where the thermal energy is used directly by the end user. Advancements in both methods have been observed throughout the last decade. One notable advancement in both methods is the innovativeness of utilizing the resource within geographic boundaries.

Water scarcity is a problem that is getting worse with increasing demand driven by population growth and urbanization. Many solutions have been proposed to combat this issue and all with varying degrees of success. Desalination units are used to turn the abundance of brackish water on earth into useable drinking water. Although significant advancements have been made in desalination units over the years, their biggest limiting factor is the amount of energy required to operate these units and, consequently, the large costs. JRG Energy has been working on ways to combine low-temperature geothermal resources to improve the efficiency and effectiveness of desalination plants in water stressed-regions.

The objective of this paper is to provide a global assessment of low-temperature geothermal desalination viability using publicly-available data and maps. The information from the assessment will be used by JRG Energy along with other stages of the project to introduce viable geothermal desalination technologies in the future.

2. RESEARCH CONDUCTED

For this paper, JRG Energy has conducted all research using publicly-available information. The first step was to perform background studies on previous attempts of geothermal desalination plants. This provided some early parameters for evaluating success and failures for any future attempts. An overview of previous attempts is provided in Section 2.1. The second phase of research was conducted to define the resource viability of geothermal desalination. This phase utilized the background understanding of the geothermal industry by the authors to draw some educated theories. Cost-effective geothermal desalination needs the three following requirements:

1. Geothermal power that can be acquired at low cost (Section 2.2 – Geothermal Energy)
2. Easily obtainable source water (Section 2.3 – Source)
3. A need/customer for fresh water (Section 2.4 – Demand)

The information obtained from these initial inputs was used to create a probability matrix and resultant viability map in Google Earth to be used for future developments. The map highlights areas of potential success based on these parameters alone, but will be used in future comparisons with other data sets such as geopolitical, financial incentives, and population density data.

2.1 Historic examples of geothermal energy use for desalination

Geothermal brine was first used for desalination in the US in the 1970s (Awerbuch et al., 1976). In this process, a separator, steam turbine and a Multi-Stage Flash (MSF) unit were used. The separator was used to ensure that the steam flashed from the hot brine extracted from the geothermal production well was circulated in the steam turbine while the non-evaporated hot brine was used as the feed water to the MSF unit to produce fresh water.

Another example of geothermal desalination was a project in Algeria where 98°C geothermal water was used to obtain distilled water from seawater (Aviña-Jiménez et al., 2016). In this process, a ground heat exchanger was used to increase the temperature of the geothermal waters acceptable for the proposed desalination process, which included evaporative and condensing surfaces while heating a greenhouse. This hybrid system was backed up by a solar energy system (Mahmoudi et al., 2010).

A more notable recorded attempt was the Kimolos Geothermal Desalination Project, funded by the THERMIE EU-DGXVII program in Greece (Table 1). This project resulted in a pilot unit being built in 1998-1999 utilizing low-enthalpy geothermal energy as heating and feed-water medium. Geothermal waters at a temperature of 61–62°C from a 188-m deep borehole. The desalination method applied was Multiple Effect Distillation (MED) with a two-stage desalination unit. Several tests took place to measure and quantify the fresh-water production rate. At a temperature of 61°C, 50 m³/hr of geothermal water was required to produce 3.24 m³/h of desalinated water. Unfortunately, no commercial use of this pilot project has taken place.

Table 1: Summary of geothermal desalination installations around the world (Gude, 2019)

Location	Process description	Process conditions	Reference
Baja California, Mexico	Combination of MED and MSF, called “Multi-Flash with Heaters” (MFWH)	At initial temperature of 150 °C, 4 m ³ of geothermal water was required to produce 1 m ³ of desalinated water. At an initial temperature of 80°C, 14 m ³ of geothermal water was required.	Rodríguez et al., 1996
Kimolos, Greece	A two stage MED with distillation under vacuum in vertical tubes	Geothermal water flow rate of 60 m ³ /h at a wellhead temperature of 61–62 °C from a borehole of 188 m deep. Total production of fresh water is 80 m ³ /day Produced water cost is estimated of the order of 1.6 €/m ³ (including only annual operation costs).	Karytsas, 1996
Tunisia	Humidification and dehumidification process (HD)	At 75–90 °C geothermal temperatures, 75% energy savings were reported for a geothermal powered desalination process. Produced water cost is estimated as \$1.2/m ³ .	Bourouni et al., 1999
Tunisia	MD coupled with multiple effect distiller (MED)	That study found that the best operating parameters are 85 °C for a feed brine temperature at the evaporator inlet and a circulation flow of about 170 kg/h. Under these conditions, a GOR value of 3.7 and a water production of 16 kg/h may be reached. The integration of one membrane module distiller as a second step at the MED outlet permits an increase of distilled water production by about 7.5% and improvement of the energetic efficiency by practically 10%.	Bouguecha & Dhahbi, 2012
Salton Sea/ Imperial Valley, USA	MED/VTE* 2 effects MED/VTE* 15 effects	T=100 (steam) at 454 kg/h; Freshwater production rate of 18.9 m ³ /d T=100 (steam) at 3402 kg/h; Freshwater production rate of 79.5 m ³ /d	Sephton Water Technology, 2010

*VTE = vertical tube evaporator

Building on the results from the Kimolos project, the MIDES project in Greece was the first to exclusively combine geothermal power generation with desalination. The MIDES project, on Milos Island, was aimed at producing sufficient quantities (> 300 m³/h) of geothermal waters at 80-100°C in order to cover the freshwater and power needs of the island. The planned approach included a water desalination unit delivering 75 m³/h of desalinated water using MED technology, and a binary power plant (ORC unit) with an installed capacity of 470 kWe (Figure 1). In the framework of this project, 10 wells (7 production and 3 reinjection wells) were drilled in the Vounalia area at a depth of between 63-184 m per well. The wells yielded 20-100 m³/h waters at 55-99°C. Unfortunately, this project was not completed for reasons that were not associated with the technical capacity of the resource.

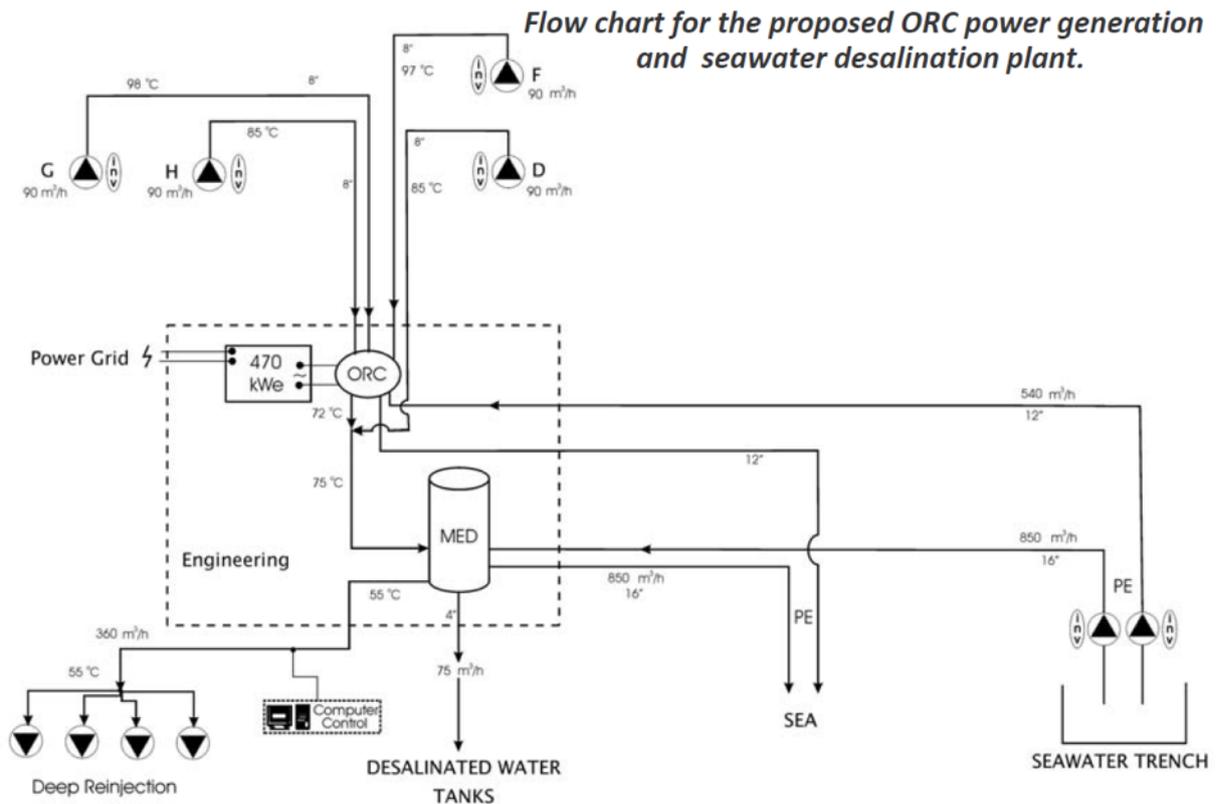


Figure 1: Flow chart of the proposed ORC power generation and desalination plant, MIDES Project, Milos Island, Greece (Fytikas et al., 2005).

Results from the first pioneers of geothermal desalination are mixed. Learnings can be summarized in two categories: technical specifications and necessity. The technical information proved that the desalination process could be completed by low-enthalpy geothermal resources. However, in order to make the process financially viable, the resource has to be readily obtainable and plentiful.

2.2 Geothermal Energy

Hot water is used in the desalination process to reduce traditional energy requirements. It can be used indirectly by heating the source water and reducing total energy use. The objective of our research was to use publicly-available information to identify areas with low-temperature (70-90°C) geothermal resources at depths <1000 m that can be reached using commonly-available water well drilling rigs.

Generating power from geothermal resources requires 3 parameters: heat, permeability, and fluid (groundwater). We have obtained publicly-available data and maps to help identify prospective areas for each of these parameters as described below.

2.2.1 Heat

We used both direct and indirect sources of subsurface temperature data. Direct sources include:

- **Global Volcanism Program** (<https://volcano.si.edu/>) hosted by the Smithsonian Institution – The Volcanoes of World database provides a catalogue of Holocene and Pleistocene volcanoes and eruptions from the past 10,000 years (Figure 2). Locations within 30 km of a recent or active volcano may provide a heat source for the target temperature (70-90°C).

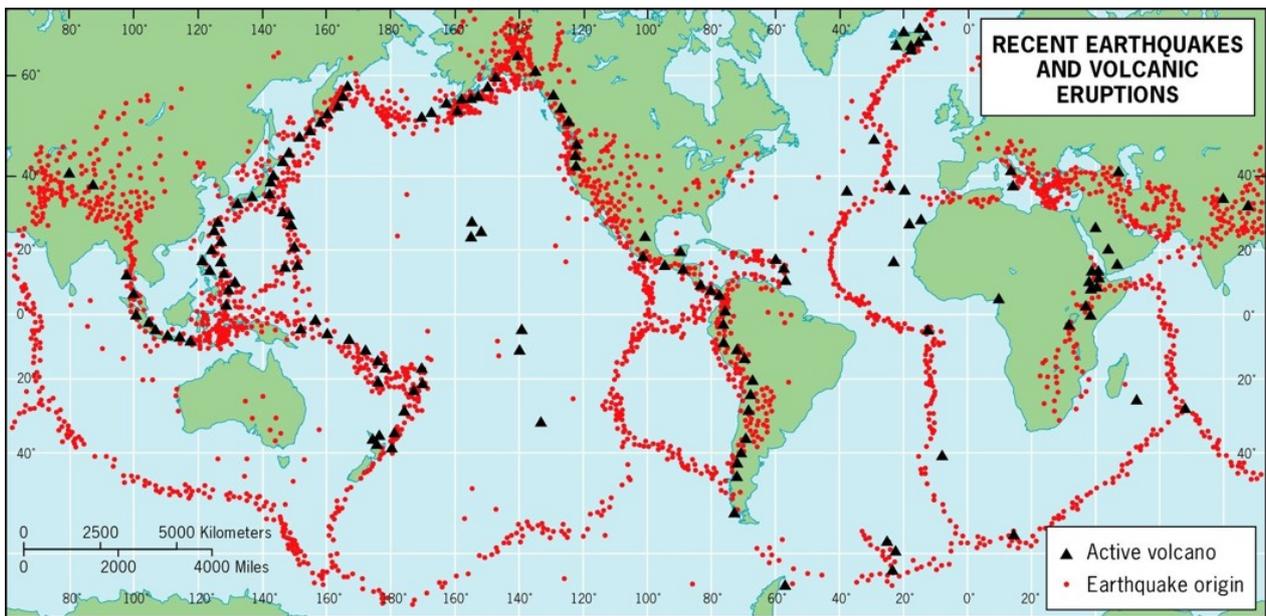


Figure 2: Global map of recent earthquakes and volcanic eruptions.

- **Active plate boundaries to identify seismically and volcanically active areas** – Especially subduction boundaries (e.g. Ring of Fire) and rift zones (e.g., mid-Atlantic; East Africa) (Figure 3). Locations within 200 km of convergent (subduction) or divergent (rifting) plate boundaries may be prospective for low-enthalpy geothermal sources.



Figure 3: Detailed world map showing the tectonic plates with their movement vectors.

Indirect sources include:

- **Global heat flow database of the International Heat Flow Commission** hosted by the University of North Dakota (<https://engineering.und.edu/research/global-heat-flow-database/data.html#>)
- **Global heat flow database** hosted by AAPG Datapages, Inc. (www.datapages.com/gis-map-publishing-program/gis-open-files/global-framework/global-heat-flow-database/)
- **Global geothermal gradient maps** (Figures 4 and 5)

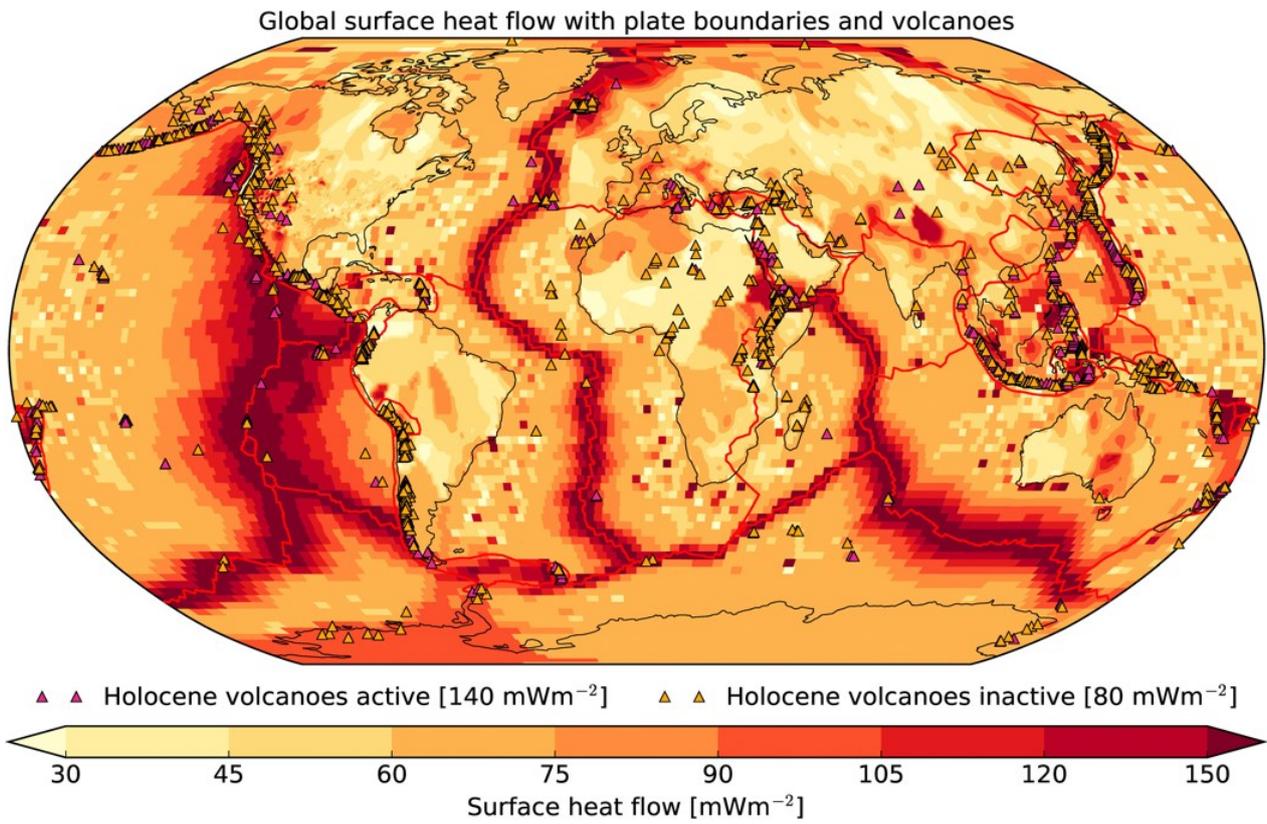


Figure 4: Global surface heat flow compilation with plate boundaries and volcanoes (Limberger et al., 2018).

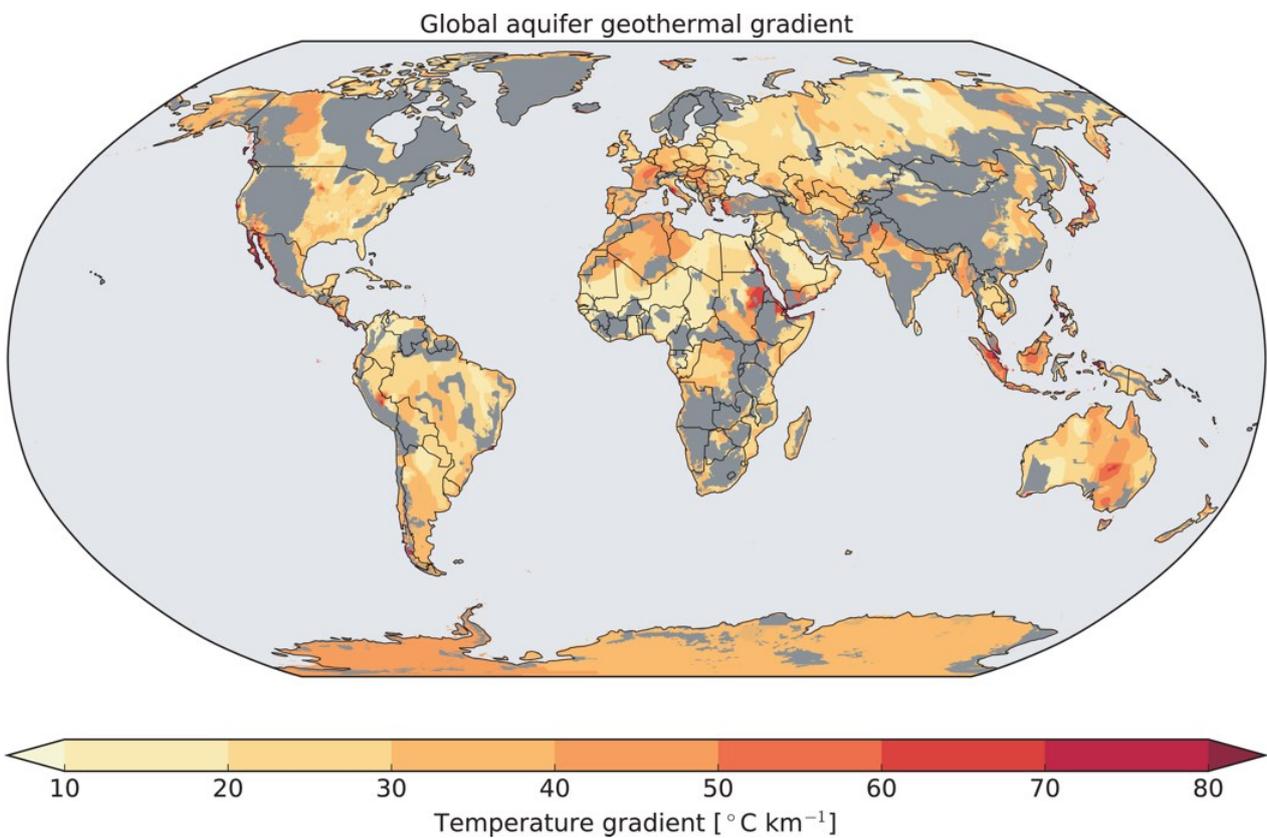


Figure 5: Computed geothermal gradient in aquifers. Grey areas on the land surface indicate a sediment thickness less than 100 m and are not included (Limberger et al., 2018).

2.2.2 Permeability

Permeability refers to the interconnectivity of a rock to allow fluid movement. Geothermal systems require adequate permeability (usually through permeable faults) to allow hot water to move from depth to a location near the surface where it can be intercepted by wells. Having adequate flow is a key constraint for the application of geothermal energy.

We used the following sources to interpret areas of higher permeability.

- **World Stress Map** maintained by the Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences (www.world-stress-map.org/download/) (Figure 6). These maps show areas of extensional and compressional stress, which are used to evaluate fault permeability (faults located in an extensional stress, or normal faulting, regime are more likely to be permeable).
- **Maps of surface faults** (many available depending on country)

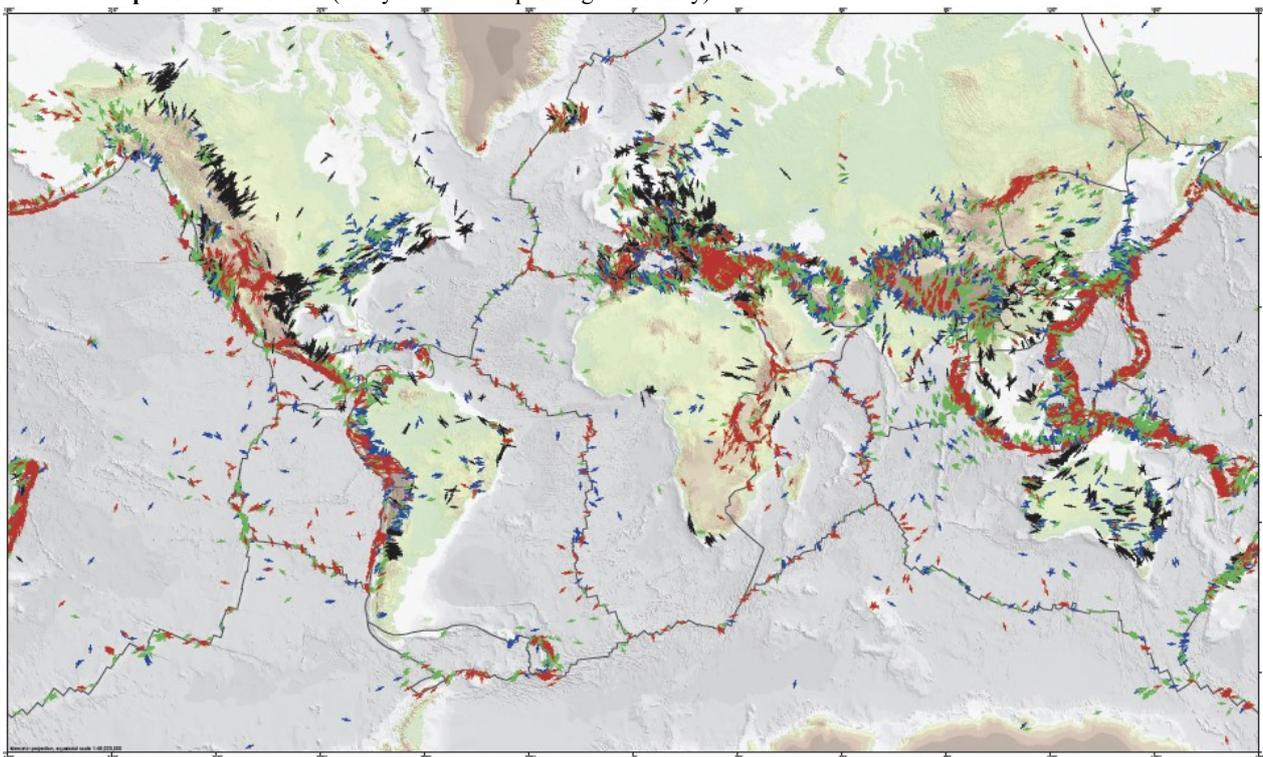


Figure 6: World stress map displaying orientation of maximum horizontal compressional stress (S_{Hmax}). Stress regime: normal faulting (red), strike-slip faulting (green), thrust faulting (blue) (Heidbach et al., 2016).

2.2.3 Fluid (groundwater)

It is important to understand the relationship between groundwater and geothermal resources to assess the viability of using low-enthalpy geothermal energy for desalination. If the depth to groundwater is too deep or the recharge rate too low, then the potential use of geothermal energy is negatively impacted.

We used the following sources to evaluate the availability of groundwater:

- **Global hydrology and groundwater maps** (many available depending on country)
- **Global groundwater recharge and water table depth maps** hosted by the University of Tokyo (<http://hydro.iis.u-tokyo.ac.jp/~sujan/research/ongoing/groundwater.html>) (Figure 7)

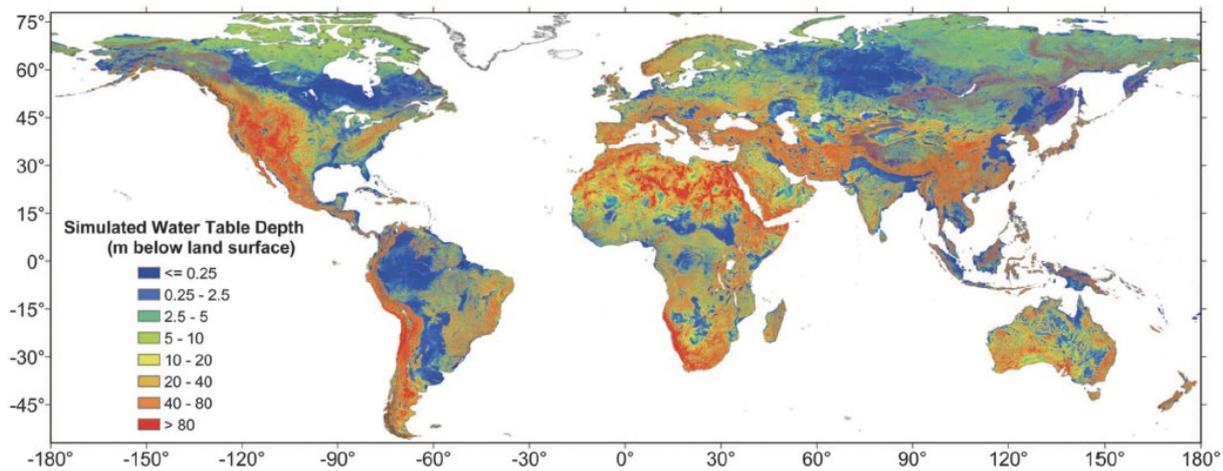


Figure 7: Simulated water table depth (m) based on observed depths compiled from government archives and literature (Fan et al., 2013).

2.3 Source Water

The objective is to identify areas where source water would be easily obtainable for desalination (not just along oceans). We used the following sources to identify possible areas of source water:

- **Seawater** – Locations up to 50 km from the ocean are feasible as seawater can be cost efficiently piped to a geothermal source
- **Saline and brackish water aquifers** – Maps and data hosted by the International Groundwater Resources Assessment Centre (IGRAC) located in Delft, Netherlands (<https://www.un-igrac.org/resource/global-overview-saline-groundwater-occurrence-and-genesis>) (Figure 8)
- **Impaired source water** – Including water that is a wastewater disposal issue (e.g., co-produced water from O&G wells; blowback water from geothermal power plants)

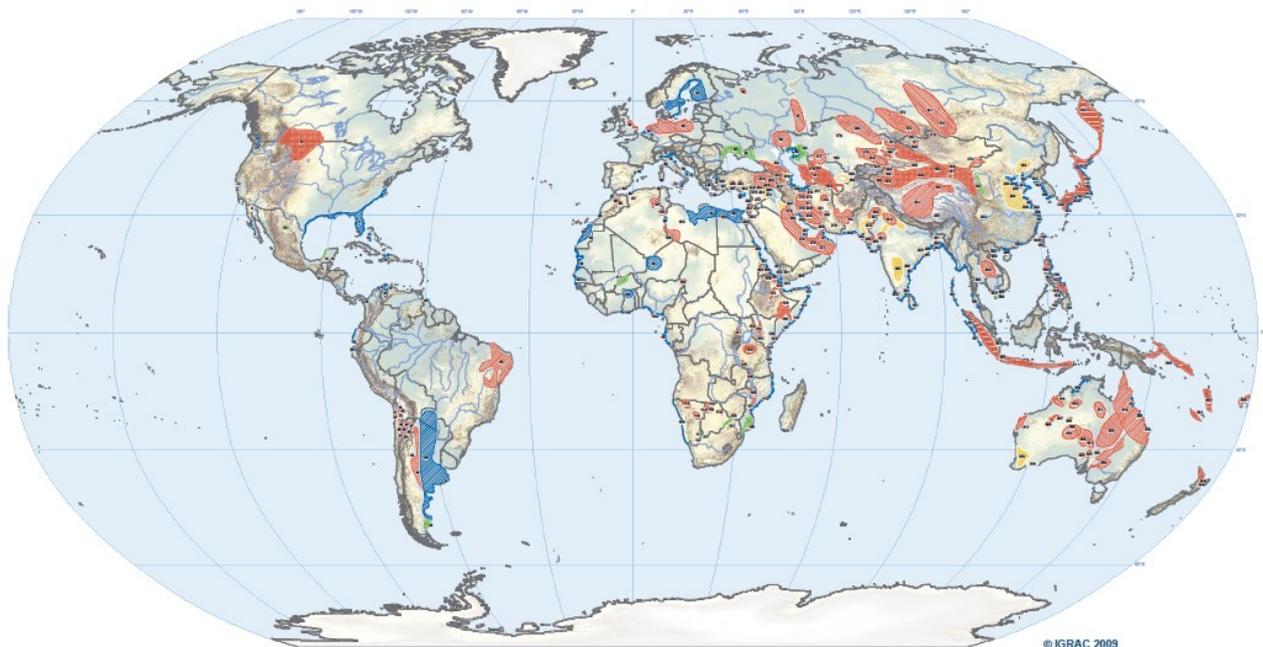


Figure 8: Global overview of saline groundwater occurrence and genesis (Van Weert et al., 2009).

2.4 Demand

The objective is to identify areas of global water need and financial necessity. We used the following sources to evaluate the future demand for drinking water:

- **World Water Stress Map** hosted by the World Resources Institute (www.wri.org). Key database and maps showing global water need. Includes the Aqueduct Projected Water Stress Country Rankings and datasets to download (ESRI geodatabase files) – Aqueduct Global Maps 2.1 Data, (Figures 9 and 10).

- **Global drought hazard maps** hosted by the National Drought Mitigation centre (www.drought.gov) and the University of Nebraska-Lincoln (www.droughtmonitor.unl.edu)
- **World population density maps and population growth maps**

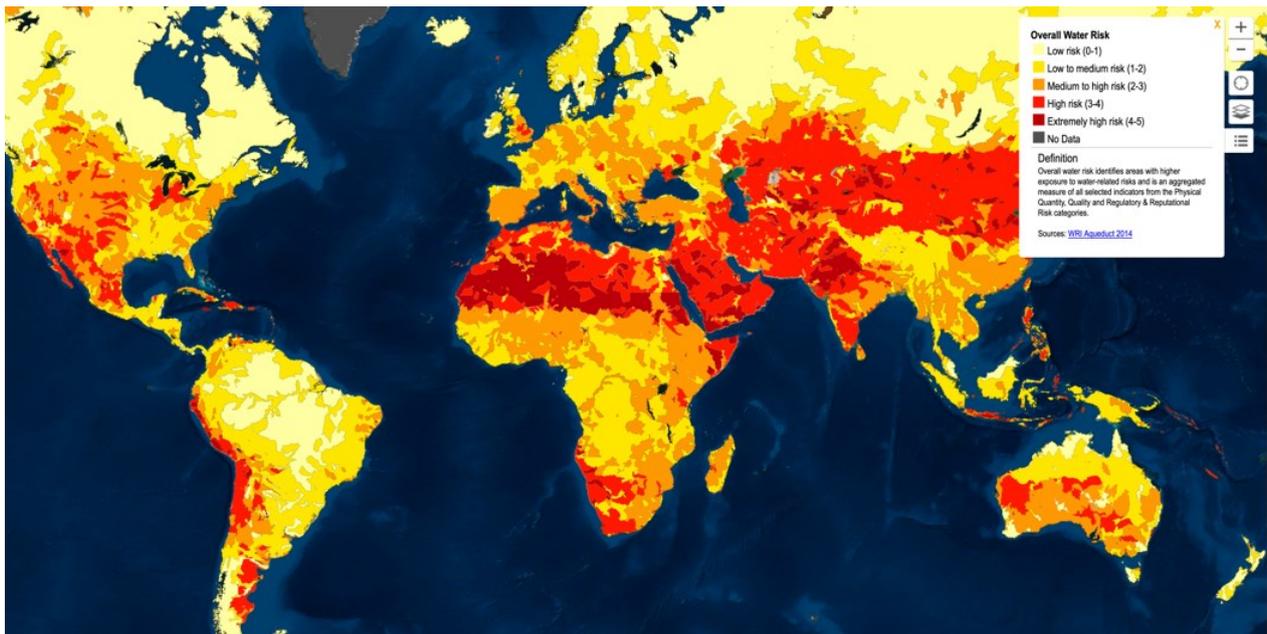


Figure 9: Global map of current overall water risk identifying area with higher exposure to water-related risks as analyzed by the AQUEDUCT Water Risk Atlas (World Resources Institute, 2019).

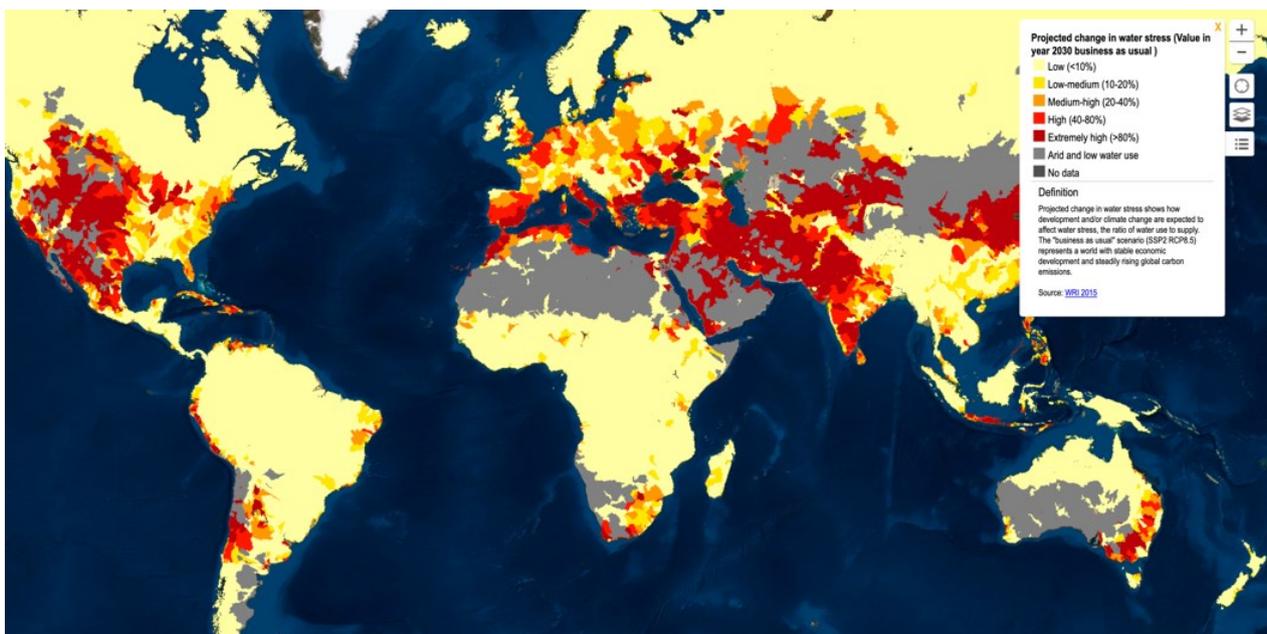


Figure 10: Global map of future water stress in 2030 as analyzed by the AQUEDUCT Water Risk Atlas (World Resources Institute, 2019).

3.CONCLUSIONS

We have researched numerous publicly-available sources of maps and data that can be used together as a set of criteria for screening locations that are prospective to low-enthalpy geothermal desalination. These criteria include parameters for geothermal prospectivity (such as temperature, permeability, and fluid (groundwater), direct and indirect sources of heat, potential alternative heat sources such as abandoned oil and gas wells, and global areas of water need.

By overlaying maps of the various technical criteria and utilizing spatial datasets, JRG Energy can create geothermal desalination potential probability maps at a country level. Much of the publicly-available data can be imported into Google Earth or QGIS either as layers or directly as .kmz or .kml files.

We have prepared probability maps using spatial datasets and GIS platform for 3 countries (Egypt, Saudi Arabia, and Vanuatu) that incorporate publicly-available data and existing maps of geothermal potential, source water, demand, and geo-political factors. The probability maps were used to identify areas within the target countries that pose high likelihood of successfully implementing geothermal desalination plants and justify further site-specific feasibility studies. Calculations of freshwater production rates were made using the available data and a basic geothermal desalination plant design. The maps are web-based platforms and are too complicated to be included in this paper, but will be presented along with the corresponding case studies at the World Geothermal Congress.

4. REFERENCES

- Aviña-Jiménez, H., De la Rosa-Urbalejo, D. & García-Gutiérrez, A.: Desalination Using Geothermal Energy, *GRC Transactions*, 40, (2016), 141-146.
- Awerbuch, L., Lindemuth, T.E., May, S.C. & Rodgers, A.N.: Geothermal Energy Recovery Process. *Desalination*, 19, (1976), 325-336.
- Bouguecha, S. & Dhahbi, M.: Fluidised Bed Crystalliser and Air Gap Membrane Distillation as a Solution to Geothermal Water Desalination, *Desalination*, 152, (2012), 237-44.
- Bourouni, K., Deronzier, J.C. & Tadrist, L.: Experimentation and Modelling of an Innovative Geothermal Desalination Unit, *Desalination*, 125, (1999), 147-53.
- Fan, Y., Li, H. & Miguez-Macho, G.: Global Patterns of Groundwater Table Depth, *Science*, 339, (2013), 940-3, doi: 10.1126/science.1229881.
- Fytikas, M., Radoglou, G., Karytsas, C., Mendrinou, D., Vasalakis, A. & Andritsos, N.: Geothermal Research in Vounalia Area, Milos Island (Greece), for Seawater Desalination and Power Production, *Proceedings World Geothermal Congress 2005*, Antalya, Turkey, (2005).
- Gude, V.G.: Chapter 15, Geothermal Desalination, In *Desalination*, 2nd Edition, Jane Kucera (ed.), Scrivener Publishing LLC, (2019), 647-682.
- Harvey, C., Beardsmore, G., Moeck, I. & Rüter, H.: *Geothermal Exploration: Global Strategies and Applications*, IGA Academy Books, IGA Service GmbH, c/o Bochum University of Applied Sciences, Bochum, Germany, (2016), 196 pp.
- Heidbach, O., Rajabi, M., Reiter, K. & Ziegler, M.: World Stress Map 2016. GFZ Data Service, doi: 10.5880/WSM.2016.002.
- Karytsas: *Proceedings Mediterranean Conference on Renewable Energy Sources for Water Production*, European Commission, EUORED Network, Santorini, Greece: CRES, (1996), 128-31.
- Limberger, J., Boxem, T., Pluymaekers, M., Bruhn, D., Manzella, A., Calcagno, P., Beekman, F., Cloetingh, S. & van Wees, J-D.: Geothermal Energy in Deep Aquifers: A Global Assessment of the Resource Base for Direct Heat Utilization, *Renewable and Sustainable Energy Reviews*, 82, (2018), 961-975, doi: 10.1016/j.rser.2017.09.084.
- Mahmoudi, H., Spahis, N., Goosen, M.F., Ghaffour, N., Drouiche, N. & Ouaqued, A.: Application of Geothermal Energy for Heating and Fresh Water Production in a Brackish Water Greenhouse Desalination Unit: A Case Study from Algeria, *Renewable and Sustainable Energy Reviews*, 14, (2010), 512-517.
- Rodríguez, G., Rodríguez, M., Perez, J. & Veza, J.: A Systematic Approach to Desalination Powered by Solar, Wind and Geothermal Energy Sources, *Proceedings Mediterranean Conference on Renewable Energy Sources for Water Production*, European Commission, EUORED Network, Santorini, Greece: CRES, (1996), 20-25.
- Septon Water Technology: VTE Geothermal Desalination Project Summary, April 2010.
- Van Weert, F., van der Gun, J. & Reckman, J.: *Global Overview of Saline Groundwater Occurrence and Genesis*, International Groundwater Resources Assessment Centre (IGRAC), Delft, Netherlands, (2009).
- World Resources Institute: *AQUEDUCT Water Risk Atlas*: www.wri.org/applications/maps/aqueduct-atlas/, (2019).