Estimating Freshwater Lens Volume based on Island Circularity

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Introduction

For many islands around the globe freshwater lenses (FWLs) are an important source of drinking water. They form when fresh rainwater infiltrates into the island and floats on top of the saltwater due to buoyancy forces caused by density differences. This study provides a new approach on estimating possible FWL volumes from the islands' shape using the circularity parameter.

Methods

Approach:

- Numerical steady state approach [1] using Ghyben-Herzberg relation [2]
- Comparison of FWLs of islands having same area but different shapes:
  - Shapes of real islands from Marshall Islands [3]
  - Elliptical islands
  - Rectangular islands

Software:

- MODFLOW 2005 [4] in FloPy [5]

Shape parameter:

- Circularity $C = \frac{4\,\pi \cdot area}{perimeter^2},\ C \in (0, 1]$ [6]

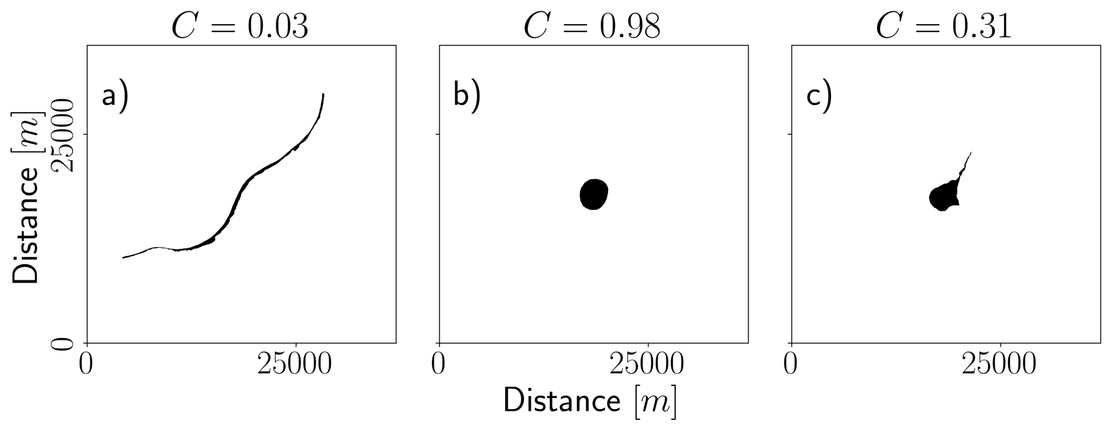

Fig. 1: Examples of three real island shapes with different circularities.

Results

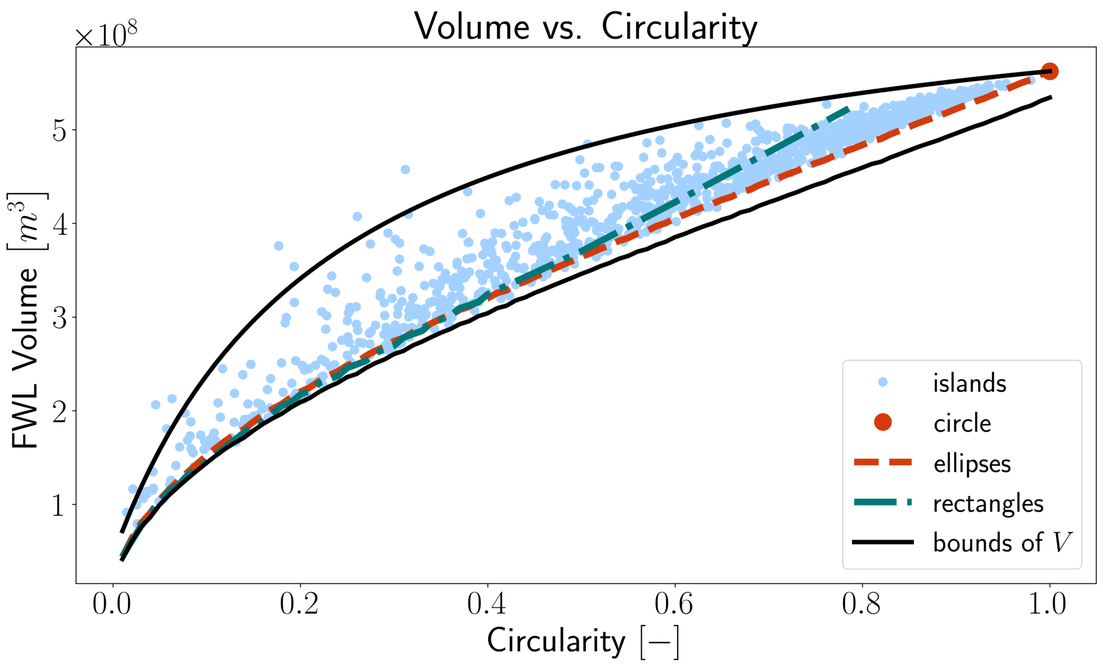

Fig. 2: Relationship between shapes of islands in terms of the circularity and the volume of their FWLs. $A = 10\ km^2,\ K = 10^{-4}\ m/s,\ R = 350\ mm/a$.

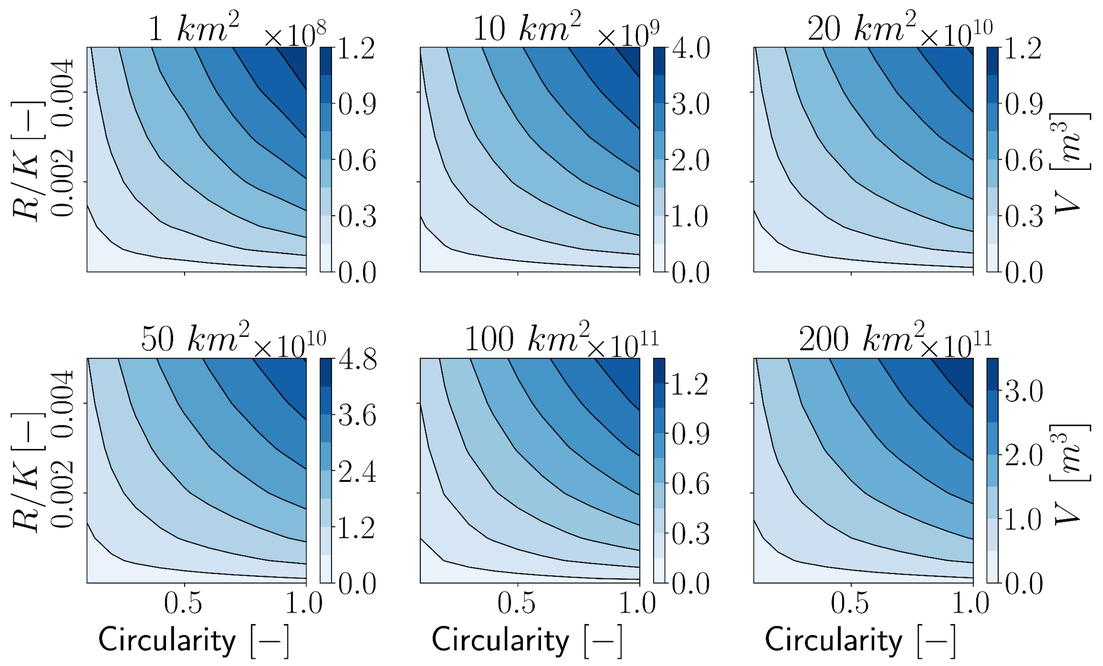

Fig. 3: FWL volumes of elliptical islands depending on island area, circularity and the ratio of recharge and hydraulic conductivity (R/K). Note the different scales of colour bars.

- For each value of C, an interval consisting of lower and upper boundaries can be defined for the FWL volume V:
  - Upper boundary: $V_{max} = \frac{b \cdot C}{C+a} + 0.08 \cdot V_{circle}$ with $a = 0.23$ and $b = 0.92 \cdot V_{circle} \cdot (1 + a)$
  - Lower boundary: 95% of V of an elliptical island with same C
- V of an island with circularity C lies with high probability within the given interval (black lines in Fig. 1).
- Generally, the larger the circularity the larger the FWL volume (Fig. 1).
- The shape of the island is as important as R and K for the steady-state FWL volume (Fig. 2).

Conclusions

- Results of this study may help to estimate FWL volumes of islands for which neither measured data is available nor an island specific model exists.
- They also can give a first indication of potential changes in V due to climate change, if island area changes due to sea level rise and/or erosion or if groundwater recharge is altered.

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