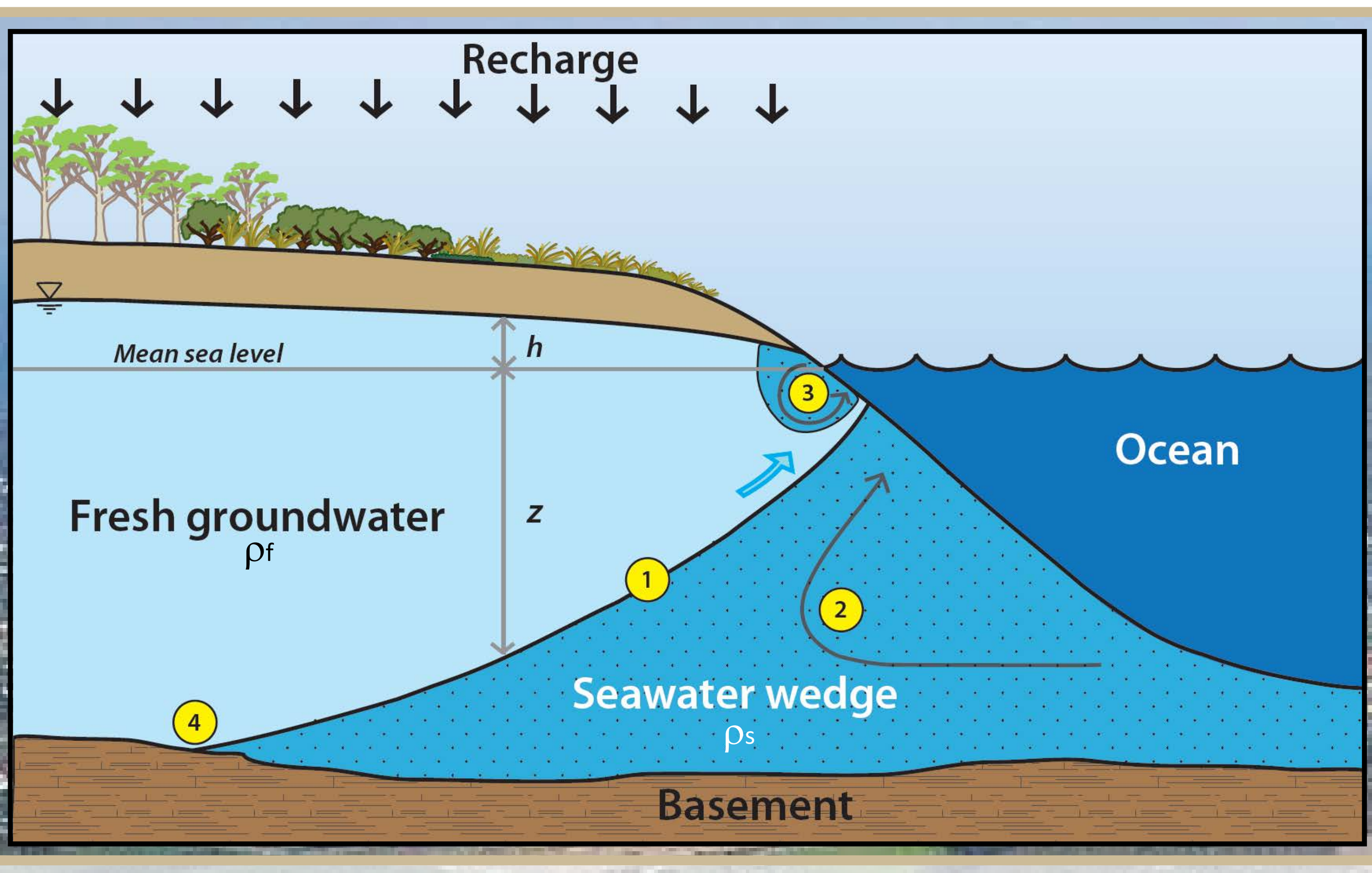
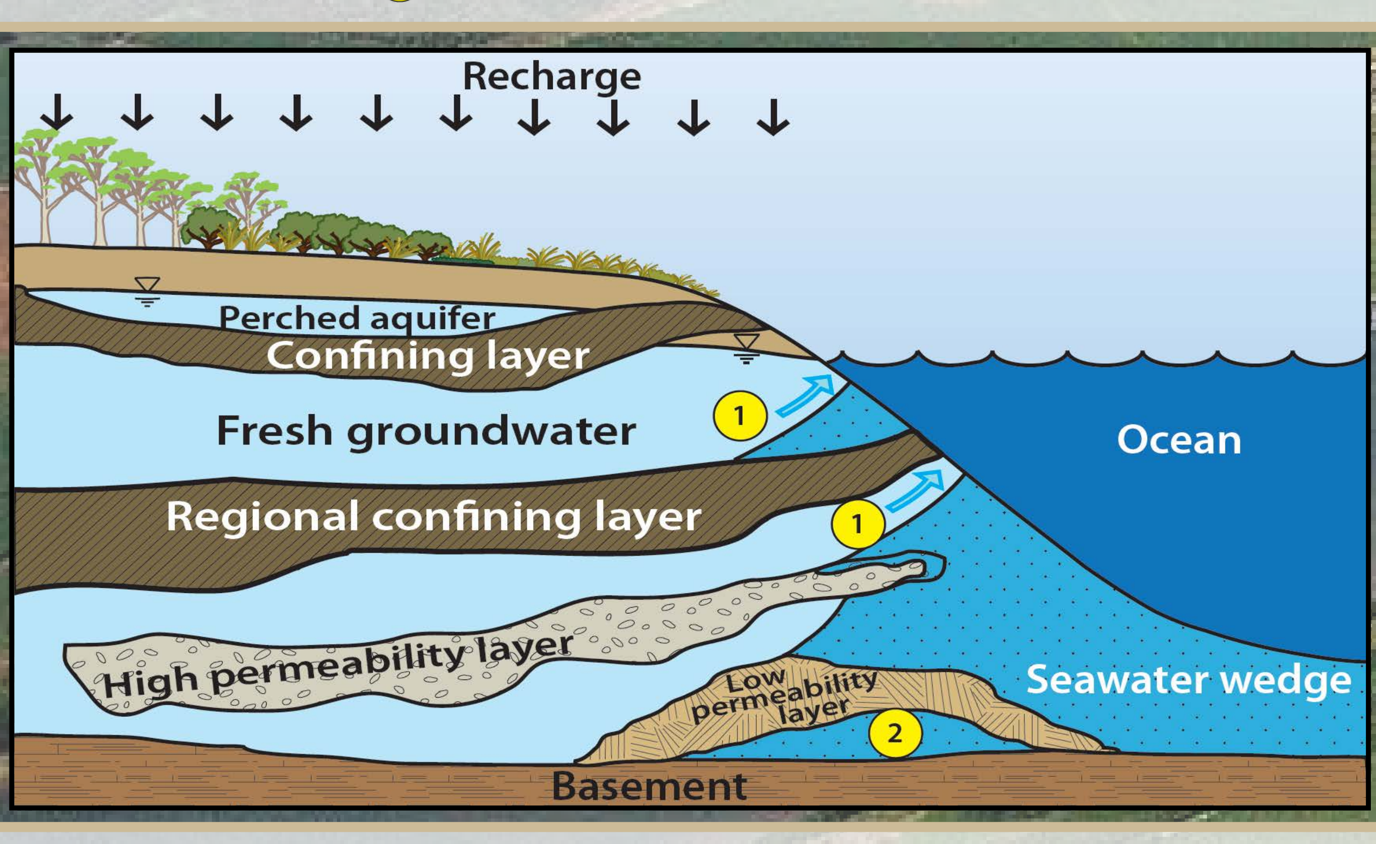
Werner, A.D., Jacobsen, P.E. and Morgan, L.K., 2013. Understanding seawater intrusion. [Poster]. Earth Sciences collection, http://hdl.handle.net/2328/26647. Flinders Academic Commons, Adelaide, South Australia.

Understanding Seawater Intrusion

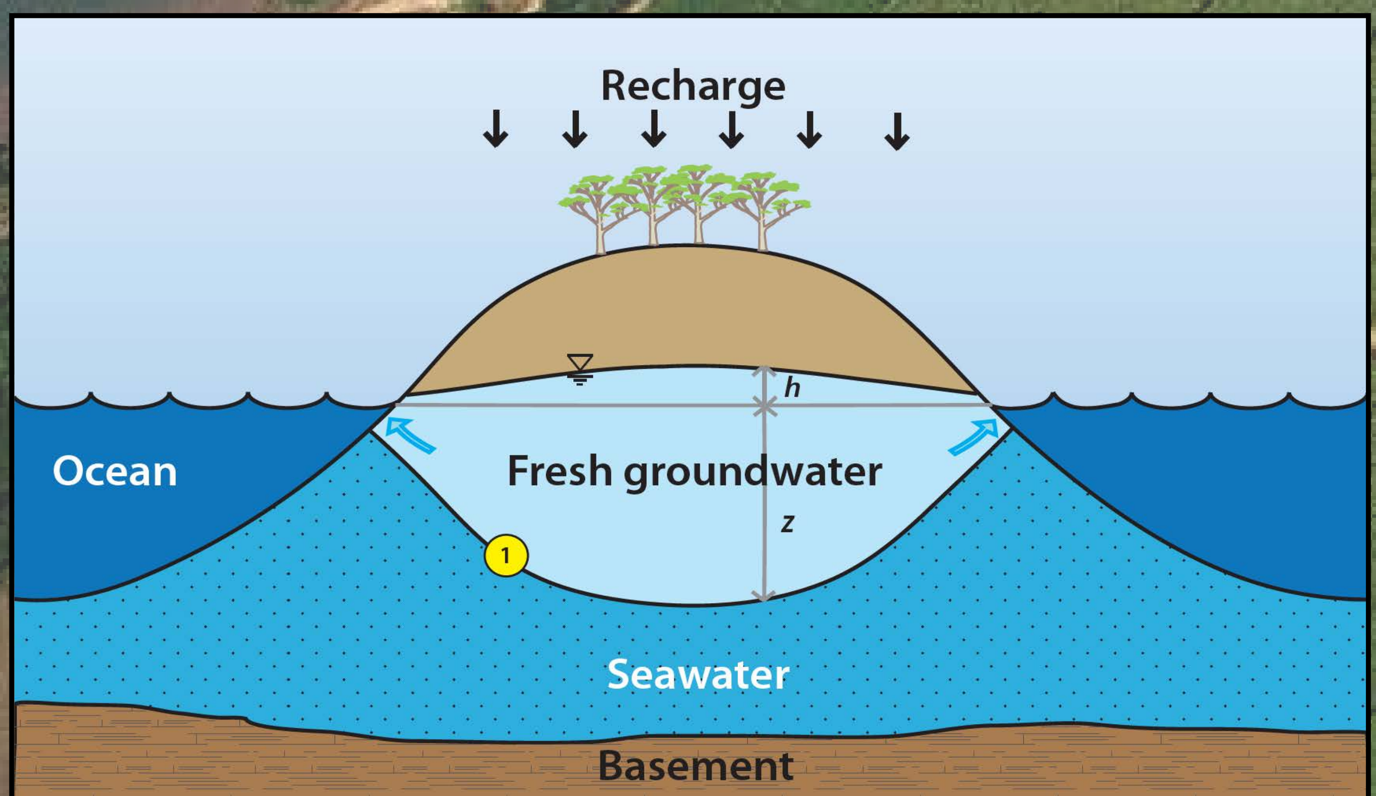
Seawater in undisturbed aquifers



Homogeneous, unconfined aquifer: the freshwater-seawater interface (1) is a gradual transition in salinity rather than the commonly assumed sharp interface (as illustrated for simplicity). The interface is stationary only under long-term, constant stresses (e.g. recharge, pumping, sea level). There are two circulating seawater plumes: (2) density driven ($\rho_f < \rho_s$), and (3) tidally driven. The wedge toe (4) location is the maximum seawater extent.

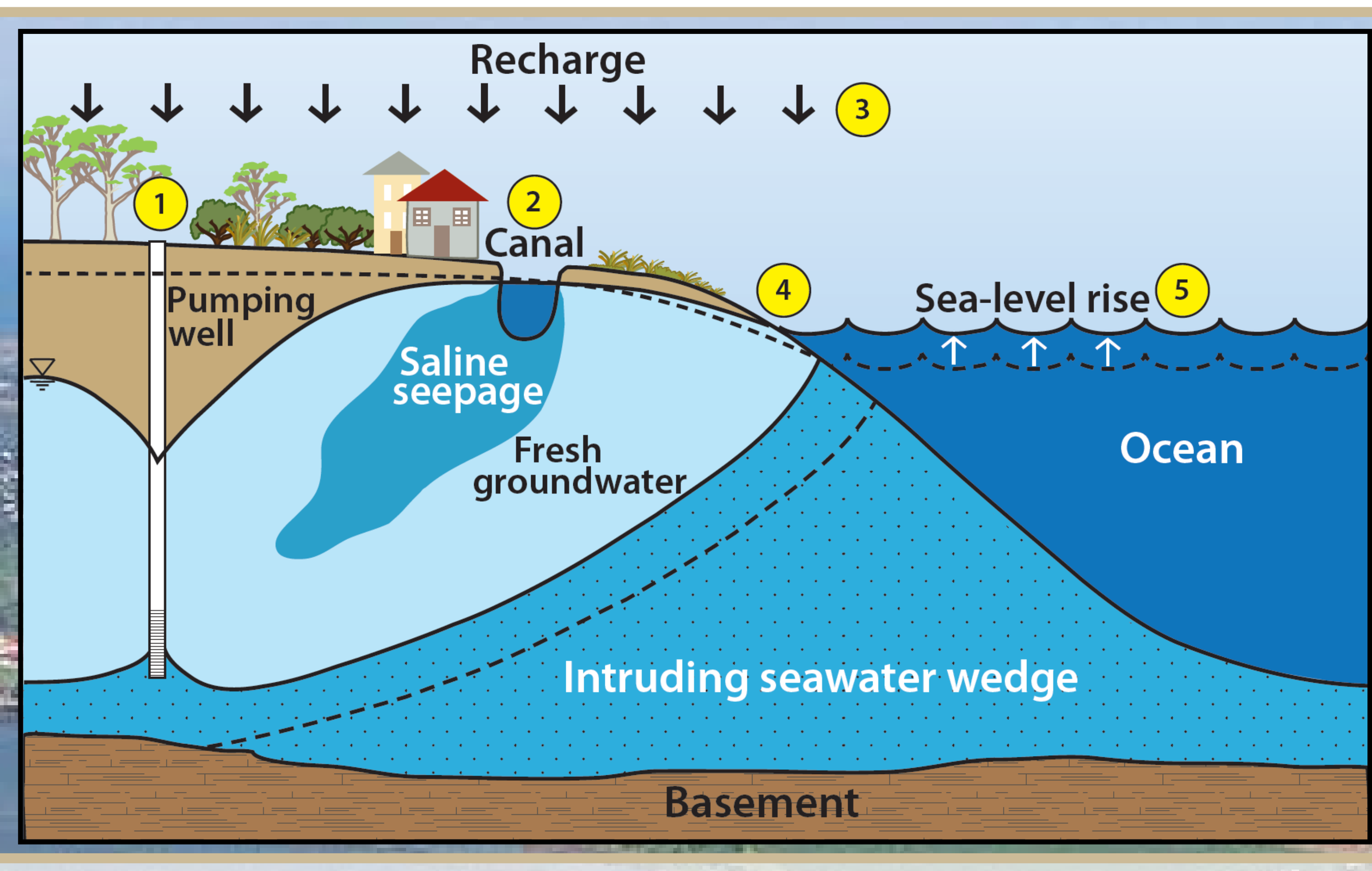


Heterogeneous, multi-layered aquifer: Multiple interfaces exist, and submarine groundwater discharge (1) occurs at several locations. Heterogeneities create wider mixing zones (not shown). Tidal circulation cell not shown for simplicity. Trapped relic seawater (2) is common.

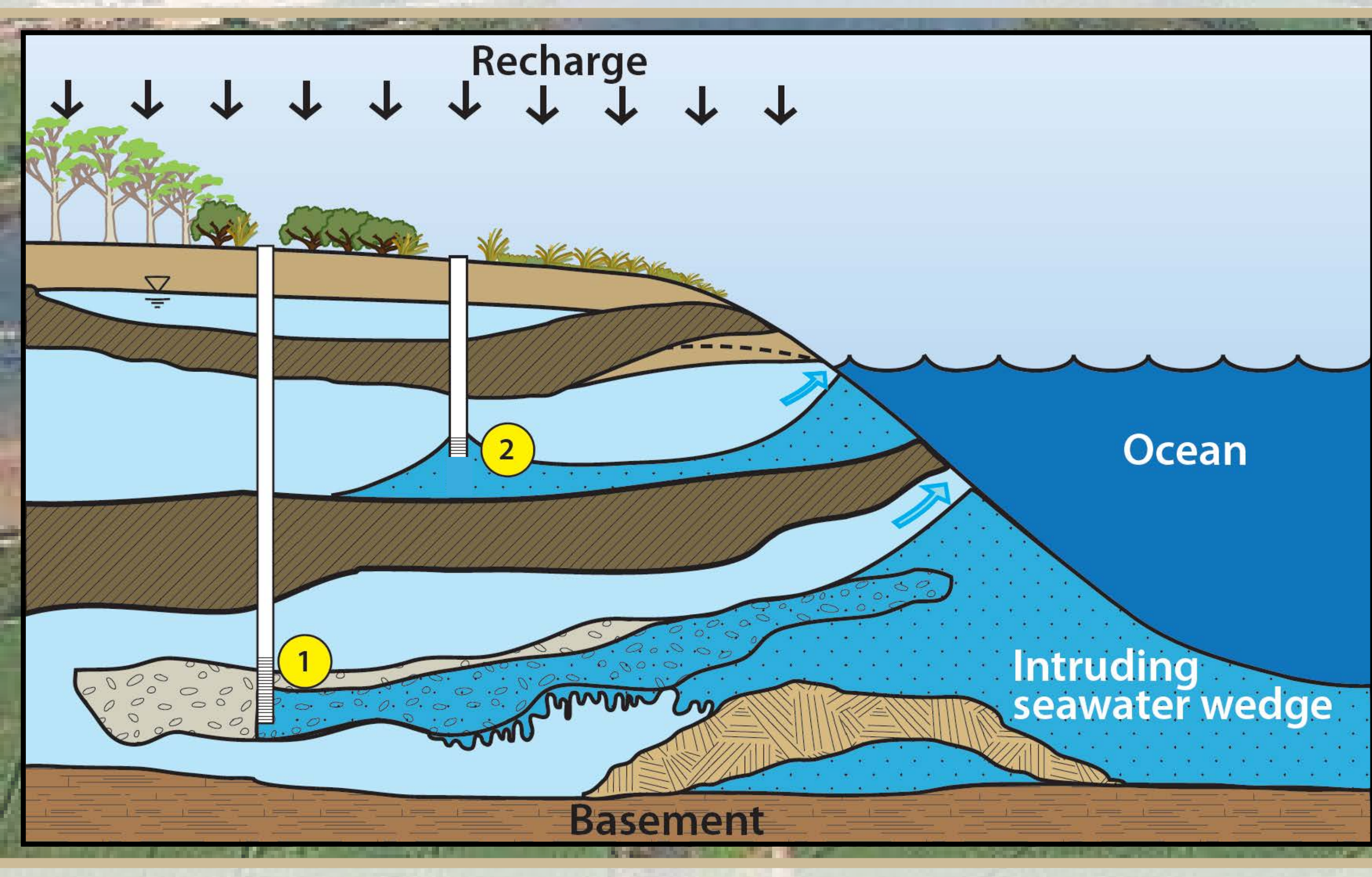


Freshwater lens in a homogeneous aquifer: Freshwater "floats" on seawater and the interface (1) defines the entire lower limit of the freshwater zone. The Ghyben-Herzberg relation provides an approximation of lens thickness: $z \approx 40h$ [1].

Seawater intrusion mechanisms



- - - - Original condition
——— Modified condition
(1) Excessive pumping
(2) Land-use change (e.g. canal development
(3) Reduction in recharge
(4) Overtopping, caused by sea-level rise, storm surges, and tsunamis
(5) Sea-level rise



(1) Preferential intrusion through high-permeability layers. Seawater can also preferentially intrude along channels and valleys in the aquifer basement.
(2) Saltwater up-coning contaminates pumping wells.

Seawater intrusion investigation

Measuring Seawater Intrusion

1. Temporal and spatial trends in salinity and hydraulic heads:
- Multiple-depth piezometer networks
- Pumping well salinities are a vital source of data
- Hydraulic head measurements are only useful when the exact depth is recorded and salinity variation inside the well is known[2]

2. Geophysical mapping:
- Resistivity and electromagnetic methods can show spatial salinity patterns

3. Origins and transport of freshwater and seawater:
- Isotopes and water chemistry can discern seawater wedge history, transport pathways and water ages, and can distinguish different salt sources (e.g. rock dissolution, irrigation returns, relic seawater, etc) [2].

Calculating Seawater Intrusion

1. Start simple, and add complexity according to specific seawater intrusion questions.
2. Simple methods for seawater intrusion calculation:
   - Sharp-interface, steady-state approaches[3,4,5], which adopt the Ghyben-Herzberg approximation ($z = \alpha h$ where z is the interface depth below sea level (L), α is the dimensionless density ratio (suggested as 40), and h is the freshwater head above sea level (L).
   - Seawater intrusion is quantified in terms of the interface position and toe location, and volume of seawater in the aquifer[5].
3. Complex methods for estimating dispersive and transient seawater intrusion:
   - Transient sharp-interface modelling is possible with the SWI package for MODFLOW
   - Groundwater flow and dispersive solute transport equations are coupled through the water density term. Popular codes include: SUTRA, SEAWAT, FEFLOW, MODHMS and FEMWATER.

Managing seawater intrusion

1. Approaches for managing groundwater pumping include flux-based (e.g. allowable pumping is linked to recharge estimates) and trigger level-based (e.g. pumping is linked to head and salinity levels).
2. Ideally, both fluxes and trigger levels control pumping[6].
3. A minimum groundwater discharge to the sea (q_{min}) is needed to avoid extensive seawater intrusion[5]:

$$q_{min} = \sqrt{\frac{WK(1+\alpha)z_0^2}{\alpha^2}}$$

Where W is net recharge (L T^{-1}), K is aquifer hydraulic conductivity (L T^{-1}), z_0 is the depth of aquifer basement below sea level (L).

4. Engineering measures to combat seawater intrusion include:
   - Regulate or relocate pumping
   - Pumping from shallow wells (skimming)
   - Hydraulic barriers formed by injection, preferably deep in the aquifer and immediately landward of the wedge toe
   - Extraction of seawater from the aquifer, either below pumping wells (scavenger systems) or near the coast
   - Subsurface flow barriers (the most intrusive and expensive strategy)

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Adrian D. Werner*
Peta E. Jacobsen
Leanne K. Morgan
National Centre for Groundwater Research & Training and School of the Environment, Flinders University
GPO Box 2100
Adelaide SA 5000 Australia
Email: adrian.werner@flinders.edu.au

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