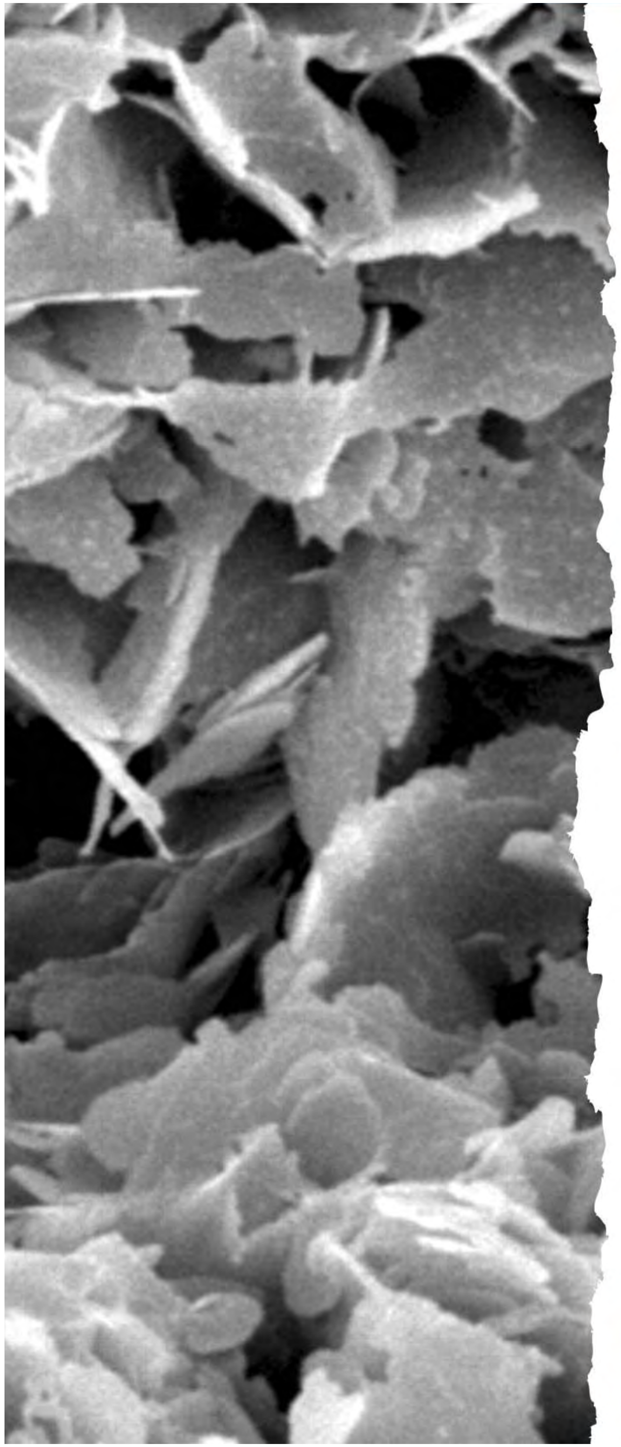


Clogging During Managed Aquifer Recharge

Russell Martin
General Manager, AGT

Australian Groundwater Technologies AGT

Presentation Outline

- Introduction to managed aquifer recharge
- Clogging types and processes
- Infiltration Basin Design Considerations
- Planning an MAR Scheme (emphasis on clogging management)
  - Know your source water
  - Know your aquifer
  - Field investigations
  - Basin Design
- Summary

Introduction

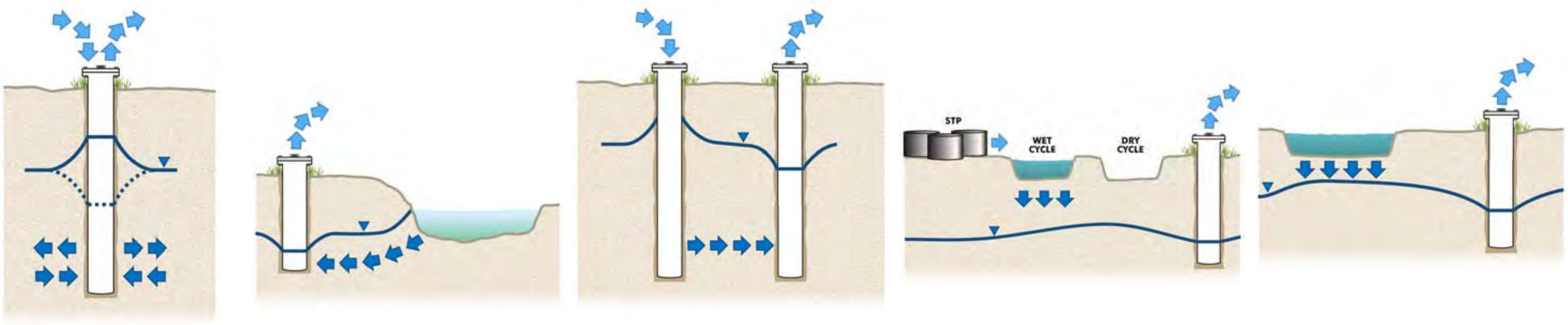
- Significant advances in the areas of geochemistry, microbiology and aquifer hydraulics regarding the science of recharge of water to aquifers have been made over the past decade.
- With the increased uptake of managed aquifer recharge as a water resources management practice:
  - that can augment traditional water supplies;
  - or address a variety of legacy issues associated with overuse:
- A greater appreciation of how complex the problems associated with aquifer recharge can be is becoming apparent.

What is Managed Aquifer Recharge (MAR)

- Managed aquifer recharge is the purposeful recharge of an aquifer under controlled conditions to store the water for later abstraction or to achieve environmental benefits.
- Potential sources of recharge water include:
  - stormwater (excess or redirected),
  - treated wastewater
  - co-produced (associated water) from mining or petroleum activities.

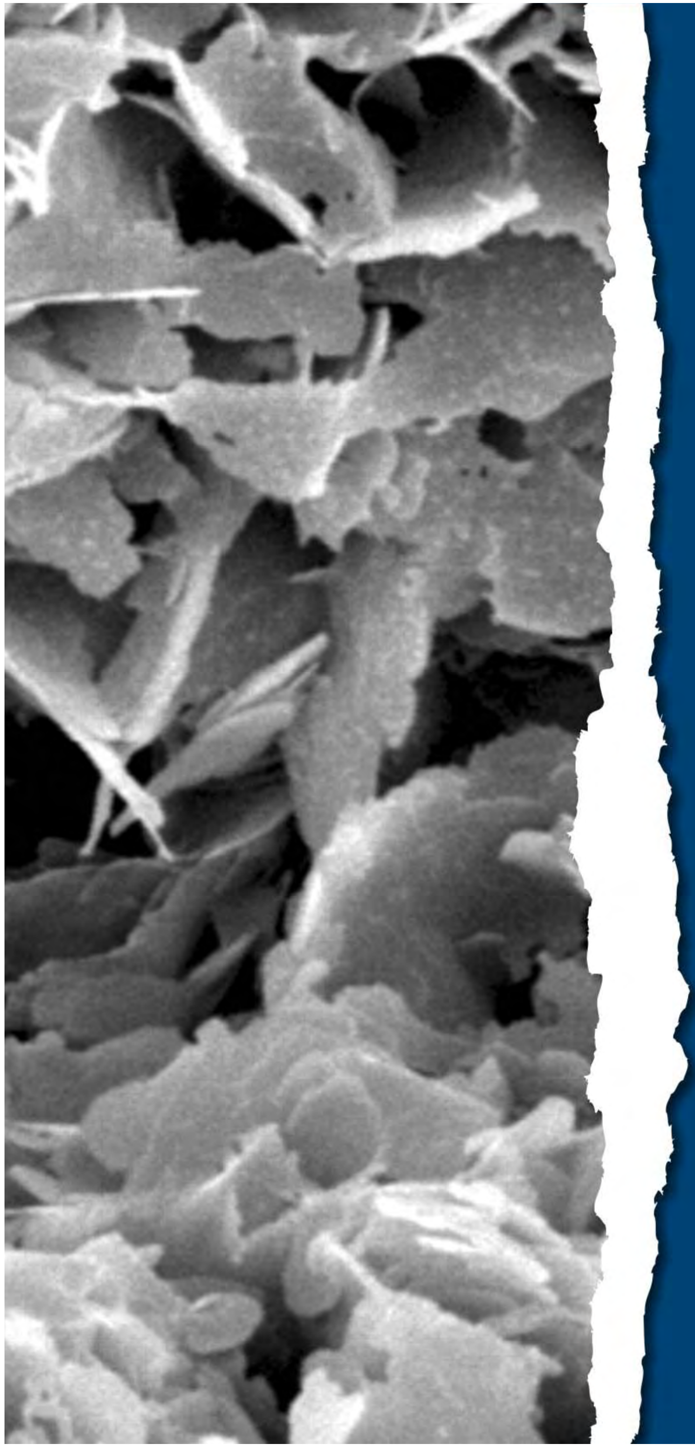
Water can be added to aquifers by ……

- infiltration (via structures such as ponds, basins, galleries and trenches) ;
- injection and recovery via purposely constructed wells (ASR, ASTR).
- Bank filtration, percolation tanks, sand dams, soil aquifer treatment



ASR **Bank Infiltration** **ASTR** **SAR** **Infiltration Basin**

- Collectively the various methods of enhanced aquifer recharge are referred to as Managed Aquifer Recharge (MAR).



Clogging Types & Processes

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Why is clogging important?

- Clogging causes impaired injectivity restricting the volume of water that can infiltrate or be injected into the target aquifer.
- Severe clogging may lead to infiltration basins or injection bores being replaced.
- It is the biggest risk to the successful & sustainable operation of any MAR scheme

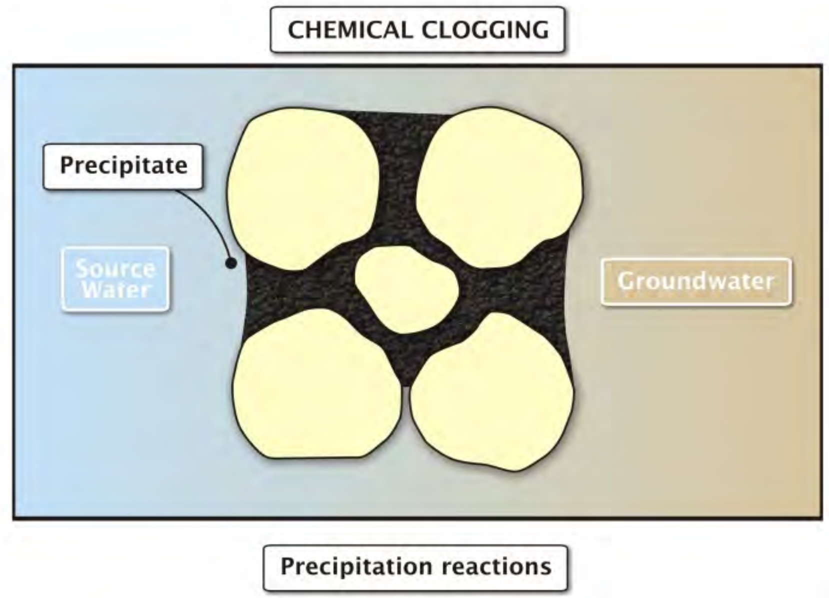
CLOGGING <u>WILL</u> HAPPEN!

Clogging can be divided into 4 principal types ……

1. *Chemical Clogging*
2. *Physical Clogging.*
3. *Mechanical Clogging*
4. *Biological Clogging*

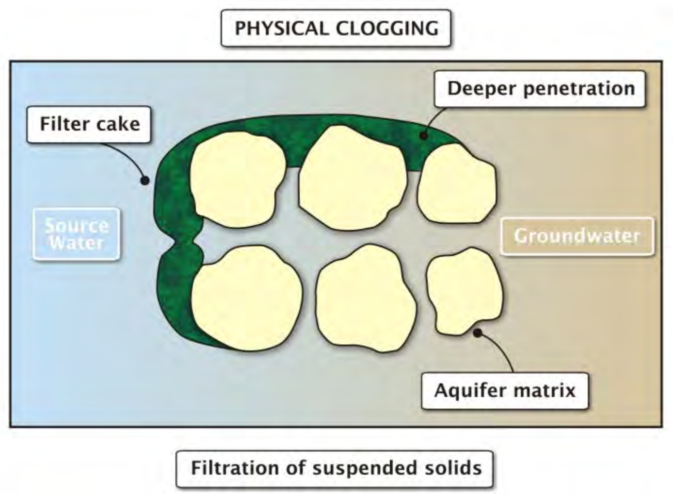
Chemical Clogging

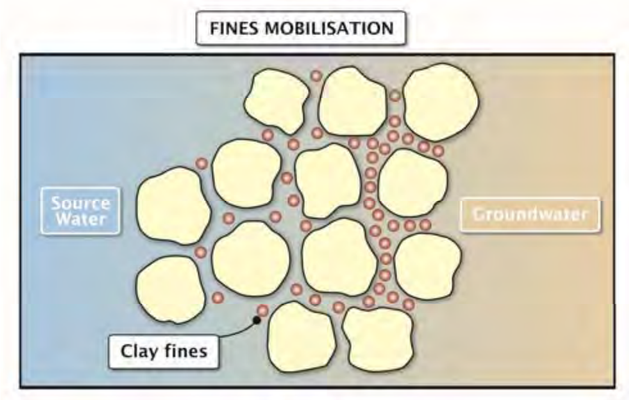
- Geochemical reactions that result in:
  - The precipitation of minerals e.g. iron aluminium or calcium carbonate growth;
  - Aquifer matrix dissolution (can also work to increase hydraulic conductivity);
  - Ion exchange;
  - Ion adsorption;
  - Oxygen reduction.
  - Formation of insoluble scales.
  - Formation dissolution.



Physical Clogging

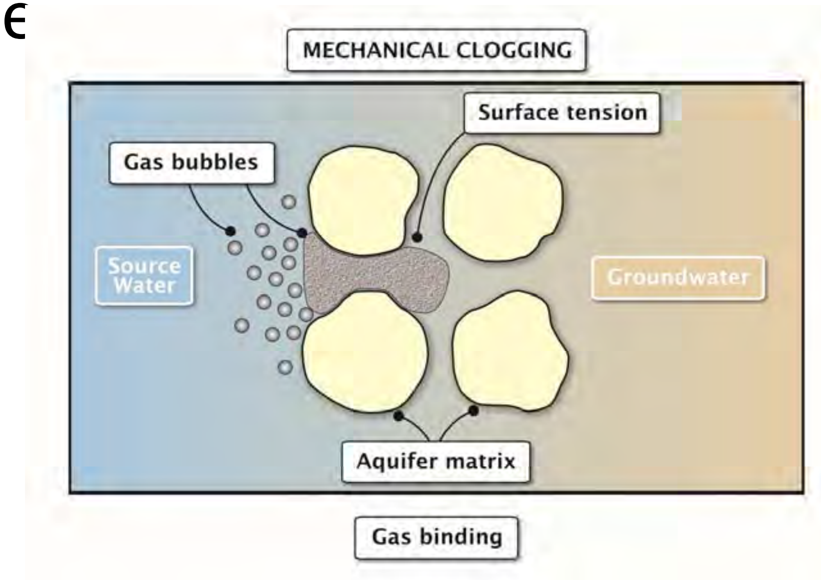
- Accumulation / Injection of organic and inorganic suspended solids.
- Clay swelling (e.g. montmorillonite).
- Clay deflocculation.
- Invasion of drilling fluids (emulsifiers) deep into the formation.
- Temperature.





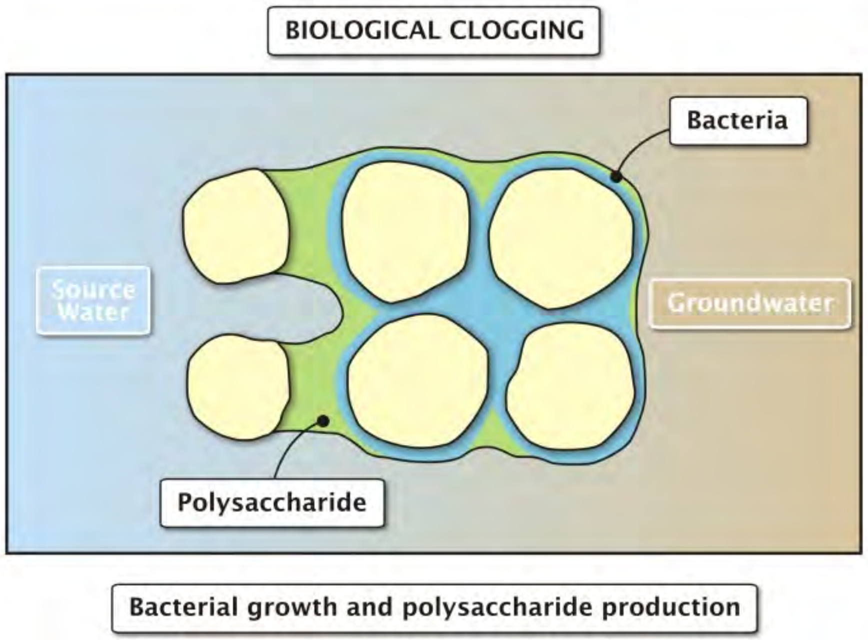
Mechanical Clogging

- Entrained air/gas binding (includes nitrogen &/or methane from microbiological activity).
- Hydraulic loading causing formation failure, aquitard failure or failure of casing around joints or seals.
- Velocity induced damage e.g. migration of interstitial fines such as illite or smectite
- Wind action (erosion) across infiltration basins.
- Smearing of clay particulates *("skin effects"*)



Biological Clogging

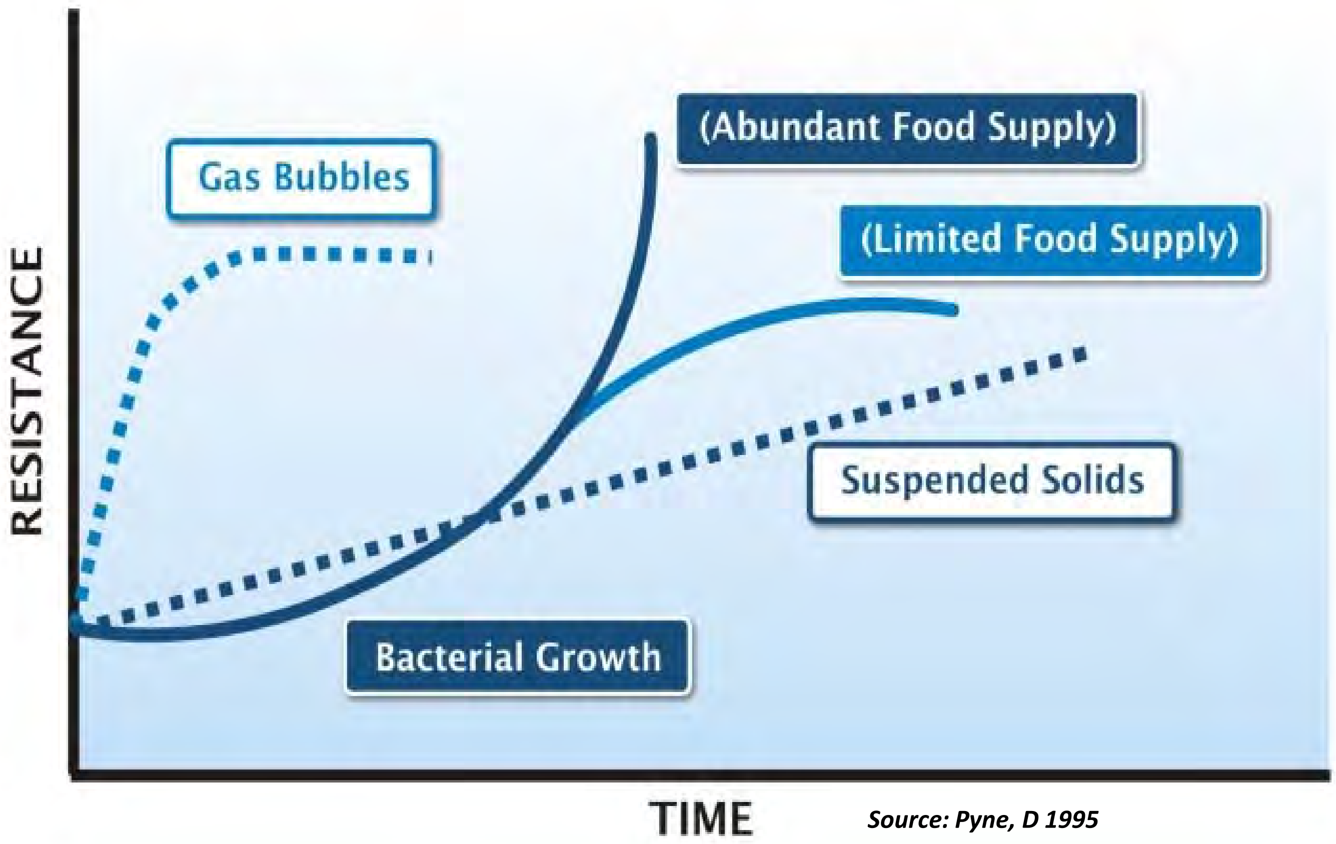
- Algae growth and accumulation of biological flocs. (infiltration basins)
- Microbiological production of polysaccharides.
- Bacterial entrainment and growth.



Risks

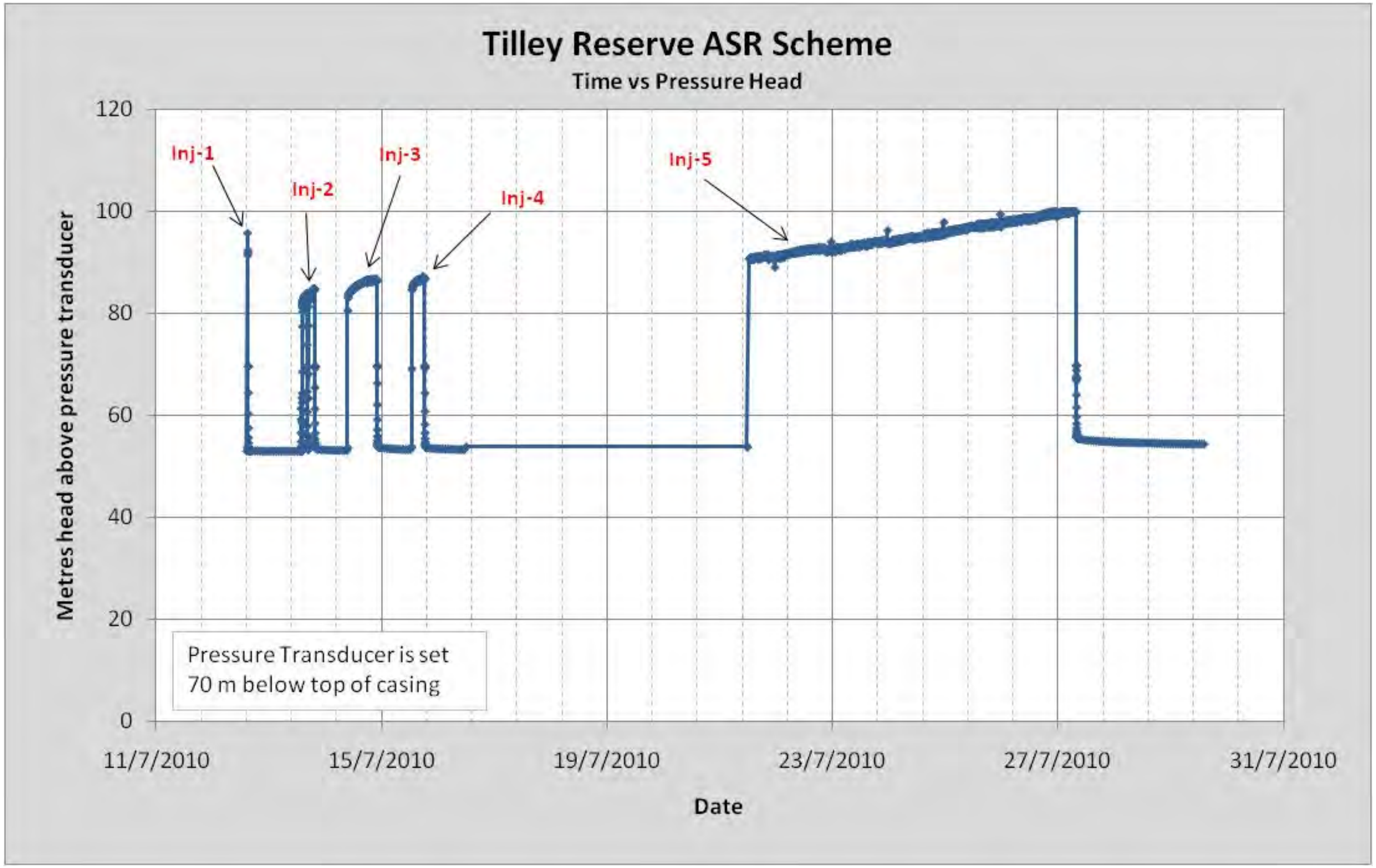
- Invariably an MAR scheme will experience clogging:
  - considerably higher risk when the selected MAR method involves and injection and recovery bore (aquifer storage and recovery) compared to surface infiltration.
- To recognise the potential for clogging and mitigate, either through engineering design or through operational management practices requires specialist knowledge and skills.
- It should also be noted that the remediation methods to address clogging are very site specific:
  - what works in one hydrogeological setting may not always be successful in another location;
  - remediation approaches may differ between injection bores across the same scheme and in the same aquifer.

Recognising Clogging



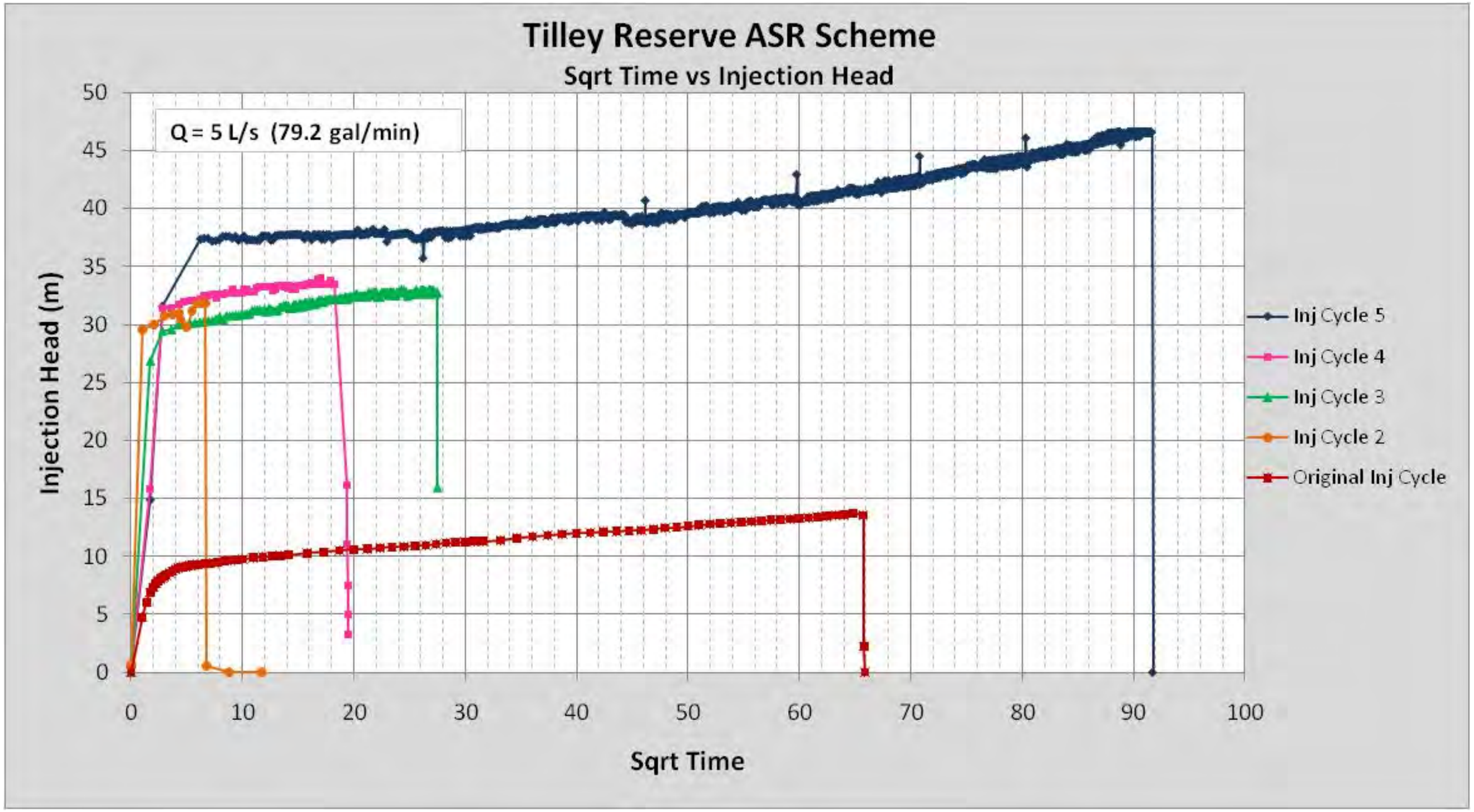
Source: Pyne, D 1995

Injection Cycles



- Results of the head build-up during five successive injection cycles.

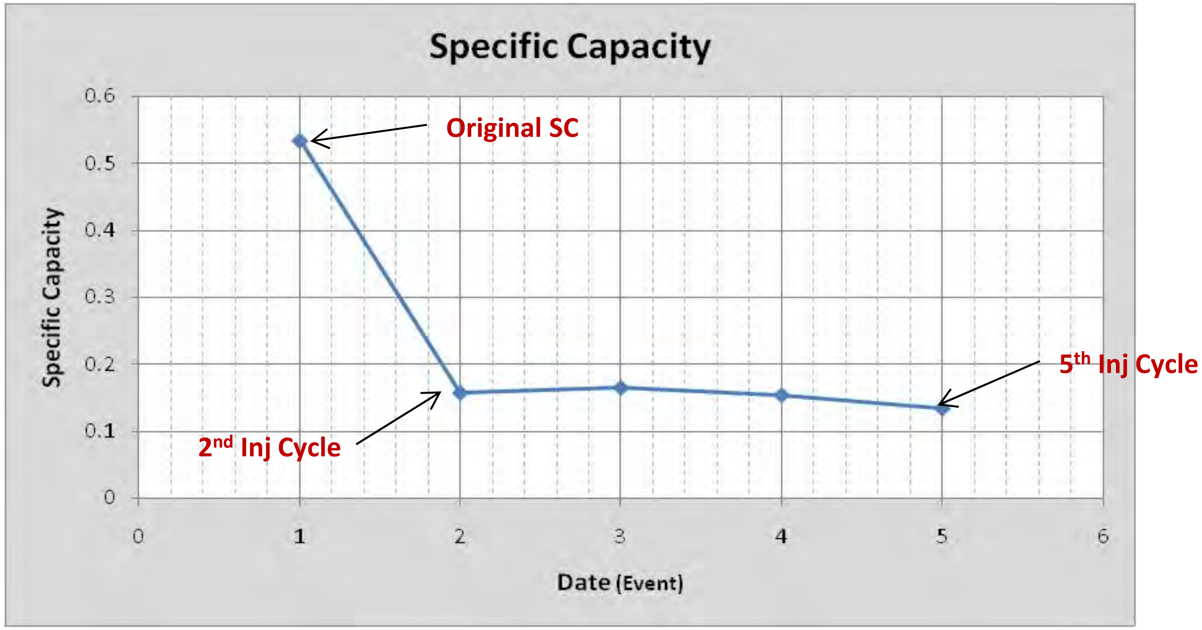
Normalised Injection Cycles



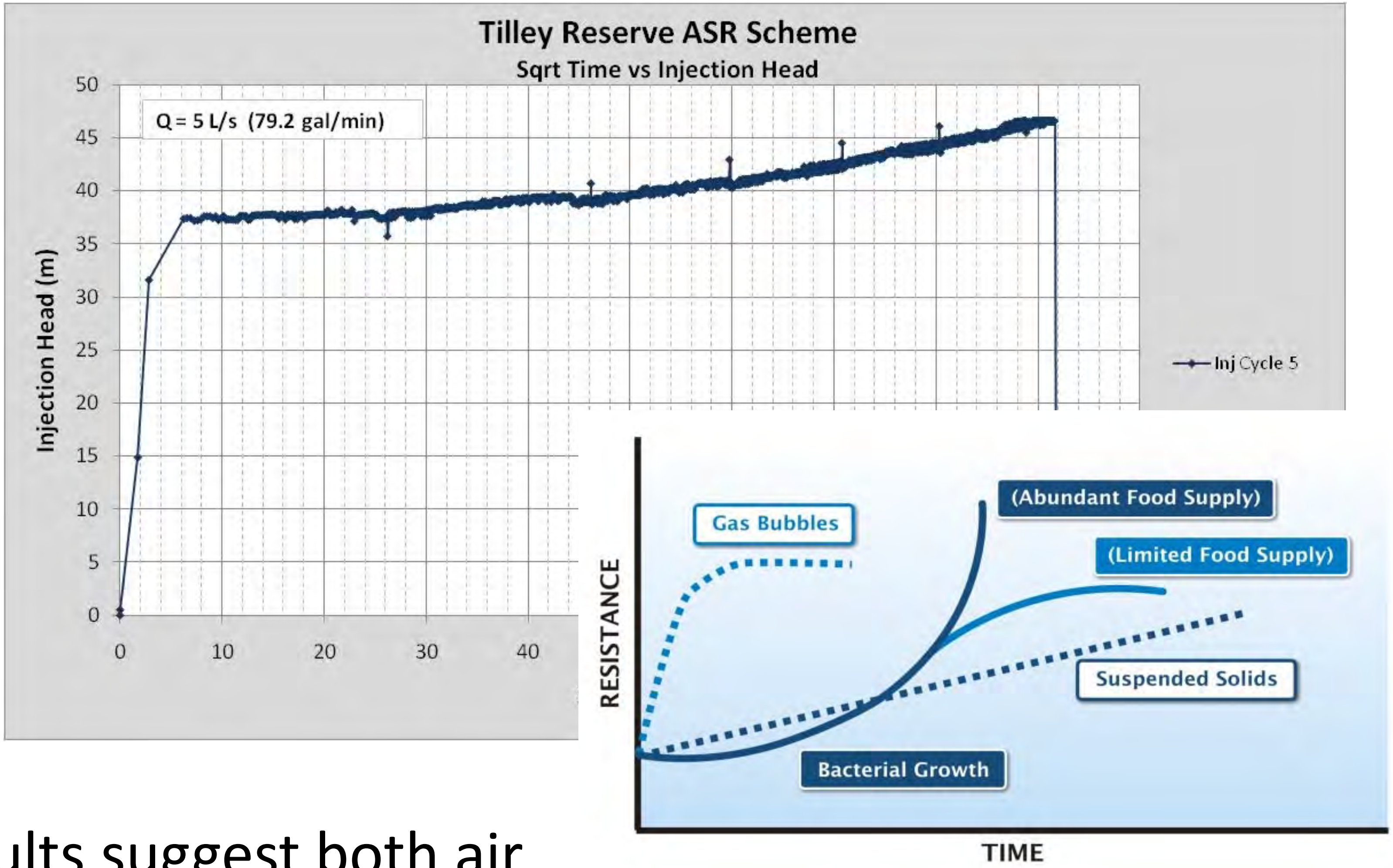
Sharp rise on early time injection is indicative of air entrainment.

Specific Capacity

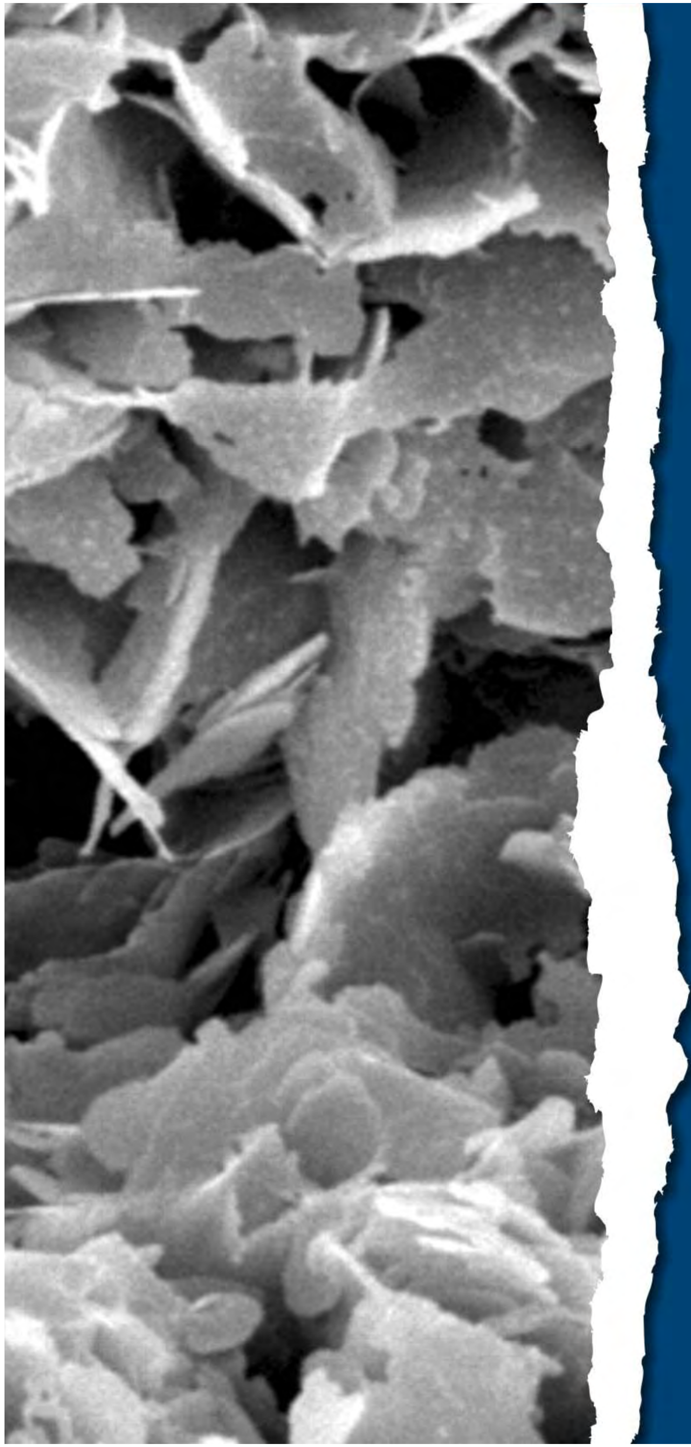
- Applied to ASR wells, SC is used to review the need for back flushing or the optimal injection flow rate or prioritising well performance
- SC = Q/s where
  - Q = the rate at which injection is occurring (in traditional sense rate at which drillhole is pumped)
  - s = the change in head at a specified time e.g. 100 minutes.



Injection Cycle 5



Results suggest both air entrainment and some microbiological clogging



Infiltration Basin Design Considerations

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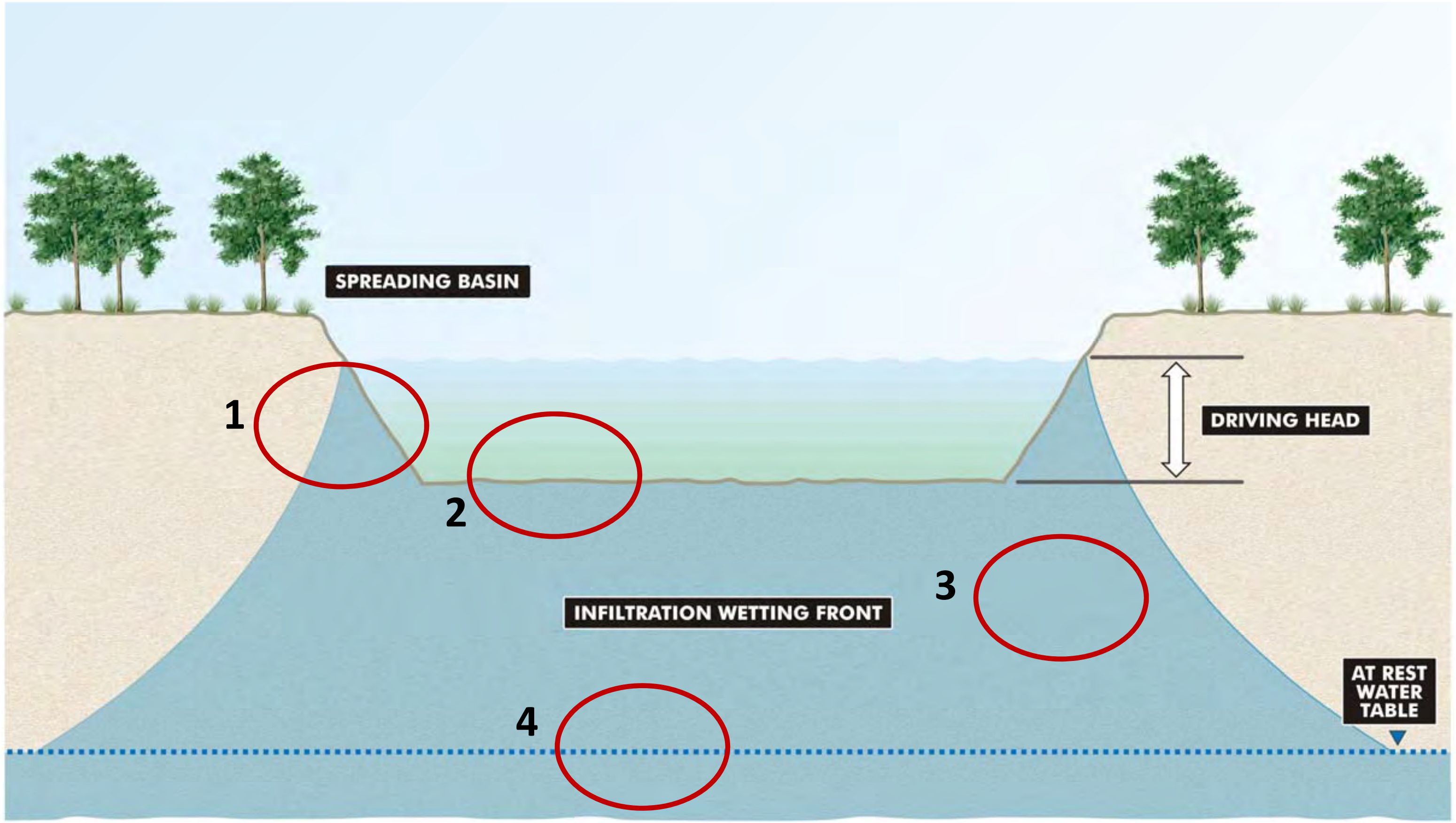
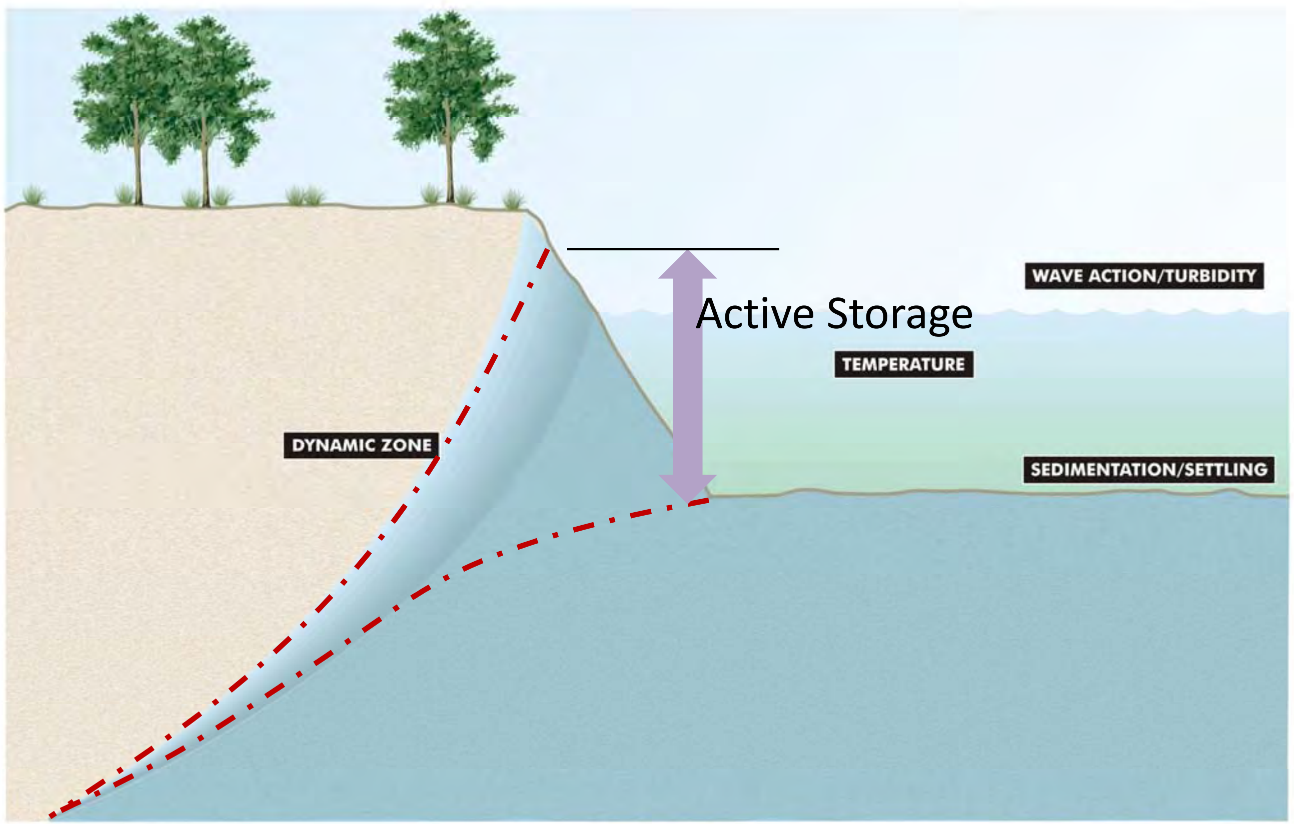
Clogging Issues Infiltration Basins & Bores

- Geochemical reactions
- Microbiological
- Acid production
- Air entrainment
- Fingering of wetting front
- Preferential rather than piston flow
- Wettability (microorganisms can change wettability of clays).
- Mineralogy
- Turbidity/sedimentation

Infiltration Basin Design Considerations

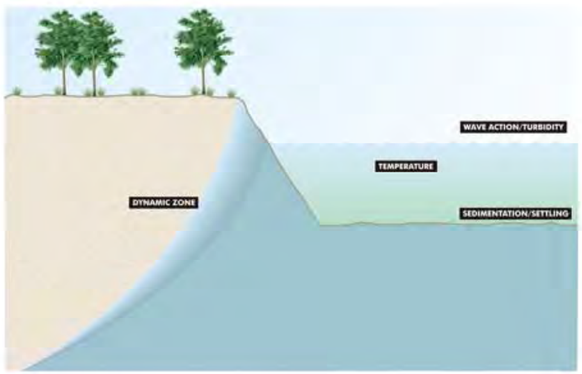


1 Dynamic Zone



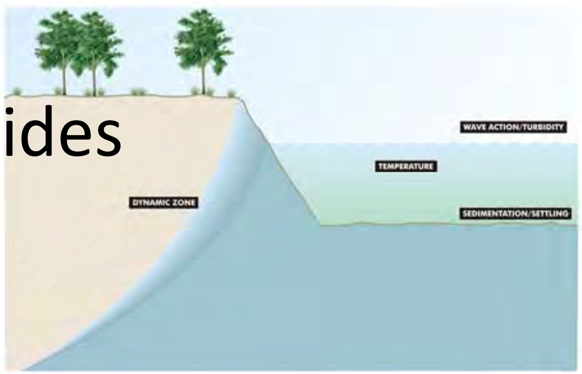
1(a) Depth of Basin

- Depth of basin may result in excessive wave action causing erosion on basin walls and increasing turbidity.
- Too deep may result in temperature thermoclines/stratification.
- Wetting and drying of basin wall over active zone may promote acid sulphate soils depending on mineralogy.
- Increased area for redox exchanges within the dynamic zone.
- Ideal active depth 3 to 5 m

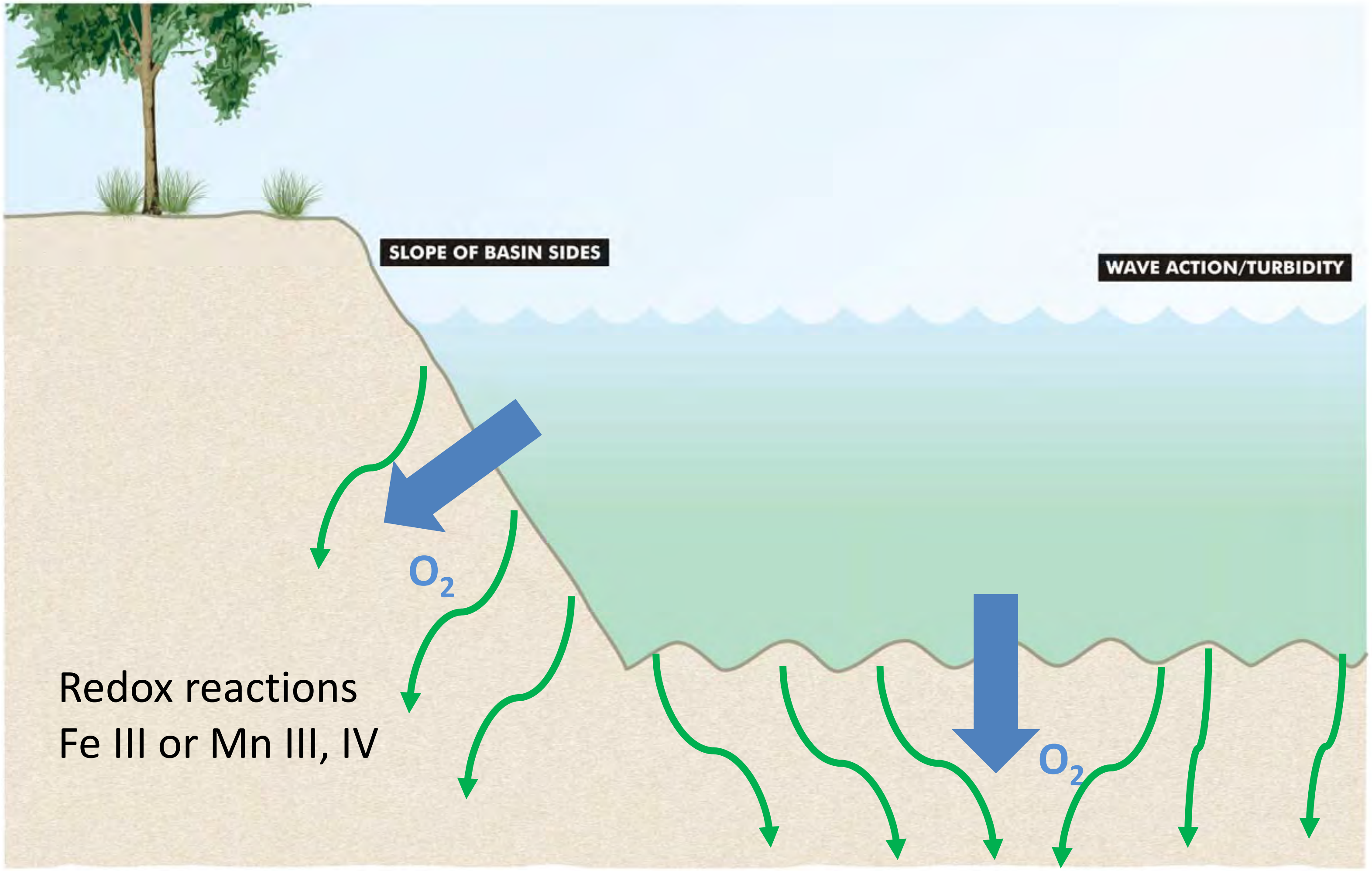


1(b) Slope of Basin Walls

- Incorrect slope of wall excessive erosion and slumping.
- Need to allow access for heavy machinery to clean basin bottom.
- Use of riprap or geotextile fabric to stabilise basin sides
  - especially where prevailing wind may drive waves against wall
- Not necessary to clean basin sides
- Ideal wall slope 1:7



Redox Reactions



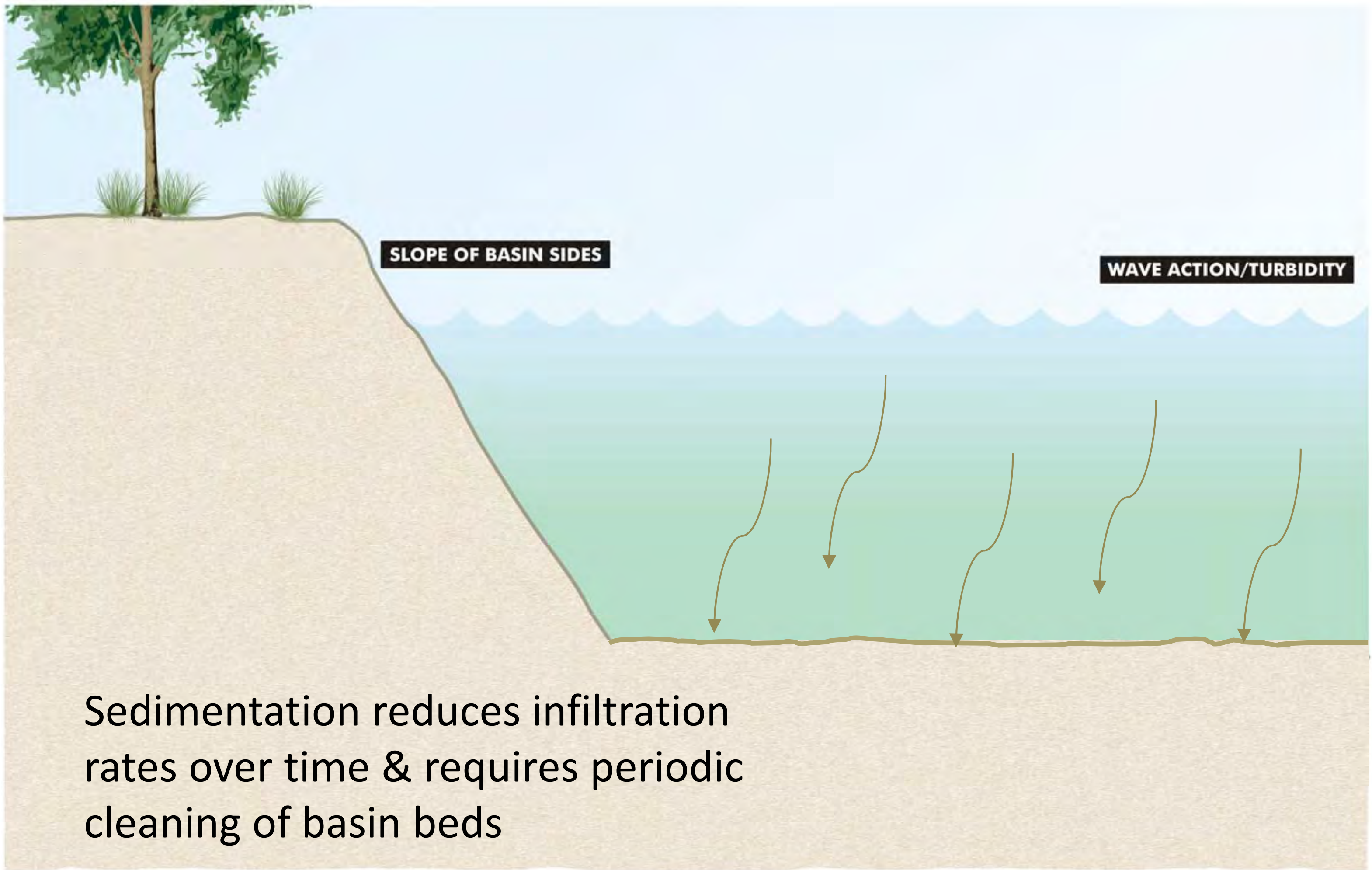
Percolation (infiltration)

- Fe III reactions can occur very fast
- Manganese precipitation occurs much slower
  - but can be accelerated where lot of biological activity which create O_2 reducing environment.
- Organic carbon (removal by microbiological activity accelerates clogging processes on bed of infiltration basin.

2(a) Sedimentation

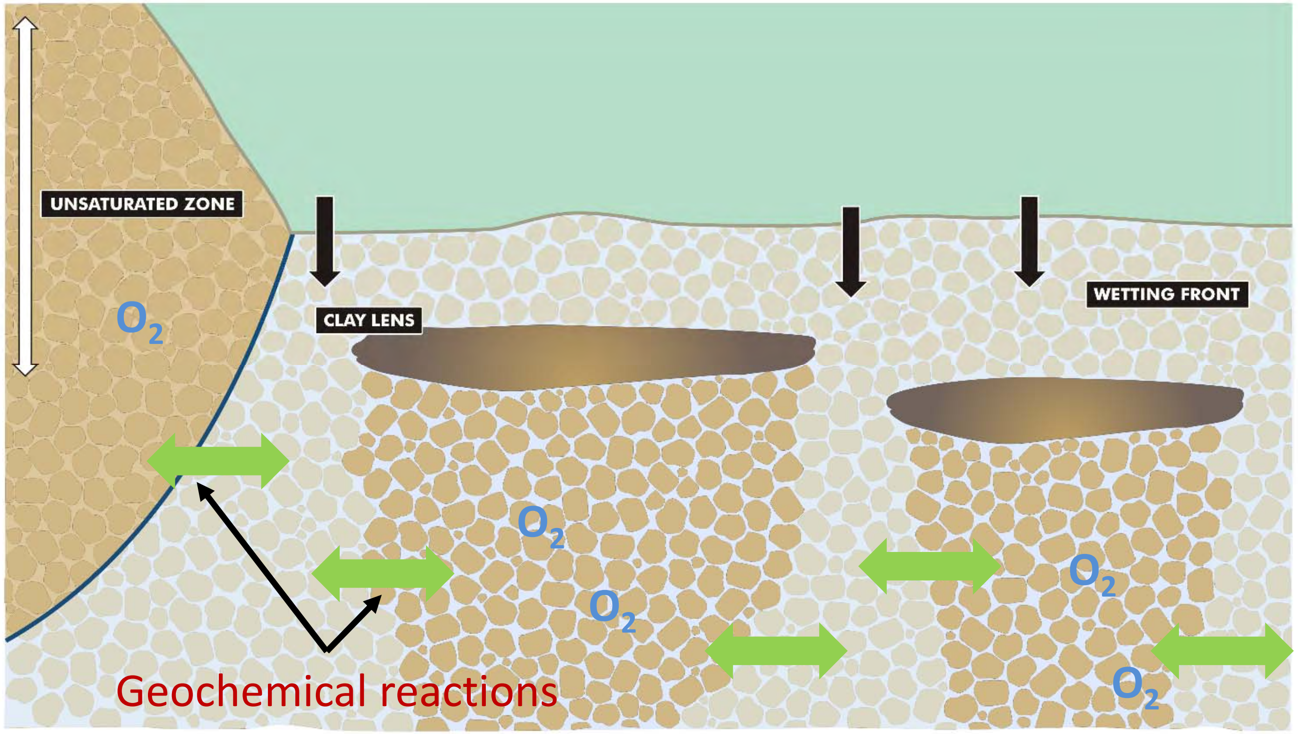
Smearing of these fine clay biscuits causes “skin effect”

Design to Manage Sedimentation



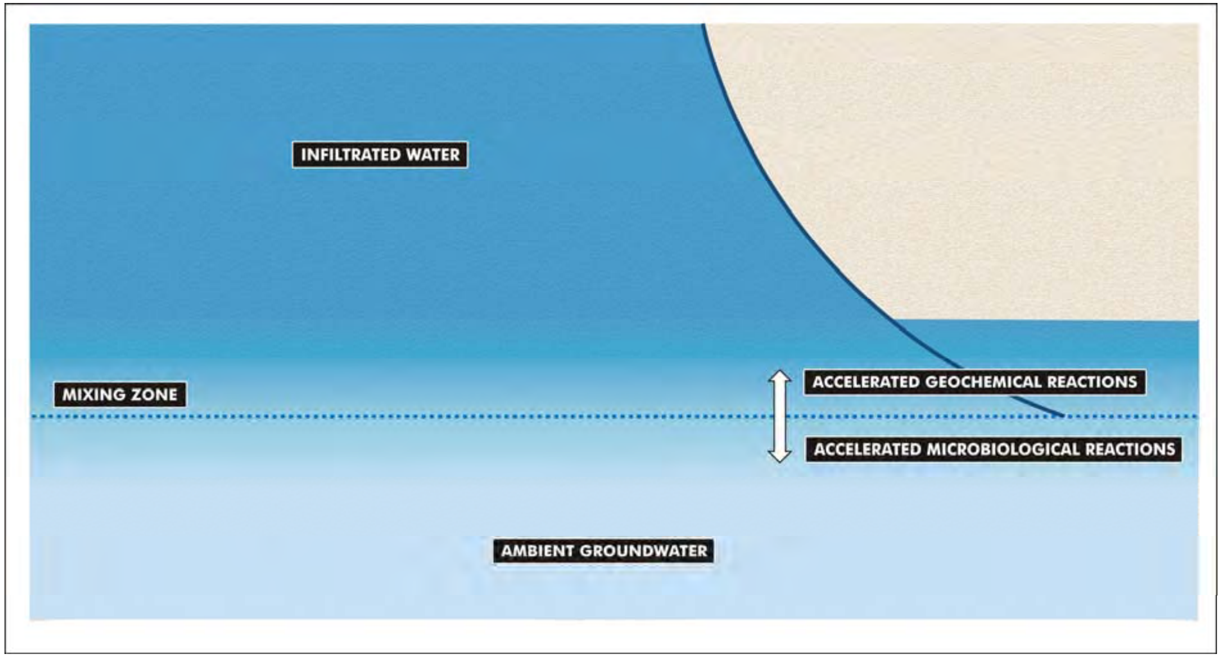
Sedimentation reduces infiltration rates over time & requires periodic cleaning of basin beds

3. Unsaturated Zone



- Subsurface heterogeneity
  - Increased fingering
  - Constant wetting & drying cycles increased
  - BOD management
  - Air entrainment causing clogging and geochemical reactions
  - Increased/prolonged microbiological activity as continual source of oxygen

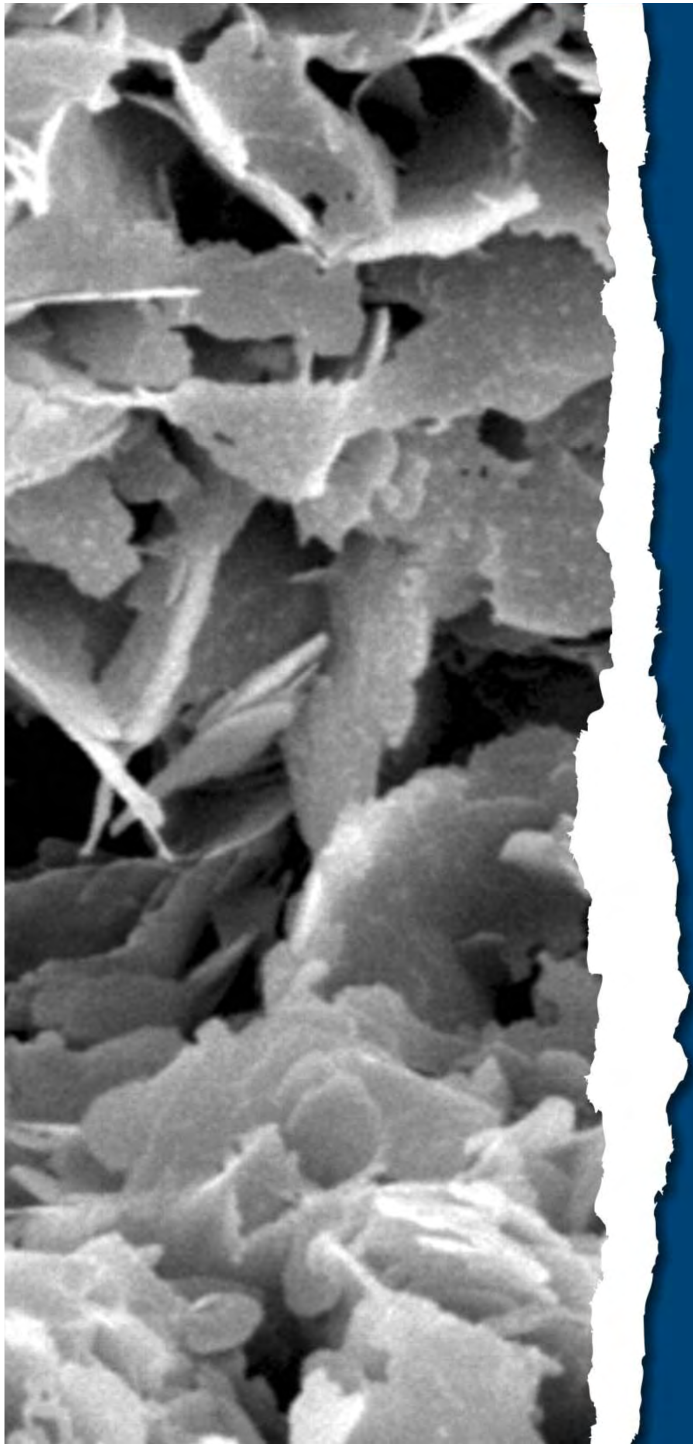
4 Water Table Interface



- Accelerated geochemical reactions at interface between ambient groundwater and percolated water.
- Air is dragged into ambient groundwater during drying cycle.

Good News ....

CLOGGING CAN BE MANAGED



Planning an MAR Scheme

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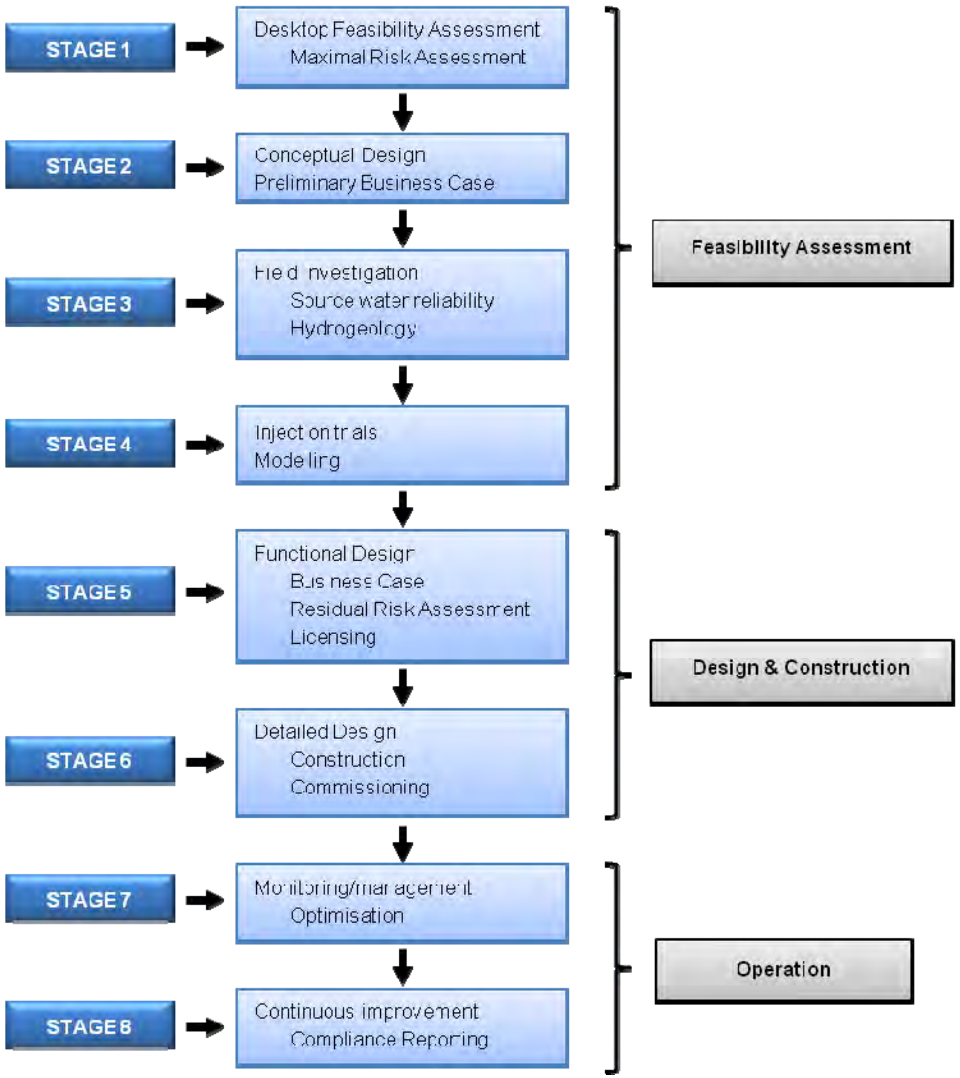
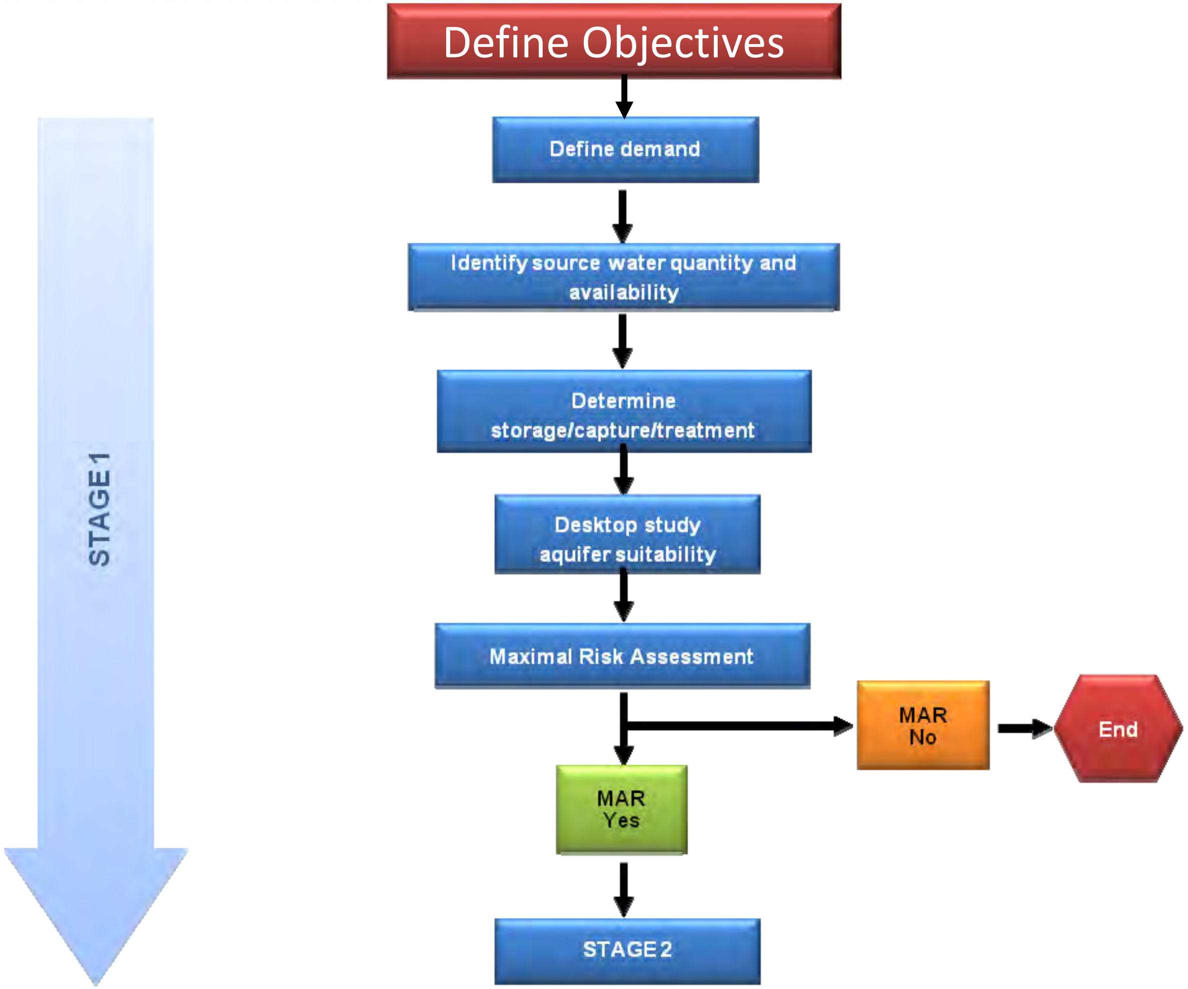
How establish an MAR scheme

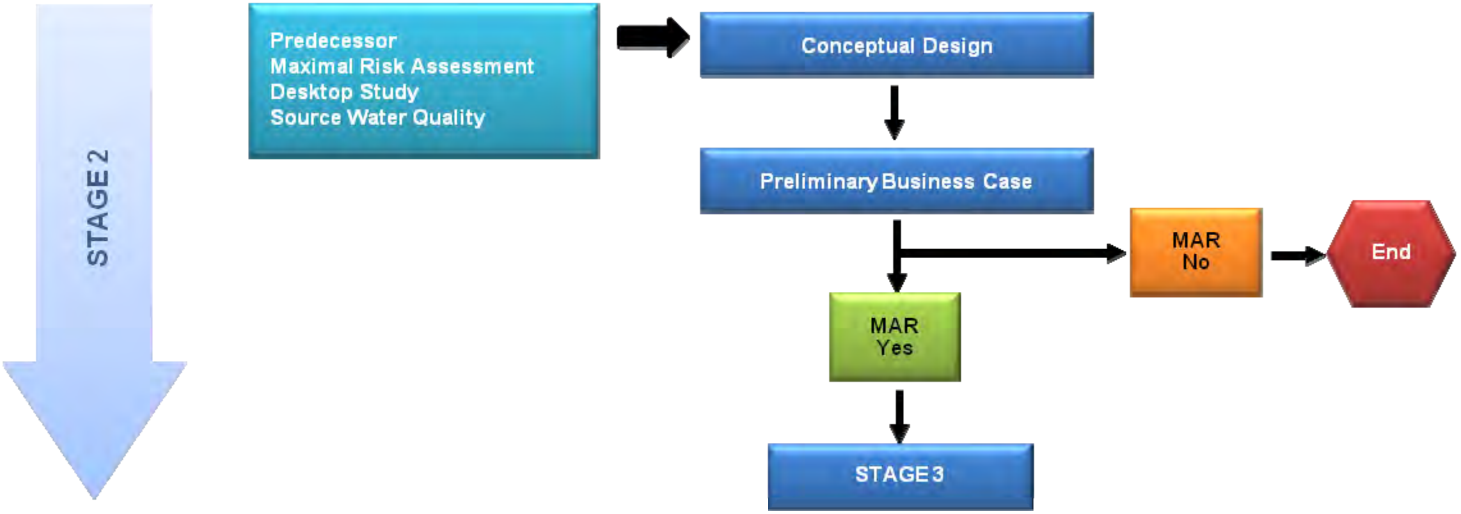


Desktop Assessment

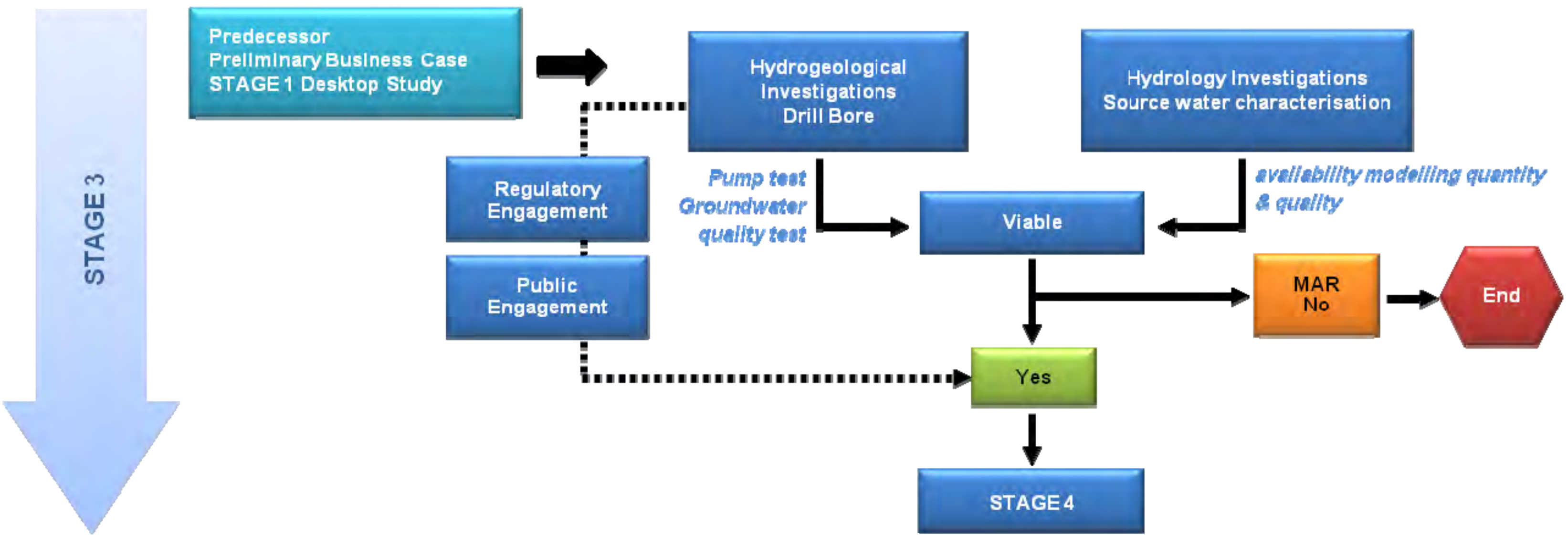


If feasible to progress to stage 2 a clear and concise project description report should be completed

Conceptual Design



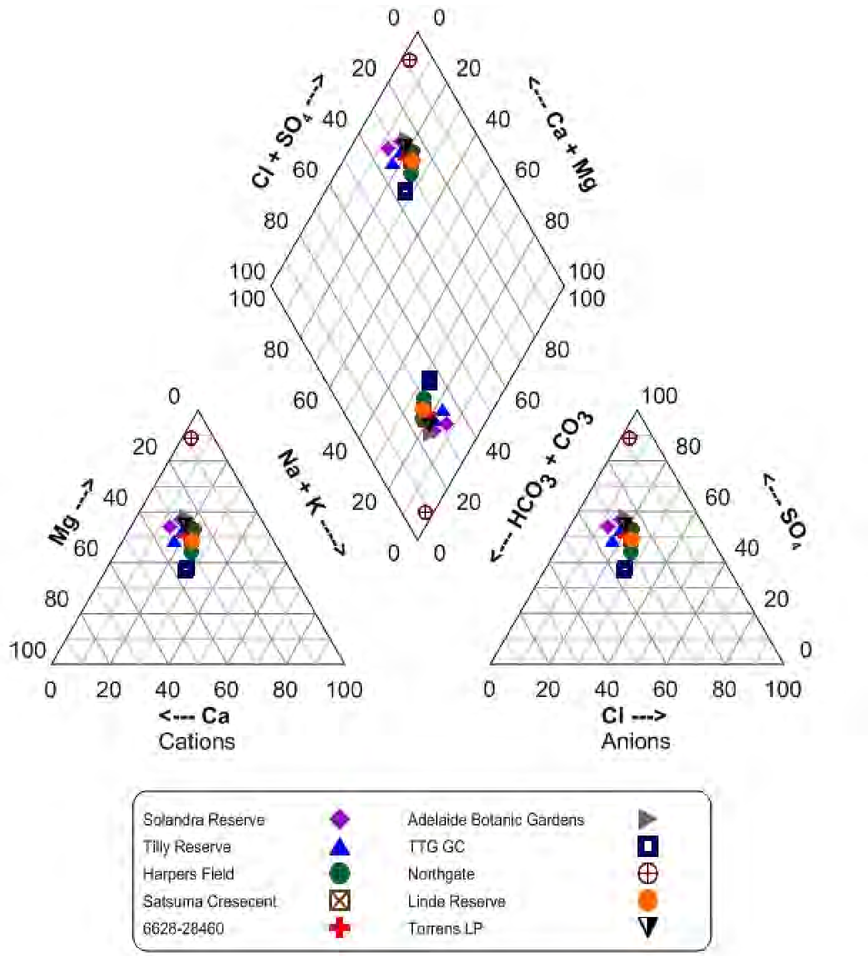
Preliminary Field Investigations



KNOW YOUR SOURCE & RECEIVING WATER

- Source Water
  - Quality
  - Availability (peaks and baseflow, constant or seasonal, environmental requirements)
  - Quantity
    - Stormwater (years where may fail to harvest required volumes)
- Receiving Water (ambient groundwater)
  - Quality i.e. composition against end use requirements (drinking or irrigation).
  - Other users
  - Environmental receptors

Receiving Groundwater Characterisation

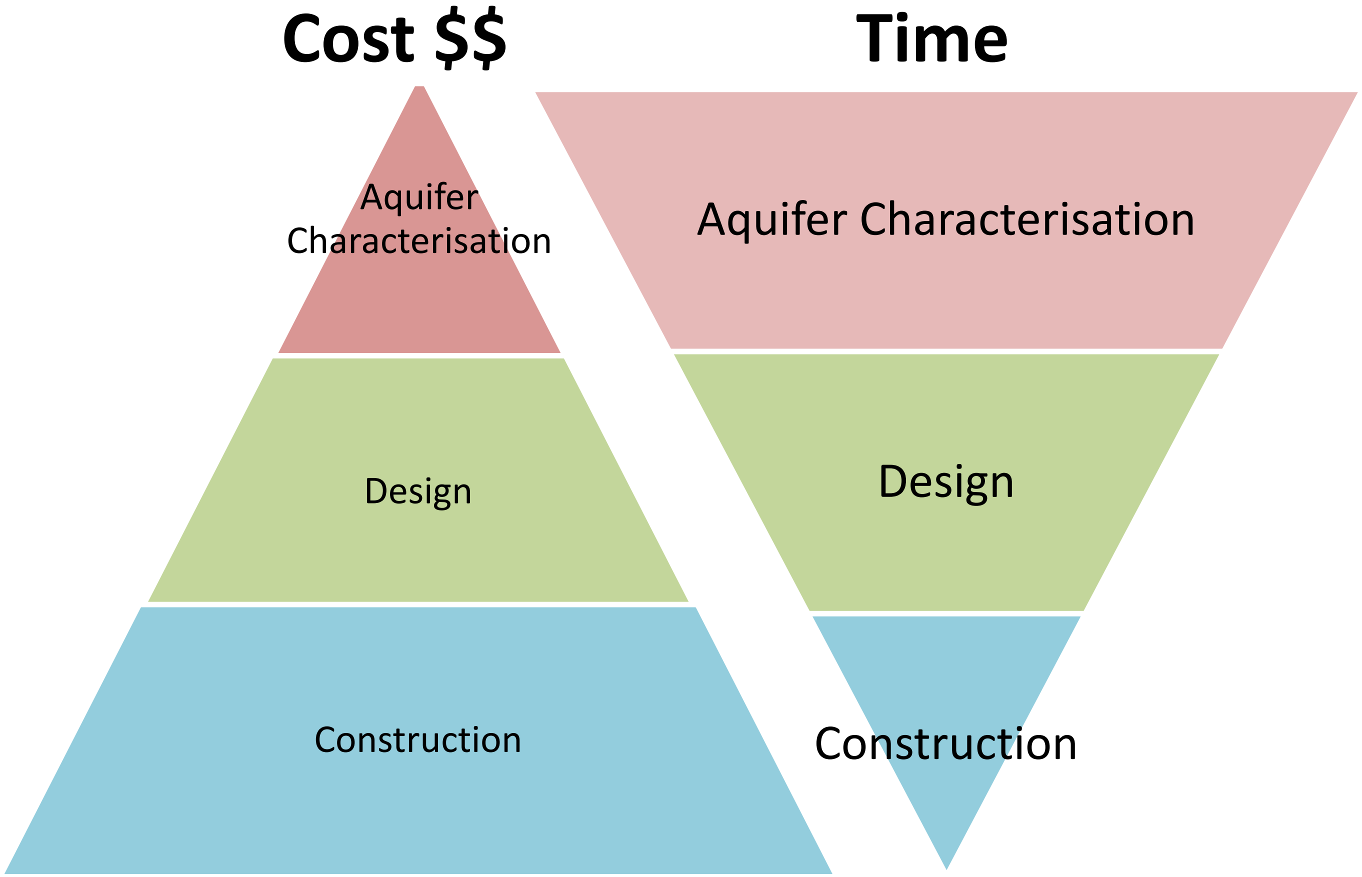


Source Water Pre-treatment

- For MAR high quality (low turbidity) water is best to prevent clogging
- Treatment such as addition of alumn to coagulate sediments can increase clogging potential in infiltration basins and bores.
- Various other water treatment options
  - Passive
    - Vegetated swales, wetlands, settlement basins
  - Mechanical
    - Filters, cyclones, beads, hyperlon covers (alge)

KNOW YOUR AQUIFER

Time and Cost



In a $30 Million scheme the aquifer characterisation may cost only 5% of the total cost however it is the most critical component of the scheme but it is the element that most proponents try to save time and money on.

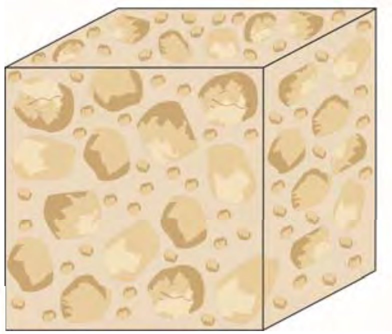
Know Your Aquifer

- Once you have determined that MAR represents the most practical (environmentally, socially and economically) water management solution the key to the sustainable operation of any MAR scheme is detailed characterisation of:
  - the target aquifer;
  - the confining bed where present;
  - the ambient groundwater quality; and
  - the source water quality.
- The next challenge is to determine the most appropriate method to recharge the aquifer

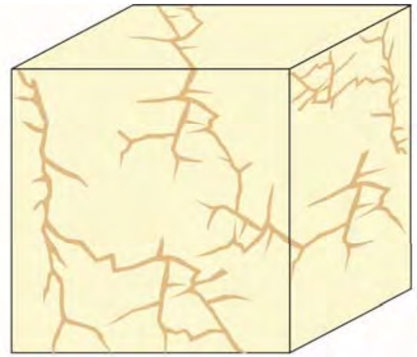
- Whichever MAR method is adopted it is critical that the aquifer is properly characterised to inform:
  - Infiltration Basin or Bore construction;
  - level of additional pre-treatment of source water that may be required;
  - Operational issues and potential for clogging;
  - operational constrains (e.g. maximum head pressure, injection or infiltration rates); and
  - recovery efficiency of the water & quality

Aquifer Types

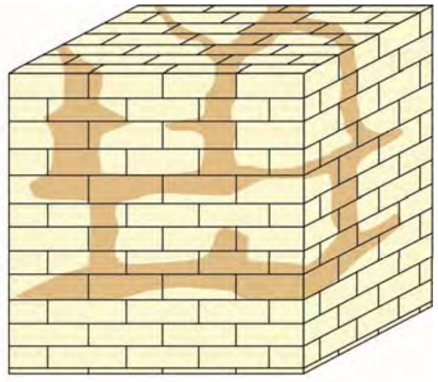
- Main aquifer types are:
  - *Sand or gravel layers or deep sandstone*



  - *Fractured bedrock*



  - *Limestone (kast)*



- *Each aquifer type requires a different approach to characterise the aquifer to enable sustainable operation of the scheme.*

Sedimentary Environments

Depositional Environment		General Characteristics	MAR
non-marine	River Channel	Variable stream current (high to low energy) poor to moderately sorted, low to high K,	✓
	Flood Plain	Floods (low energy), fine moderately sorted, drying, low to moderate K	✓
	River Delta	Stream current, tides (low energy), moderate sorting low to moderate K	✓
	Alluvial Fan	Periodic flash floods, mudflows, (high energy) low to high K	✓
	Desert Dune	Variable wind current (high to low energy) low to high K (coarsening upwards sequences)	✓
	Playa	Periodic floods (low energy) low to moderate K	✗
	Lake	Settling of sediments, organic matter (low energy) well sorted, low K	✗
	Glacier moraine	Poorly sorted, high clay content (low energy) low K	✗
transition	Beach	Waves , (high energy) moderately well sorted, moderate to high K	✓
	Lagoon	Tidal, (low energy) high silt, organic matter, low K	✗
marine	Shallow Marine	Waves, (high to low energy), moderate sorting moderate to high K	✓
	Reef	Waves, dissolution features, (high to low energy) moderate to very high K	✓

Preferred Aquifer Attributes for MAR

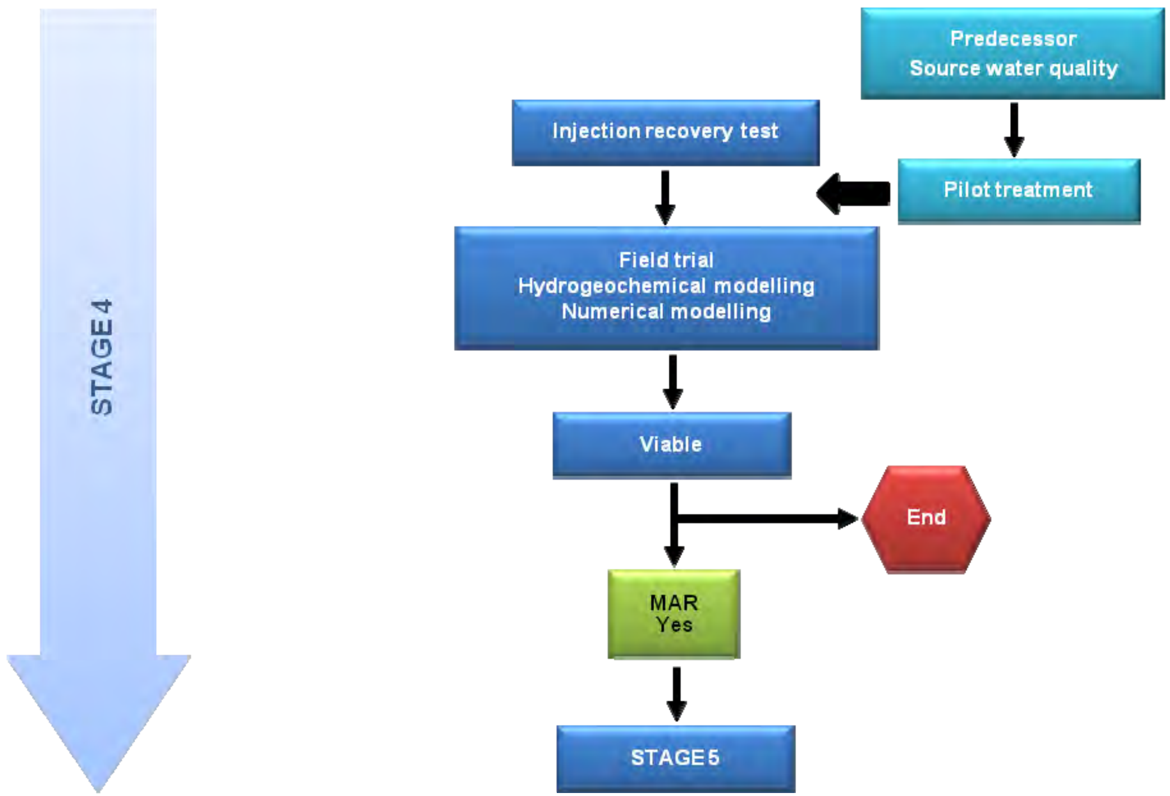
Criteria	Preferred	Reason
Groundwater gradient	Low	A small gradient means a low groundwater velocity, which results in a higher recovery
Bore Yield	>6-10L/sec	to reach maximum recharge potential
Depth to Water	>10m bgl	sufficient underground storage, avoid evaporation, water logging
Groundwater Quality	Poorer or equal to injected water	injected water needs to be of better quality than groundwater
Aquifer characteristics	- high storage - high effective porosity - competent rock -Permeability -Aquifer thickness - unconfined or confined aquifer	- allow all injected water to be stored - low flow velocity; high recovery - allow open hole completion

Factors influencing target aquifer selection

Factor	Advantages	Disadvantages
Low Permeability	Nil	Low injection and recover rates Risk of low recovery efficiency
High Permeability	Greater injection and recover rates Increased potential for high recovery efficiency	Risk of decreased recovery efficiency if long storage periods are used (i.e. >5 years)
Shallow Depth	Lower cost for bores, pumps, power	Reduced capacity for high injection and recovery rates
Large Depth	Greater capacity for high injection and recovery rates (i.e. greater impressed head and drawdown)	Increased cost at greater depths
Thin aquifer	Increased potential for high recovery efficiency	Risk of low aquifer transmissivity (i.e. lower injection and recovery rates)
Thick aquifer	Potential for greater aquifer transmissivity (i.e. higher injection and recovery rates)	Risk of low recovery efficiency

Factor	Advantages	Disadvantages
Fresh Groundwater	High recovery efficiency	High barriers to regulatory approval
Brackish Groundwater	Reduced regulatory barriers compared to fresh groundwater aquifer	Reduced recovery efficiency compared to fresh groundwater aquifer
Presence of carbonaceous material and/or sulphide minerals in aquifer	None	Dissolution of metals from sulphide minerals (often present in carbonaceous material) into the injected water (e.g. Arsenic, Iron, Manganese)
Calcareous (i.e. limestone) aquifer	Increase in aquifer transmissivity over time due to dissolution of limestone (from organic matter, dissolved oxygen, and low pH of injected water)	Collapse of uncased bores Increase in sand production from bore during recovery phase Increased potential for scaling of pumps and pipes (due to increased Calcium concentration in stored water)
Unconfined	Higher injection and recovery rates relative to confined aquifers if water table is deep (>20 m)	Lower injection and recovery rates with shallow water table depths (i.e. <10 m) Potential losses to surface water and vegetation Ground surface salinisation
Confined	Reduced risk of losses to ground surface, surface water, vegetation	Lower injection rates per meter of impressed head or drawdown compared to unconfined aquifers

Field Trials

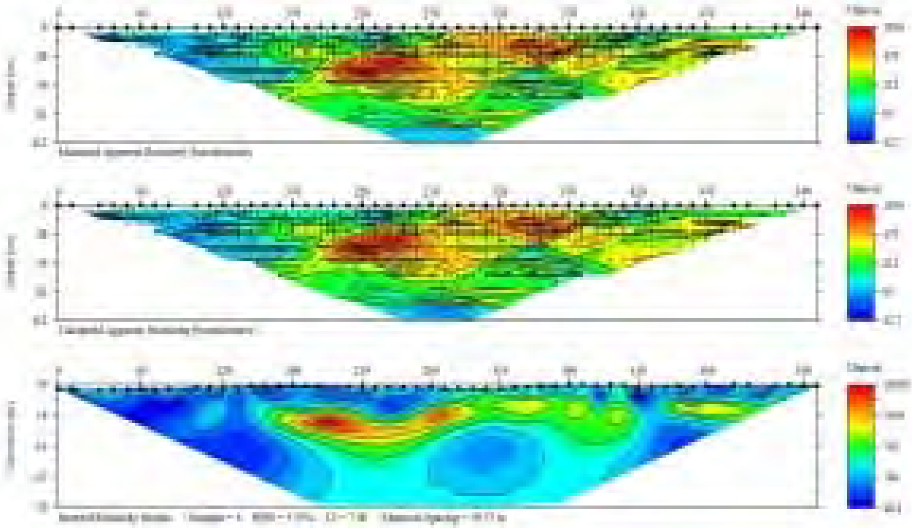


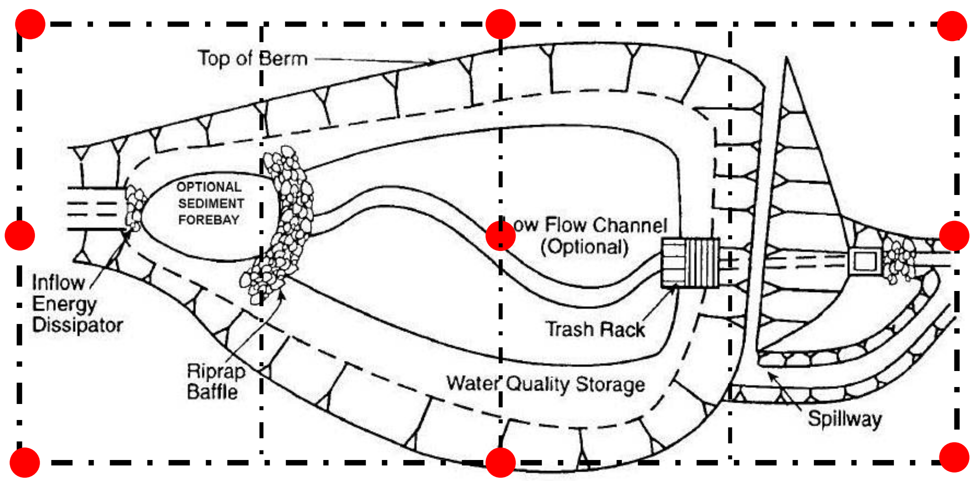
FIELD INVESTIGATIONS

Field Investigation Programs

- Plan well
- Non-invasive investigations
  - Ground penetrating radar
  - Surface geophysics
  - Aerial photographs
- Invasive investigations:
  - Drilling
    - how will the drillhole, grout, casing, casing bells, screens, gravel pack and pump diameters fit together?
    - What drilling method?
    - What casing type (burst pressures etc)?
    - Will the internal casing diameter fit the intended pump?
    - What completion type?
    - Sampling lithology & water quality
    - What types of geophysical logs?
    - **Well development & for how long?**
    - Pumping test (type and duration)
    - What type of well head protection?
  - Downhole geophysics
- Infiltration basins require both invasive and non-invasive investigations

Surface Geophysical Investigations

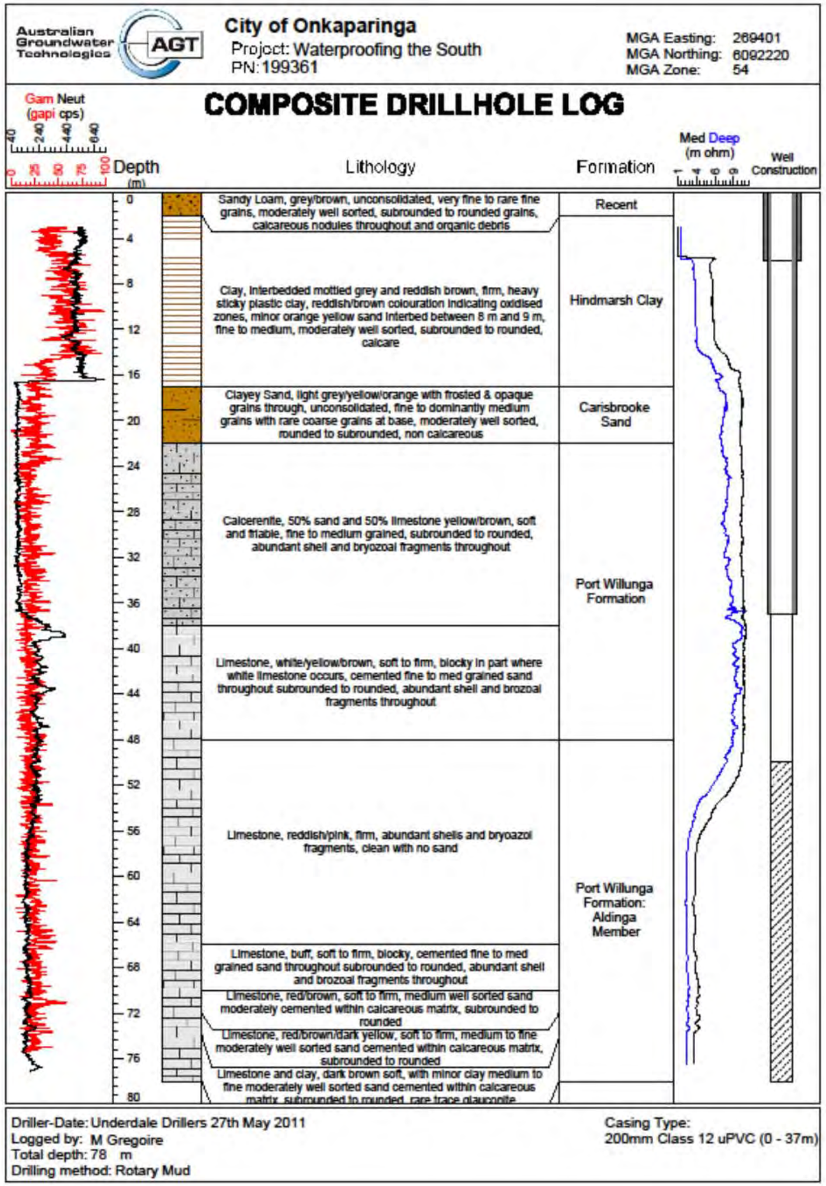




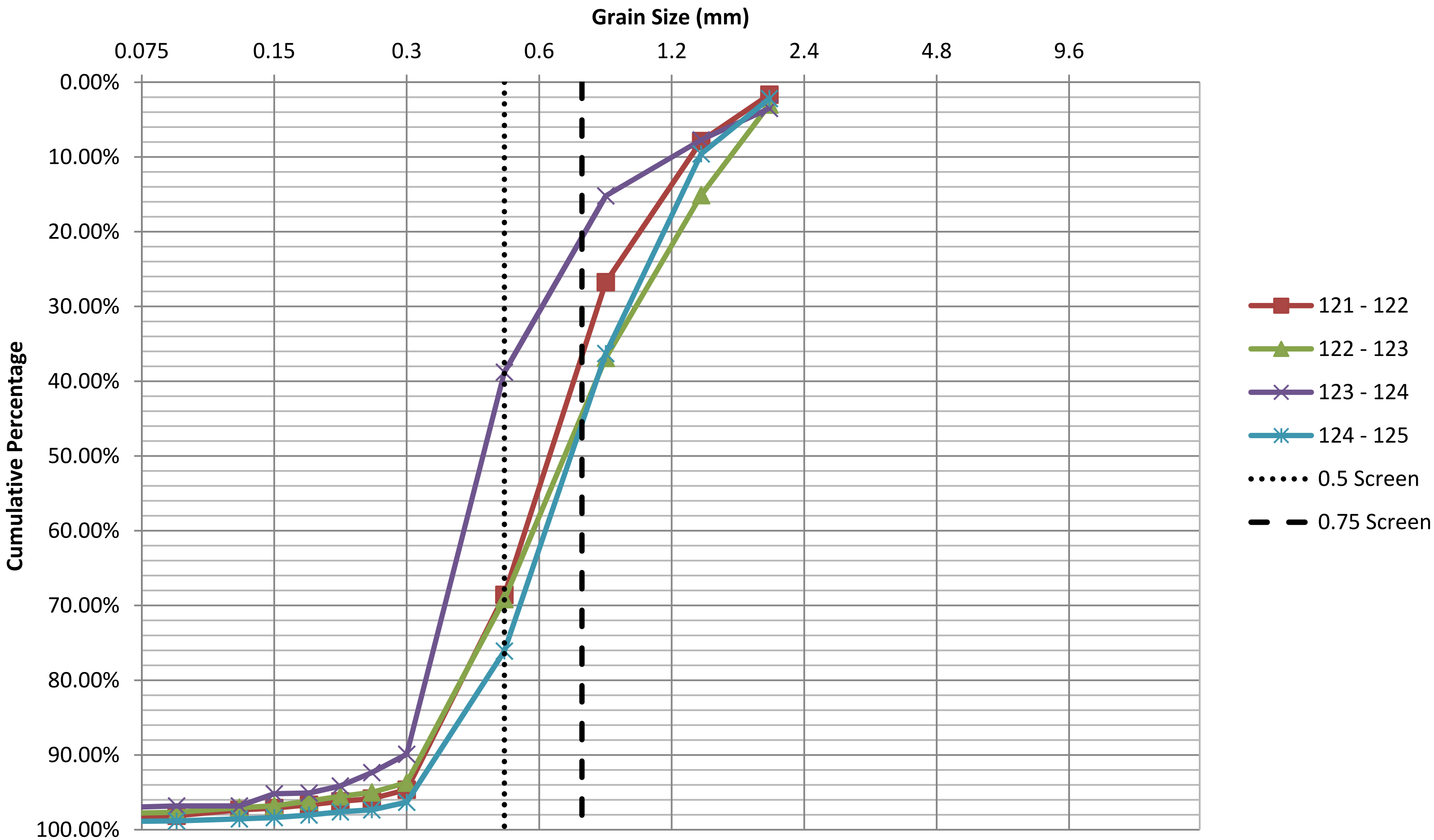
- Cost effective method to characterise subsurface heterogeneity
- Can be undertaken rapidly over large areas.
- Surface geophysics should always be supported by bore hole geophysics.

Borehole Geophysical Logging

- Types of Logs
  - Gamma,
  - Neutron,
  - Density,
  - Dual Laterolog,
  - Caliper,
  - Resistivity
  - Downhole camera
  - Acoustic Televiewer (Fractured bedrock)

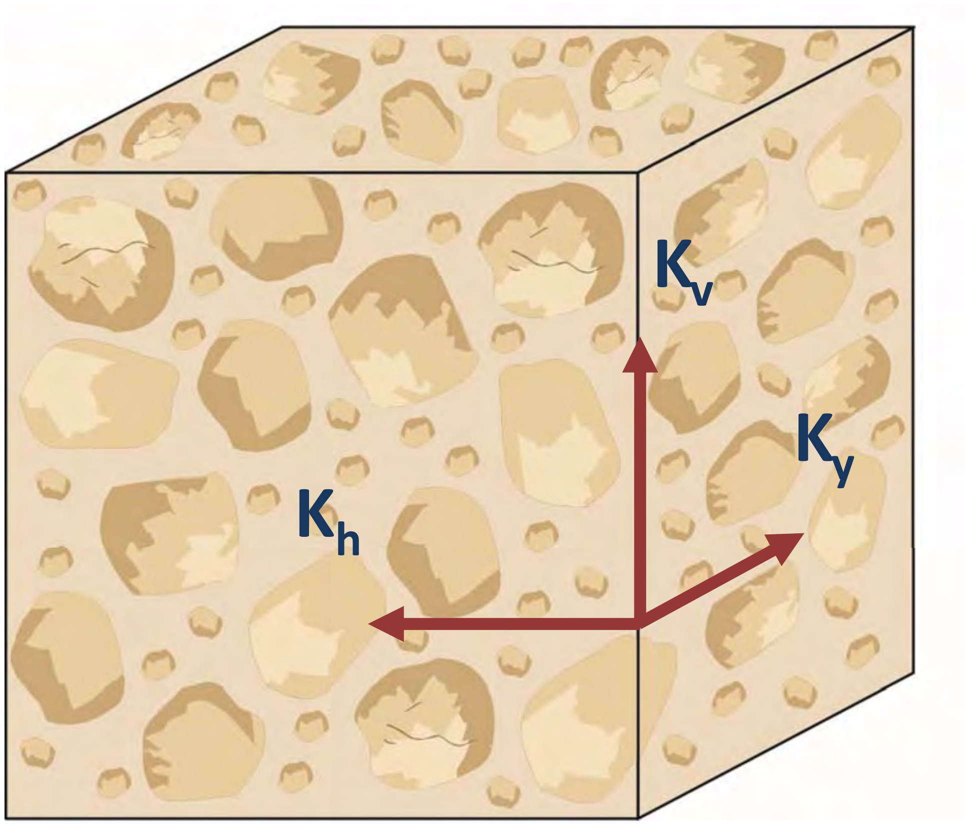


Grain Size Analysis



Infiltration Beds

- Of critical importance in infiltration basins is anisotropy in particular $k_{v.}$



Core Studies

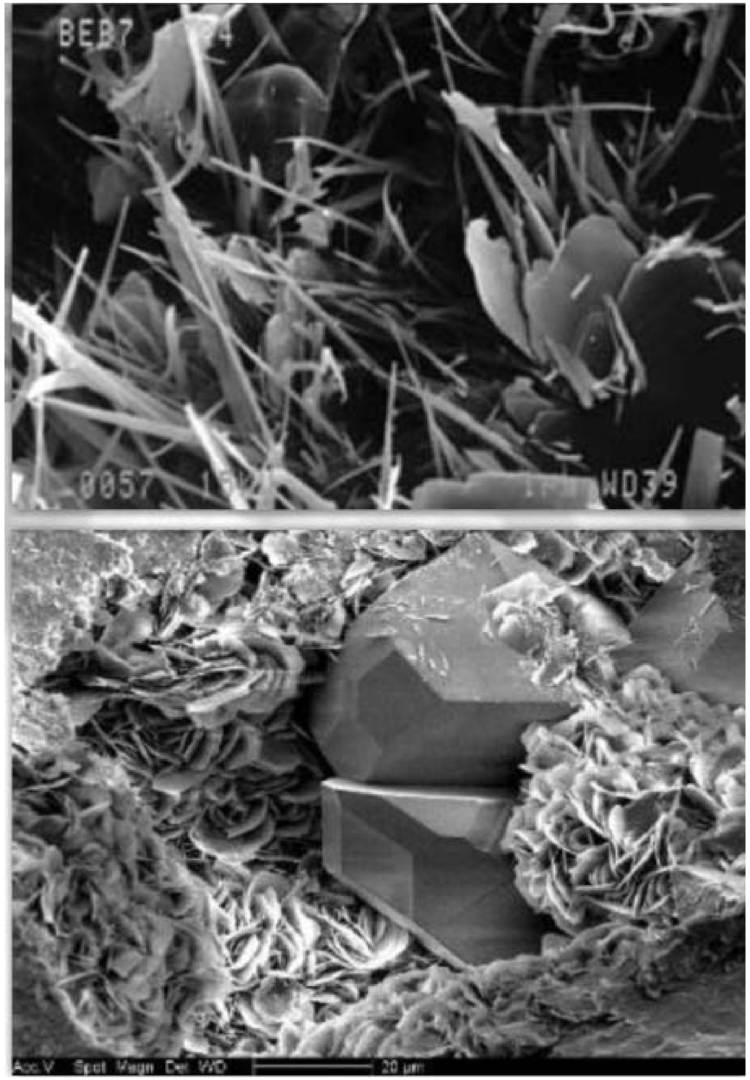
Best way to determine insitu K_v is through core investigations

Cation Exchange Capacity

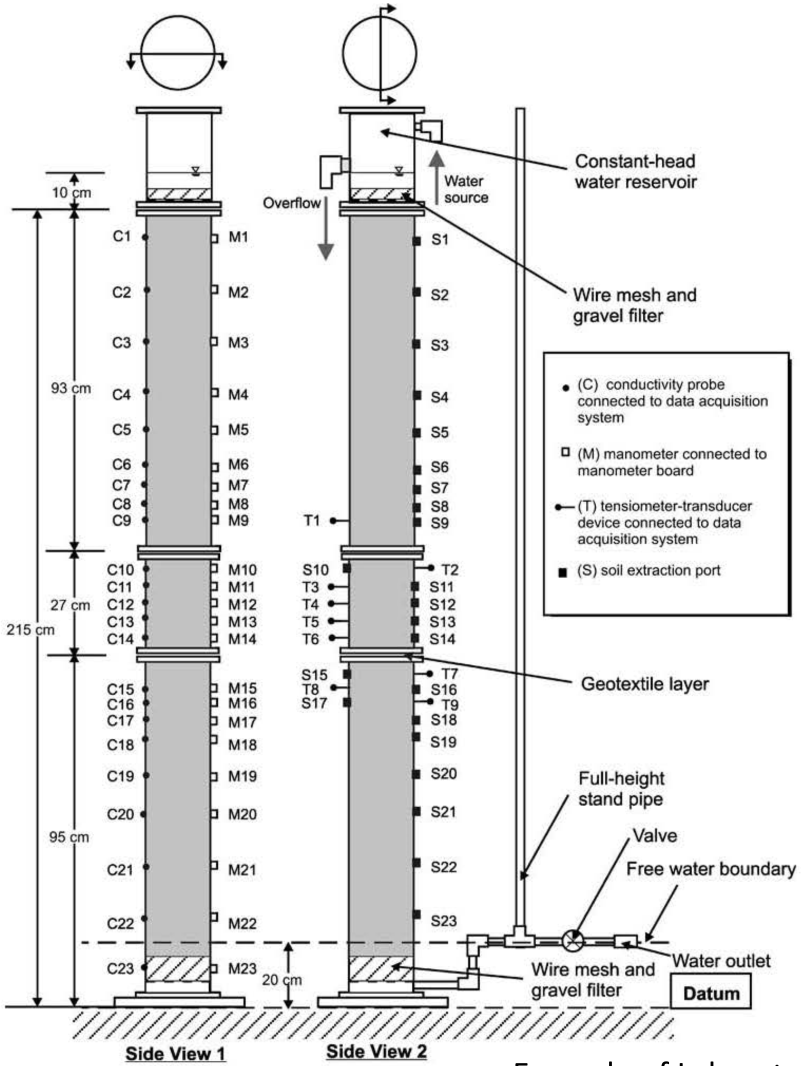
- **Cation-exchange capacity** (CEC) is the maximum quantity of total cations, of any class, that a Soil is capable of holding, at a given pH value, available for exchange with the soil solution.
  - Usually completed on fresh core sample (never cuttings) and on crushed <2 micron clay fraction following sieving
  - High CEC may mean highly reactive clays
  - Care required when assessing results as sample preparation (crushing) will release additional clay surfaces that in the rock matrix may otherwise be occluded
    - needs to be reviewed in conjunction with SEM/XRD and XRF results
    - also needs to be reviewed based on percentage of <2 micron sample from bulk sieve analysis

XRD/XRF and SEM

- Important that the micro and accessory mineralogy in the target aquifer or through the unsaturated zone are adequately characterised.



Column Studies



Example of Laboratory Column

source Bathurst, Ho & Siemens 2007

- Column studies useful to assess clogging potential and water quality.
- K_v in columns cannot replicate field conditions.
- If K_h and/or K_v known columns can be repacked to reflect insitu conditions.
- Many column experiments on field materials not conducted using controls (e.g. Glass beads)
- Degassing of trial fluids is required.

Aquifer Discharge Tests

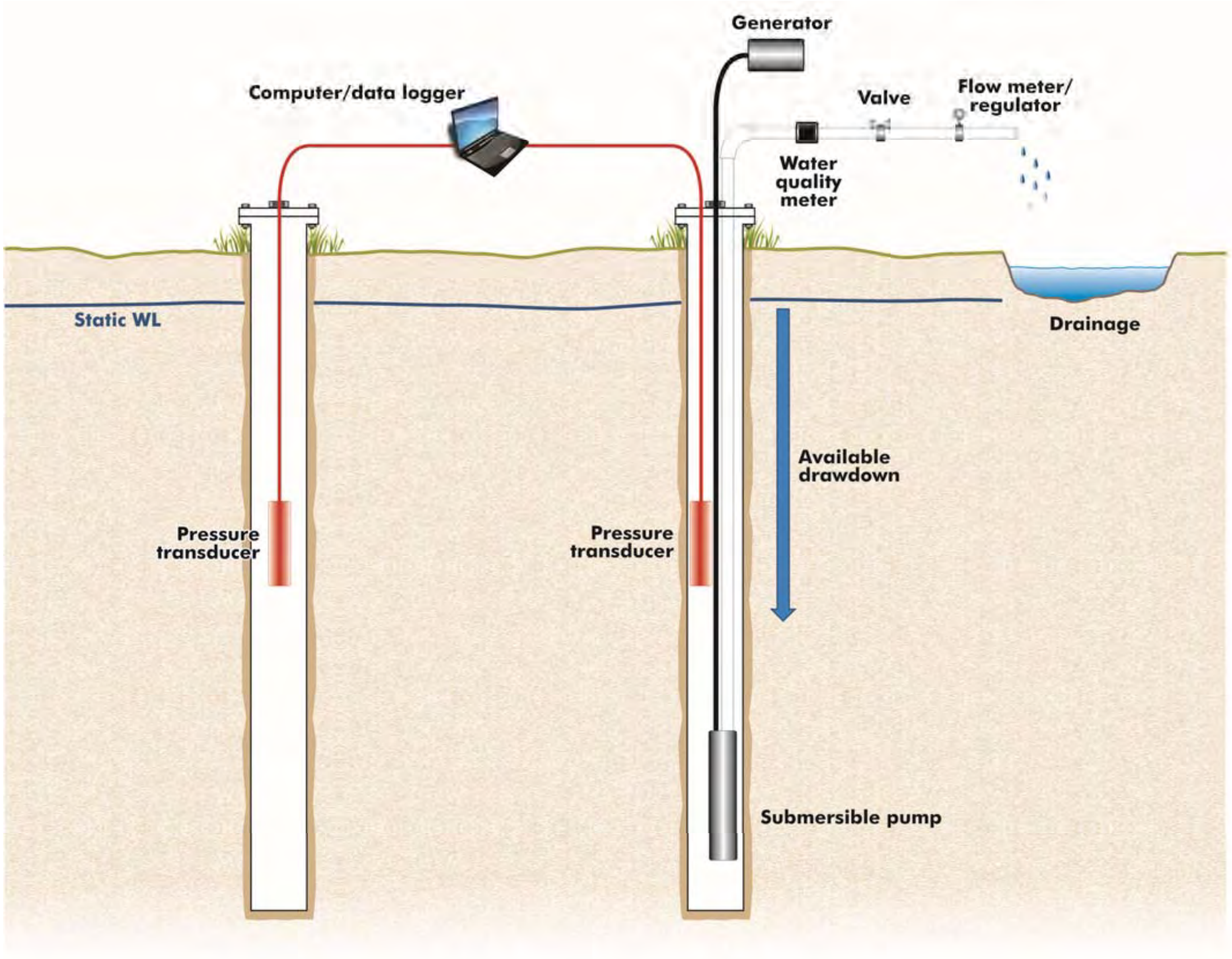
Conducted to determine:

- The capability of the aquifer to sustainably deliver water to the aquifer via percolation of injection well over extended periods of operation.
- The area influenced by pumping
- Lateral boundary conditions that may influence the drawdown
- Vertical boundary conditions – upward or downward leakage from underlying or overlying aquifers
- Maximum expected drawdown (and injection head) at nominated pumping rates
- Pump size and pump depth setting, and
- MAR: a baseline for aquifer capability against which cycles of infiltration or injection and recovery can be measured to assess scheme operation
- For infiltration basins critical to understand the relationship between K_v and K_h

Types of Aquifer Discharge tests

- Step-drawdown test
  - Determines well efficiency
  - Determines effective pumping rate for constant-rate pump test
- Constant-rate pumping test
  - Single well – Transmissivity and hydraulic conductivity
  - Multi-well – Transmissivity, hydraulic conductivity, storage coefficient, verify yield of a production well

Test Setup

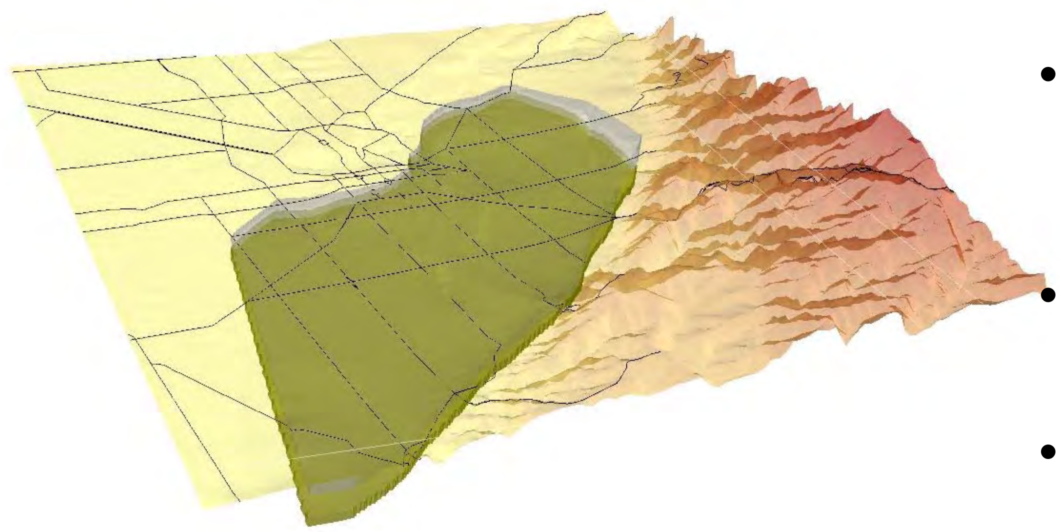


Generator
Computer/data logger
Valve
Flow meter/
regulator
Water
quality
meter
Static WL
Drainage
Available
drawdown
Pressure
transducer
Pressure
transducer
Submersible pump

Injection, Residence & Recovery Trials

- Injection or infiltration and recovery trials are expensive but are considered crucial to understanding how the aquifer will respond.
- These tests provide an indication of:
  - the injection head buildup;
  - Infiltration (percolation) or recharge rates;
  - potential clogging issues (e.g. precipitation);
  - recovery efficiency
- The results are used to provide better predictions in numerical modelling.
- The results assist in design optioneering.

Numerical Modelling



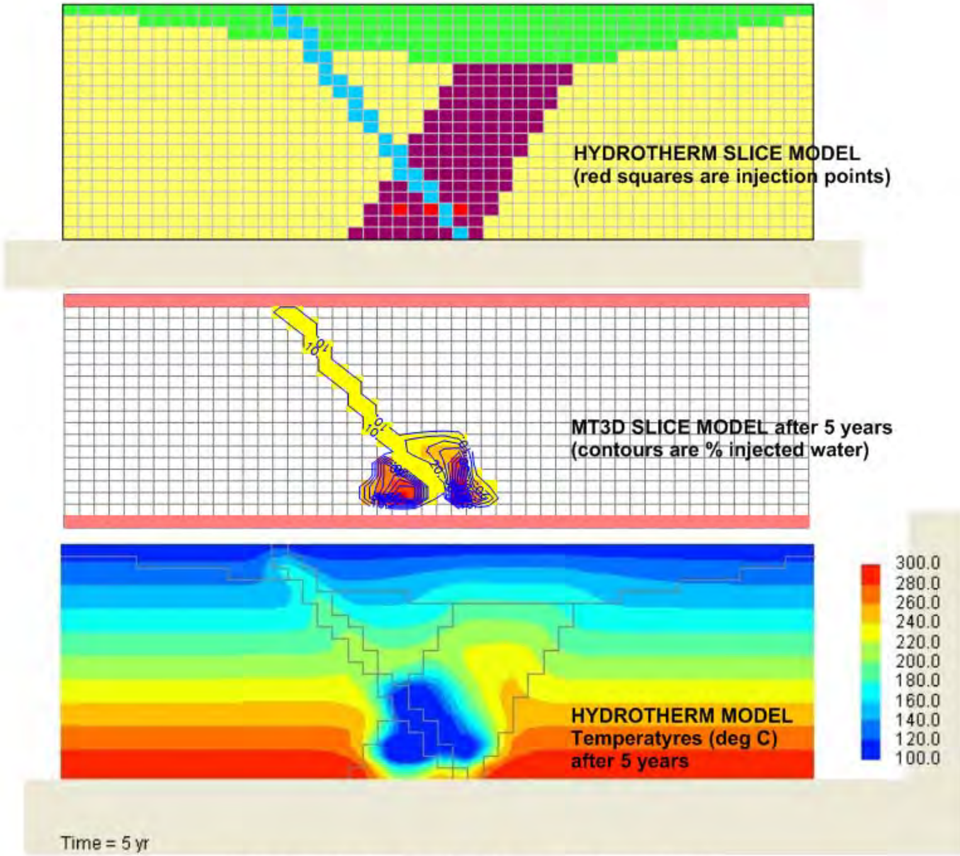
- Used to predict aquifer response over time.
- Used to predict infiltration rates and spread infiltrated water down gradient.
- Assists in locating recovery wells.
- Prediction of impacts on and of any existing users.

Hydro geochemical Modelling

- Used to predict potential for source and receiving water interactions or rock water interactions.

Rock Properties

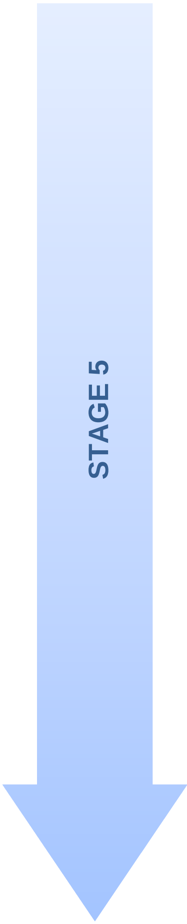
Color	Name	Poros	X-perm	Z-perm	ThCond	SpHeat	RxDen	Comprs
	inactive	0	0	0	0	0	0	0
	low K	0.001	1E-13	1E-14	1.67E5	9.5E6	2.65	1E-10
	shear	0.005	1E-7	1E-7	1.67E5	9.5E6	2.65	1E-10
		0.01	1E-9	1E-10	1.67E5	9.5E6	2.65	1E-10
	argillitic cap	0.008	8E-13	8E-14	1.5E5	9.5E6	2.65	1E-10



Each injection point injects 0.864cum/d into
a 1m thick x 16m x 12.5m cell.

INFILTRATION BASIN FUNCTIONAL DESIGN

Functional Design

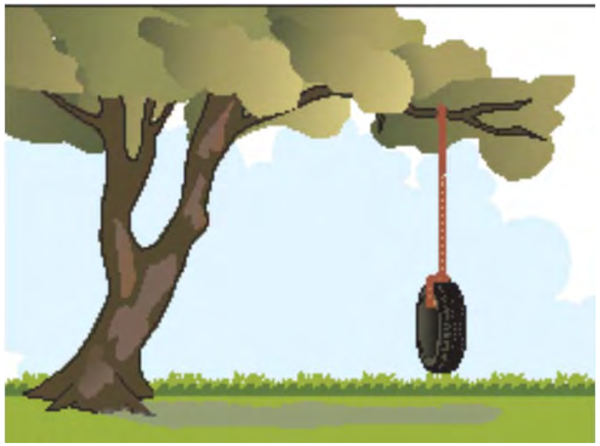


Predecessor STAGE 3 & 4 results

Functional Design

Elements include:

- Description of scheme objective
- Reference to supporting investigations
- Summary of regulatory approvals and when
- Treatment process
    - Wetland (volume & active capacity)
    - Biofiltration
    - Mechanical
- Infiltration pond or bore design



Functional Design Elements

- Description of scheme objective
- Reference to supporting investigations
- Summary of regulatory approvals and when
- Treatment process
  - Wetland (volume & active capacity)
  - Biofiltration
  - Mechanical
- Infiltration basin and/or bore design
- Pump specifications
- Pipe specifications
- Instrumentation
- Process Logic Control (PLC) and SCADA
- Monitoring needs
- Data management and storage
- Operation (who and when)
- Connections to existing infrastructure (irrigation)

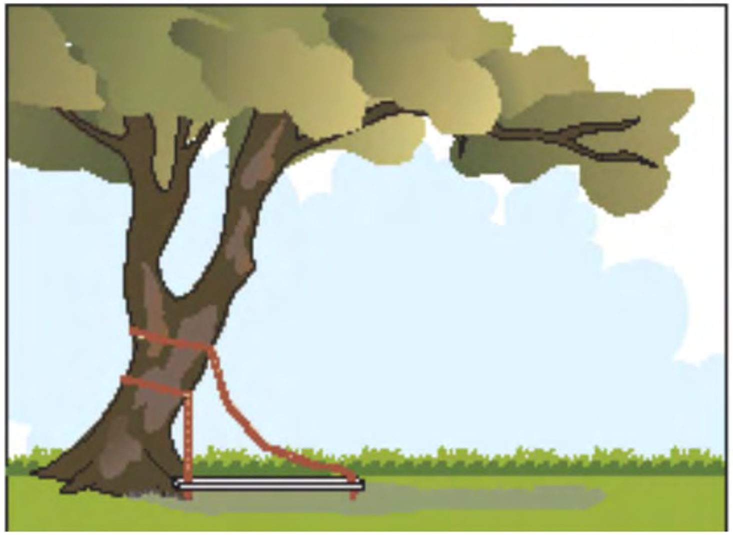
Functional Design

STAGE 5

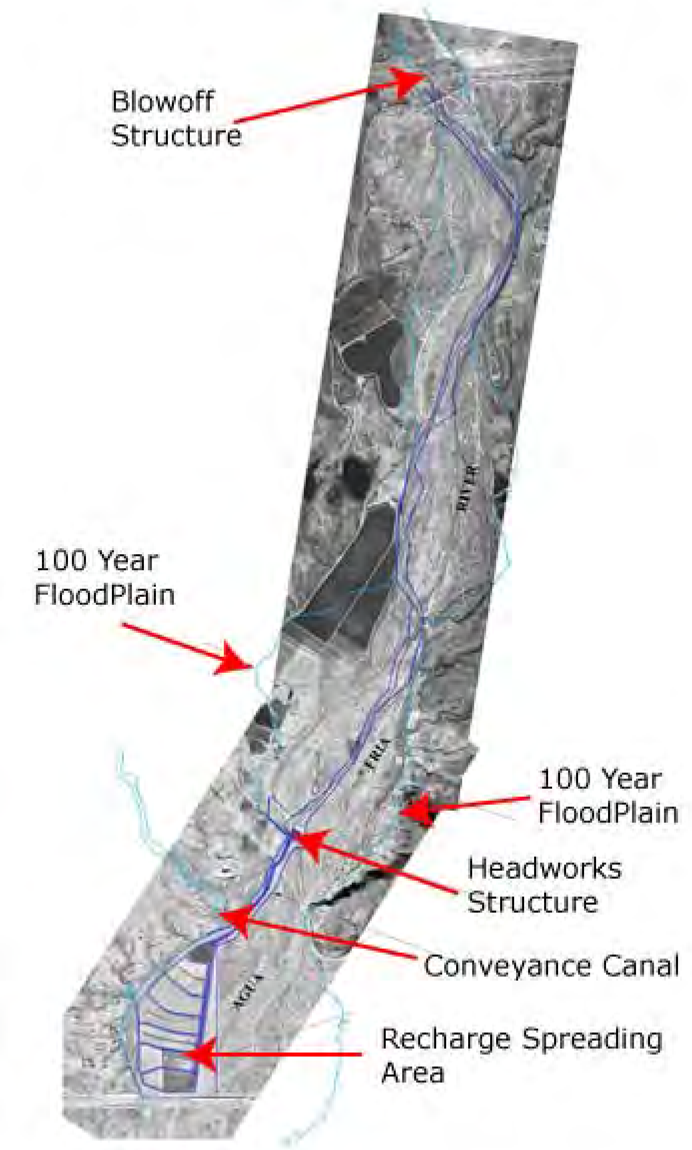
Predecessor
STAGE 3 & 4 results → Functional Design

The functional design is a ***critical*** step in the whole process which appears to be downplayed or even overlooked.

Without it there is a high probability that you will end up with something that is ***Functionally inadequate***

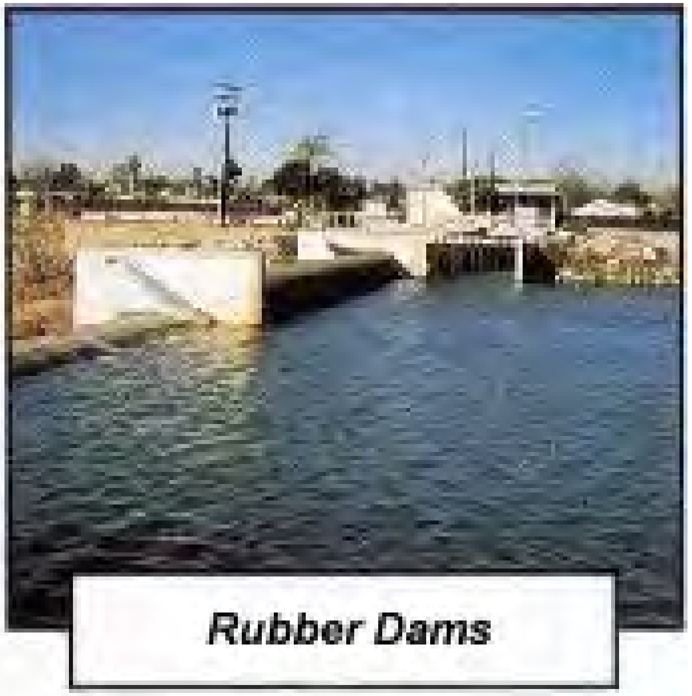


In Channel or off Channel



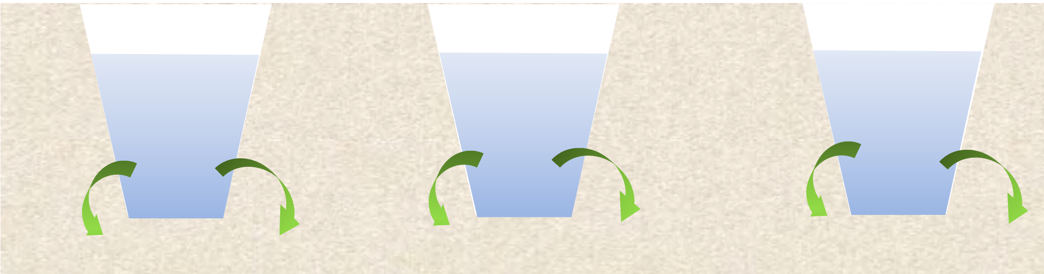
Agua Fria Recharge Project

In Channel



- Inflatable Rubber Dam
  - Allows easy capture of water for diversion.
  - Allows environmental base flows to pass during periods of low flow.

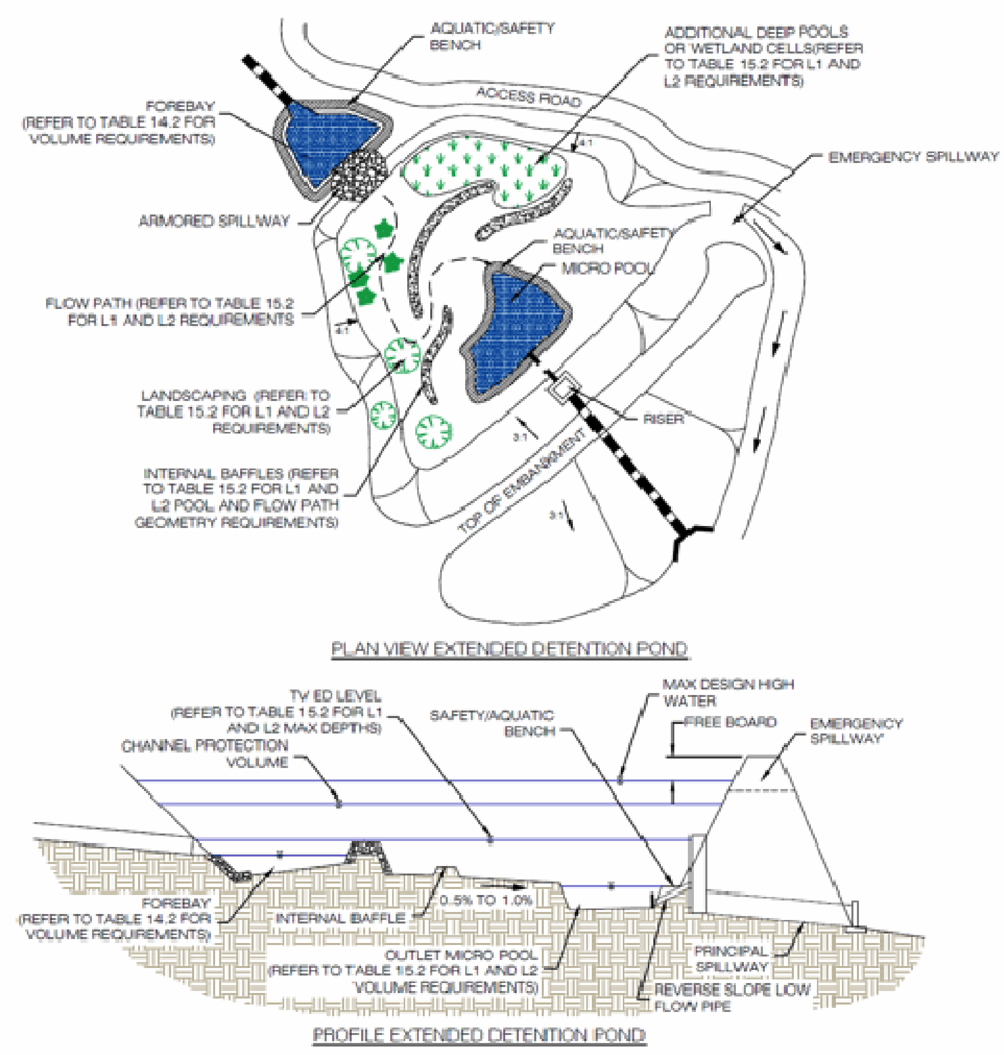
Infiltration Trenches



- Advantages
  - Percolation mainly through sides of trench.
  - Not concerned so much about clogging on base of trench.
  - Wind action minimised
- Disadvantages
  - Shallower depth
  - Maintenance when required may be difficult.
  - Larger footprint to achieve same percolation area as equivalent sized basin.

Natural Infiltration Basin

Multiple Basins



- May wish to consider multiple basins depending on source water quality
  - Allow one basin for settling out fines or other material (lined)
  - Deep open basin to assist with removal of pathogens by exposure to UV (lined)
  - Infiltration basin

Managing Algae

- Discharges to basin to manage algae growth
- Note:
  - Introduces increased aeration and potential for increased geochemical reactions.

Management of Sedimentation

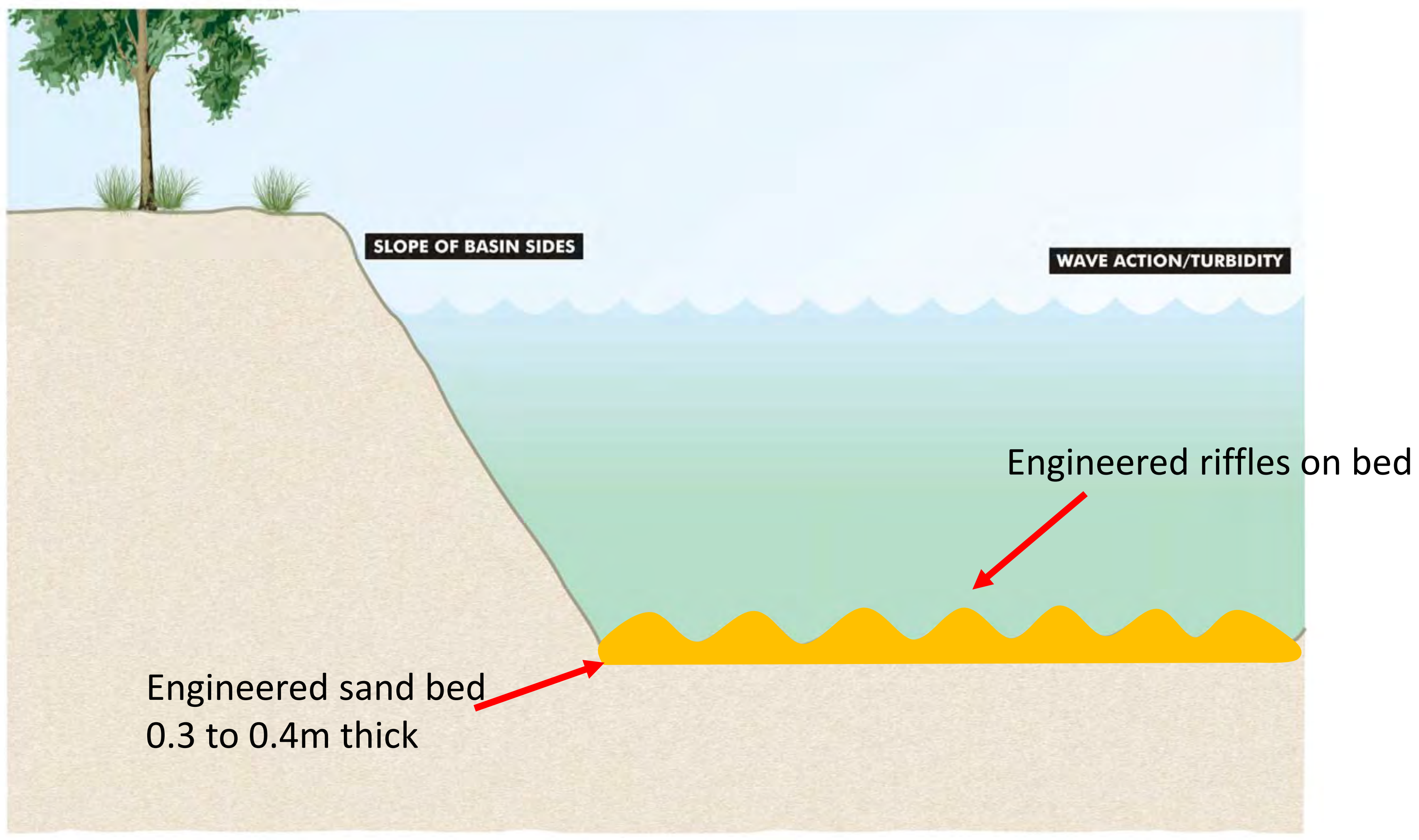
- Design should include capability to drain basin when remediation required.
- Need to consider management of sediments removed (possible contamination) depending on source water and activities in catchment.
- Scraping & sediment removal dependent on sediment loadings entering basin
  - once every 2-3 years
  - monitor percolation performance

Remediation

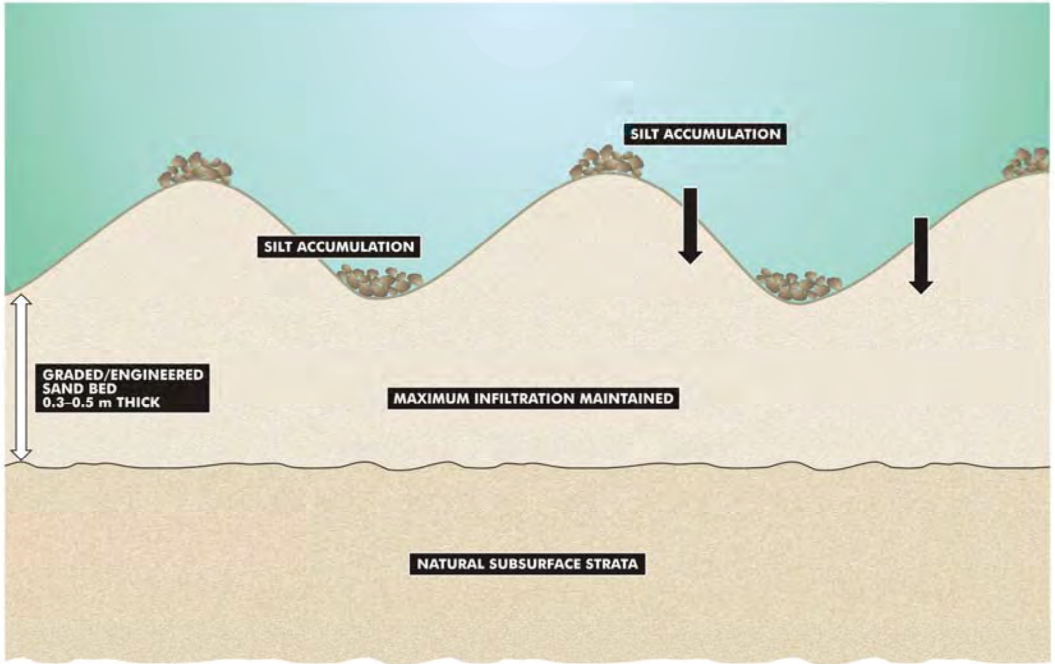
Tujunga Wash – Hanson Spreading Grounds Basin

- Takes approximately 8-12 days to drain, scrape and refill basin.
  - Issues of silt management
  - Disposal of soil (landfill?) if not contaminated
  - Gradual deepening of basin each time sediment removed
  - Minor compaction by movement of heavy vehicles

Design to Manage Sedimentation



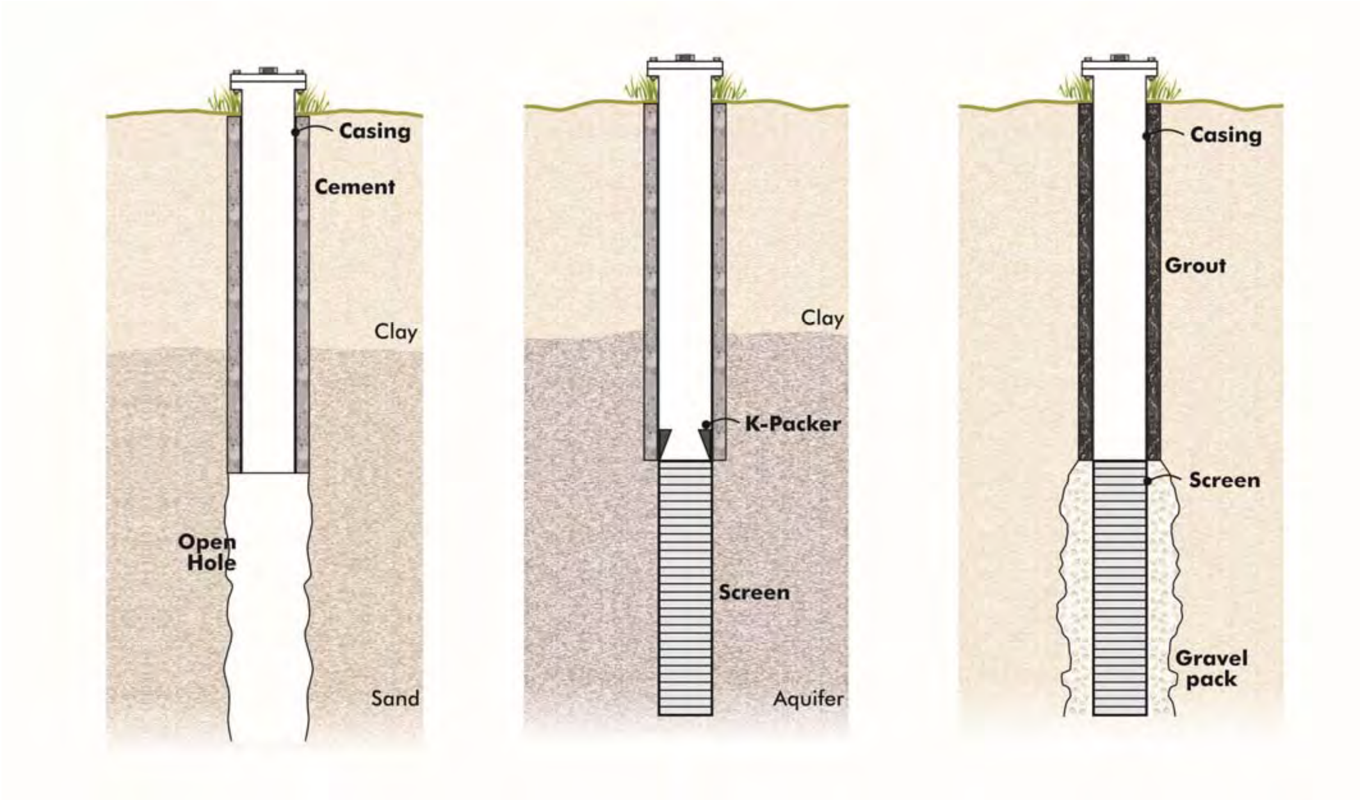
Engineered Riffles



- Reduces frequency of draining/cleaning basin.
- Percolation rates can be maintained by raking new riffles.
- Depending on depth of raking natural strata need not be removed.
- A stockpile of graded washed sand can be on hand to replace removed material reducing turn-over time.
- Removed material can be rewashed and reused for next cycle minimising disposal cost.
- System not tried yet and depend on
  - Economics
  - Likely reactions at contact between natural strata and engineered sand bed.

INJECTION & RECOVERY BORE DESIGN

Types of Borehole Completion



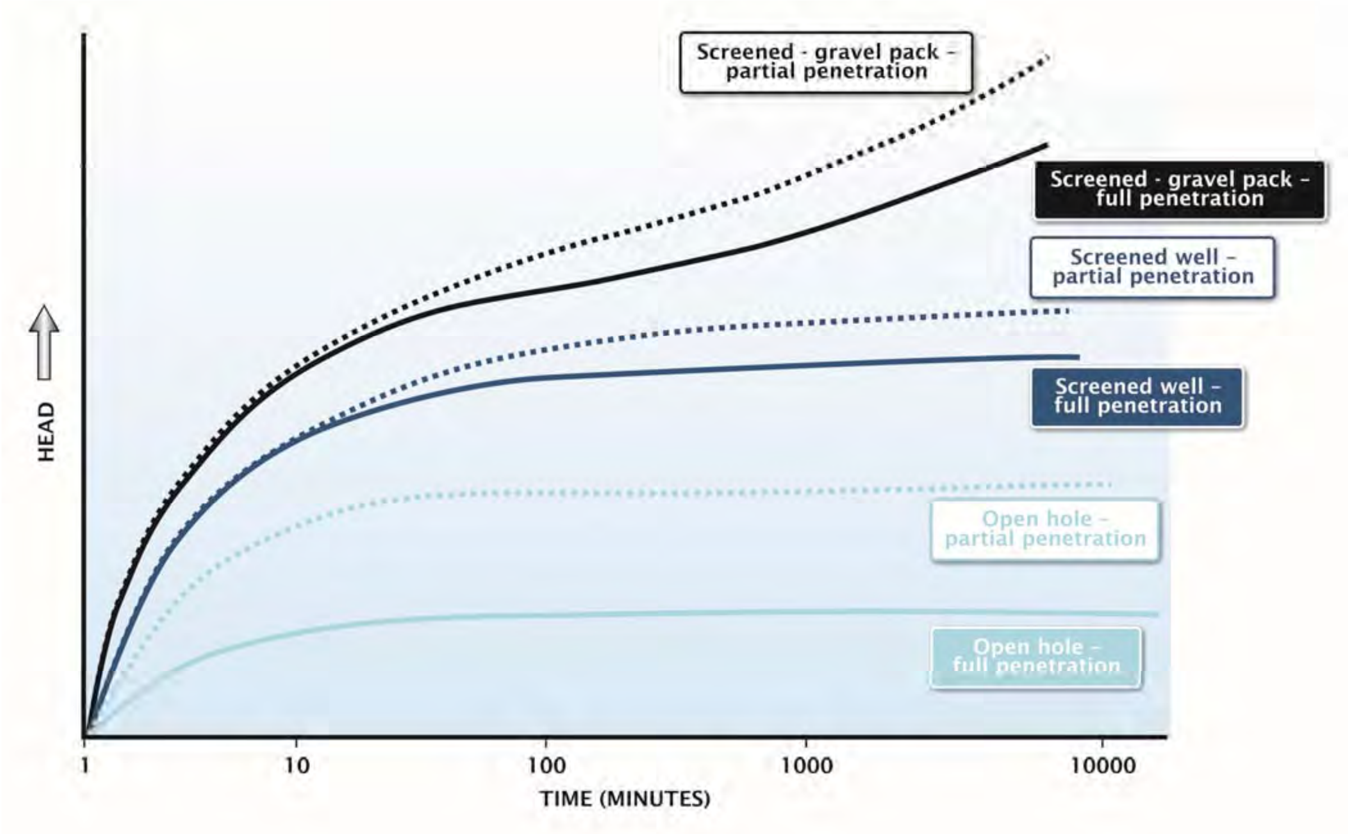
Root Cause of Clogging Issues in ASR Bores

- Well Construction
  - These are not standard pumping bores
  - Use experienced drillers.
  - Come up a couple of sizes on production casing to allow room for all equipment.
  - Insufficient time allowed for development
- Pump hydraulics
  - Larger diameter allows larger pumps to be inserted in case of need for high backwash rates to recover bore

Root Cause of Clogging Issues in ASR Bores continued……

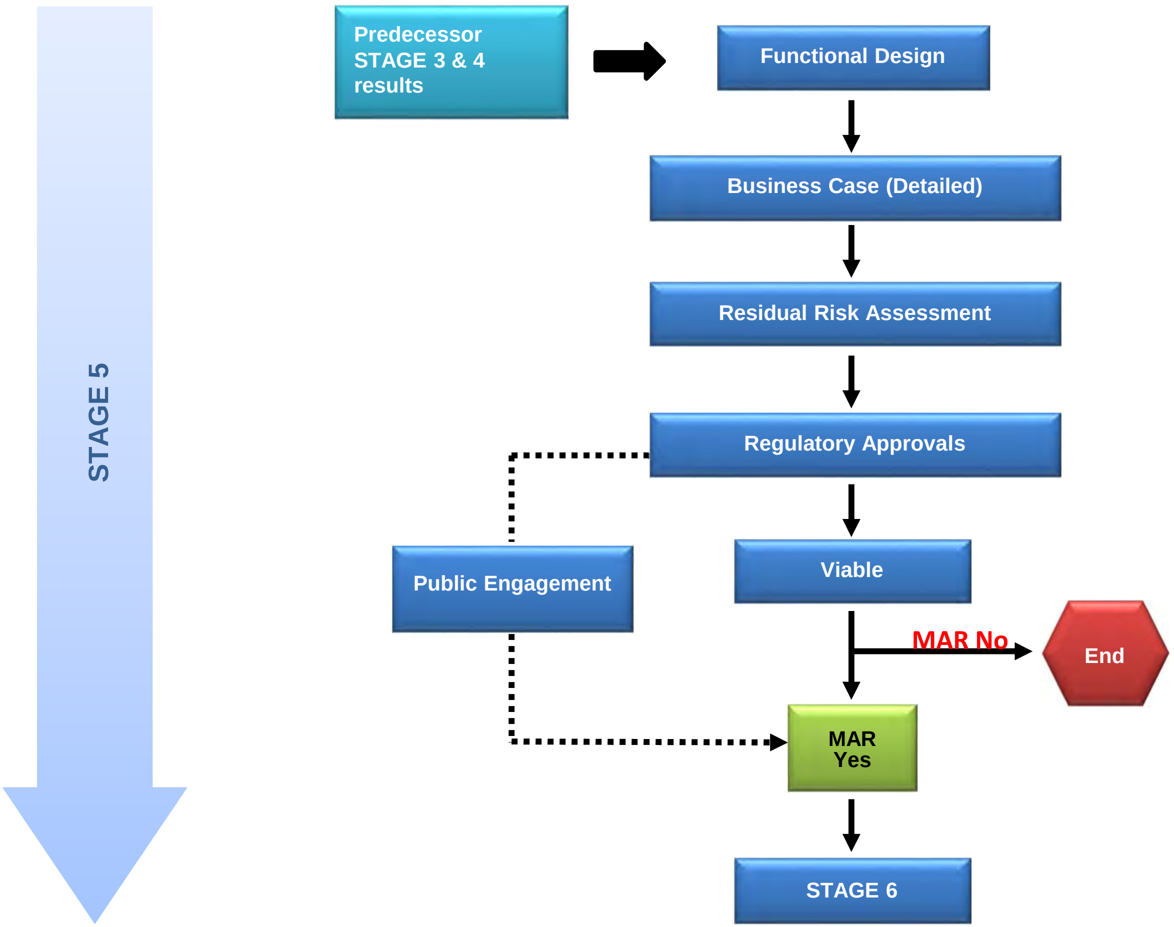
- Operational Budgets
  - Generally overlooked in planning stages
  - Expectation that existing staff can just pick up and run with it
  - Mostly woefully inadequate
  - Insufficient to engage experienced professionals to train and guide staff tasked with day to day operations.
- Time
  - Write off first year of injection as part of commissioning (Target Storage Volume)
- Screen selection
  - Try and come us a few notches on screen aperture/gravel and allow slightly longer time for initial development

- Completion affects injection performance
- Completion also influences available remediation options in the event rehabilitation is required.

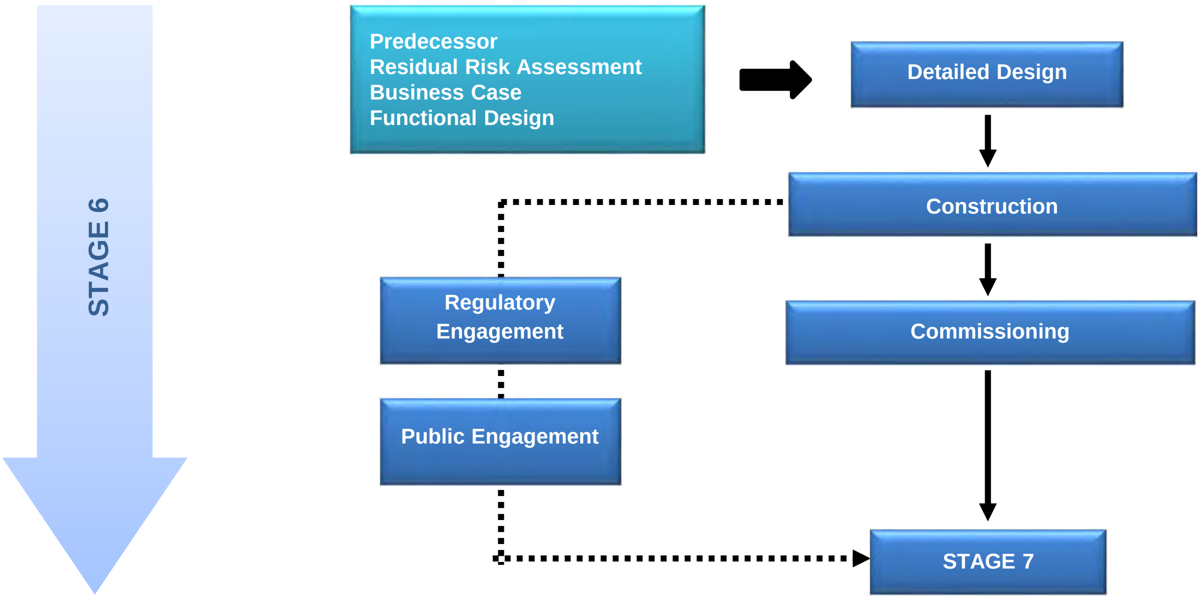


REGULATORY APPROVALS & DETAILED DESIGN

Regulatory Approvals

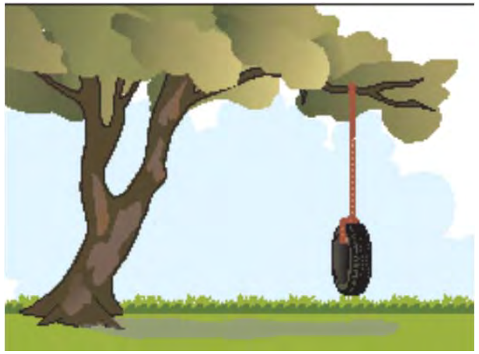


Detailed Design

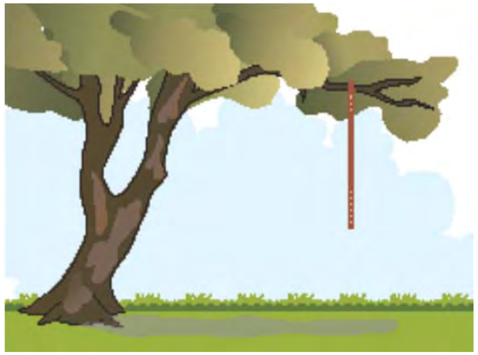


The Design Specification & Budget

- Design Specification



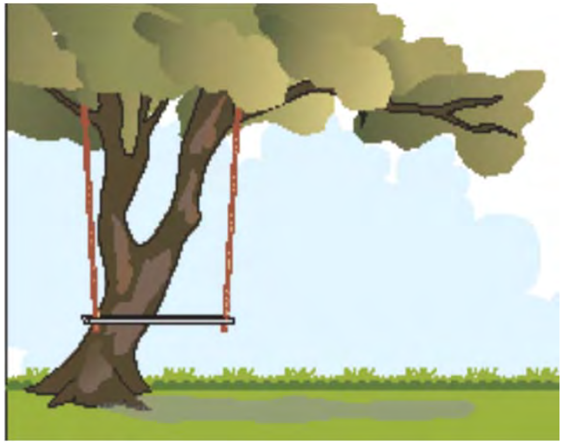
- *what the customer wanted*



- *what got budgeted*
  - *Failure to understand all of the costs including operational*

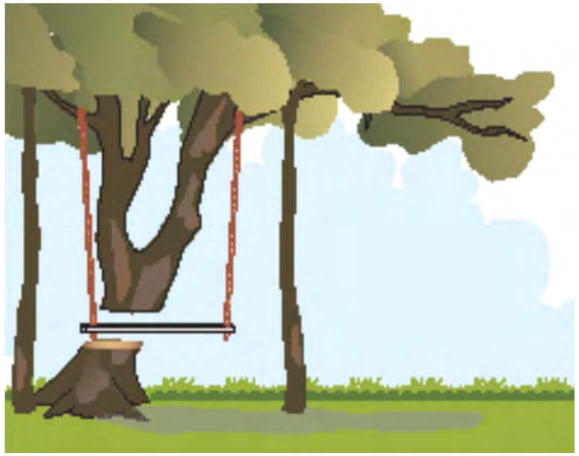
Engaging Contractors

- Early Contractor Involvement (ECI) has proved successful
  - Gain understanding of project
  - Work with design team to ensure all components and project deliverables are met
  - Take ownership of project costs
  - Eliminates surprises and cost variations
- Don’t overlook monitoring & data capture/storage to assist in assessing scheme performance over time.



- *What was designed*
  - *Failure to communicate or poor understanding of the operational requirements by the design team*

- *What was installed*
  - *Poor scoping leads to significant workarounds*



- *What got documented*
  - *No one took responsibility for documenting as constructed design*

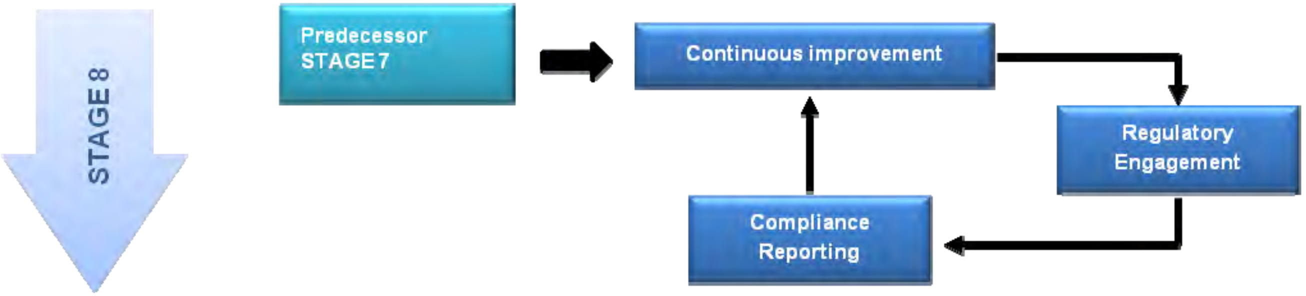
COMMISSIONING & OPERATION

Commissioning

- Construction team should be working closely with the client and client's operations team to provide training in the operation of system and minor trouble shooting.

- Critical that there is a handover from the design and construction team to the operations team including all as constructed drawings and equipment documentation

Operation


STAGE 8
Predecessor
STAGE 7
Continuous improvement
Regulatory
Engagement
Compliance
Reporting

Operational Bores

- Backwashing
- Water Quality monitoring
- Monitoring
  - Injection rate versus pressure response
  - Inline turbidity
  - Inline EC
  - Inline flow meters
- Bore redevelopment (method dependent on completion)
  - Scrubbing
  - High velocity jetting
  - Vacuum pumping
  - Under reaming
  - Biocides
  - Surging
- Acidisation

SUMMARY

Summary

- Clogging presents the single biggest risk for the successful operations of an MAR scheme
- There are four principal types and they may occur individually or there may be multiple processes occurring
  - e.g. microbiological activity produces slimes and also creates a reducing environment which causes mineral precipitation
- Types include:
  - Chemical
  - Physical
  - Mechanical
  - Biological

Clogging Can be Controlled

- Detailed and extensive aquifer characterisation will determine which of the various methods of MAR are suitable for your intended site.
- Aquifer characterisation includes:
  - Field investigations including drilling supervision by an appropriately qualified hydrogeologist.
  - Field trials
  - Chemistry of source and receiving waters
  - Aquifer characterisation
    - Geophysical logging
    - Pumping tests
    - Coring
    - XRF/XRD
    - Sieve analysis
    - Column studies
    - CEC analysis
  - Analytical / Numerical modelling
  - Hydrogeochemical modelling
- These investigations are critical to informing the engineering design of the scheme and identifying if there are any potential show stoppers.

Design & Operation Controls to mitigate Clogging

- Engineering design;
- Chemical intervention;
- Operational practices;
- Monitoring of scheme performance; and
- Periodic remediation.
- It should also be noted that the remediation methods to address clogging are very site specific and what works in one hydrogeological setting may not always be successful in another location.

Design Considerations

- Water should be as clean as possible (very low turbidity, no silt sediments or other suspended material).
- Slope of basin sides 1:7 prevent erosion (riprap).
- Depth of basin should be < 5 m
- Spend time and effort to characterise your aquifer.
- Characterise your source water to assess potential for redox reactions.
- Key areas to focus on include:
  - Basin walls
  - Basin floor
  - Unsaturated zone
  - Interface between ambient groundwater and percolation water
- Monitoring and operator training.

Thank you for your attention

Contact details:

rmartin@agwt.com.au

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