Mitigating salinity impacts on drinking water in Bangladesh

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1. Background

- **Availability of Arsenic-free fresh groundwater resources:** wide availability of fresh groundwater in the deep aquifer in the coastal areas (<300-400 bls) and in inland areas (<150m bls). Limited model simulations indicate that groundwater in the deep aquifer can provide safe drinking water for 100 years if it is only used for domestic water supply.

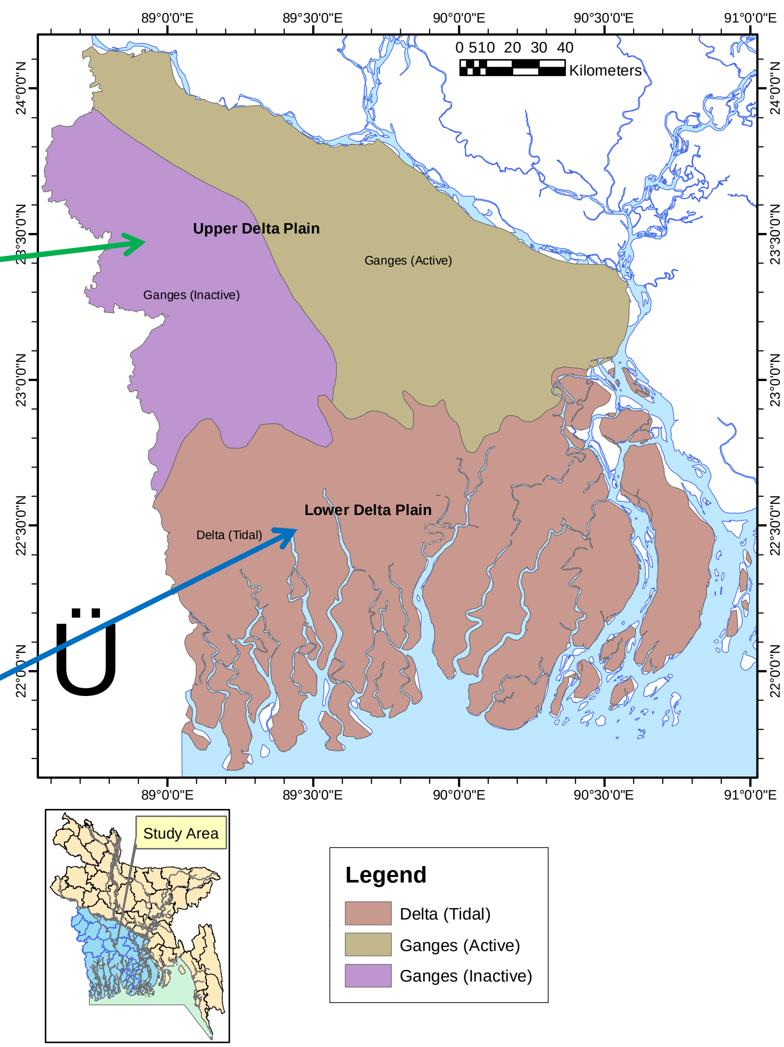
- **Salinity distribution and saline water intrusion pathways:** groundwater in the shallow and middle aquifers in the coastal areas are brackish or saline. Pockets of saline groundwater exist in the inland areas. The main pathways of saltwater intrusion include lateral seawater intrusion, vertical leakage of inundated seawater, and mixing of saline groundwater induced by pumping.

- **Impacts of climate change and human activities on saltwater intrusion:** The impact of sea level rising on seawater intrusion is only limited in fresh/sea water interface. The flooding seawater during periodic storm surges may have large impacts on increasing surface water and shallow groundwater salinity. Groundwater abstraction is a very important driver causing mixing of pre-existence saline groundwater in the middle and deep aquifers.

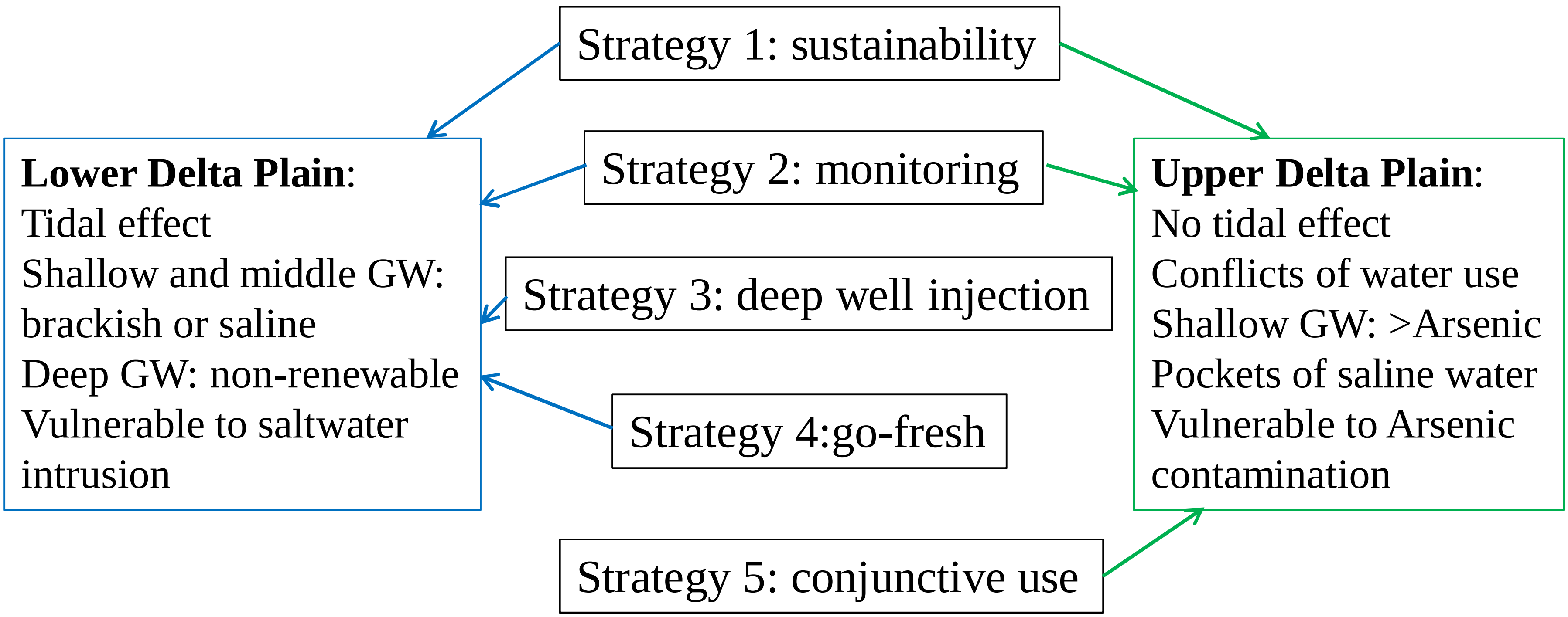
1. Background

Upper Delta Plain:
No tidal effect
Conflicts of water use
Shallow GW: >Arsenic
Pockets of saline water
Vulnerable to Arsenic contamination

Lower Delta Plain:
Tidal effect
Shallow and middle GW: brackish or saline
Deep GW: non-renewable
Vulnerable to saltwater intrusion



1. Background



Strategy 1: sustainability

Current situations:

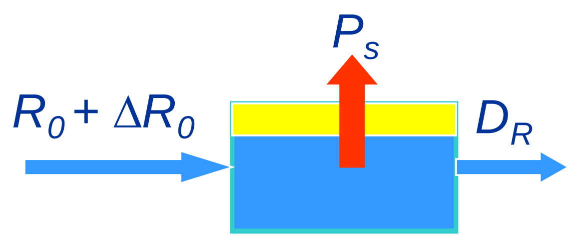
- Deep groundwater is practically non-renewable.
- Deep groundwater is arsenic-free and becomes only safe drinking water in Lower Delta Plain.
- The number of deep pumping wells is increased rapidly in past decades.
- Abstraction of deep groundwater is not regulated, not managed, and not systematically monitored.
- Potential risks:
  - ✓ Migrating arsenic from shallow aquifer.
  - ✓ Saltwater intrusion.
  - ✓ Aquifer depletion.

Strategy 1: sustainability

Water balance principle – renewable resources

Sustainable yield = Natural recharge plus induced recharge by pumping and minus residual discharge (environmental flow)

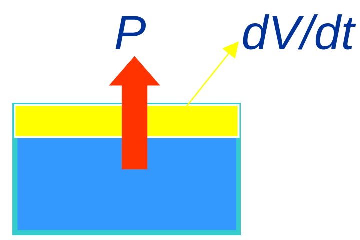
$$P_S = R_0 + \Delta R_0 - D_R$$



Water balance principle – non-renewable resources

Managed yield = controlled depletion of groundwater storage

$$P = \frac{dV}{dt}$$



Zhou, 2009, JH 370 207-213
Gleeson/Zhou et al, 2010
Nature Geoscience 3

Strategy 1: sustainability

Recommended actions:

- Characterization of the deep aquifer system and assessment of groundwater storage for every district.
- Projection of drinking water demand for every district.
- Optimization of well locations and production rates in order to meet drinking water demand and to prevent saltwater intrusion. Numerical groundwater models should be used to optimize well locations (distance between wells, and depth of wells) and pumping rates.
- Simulation of the response of the aquifer system to planned groundwater abstraction to assess viability of long-term safe drinking water supply (for example, 100 years planning period).
- Implementation of the groundwater development plan:
  - ✓ Licensing and register of abstraction permits.
  - ✓ Monitoring and control of pumping rate.
  - ✓ Who?

UCL, 2013

Strategy 2: monitoring

Current situations:

- BWDB (2013): 42 groundwater monitoring well nests, each nest consists of 3 to 5 piezometers down to the maximum depth of 350 m; 102 line wells, each line well consists of 5 wells down to the maximum depth of about 100 m. Groundwater levels are measured once per week, water samples are taken at the wet and dry season for water quality monitoring (25 parameters).
- BADC: 158 water quality monitoring stations for salinity monitoring in coastal areas. EC is measured with portable EC meter twice in a day, during the tide and after the tide. BADC also measures groundwater levels twice a month in about 3000 wells.
- BRAC WASH: >6000 wells for drinking water supply. Five water quality parameters are measured in these wells (pH, Cl, Fe, Mn and As).
- A unified national groundwater monitoring network is not available.
- A national groundwater database and information system is not constructed.
- Information for salinity management is not available.

Strategy 2: monitoring

Principles:

- National baseline monitoring
  - ✓ Regular monitoring wells for combined groundwater level and quality monitoring
  - ✓ Multiple piezometers for major aquifers (shallow, middle, and deep)
  - ✓ Integration of modelling and monitoring
- Early warning monitoring
  - ✓ Measuring EC monthly from all pumping wells
  - ✓ Targeted monitoring wells in fresh/salt water interfaces
- Fresh/salt water interface monitoring
  - ✓ Multiple piezometers with resistivity cable
  - ✓ Resistivity profiling

Strategy 2: monitoring

Recommended actions:

- Capacity building of the national authority for managing groundwater monitoring: WARPO
- Integration of various groundwater monitoring networks into a national groundwater monitoring network with the optimization of:
  - ✓ Objectives for groundwater quantity and quality monitoring
  - ✓ Network density: spatial locations and multiple depths
  - ✓ Observation/sampling frequency: weekly levels, twice/year quality
  - ✓ Monitoring instruments: automatic loggers and hand measuring
  - ✓ Operation and maintenance of observation wells
- Development of a national groundwater database and information system:
  - ✓ Web-based and free access
  - ✓ Integration of hydrological conceptual model, groundwater levels and groundwater quality
  - ✓ DINO as an example: http://www.dinoloket.nl/

Strategy 3: deep well injection

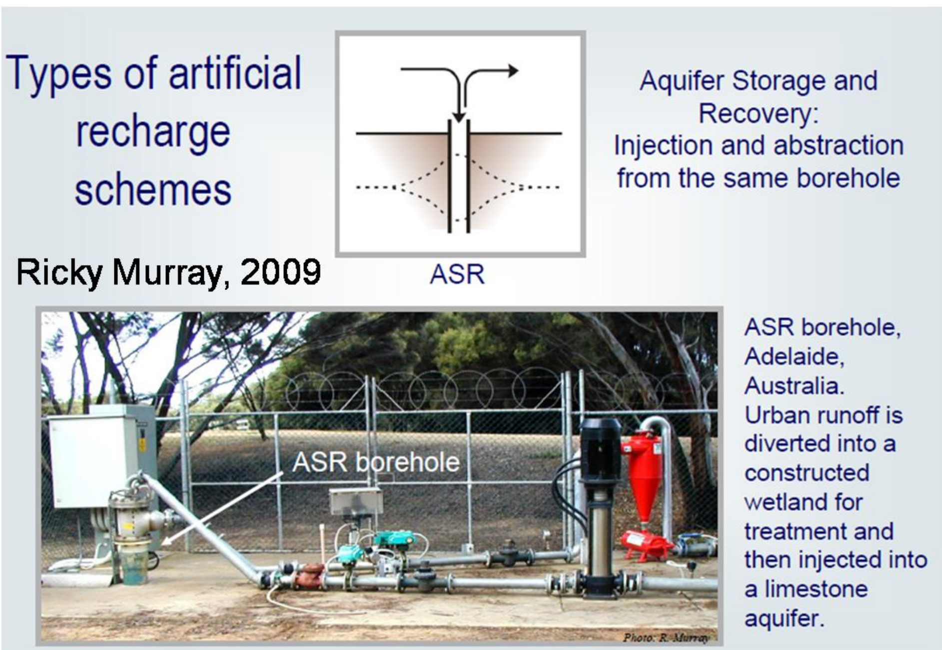
Current situations:

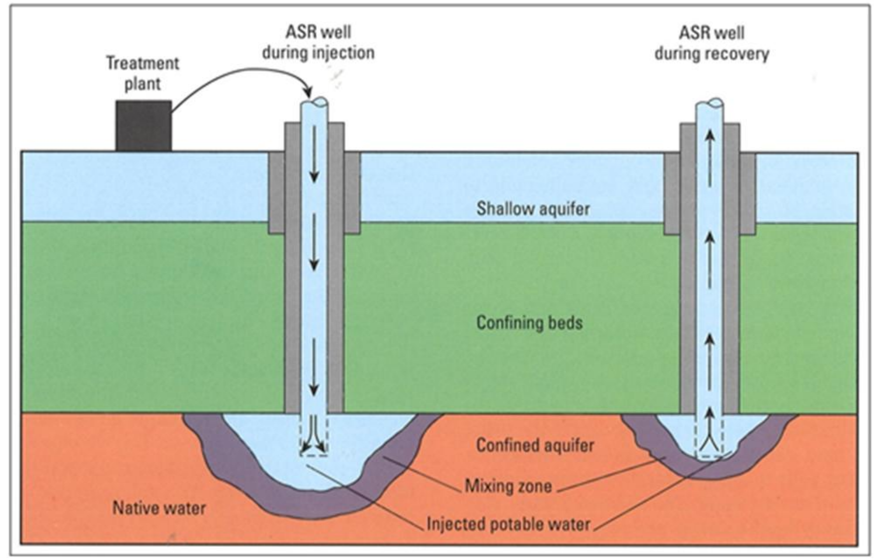
- There is abundant water resources in Bangladesh: average annual rainfall in the coastal area > 2000 mm/a.
- 70-80% of the annual rainfall occurs during the monsoon period (Jun.-Oct).
- Flat geomorphology does not allow for surface storage (reservoirs).
- Groundwater storage in aquifers provides an attractive option to achieve long-term water supply sustainability.
- Deep well injection (ASR technology) has been applied to:
  - ✓ provide the seasonal storage of water,
  - ✓ reduce groundwater overdraft,
  - ✓ replenish the depleted aquifer,
  - ✓ create pressure barriers to prevent saltwater intrusion,
  - ✓ improve the water quality for drinking water supply.

Strategy 3: deep well injection

ASR technology:

Injection and abstraction using wells





System of Aquifer Storage and Recovery well (Maliva and Missimer, 2010)

Strategy 3: deep well injection

Conditions for ASR application:

- The transmissivity of the aquifer should be sufficiently large to allow for the injection and recovery of water at the target well capacities.
- The storage zone of the aquifer should be confined by top and bottom less permeable layers so that a large percentage of the injected water can be recovered.
- Availability of water sources of good quality for injection in order to prevent clogging and pollution of native groundwater.
- The interactions between the injected water, native water, and soil media should not result in the deterioration of the quality of the stored water.
- Land availability and site accessibility.
- Technical capacities on well drilling, maintenance, and operation.
- Proximity to electric power infrastructure and water distribution infrastructure.

Strategy 3: deep well injection

Advantages:

- Aquifer provides large storage space at no cost;
- Aquifer storage does not loose water due to evapotranspiration;
- There is reduced risk of pollution;
- Less land is needed than for surface reservoirs;
- Less impacts to environment, and impacts are most likely positive;
- Water quality may be further improved with flow passages.

Limitations:

- Prevention of well clogging requires good quality of source water (pre-treatment) and proper operation and maintenance (technical capacity);
- Changes of water quality by mixing and reactions must be monitored;
- A legal and regulatory framework is needed to protect stored water.

Strategy 4: go-fresh

Technology:

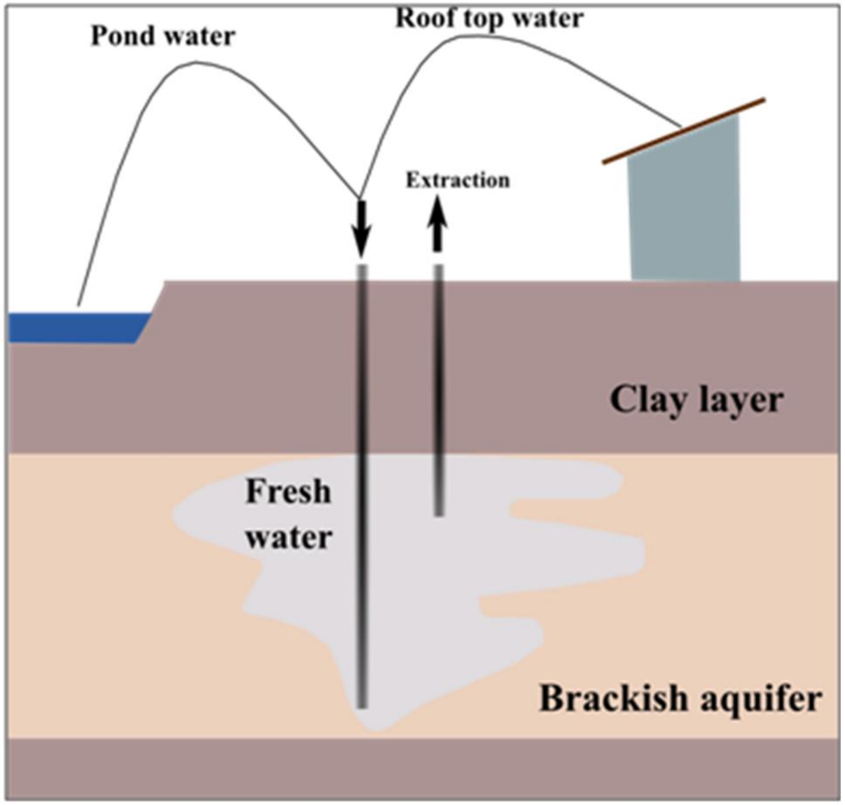
Create fresh water lens in storing fresh water in shallow brackish water aquifer.

The test system in Khulna and Satkhira from 2009 to 2012 consists of:

(1) harvesting of rainwater from a pond and /or a roof;

(2) injection of the water into the shallow aquifer by 4 to 6 infiltration wells with diameters of 12 or 22 inches;

(3) an extraction well installed in the middle equipped with a hand pump for drinking water supply.



Creation of a fresh water lens by infiltrating rainwater in the brackish aquifer (Acacia Water, 2011)

Strategy 4: go-fresh

Conditions for application:

- Relatively thin clay cover on the top (less than 15m);
- Considerable thick shallow aquifer (20m) with good hydraulic conductivity (>5 m/d);
- Moderately groundwater salinity (<10,000 uS/cm);
- Low concentrations of iron and arsenic;
- Availability of suitable source water from pond (government or privately owned, fresh water, not fish culture) and roof (community or government owned building or corrugated iron roof with adequate size);
- Socio-economic factor such as local partner NGO, good accessibility and willingness of the community to participate; and
- Agreement with (and approval of) the district and upazila level DPHE officials and local government institutions such as union parishads.

Strategy 4: go-fresh

Advantages:

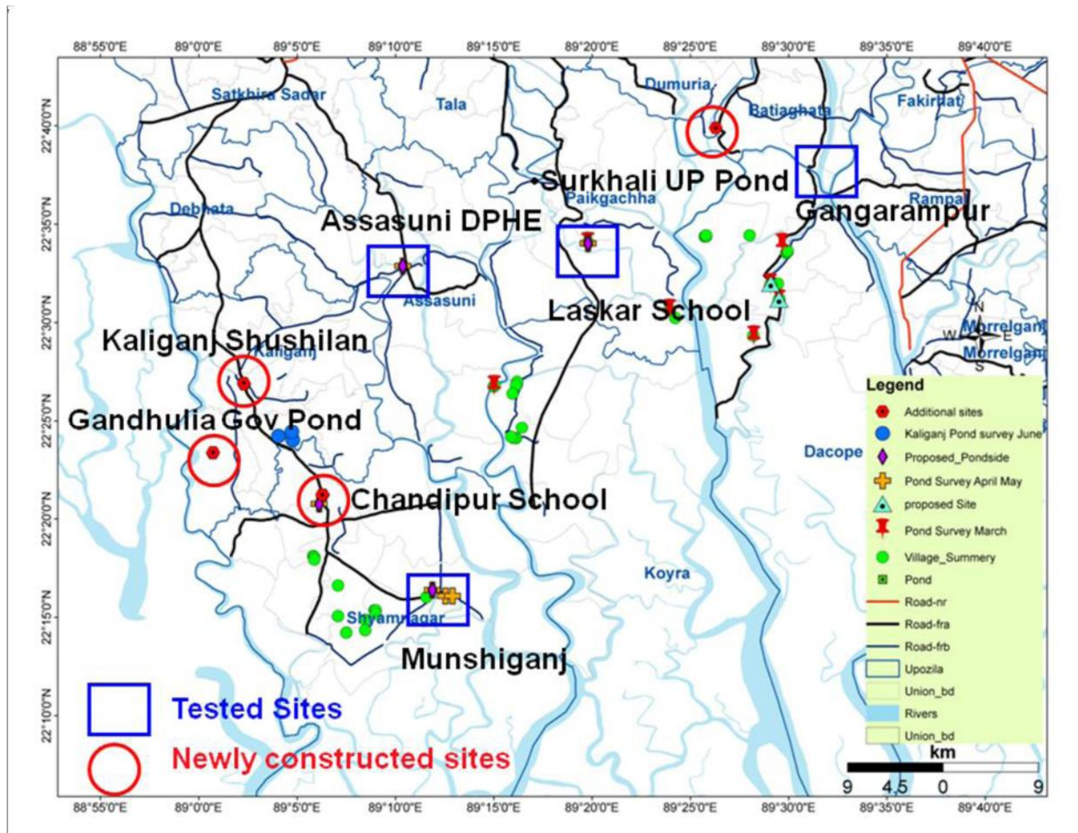
- Water is stored in the subsurface, no evapotranspiration loss, less vulnerable to pollution and damage by storm surge/cyclones comparing to surface storage (such as ponds);
- Less land is required;
- Positive environmental impacts.

Limitations:

- Availability of good quality of source water (collection and pre-treatment of storm water);
- Prevention of brackish water intrusion by optimizing infiltration and extraction (technical capacity).

Strategy 4: go-fresh

Creating fresh water bubbles in brackish aquifer in Bangladesh 20009-2011
Acacia Water and Dhaka University, in partnership with UNICEF and DPHE



Strategy 5: conjunctive use

Current situations:

- In Upper Delta Plain, surface water (rivers) is available in wet season. This provides opportunities for conjunctive use of surface and groundwater.
- The objective of conjunctive use is to increase the yield, reliability of supply and efficiency of a water system by diverting water from streams or surface reservoirs to storage in aquifers for later use when surface water is not available.
- Advantages of a conjunctive use system are:
  - ✓ Increase in yield.
  - ✓ Offset uneven distribution of runoff.
  - ✓ Stores water in aquifers closer to users.
  - ✓ Can operate with smaller surface distribution.
  - ✓ Can function with smaller surface reservoirs or diversion structures.
  - ✓ Can prevent or reduce drainage problems.
  - ✓ Canal lining is not necessary.

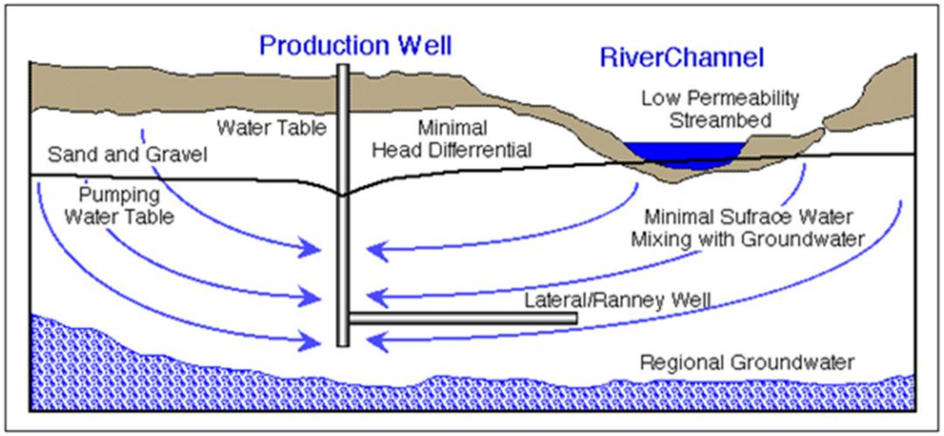
Strategy 5: conjunctive use

Technology - River bank infiltration:

Install a line of wells at a short distance from, and parallel to the bank of a river which is hydraulically connected to an aquifer through the permeable riverbed.

The quantity of surface water that can be induced to recharge the aquifer depends on:

- Amount and proximity of surface water;
- Hydraulic conductivity of the aquifer;
- The area and permeability of the stream bed deposits;
- The hydraulic gradient created by pumping.



Scheme of a river bank filtration system (University of Hawaii, 2000)

Strategy 5: conjunctive use

Technology - River bank infiltration:

Advantages:

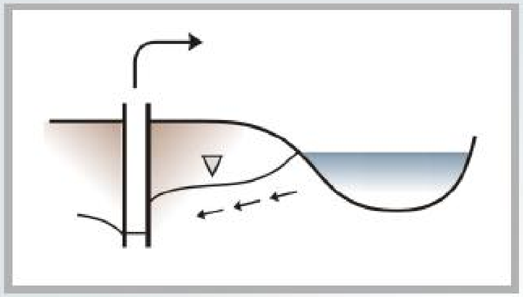
- The possibility to extract large volumes of water is the biggest advantage. The abstracted amount is limited by the infiltration capacity of the river bank only, because the discharge of the river is an order of magnitude greater than the abstracted amount.
- Compared to surface water abstraction, the post treatment requirements of the water are reduced. The natural filtration capacity of the aquifer can remove most micro-pollutants.

Limitations:

- Long-term contamination of river water by persistent organic compounds (such as pesticides and pharmaceuticals) may contaminate the groundwater.

Strategy 5: conjunctive use

Technology - River bank infiltration:



Maximising river bank storage and filtration

Bank Filtration

South Korea. River water is induced to flow through the alluvium to wells located alongside the river.

Ricky Murray, 2009

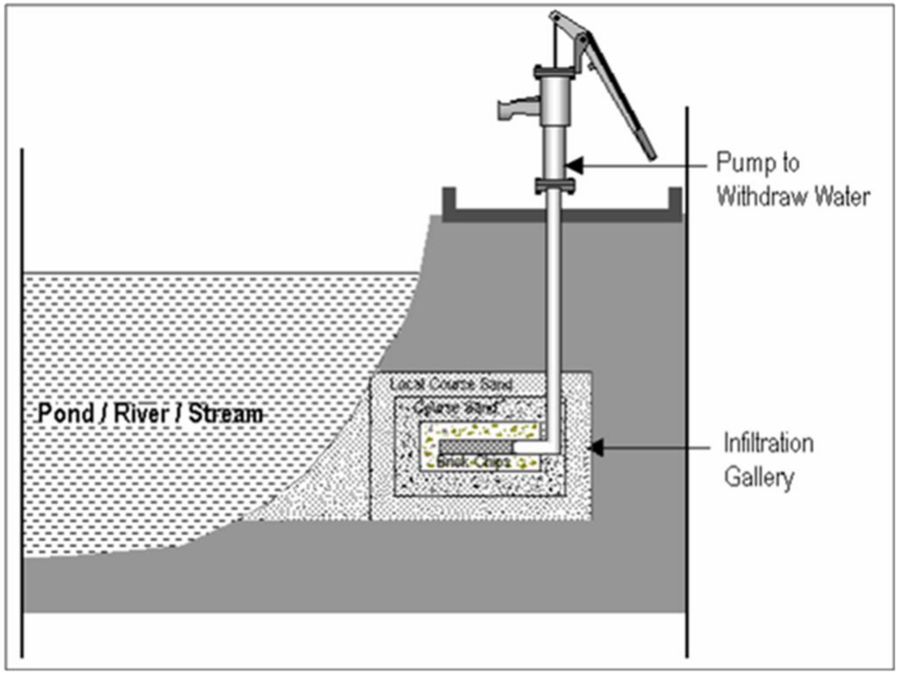
Strategy 5: conjunctive use

Technology - Infiltration gallery:

Infiltration gallery is installed below the bed of ponds, rivers, streams or other surface water sources to collect fresh water for water supply.

The selection criteria for installing infiltration gallery are (WaterAid Bangladesh, 2006):

- River or ponds with bottom permeable sandy soils.
- Source water is available whole year round and close to the community.
- Source water is not polluted.
- Community is willing to pay for the service.



Scheme of an infiltration gallery system (WaterAid Bangladesh, 2006)

Strategy 5: conjunctive use

Technology - Infiltration gallery:

Advantages:

- Large amount of water can be extracted from less permeable aquifers.
- Natural infiltration can significantly improve water quality.
- Whole-life costs may be less than alternative river intake types.
- The system has less detrimental impact on the local environment than more conventional river intake systems.

Limitations:

- Poorly designed systems can experience a significant reduction in yield if the filter pack becomes blinded through ingress of silt.
- The presence of clay can present many technical difficulties and hinder gallery performance.

Strategy 5: conjunctive use

Infiltration gallery in Taiwan
Pingtung County Linbian river
since 1923, 70,000-250,000m^3/day

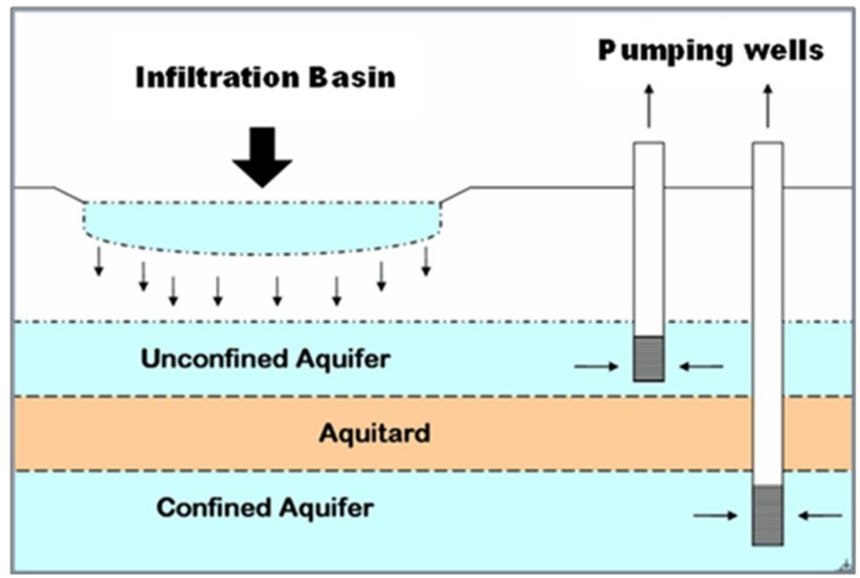
Strategy 5: conjunctive use

Technology - Infiltration basin:

Infiltration basins are either excavated, or are enclosed by dikes or levees which retain the recharge water until it has infiltrated through the bottom of the basin.

Conditions for application:

- Unconfined aquifer with permeable unsaturated zone (sand and gravel).
- The thickness of the unsaturated zone is sufficiently large for storage.
- Hydraulic conductivity is large for well recovery.
- Availability of water sources of good quality for infiltration.
- Land availability.



Infiltration basin and pumping wells (Johnson, 2008)

Strategy 5: conjunctive use

Technology - Infiltration basin:

Advantages:

- Low cost technology, simple maintenance.
- Ability to infiltrate large quantity of water.
- Clogging is a less problem.
- In combination with nature conservation.

Disadvantages:

- Require large surface area.

Strategy 5: conjunctive use

Infiltration basin Cebu, Philippines since 1997

The design parameters and capacities are:
- Mananga River catchment area above the weir: 71 km^2
- Average river discharge: 135,000 m^3/d (1.6 m^3/s)
- Weir height: 5m
- Surface storage behind the weir: 500,000 m^3
- Design flood: 1,000 m^3/s

Aquifer characteristics:
- Aquifer area in the valley: 1 km^2
- Aquifer thickness: 20-30 m sand and gravel
- Aquifer storage: $3.2x10^6$ m^3

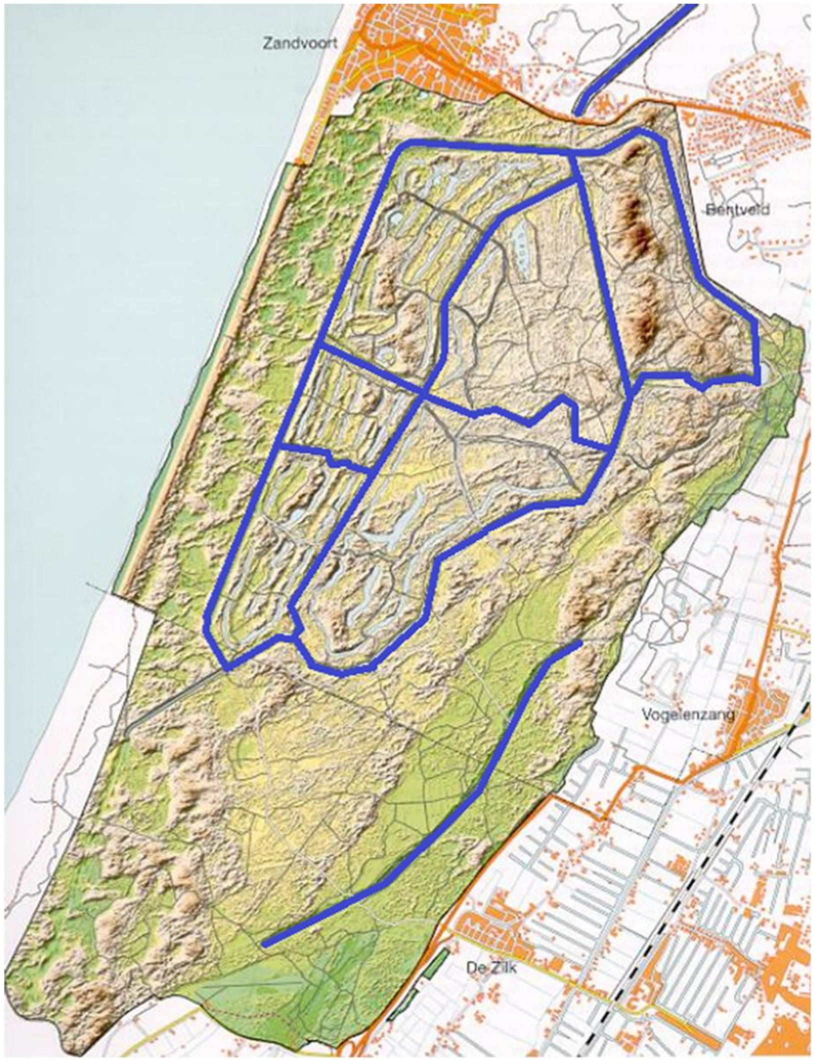
Artificial recharge scheme:
- Settling basin: 86,000 m^2
- Infiltration basin: 45,000 m^2
- Infiltration rate under 1m head: 100,000 m^3/d (2.5m/d)

Production capacity:
- Design production capacity: 33,000 m^3/d
- Production in dry season: 22,000 m^3/d

Strategy 5: conjunctive use

Dune water supply for Amsterdam:

- Artificial infiltration of river water from Rhine River started in 1957
- 40 km of abstraction canals
- 9 km of drains
- 40 recharge ponds (86 ha)
- 65 Mm^3/year
- 60% Amsterdam water supply



7. Conclusions

- Deep groundwater is the most reliable source for drinking water supply, but is likely not renewable and must be used only for drinking water supply. The abstraction must be managed and monitored systematically.
- In Lower Delta Plain, strategies for go-fresh and deep well injection should be implemented to achieve long-term sustainability of safe drinking water supply.
- In Upper Delta Plain, conjunctive use of surface and groundwater should be investigated. Feasible technologies include river bank infiltration, gallery, and infiltration basin.

Thank You!

Questions and remarks