Groundwater Salinity in Coastal Areas - Possible Interventions

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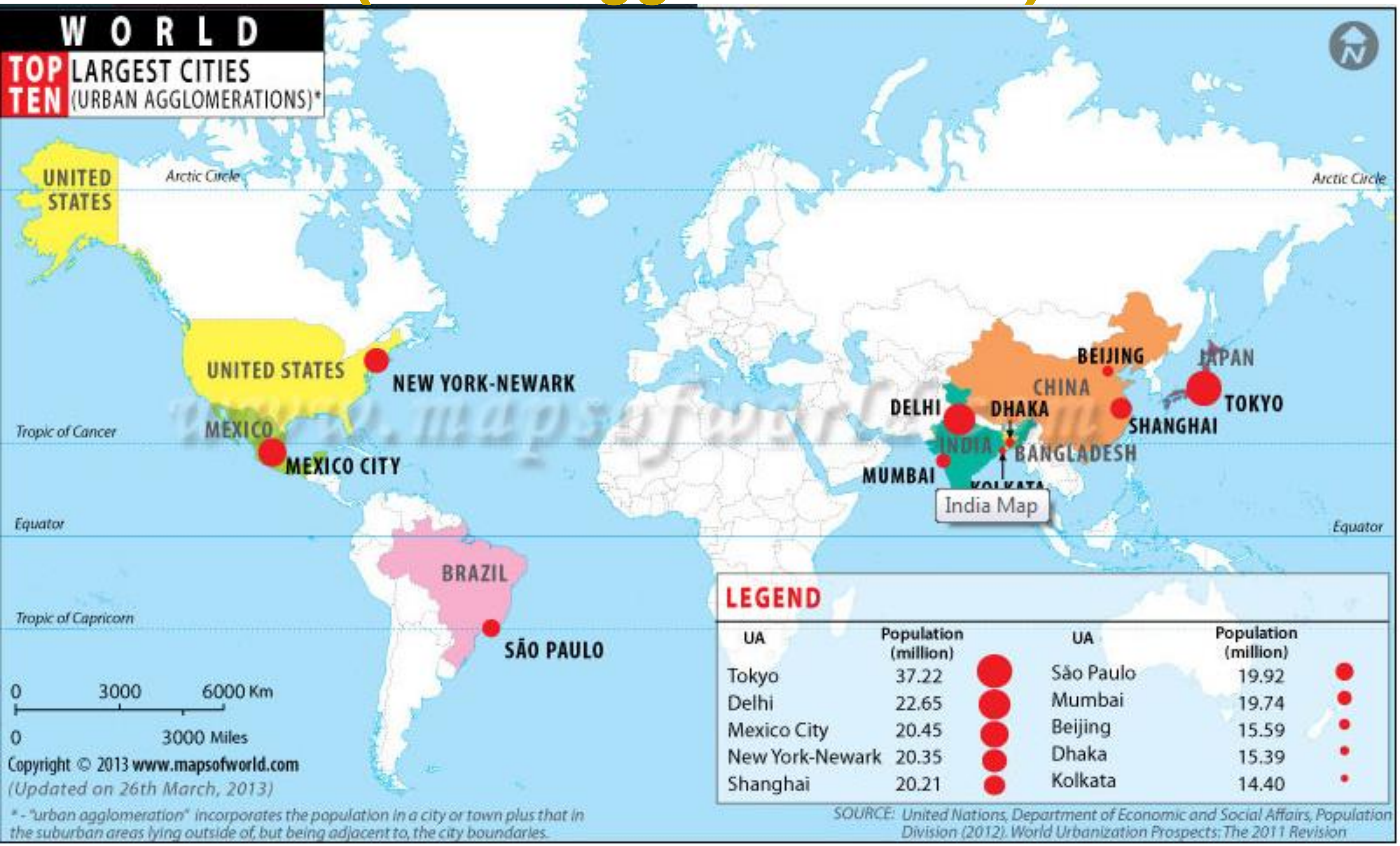
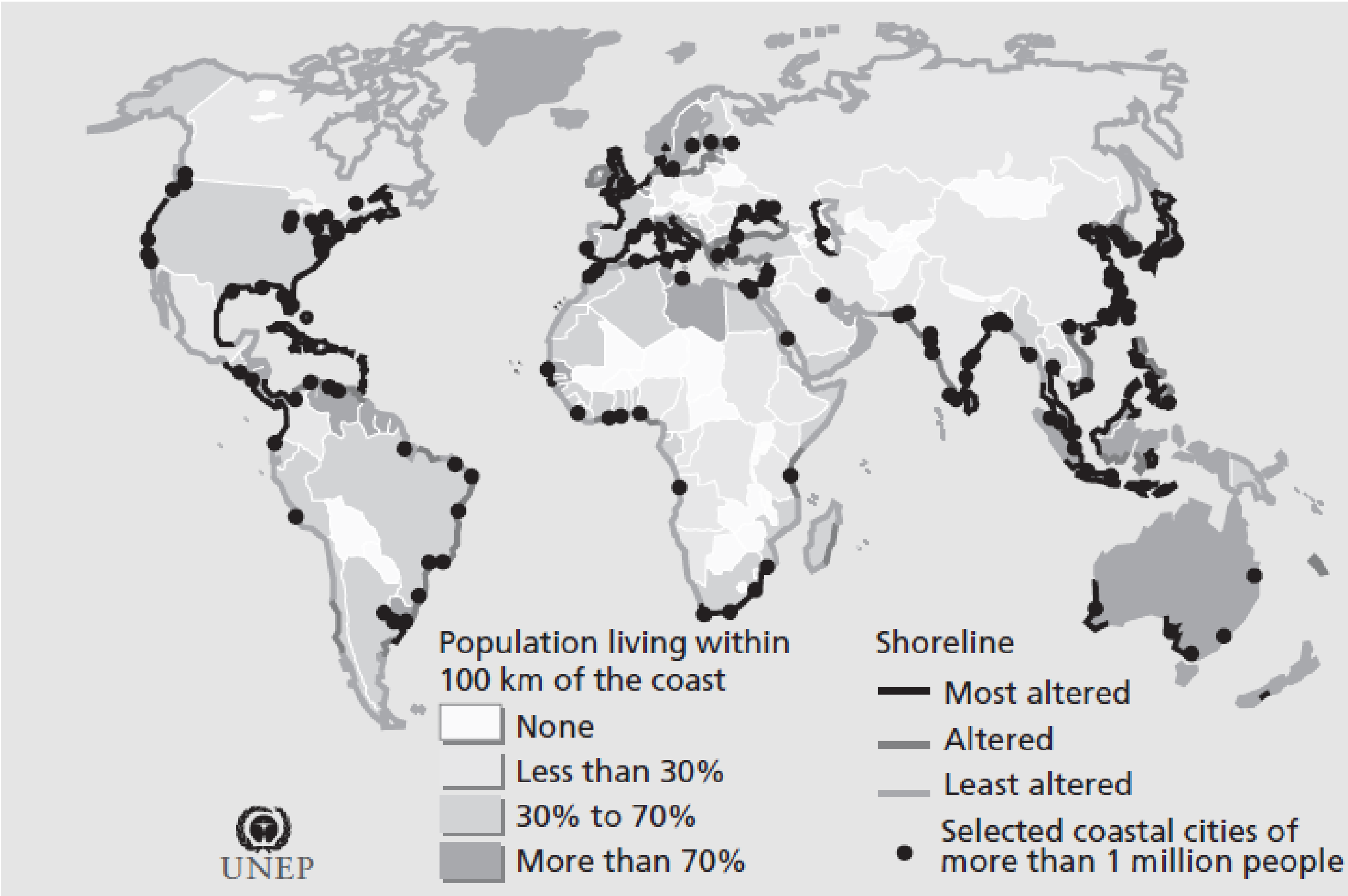
Coastal Zones

- Coastal zones are unique and dynamic environments.
- Contain some of the most densely populated areas in the world as they generally present the best conditions for productivity.
- Presently about 40% of the world's population lives within 100 km of the coast.

World's top ten largest cities (urban agglomerations)



Selected coastal cities > 1 million people



SOURCES: Lauretta Burke et al., *Pilot Analysis of Global Ecosystems: Coastal Ecosystems* (2001); and Paul Harrison and Fred Pearce, *AAAS Atlas of Population and Environment 2001*(2001).

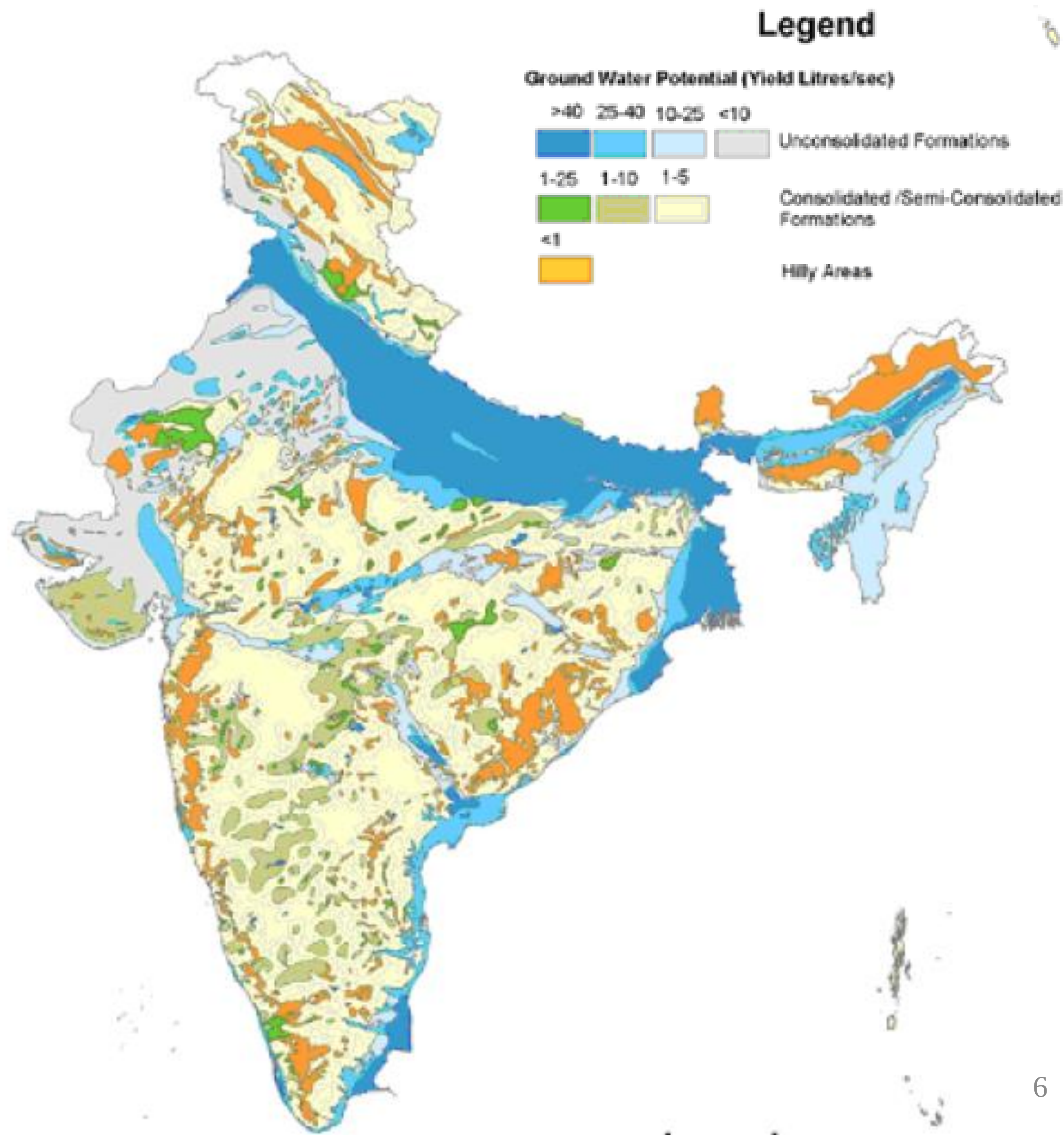
Groundwater

In India, groundwater is a critical resource - ***largest user of groundwater in the world***

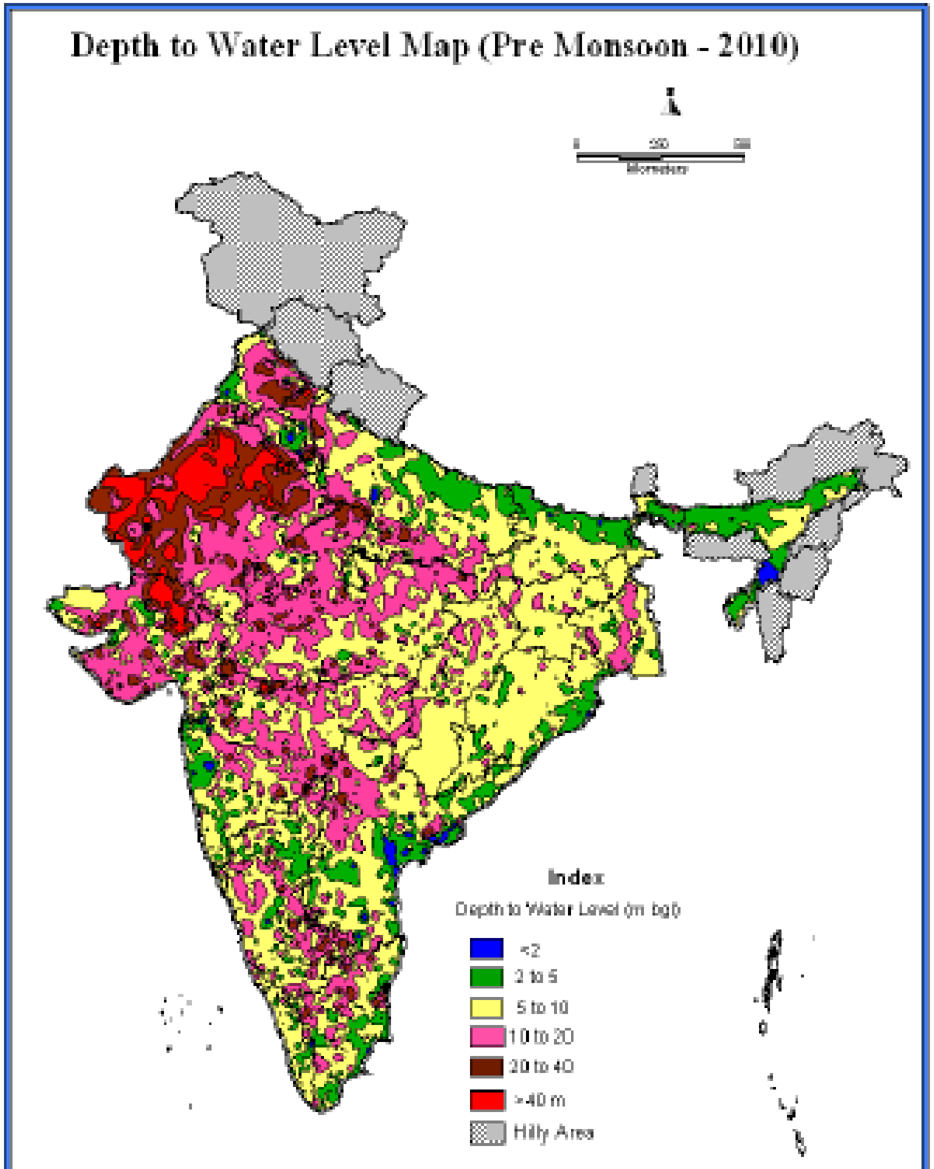
- More than 60% of irrigated agriculture and 85% of drinking water supplies are dependent on groundwater.
- Urban residents rely on groundwater due to unreliable and inadequate municipal water supplies.
- Groundwater acts a critical buffer against the variability of monsoon rains.

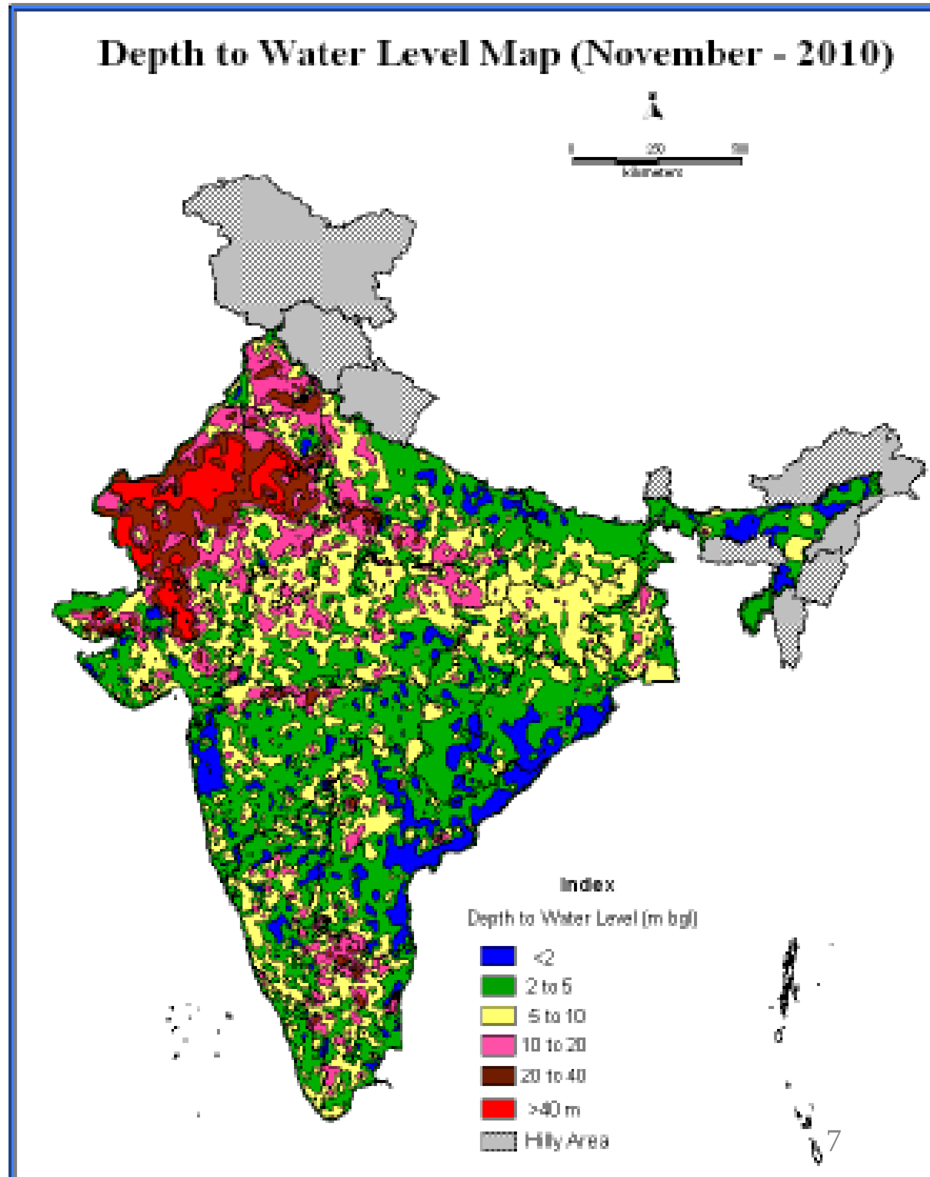
India Hydrogeology Map (CGWB)

India has both hard-rock & alluvial aquifers.



Depth to Water Level Maps (CGWB)





Coastal Lowlands

- **Low elevation coastal zone LECZ** (elevation less than 10 m above msl) covers 2% of world's land area but contains 10% of world's population and 13% of world's urban population.

- India has a long coastline of about 7500 km of which about **5400 km belongs to peninsular India** and the remaining to the Andaman, Nicobar and Lakshadweep Islands.

- **India** houses more than **63 million people living in LECZ** and nearly **250 million people living within 50 km** of the coastline.

India's Coastal Zone & Lowlands

- India's coastal zone is endowed with abundant coastal & marine ecosystems. Includes a wide range of mangroves, coral reefs, salt marshes, estuaries, lagoons, and unique marine & coastal flora/ fauna.
- **Provides sites for productive agriculture, industries, export-processing zones, harbors, airports, land ports, and tourism.**

Coastal Zone - Vulnerability

Vulnerable to variety of hydrological problems

- **cyclones,**
- **storm surges,**
- **flooding,**
- **seawater sprays,**
- **seawater ingress through surface waters & porous media.**

→ *Lead to coastal water salinization (both surface and ground water)*

Coastal Lowlands – Vulnerability to Salinity

- In addition, anthropogenic pressures (indiscriminate groundwater pumping, irrig. return flow, waste water disposal) and other human activities that affect local / regional hydrological conditions (e.g. mining / land reclamation) are strong drivers for inducing seawater ingress leading to **gw salinity**.
- Compounding these issues are increasing risks from climate change, particularly sea-level rise.

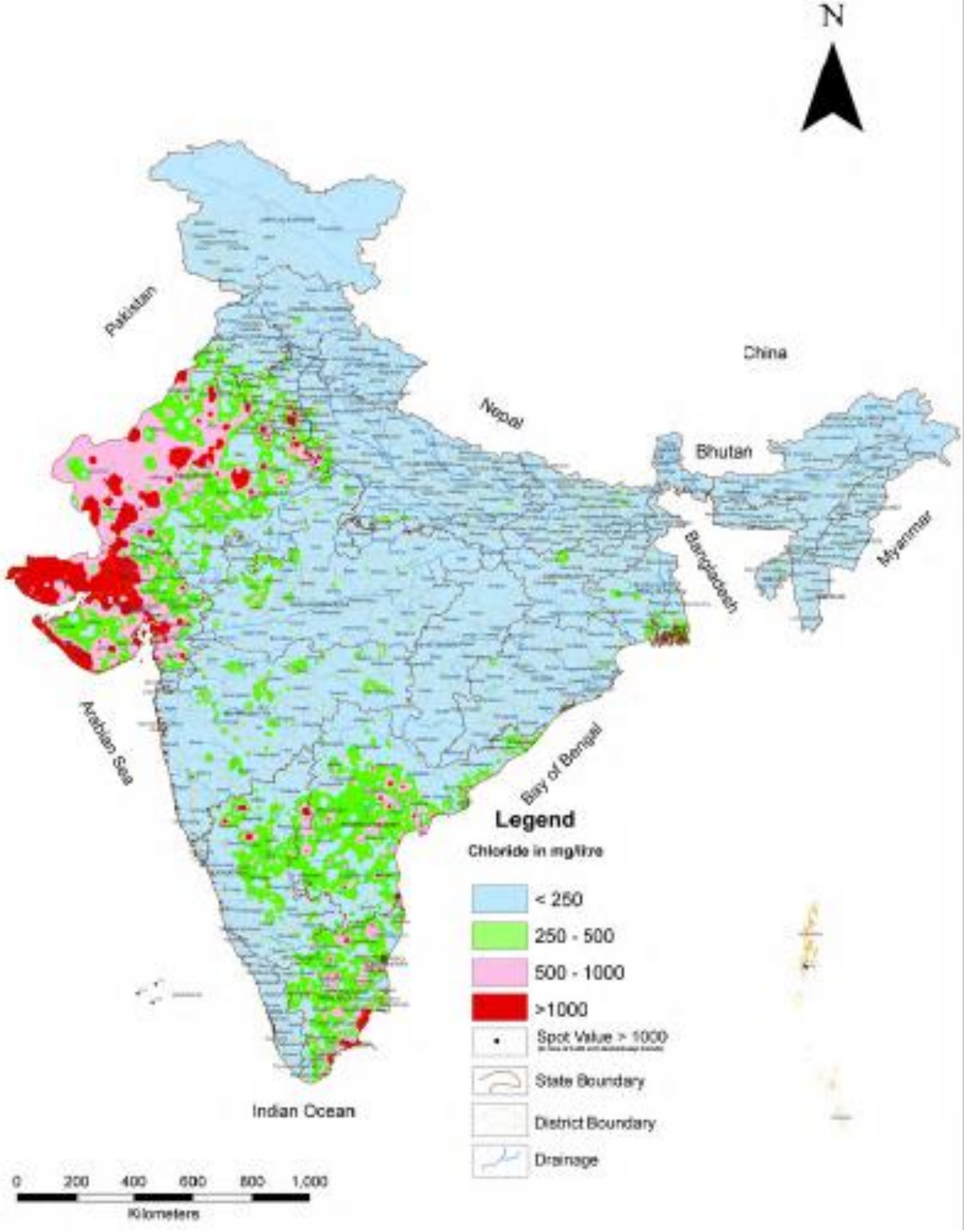
Coastal Areas: Water Supply

- With economic & population growth, freshwater supply is becoming short.

- With surface water getting scarce & polluted, coastal communities have turned to gw to make up for the shortfall. For domestic supply, % of gw use has increased more than 40% on a worldwide basis.

- *Coastal aquifers are highly sensitive to anthropogenic disturbances.* **Inappropriate management of coastal aquifers can lead to irreversible damages, leading to their destruction as fw sources.**

Chloride in Groundwater (CGWB)



Coastal Areas: Water Supply

- Being aware of the inc. vulnerability, state & local agencies have intensified water level & quality monitoring and water conservation projects, and increased coastal aquifer planning and management efforts.

- In the last two decades, *a significant amount of knowledge has been accumulated and new technologies developed.*

Knowledge in terms of coastal dynamics & resource management

Coastal aquifer contamination

Typical sources of contamination:

irrigated agriculture, industrialization, urbanization etc.

+

Additional source of contamination:

seawater intrusion

(unplanned gw development ➡ lowered water table + water quality deterioration)

Freshwater/Saltwater

Freshwater generally refers to water containing TDS < 1000 mg/l.

Salinity levels in freshwater

drinking purposes < 500 mg/l

irrigation purposes < 2000 mg/l

Possible sources of saltwater

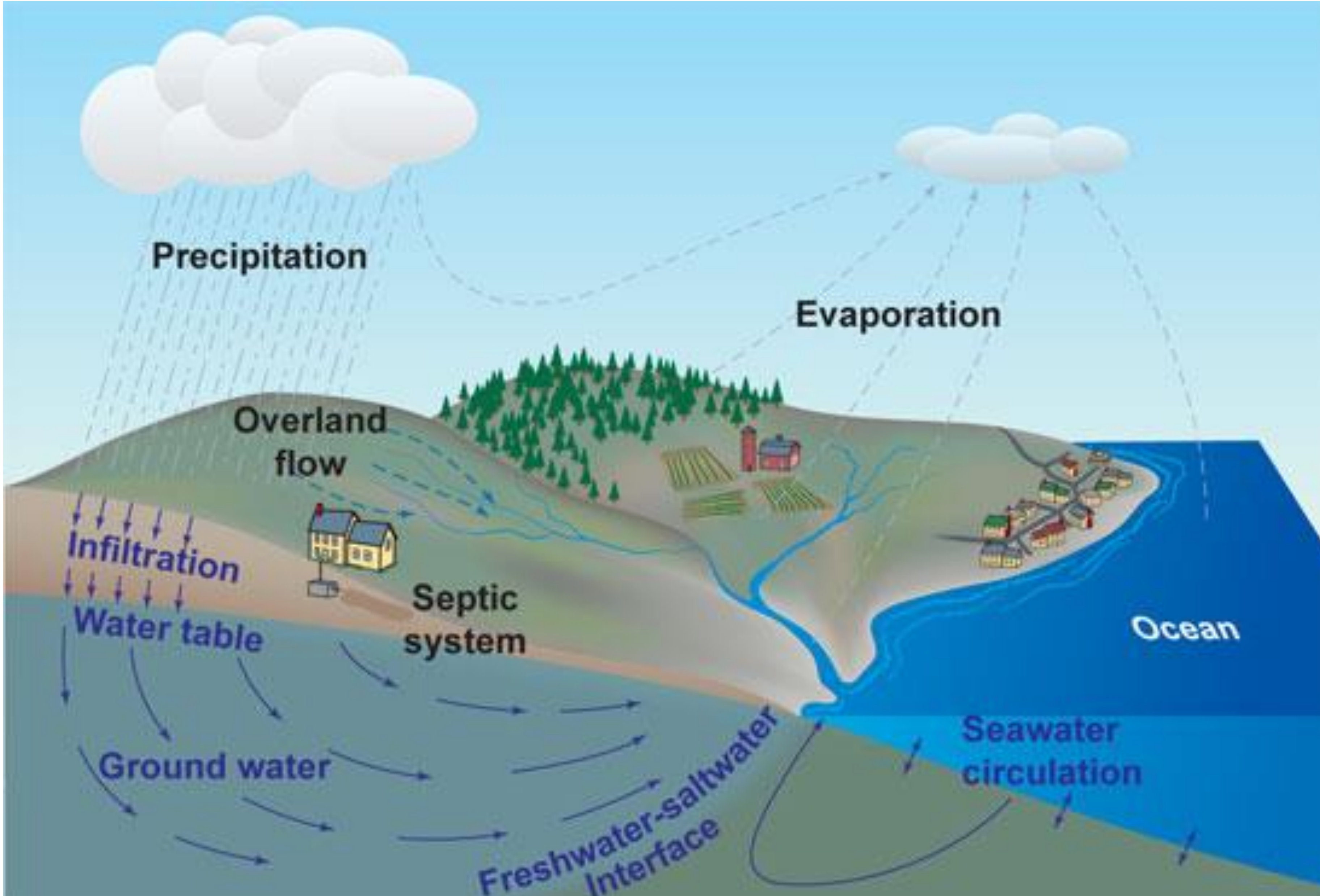
- Intrusion of saltwater from the sea
- Seawater entrapped in aquifers
- Salts in water concentrated by evaporation
- Return flow from irrigation
- Leakage from sewer systems and industrial effluents etc.

Some mechanisms of saltwater intrusion

- Reduction or reversal of WT gradients due to heavy pumping, which permits heavier saline water to displace lighter freshwater,

- Destruction of natural barriers that separate fresh and saline water e.g., construction of a coastal drainage canal,
- Improper subsurface disposal of waste saline water into disposal wells or landfills.

Hydrologic Cycle in Coastal Zones

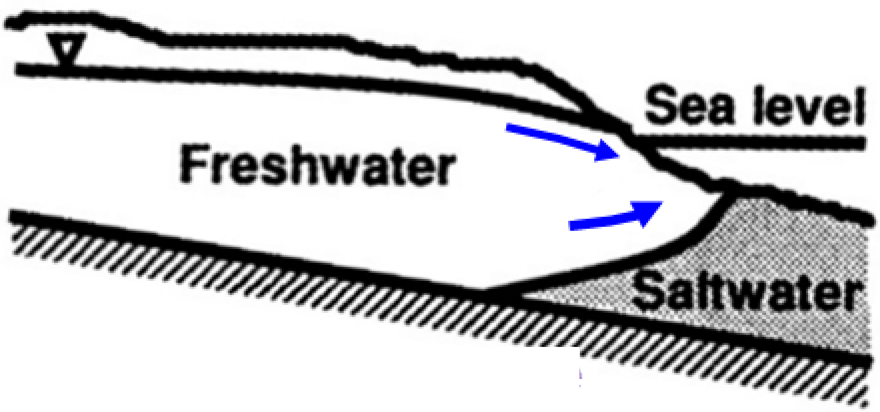


Coastal Aquifer Setting

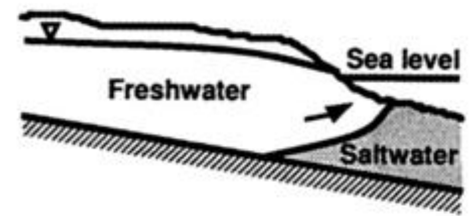
direct contact between freshwater & seawater

density seawater = 1025 kg/m^3 TDS = 35000 mg/l

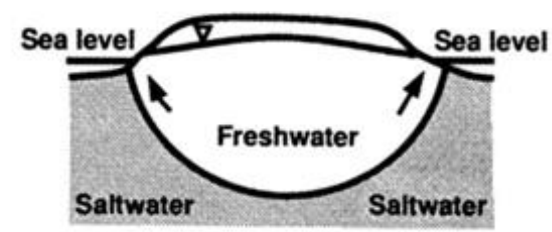
density freshwater = 1000 kg/m^3



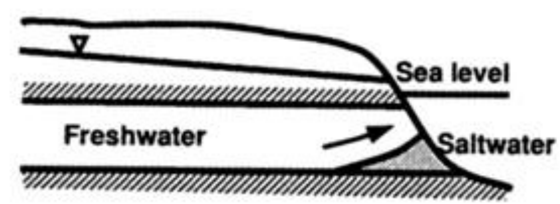
unconfined



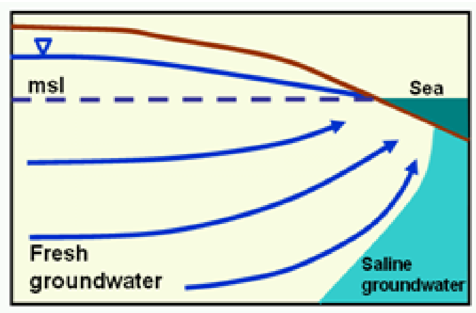
island



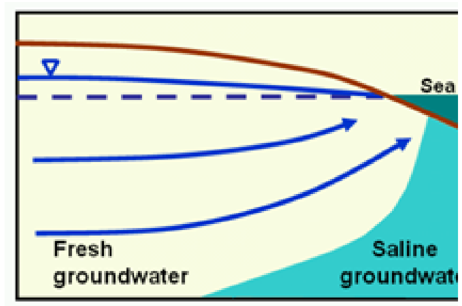
confined



Passive Intrusion: density-driven



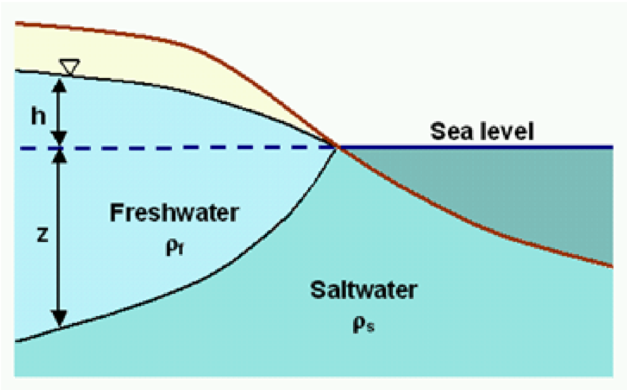
Pre-development



Post-development

reduced outflow

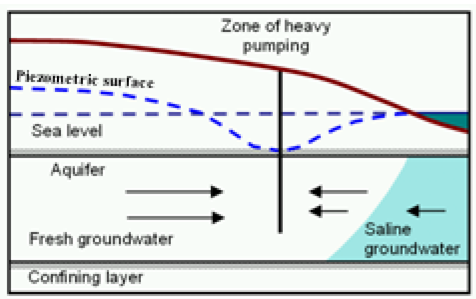
Ghyben-Herzberg Relationship



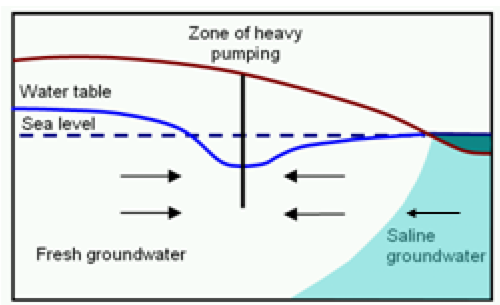
$$z = \frac{\rho_f}{\rho_s - \rho_f} \times h = 40 \times h \quad \text{for} \quad \rho_f = 1000 \text{ kg/m}^3, \ \rho_s = 1025 \text{ kg/m}^3$$

Active Intrusion: gradient-driven

(dominated by advective transport of saltwater)



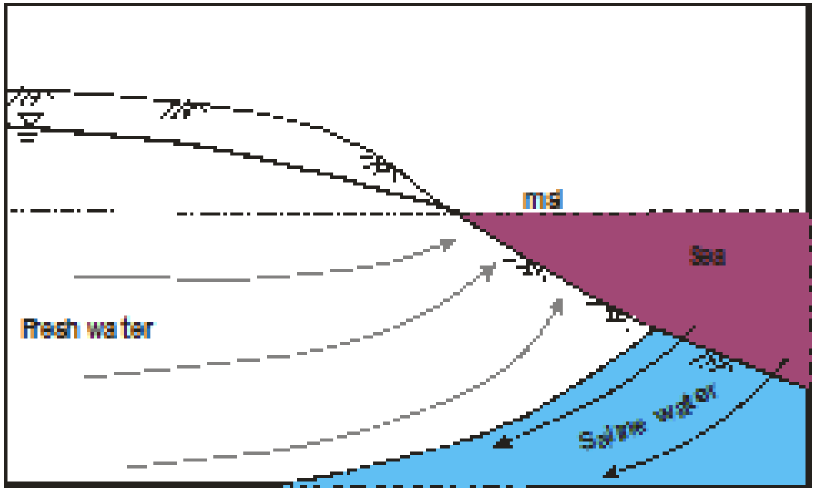
confined aquifer with piezometric surface below sea level.

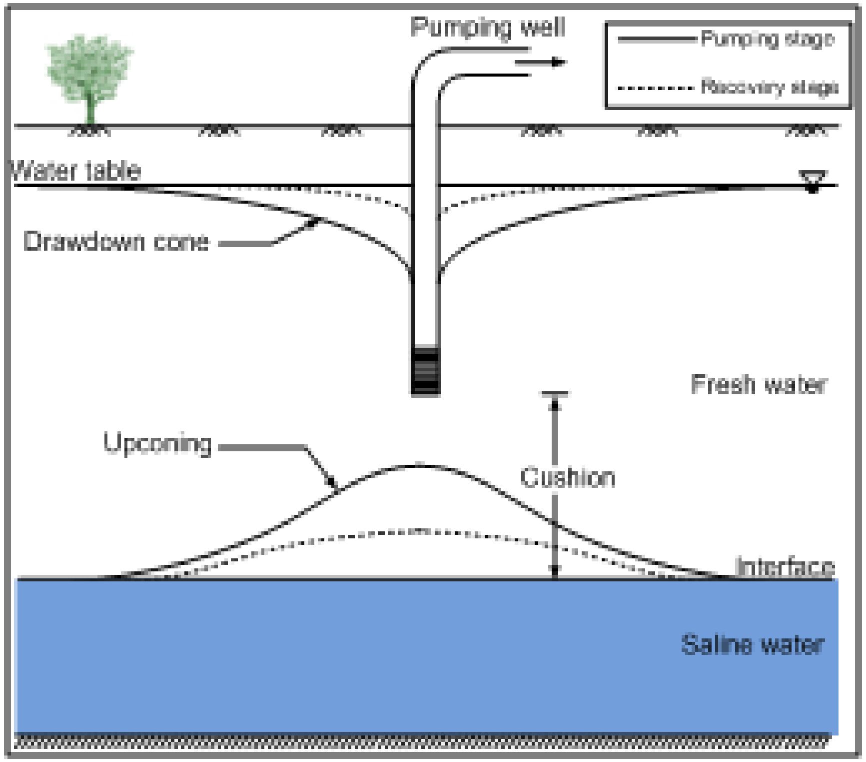


unconfined aquifer with water table below sea level.

Coastal hydrogeologic conditions

Regional Conditions





Localized Conditions

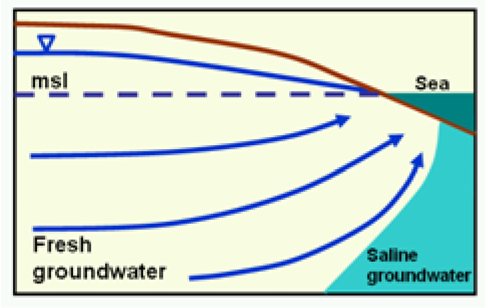
Planning issues

Regional Groundwater Development

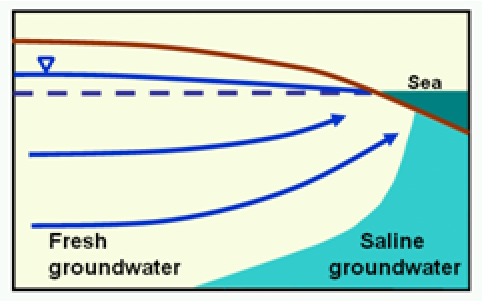
Planning of gw development ensuring that fw-sw interface is sufficiently below well screens in the area.

This requires adequate outflow to sea, which may be implemented by restricting gw development or enhancing recharge, or both.

Regional Planning



Pre-development



Maintain optimal outflow
after GW development

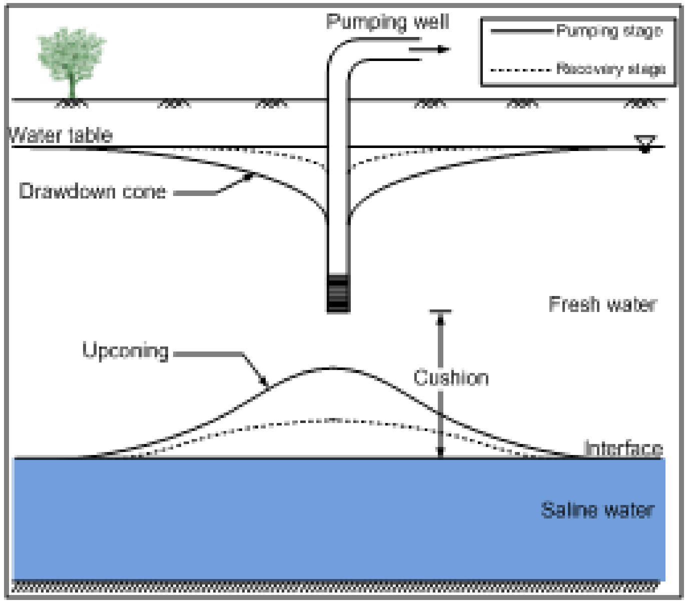
Planning issues

Localized Conditions - Design of Wells

Wells in the area must be designed to restrict upconing to available cushion between well screen & regional interface (the cushion is determined by regional gw development).

Planning issues

Localized Conditions - Design of Wells



- ❑ Providing sufficient cushion between well screen & rest position of interface.
- ❑ Restricting pumping rate/ duration.
- ❑ Providing sufficient 'rest period' between two successive pumping spells.
- ❑ Localized lowering of interface by pumping saltwater [Scavenging well] or by recharging a part of pumped freshwater [Recirculation well].

Management of coastal aquifers

- Planning of gw development in coastal aquifers is far more complex than traditional planning in inland aquifers.
- Variety of regional and local issues.
- Regional issues relate to position of fw-sw interface at a macro scale, while local issues address problems of well design & well operation.
- Mathematical models of varying complexity can be employed to plan gw development at both the levels.

Identify problem & develop conceptual model

A conceptual model of the mechanism of intrusion must be formed as a working hypothesis for further study.

Intrusion to be generally categorized into one or more of several types of intrusion:

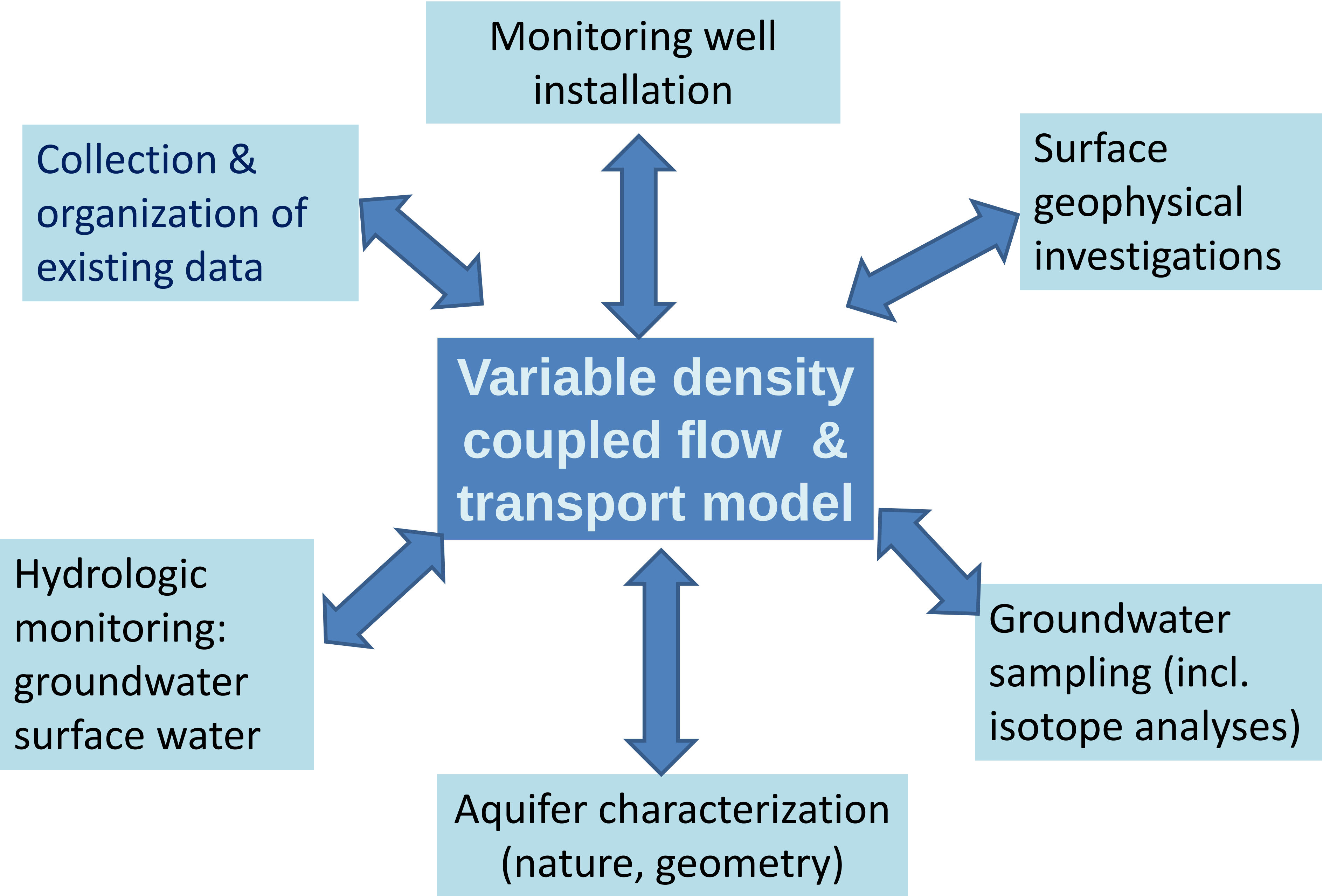
- horizontal & upward movement of interface (regional scale),
- downward leakage of brackish water from surface water (such as in estuarine environments), or
- saltwater upconing beneath a well field.

Numerical Modeling

Much insight can be gained from the process of collecting & analyzing the data.

Plausibility of conceptual model can be tested only through modeling of mechanism of saltwater intrusion, & deeper understanding of mechanism of intrusion be gained.

Modeling lies at the heart of the planning process, and interacts with all other study activities.


Monitoring well installation
Collection & organization of existing data
Surface geophysical investigations
Variable density coupled flow & transport model
Hydrologic monitoring: groundwater surface water
Groundwater sampling (incl. isotope analyses)
Aquifer characterization (nature, geometry)

Groundwater Salinity in Coastal Areas – Possible Inteventions

I. Scientific Monitoring, Assessment & Modeling

II. Behavioural & Institutional Approaches

III. Engineering Measures

I. Scientific Monitoring, Assessment & Modeling

Data Collection and Analysis

sufficient data to adequately define and understand the coastal aquifer system, its pumping stresses, and its associated saltwater problems.

Integrated Database

Data elements and map coverages in GIS database

Scientific Assessment & Modeling

Conceptual model of mechanism of intrusion

- horizontal & upward movement of interface,
- downward leakage of salt water from surface water,
- salt water upconing beneath a well field.

II. Behavioural & Institutional Approaches

Water supply and demand management

- limit amount of gw abstracted.
- relocate wells farther inland.
- Possible water-saving measures - reduction of evaporative & leakage losses, increase of irrigation efficiency, a change to less water demanding land uses and to find alternative sources of water (surface water / re-use of waste water).

Salt tolerant crops

Farmers can grow crops profitably by changing to more salt-tolerant crops. Crop adaptation accompanied by nutrients augmentation (in fertilizers) and soil quality improvement.

II. Behavioural & Institutional Approaches

Usage of blended water

poor quality gw physically blended with freshwater to provide water with an acceptable salinity level. Alternatively, poor quality gw could be applied in an alternating fashion with better quality surface water.

Coastal protection measures

Coastal protection measures in coastal zones prone to regular seawater flooding & seawater spray: e.g. levees, dikes, natural protection like dunes & mangrove vegetation, and forestation with high & dense trees can limit the susceptibility to salinization.

II. Behavioural & Institutional Approaches

Institutional approaches practiced to control gw salinity:

- **regulatory** (like well registration, licensing, groundwater abstraction rights and quota, land use restrictions),
- **economic** (subsidies for individuals or groups/sectors to invest in new technologies to manage salinity, investments in governmental aquifer storage & recovery programs, environmental taxes to discourage salinity increasing practices, compensation for financial losses caused by salinity)
- **advisory** (enabling access to information, expertise, funding and creating awareness and training).

III. Engineering Measures - effectiveness depends on local conditions

(A) Control Measures for Intrusion into Estuaries

- Barriers. Dams that physically prevent the seawater from moving past a certain point in the estuary.
- Restrictions on pathways for seawater intrusion. Construction of canals allows seawater to migrate into inland areas and allow a pathway for intrusion to occur; this should be minimized.
- Alternate sources of water. Water users may be able to obtain water from other sources
- Restrictions on use of water. During periods of higher sea-level or drought, stricter conservation and restrictions on export of water from the river basin may be considered for short durations.

III. **Engineering Measures** effectiveness depends on local conditions

(B) Control Measures for Intrusion into Coastal Aquifers

Seawater barriers. *Low permeability subsurface barriers*, and, *hydraulic barriers* viz., injection hydraulic barriers, extraction hydraulic barriers and mixed hydraulic barriers

Aquifer storage and recovery (ASR). Freshwater is injected into aquifer during high-supply seasons; recovered (pumped) during low-supply seasons.

Increased recharge. Spreading of water in upland recharge areas allows more percolation (infiltration into aquifer), which retards saltwater intrusion.

Skimming wells.

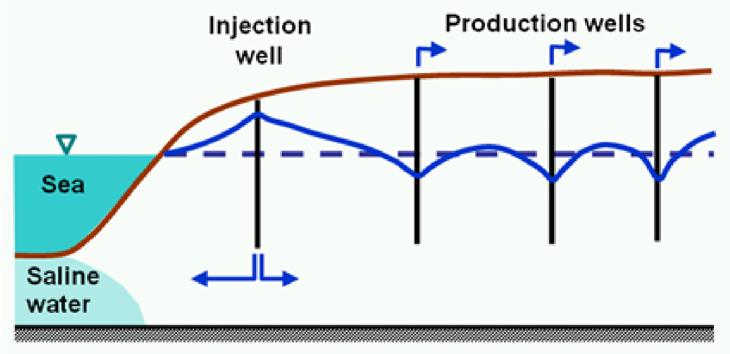
Strategies to Combat and Mitigate Intrusion

1. Enhancement of outflow

- reduction of pumpage
- re-location of wells
- enhancement of regional recharge
- recharge barriers
- tapping alternative aquifers

Enhancement of outflow – recharge barriers

(Usage of coastal canals, trenches, infiltration fields or injection wells)



Use of injection wells to form a pressure ridge

Strategies to Combat and Mitigate Intrusion

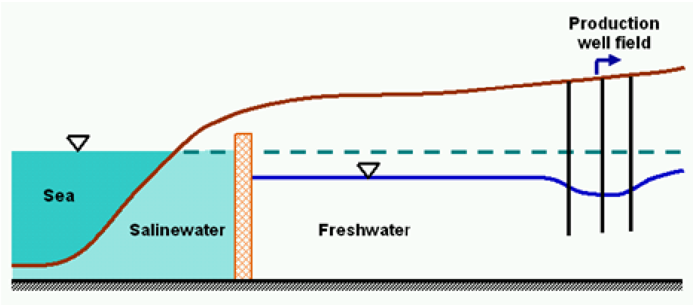
2. **Using barriers to demarcate the production zone**

- construction of physical barriers

- hydraulic barriers

  (pumping barriers or pumping-injection barriers)

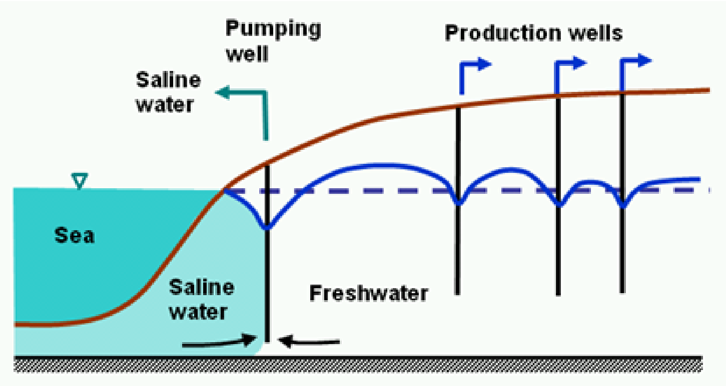
Using barriers to demarcate production zone – physical barriers



Subsurface barrier parallel to the coast

Using barriers to demarcate production zone – hydraulic barriers

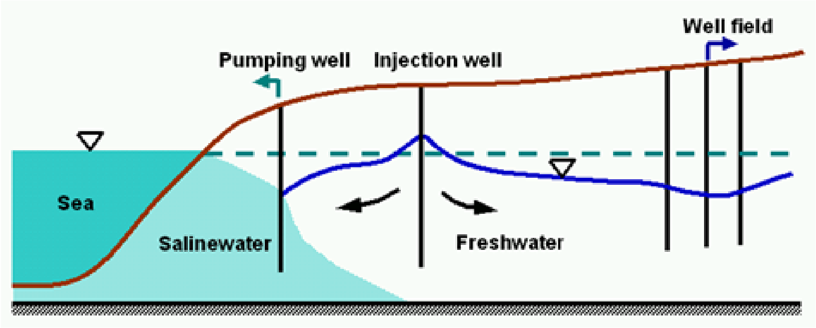
(Pumping barriers or pumping-injection barriers)



Pumping wells located parallel to coastline form a trench in the water table.

Using barriers to demarcate production zone – hydraulic barriers

(Pumping barriers or pumping-injection barriers)



Combination of pumping-injection well system

Interventions in Saurashtra Peninsula

Various measures taken by Gujarat State Government to enable control on GW salinity in Saurashtra Peninsula:

- **Physical structures**
  - Bandharas/Tidal regulators
  - Checkdams
  - Spreading channel along coastal tract
- **Shelterbelt plantation**

Tidal Regulators/Bandharas

- Concrete /solid masonry structure
- Built across mouth of creeks to prevent sea water incursion
- Tidal regulators – Gates are present for its operation.
- Bandharas – No gates are present. Height of this structure kept at an elevation more than high tide elevation

Tidal regulator

Medha creek bandhara


Inland stored water
Sea Side
Bandhara

Spreading Channel

- 8-10 m wide, 6-8 m deep channel
- Parallel to the coast within 1 km
- Arrests excess runoff/rainfall - augmenting recharge
- Act as hydraulic barrier to prevent subsurface sea water intrusion (lateral intrusion)
- Water availability for lift irrigation
- Carries freshwater from water surplus basin to water scarce basin

Checkdams

- Built across channels and tributaries
- Checks fast moving runoff, increases ponding time allowing water to infiltrate into subsurface
- Increased water availability through surface storage for irrigation in rabi season in normal rainfall years and through sub-surface storage in drought years

Shelterbelts - protection from sea sprays

- Coastal areas that receive consistent salt spray from the sea have elevated levels of soil salinity.

- Shelterbelt plantation (casuarinas) undertaken in the coastal region by Forest Department of Gujarat.

- Such shelterbelt plantations, including mangroves, along the coastline act as a bio-shield against coastal storm surges.

Effectiveness

Engineering technologies

- effective in addressing problems of groundwater quality and quantity in a coastal aquifer system

- generally more expensive, invasive, and site-specific than the adaptation options of scientific monitoring, assessment and modeling, and, behaviour and institutional approaches.

To sum up…

Coastal aquifers present very complex & unique management challenges to combat groundwater salinity.

Effective management requires balancing many competing demands, & typically requires use of a suite of numerical models, field investigations, long-term data monitoring, and development of a consensus on proposed management options by many levels in state, local governments, & concerned groups.

Water for their future …

THANK YOU !