TRAINING DOCUMENT

GROUNDWATER USAGE EXPLANATIONS & QUALITY CONTROL

The “water level” Explanation

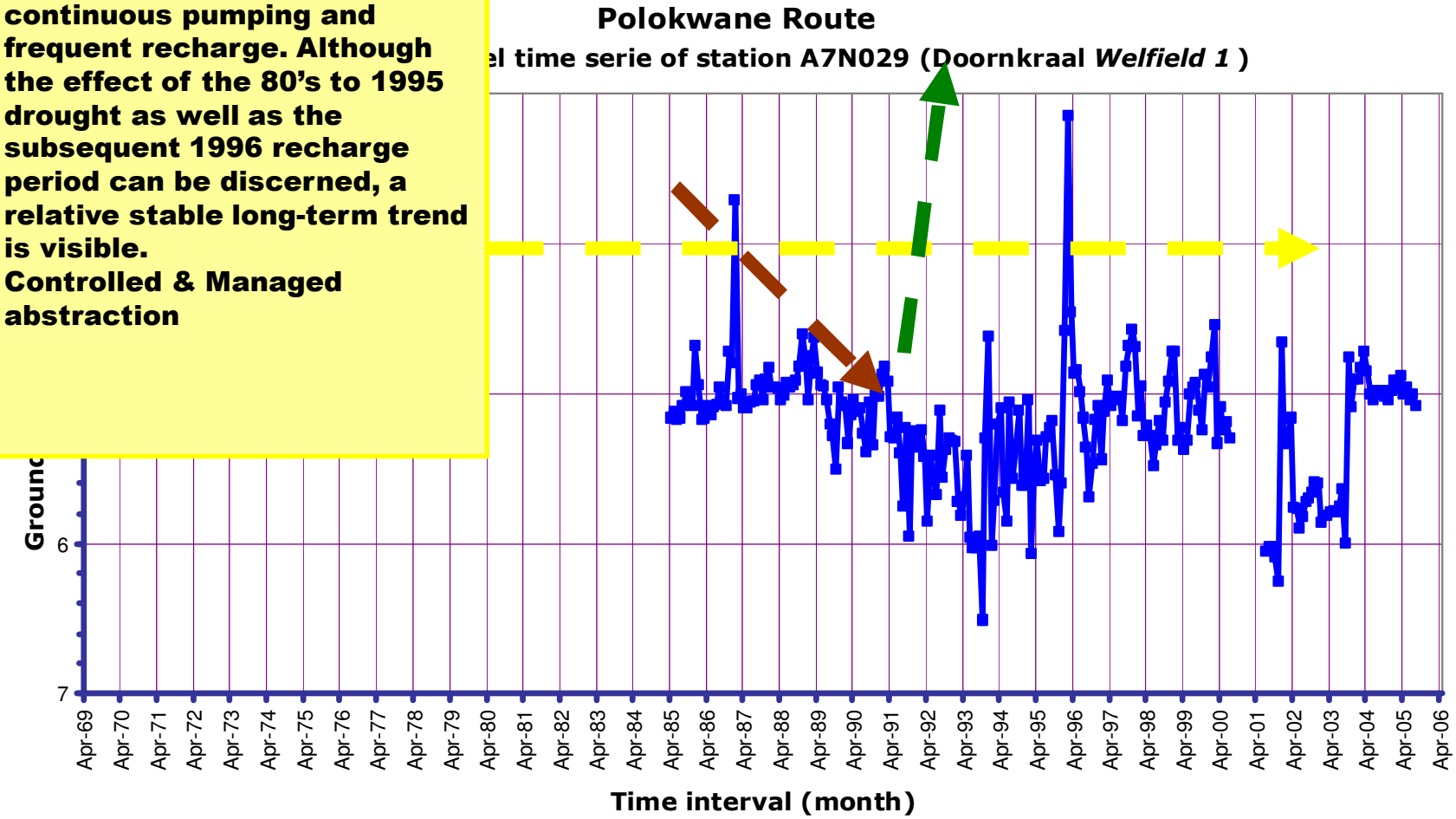
- The measured or listed water level on most documentation is a static or rest water level and indicates:
  - a measured depth from the surface to the water inside the borehole
  - the level measured when the borehole is not in use – being pumped,
  - the shallowest level measured at the source during any period,
  - taken after a recovery period that differs for every source,
  - the saturation of the water bearing source – the extent to which the source is filled up,
- The water level is not always a fixed or constant value and could:
  - fluctuate from time to time,
  - be shallower during good rain periods,
  - be deeper during drought periods,
- The water level will always be shallower than the depth of the first water strike noted during the drilling phase,
- The water level will be deeper during the pumping cycle, but will return to a similar level than the static level after a period of no abstraction.

The value of known water levels

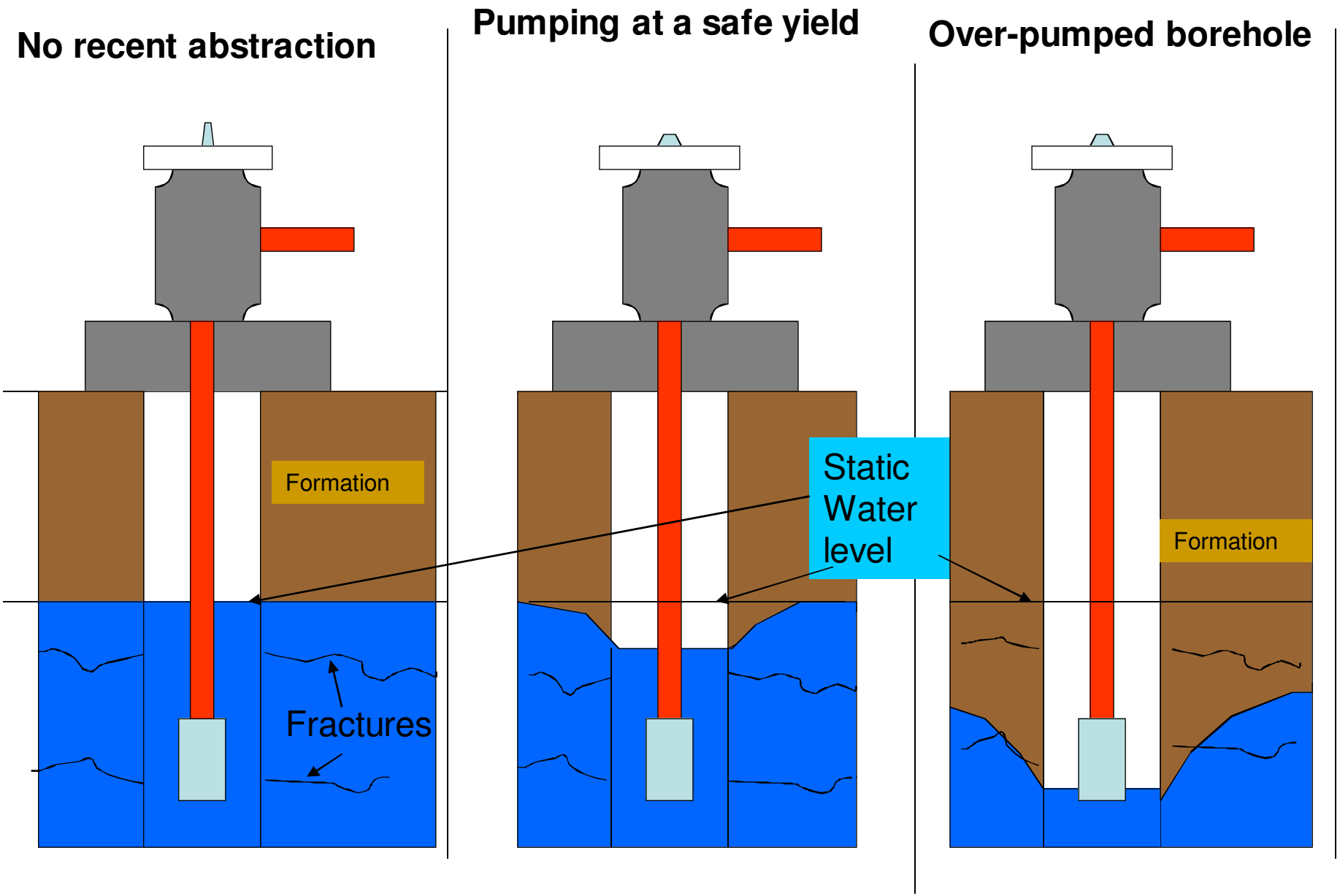
- The static water level is a valuable parameter when utilizing groundwater:
  - groundwater levels varies from area to area and can even be negative (artesian boreholes).
  - the two most important parameters noted when a yield test is performed is the water level and the abstraction yield measured at the same time,
  - water levels measured at boreholes nearby the tested source (monitoring) will assist in calculating a more accurate or saver abstraction value,
  - the yield and water levels monitored during a yield test is utilized to analyze the test data and through various methods or calculations a saver or correct abstraction is recommended as well as other values such as permeability (T-value) and Storage (S-value) is obtained,
  - measured levels (monitoring) will indicate the over or under utilization of the source,
  - large variations during use indicates that the equipment selection or the recommended abstraction is most probably incorrect,
  - most equipped sources is fitted with electronic devices to protect the equipment (Low level probes / motor scopes etc.) from “dry run” scenarios. - equipment to be re-designed when pump inlet is reached,
  - the monitoring of water levels, rainfall and abstraction yields will assist in calculating the sustainability of groundwater sources - not only for well fields but also on a regional scale,

Management and Monitoring

Fluctuating water level due to continuous pumping and frequent recharge. Although the effect of the 80's to 1995 drought as well as the subsequent 1996 recharge period can be discerned, a relative stable long-term trend is visible.
Controlled & Managed abstraction



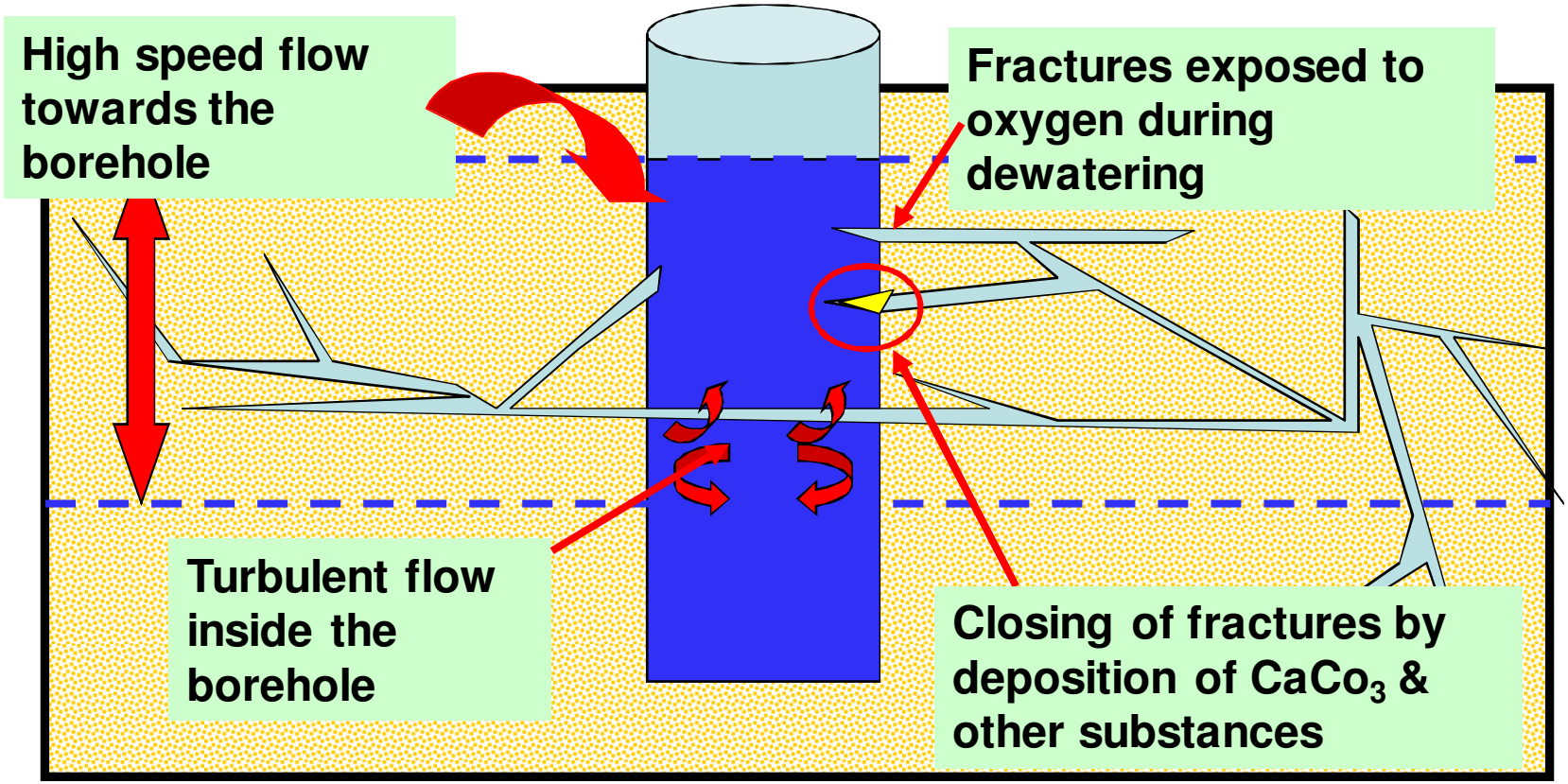
Water level explanation



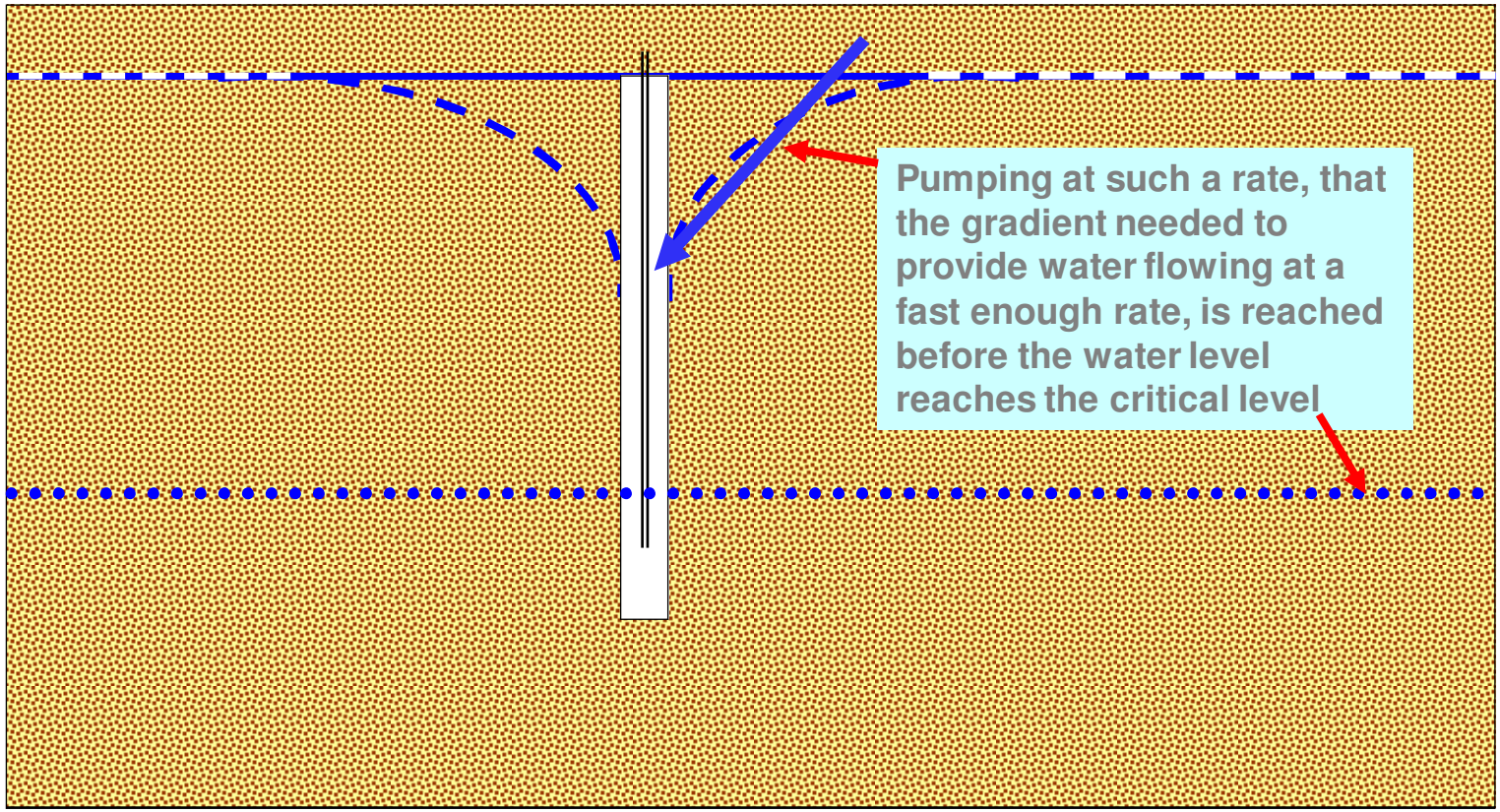
Weathering / Fracturing

- In most cases the weathered zone of the geological formation represents only the first few metres when drilling a borehole and is seldom deeper than 36m,
- Weathering is mostly represented by small particles or softer material (sometimes clay) and will seldom deliver high yielding water strikes,
- Within some boreholes, the weathered zone will become harder and often start to break into larger pieces before being solid – this area will be the first fractured zone and can often represent higher yields,
- Fracturing is often encountered within solid rock, on contact zones between different formations and on linier structures such as faults (zones of weakness),
- Fractures or weathering intersected above the water level at the time of drilling will deliver no water,
- Equipment designed for each borehole should be selected to deliver water at a rate that will not lower the water level below any water strike (fractured zone below the water level),
- Keeping the water level above the water strike will protect the fracture through minimizing water movement and oxygen contact which can stimulate bacterial growth or chemical reactions,
- At production boreholes, the weathered formation must be cased and in many cases the higher yielding zones also collapse due to larger size rocks (fractures) and should also be cased with perforated casing,

Negative effects resulting from over abstraction: turbulent flow & oxygenating



The ideal situation



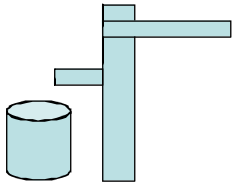
Recommended abstraction - Summary table

Rec. yield (l/s)	Duty cycle (Hours)	Daily abstract. (Litres)	Rec. Equipment	Persons at 60 l/p/d
0.1	8	2880	Hand pumps (Including play pumps)	46
0.1	24	8640	Submersible, Windmill or Hand pump	144
0.15	8	4320	Windmill or Hand pumps	72
0.15	24	12960	Submersible, Windmill or Hand pumps	216
0.3	8	8640	Submersible, Windmill or Hand pumps	144
0.3	24	25920	Submersible or Windmill	432
0.5	8	14400	Motorized (Diesel), Windmill or Submersible	240
0.5	24	43200	Motorized (Electrical) or Submersible	720
1.0	8	28800	Motorized (Diesel or Electrical)	480
1.0	24	86400	Motorized (Electrical)	1440
3.0	8	86400	Motorized (Diesel or Electrical)	1440
3.0	24	259200	Motorized (Electrical)	4320
5.0	8	144000	Motorized (Diesel or Electrical)	2400
5.0	24	432000	Motorized (Electrical)	7200
10.0	8	288000	Motorized (Diesel or Electrical)	4800
10.0	24	864000	Motorized (Electrical)	14400

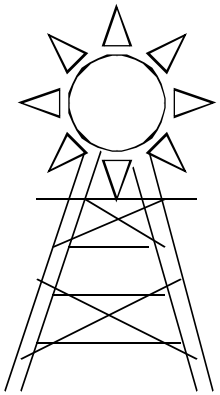
RECOMMENDED ABSTRACTION - Explanation

0.1 LITRE PER SECOND (0.1 l/s)

FOR 8 HOURS PER DAY
= 2880 litres per day



FOR 24 HOURS PER DAY = 8 640 litres per day
or 144 persons at 60 litres per person per day



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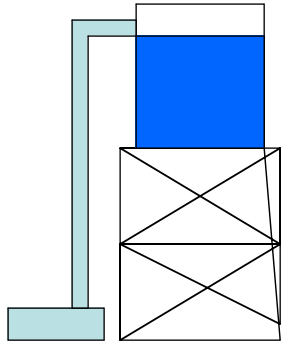
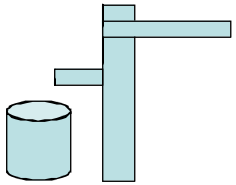


Submersible

0.15 LITRE PER SECOND (0.15 l/s)

FOR 8 HOURS PER DAY
= 4320 litres per day



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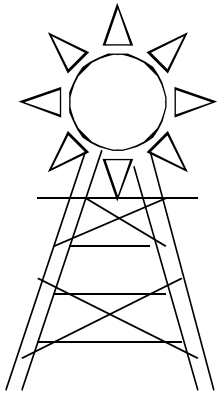
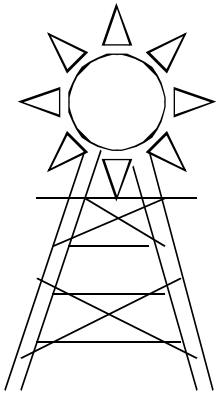


FOR 24 HOURS PER DAY = 12 960 litres per day
or 216 persons at 60 litres per person per day



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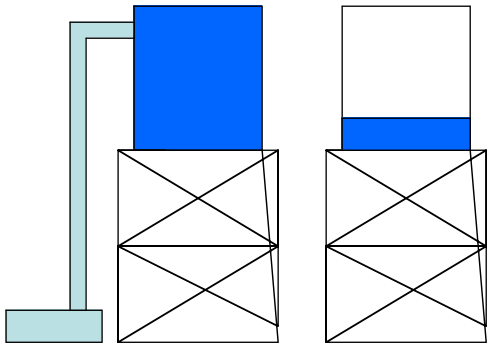
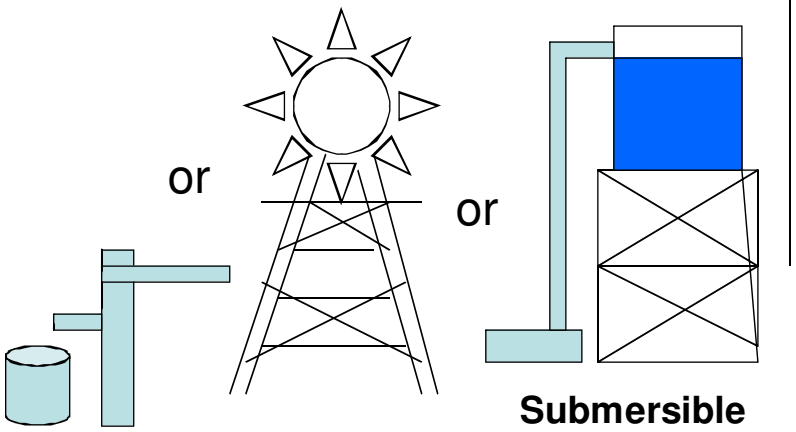


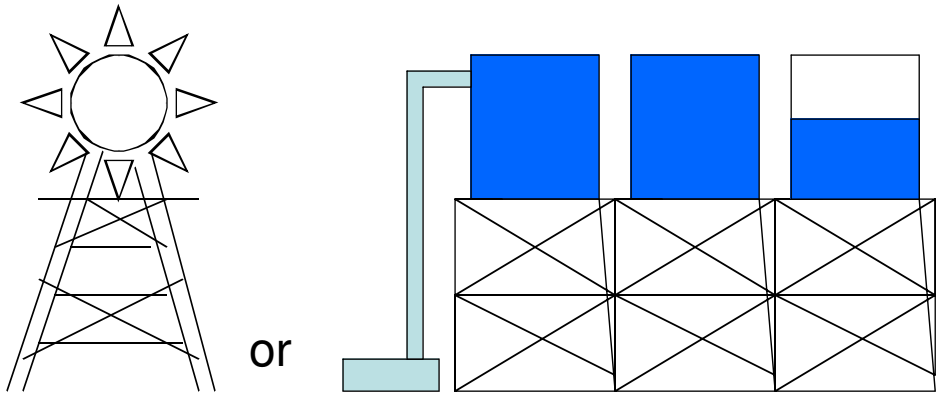
Submersible

0.3 LITRE PER SECOND (0.3 l/s)

FOR 8 HOURS PER DAY
= 8640 litres per day



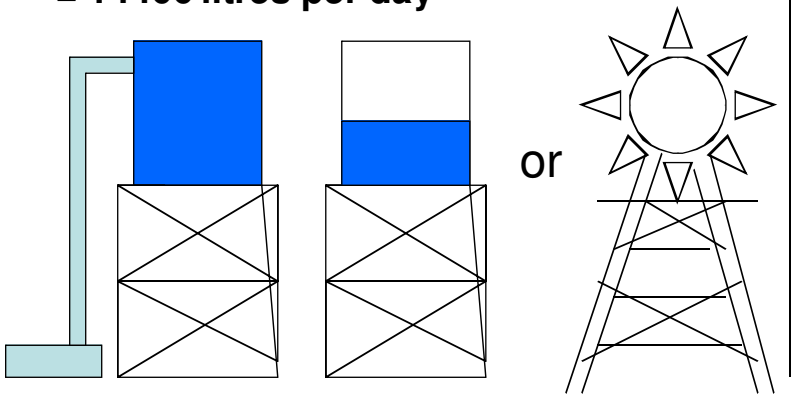
FOR 24 HOURS PER DAY = 25920 litres per day
or 432 persons at 60 litres per person per day



Submersible

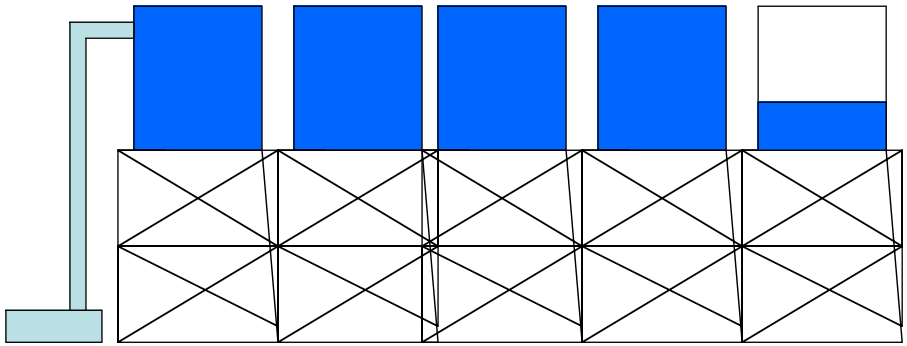
0.5 LITRE PER SECOND (0.5 l/s)

FOR 8 HOURS PER DAY
= 14400 litres per day



Submersible

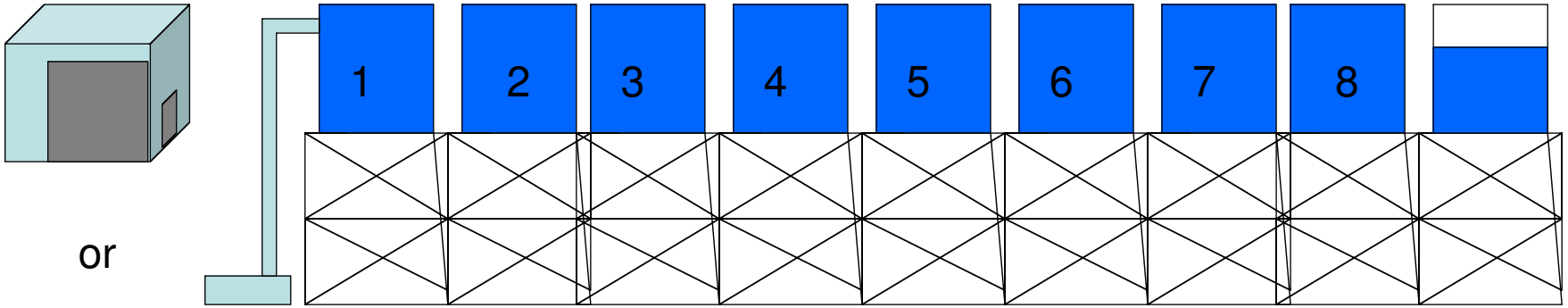
FOR 24 HOURS PER DAY = 43200 litres per day
or 720 persons at 60 litres per person per day



Motorized or Submersible

3.0 LITRE PER SECOND (3.0 l/s)

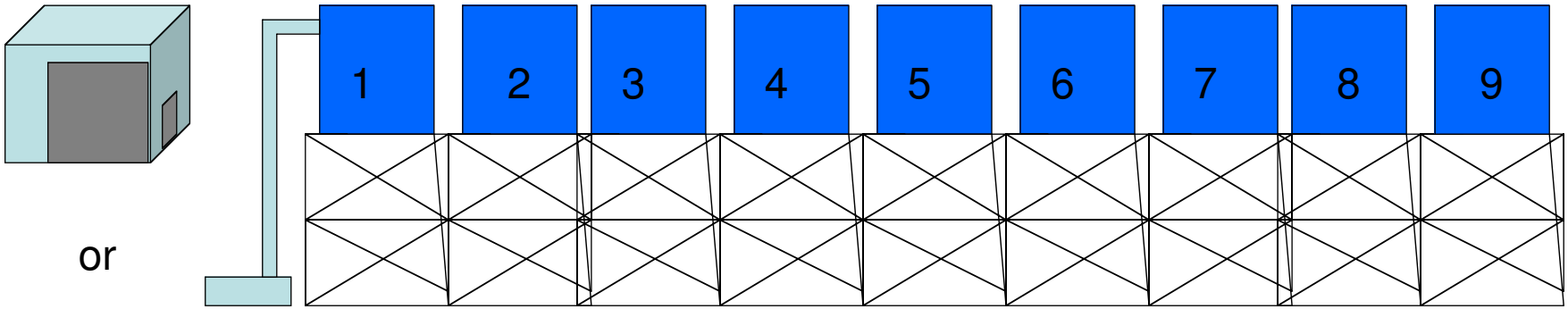
FOR 8 HOURS PER DAY = 86400 liters per day



or

Motorized or Submersible

FOR 24 HOURS PER DAY = 259200 litres per day or 4320 persons at 60 litres per person per day



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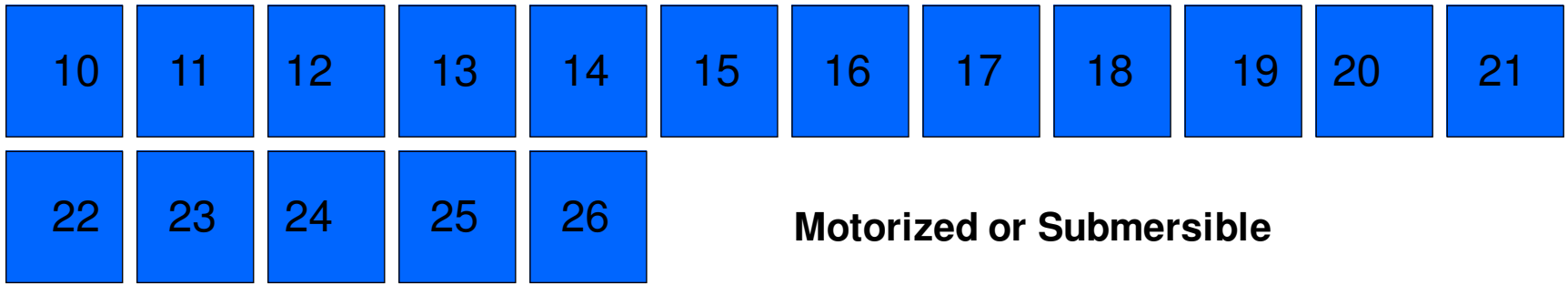
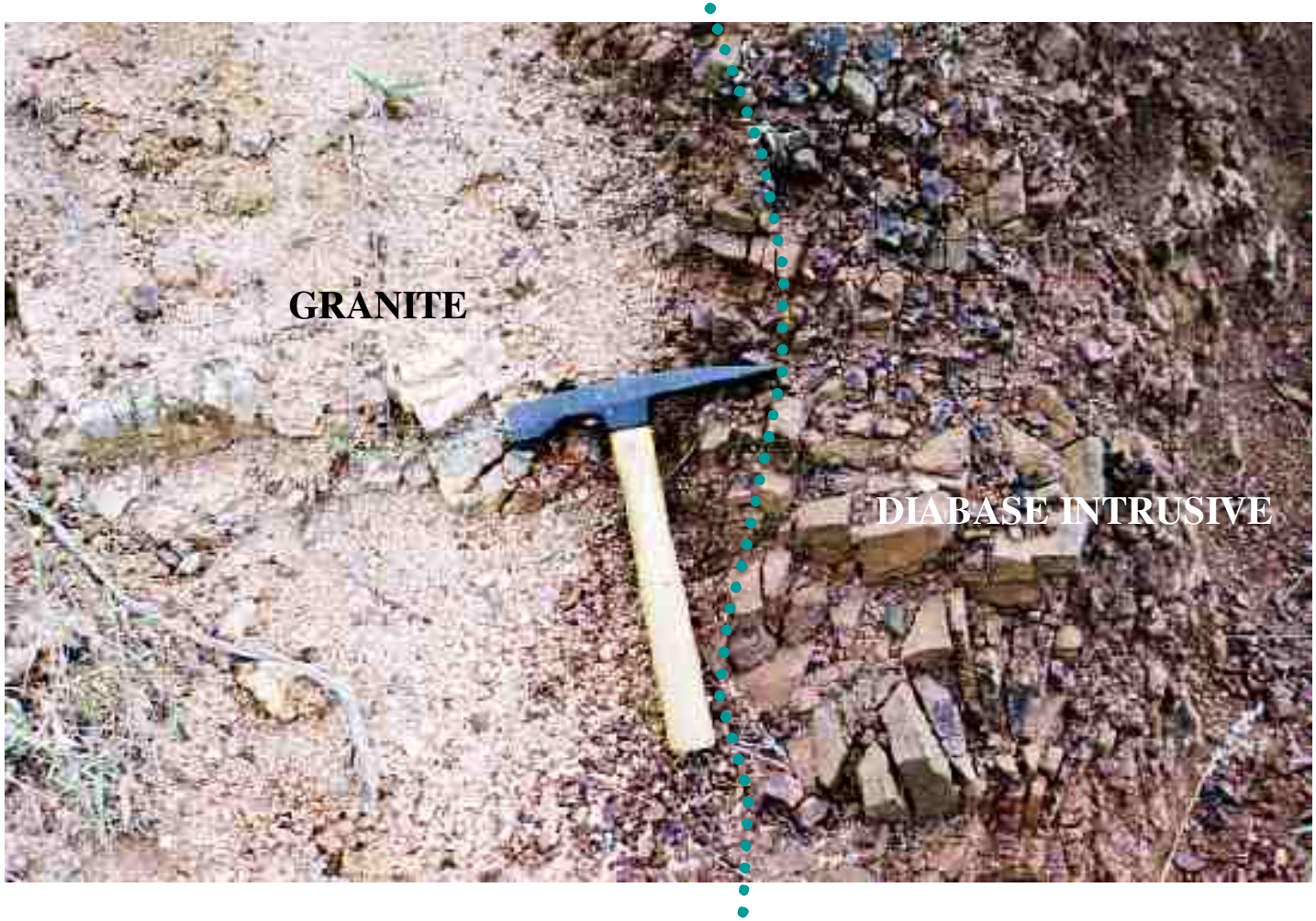


Motorized or Submersible

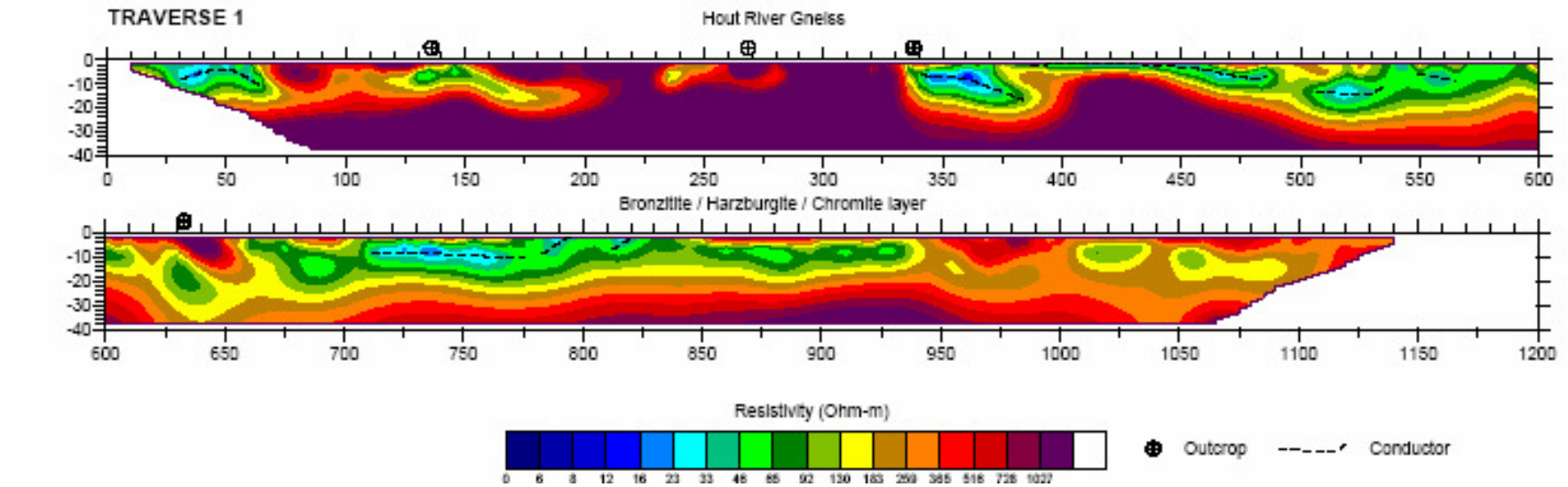
Geophysical drill site selection

- Many individuals or even contractors claim that they can determine where groundwater will be intersected without the use of scientific methods and although many successes are noted, no reporting or statistics are available,
- Geophysical investigations is executed by the hydrogeologist to assist him in determining geological structures or features that could contain or bear groundwater. It involves the following:
  - Discussions with the client and also the users regarding the proposed drilling phase and the first prioritized area to be investigated,
  - Desk study to evaluate existing data such as the geological formation, groundwater levels etc,
  - Structural analysis (Aerial photos, Satellite imagery (ASTER SAT etc), existing mapped geological lineaments etc,
  - Planning the geophysical traverses should be according to the information collected and to intersect interpreted structure as far as possible at ninety degrees, but the terrain conditions, accessibility, existing infrastructure etc. should be considered,
  - Determine the most applicable geophysical equipment to used for the specific geological environment,
  - Conduct the geophysical survey using at least two types of instruments and if possible even more than two, but seldom with only one type,
  - It will be essential to conduct a geological investigation, either during the geophysical field phase or at least before final selection of the drill sites. When the visible geology, soil type etc. is available during the geophysical data interpretation it will assist in better decisions being made when final drill sites are selected,
  - The best drill site will be selected when all or most of the above actions are included during the evaluation or interpretation of the geophysical data.

Geological Mapping



Electrical Resistivity 2D Profiles



DRILLING

Drilling is a specialist action and should not be regarded as digging a deep hole, but rather as the construction phase of a life depending source,

Borehole design or construction

- Correctly constructed boreholes will last a lifetime and supply clean water, when correctly drilled and constructed:
  - must be straight,
  - be drilled vertically,
  - cased correctly,
    - reamed and cased into solid formation,
    - must seal at bottom of casing,
    - should seat on the final reamed depth
    - must have no protruding welding at inside of the casing,
    - each casing must fit on the next casing before being welded
    - welding must be done with the correct welder to ensure the correct penetration is maintained,
    - casing thickness must be according the DWAF guidelines – 4mm thick and 165mm ID,
    - perforation must be correct – size and placement of openings for each meter,
    - correct placement of perforated casing – at water strikes (place where water enter the hole)
  - perforation to be covered with the correct formation stabilizer,
  - reamed area between the casing must be sealed at the surface - correct sanitary seal and concrete collar,
  - especially for stronger boreholes the drill bit size should be within the specifications,
  - developed sufficiently before the drilling contractor leaves the site,

Un-supervised drilling

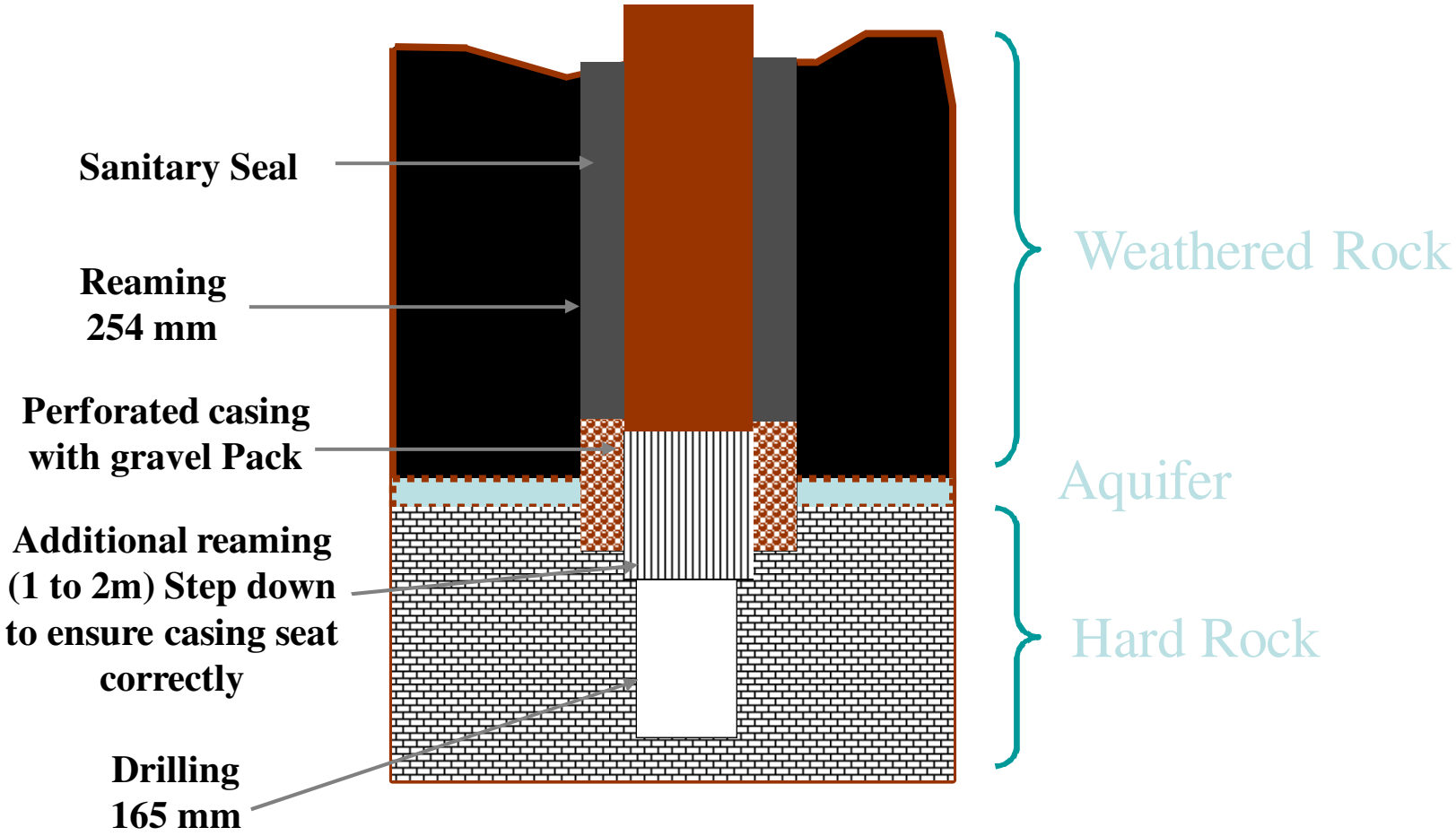
- Experienced drilling contractors are capable of constructing a borehole, not only to last the guarantee period but for a lifetime. It should however be noted that although sufficient casing could be installed and the borehole construction seem to be correct, wrong placement of the perforated casing will reduce the yield of the source,
- One of the most common reasons why boreholes collapse is because of insufficient casing and without receiving instructions during the drilling phase, contractors can decide to install casing into still unstable formation,
- Equipping a poorly constructed source will have huge maintenance implications and even a total loss of the capital expenditure as well as unhappy communities without water.
- A collapsed strong yielding borehole is worth less than a weak hand pump borehole that was correctly constructed
- A collapsing cased borehole cannot be rehabilitated without installing a smaller diameter casing and even this is often impossible,
- Be aware that contractors could, without supervision, claim a borehole to be "not drillable" or even dry without even intersecting solid formation because drilling is difficult (clayey or loose),
- With no supervision during the drilling phase, the contractor will make the decisions and the client (when not present) will accept the quality and quantities claimed according the invoice,
- No or very little information or reporting (drilling tempos, geology, water strikes, numbering etc.) will be available for future verification.

Supervised drilling

- For the best results, supervision can be the clients proof and insurance when paying for a reliable water source. Technology has also improved and claimed casing and depths drilled can be verified during the testing phase.
- Proper planning when designing the final construction of a borehole will ensure no collapsing and a clean sustainable and reliable source,
- The contractor can not claim for any actions not delivered according the instructions, and include
  - reaming the drilled diameter to a size suitable for successfully installing the casing,
  - installing the correct casing up to the reamed depth,
  - drilling up to calculated of sufficient depth – not too shallow but also not unnecessary deep,
  - installing sufficient and the correct size and type formation stabilizer,
  - Inserting the correct quantity and cement / bentonite mixture for a proper sanitary seal,
  - ensure the borehole is developed properly before the contractor remove the drill pipes,
  - correct protection of exploration or dry boreholes,
  - supplying the correct borehole number for the area being drilled (H-Number) and planting of that correct numbering pole,
  - Will assist or instruct the contractor regarding the method to be utilized – normal, drill & drive, odex etc.
  - cleaning the site (smoothing of drilling formation as well as removing rubbish) before demobilizing,
  - Approve the invoice according the actions completed,
  - Will not accept an incomplete borehole,
- During supervised drilling the contractor and the consultant accept the quality and quantities claimed to be correct,
- Supervision ensures that results (drilling tempos, geology, water strikes, numbering etc.) will be reported and available for future verification,

Drilling in progress

Typical Drilling Scenario

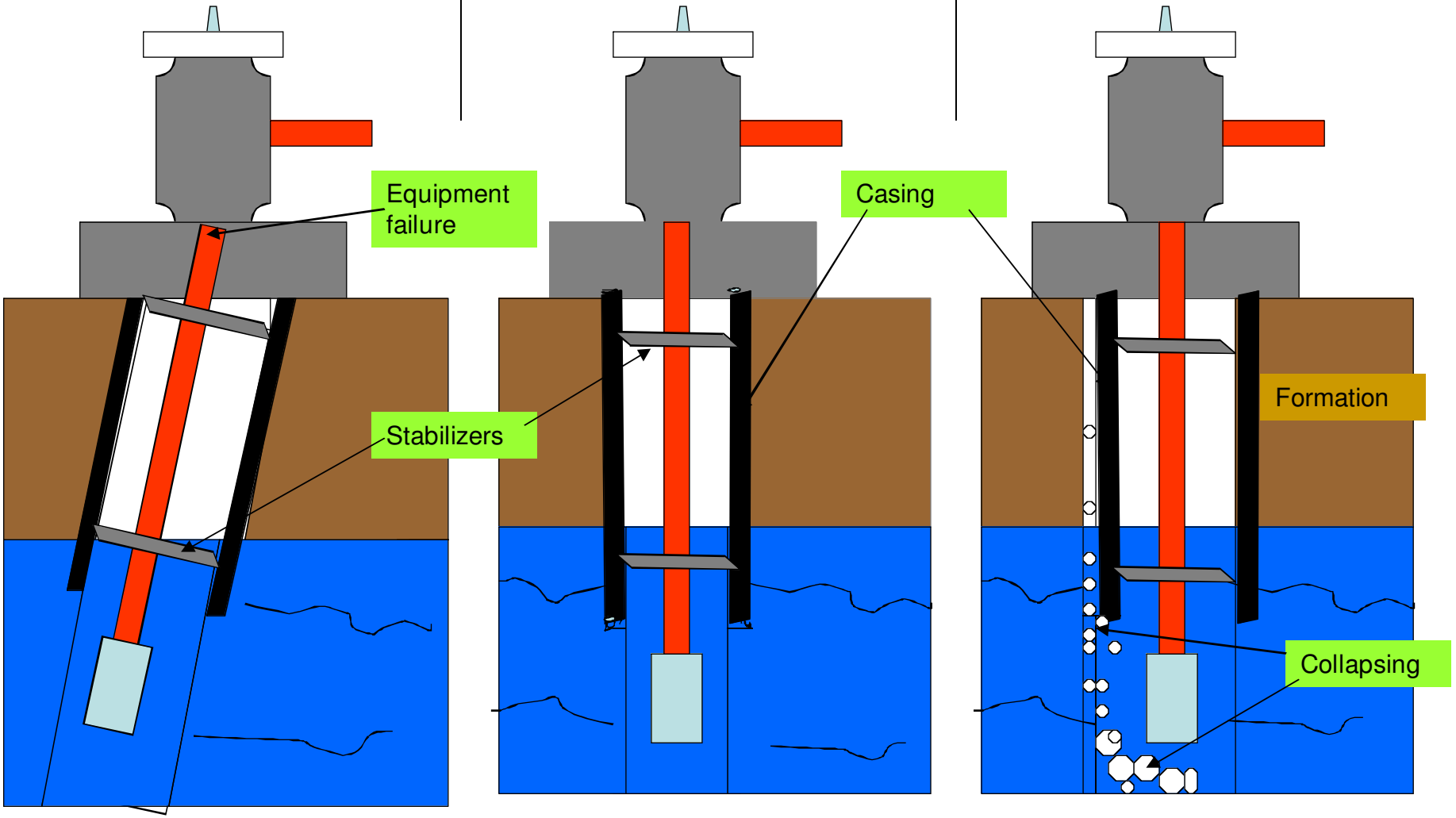


Typical borehole constructions

Borehole not straight or not vertical – high maintenance cost!!!!

Borehole correctly constructed – safe to install equipment and low maintenance!

Borehole not reamed & cased correctly – collapsing borehole. Possible equipment loss and high maintenance cost.

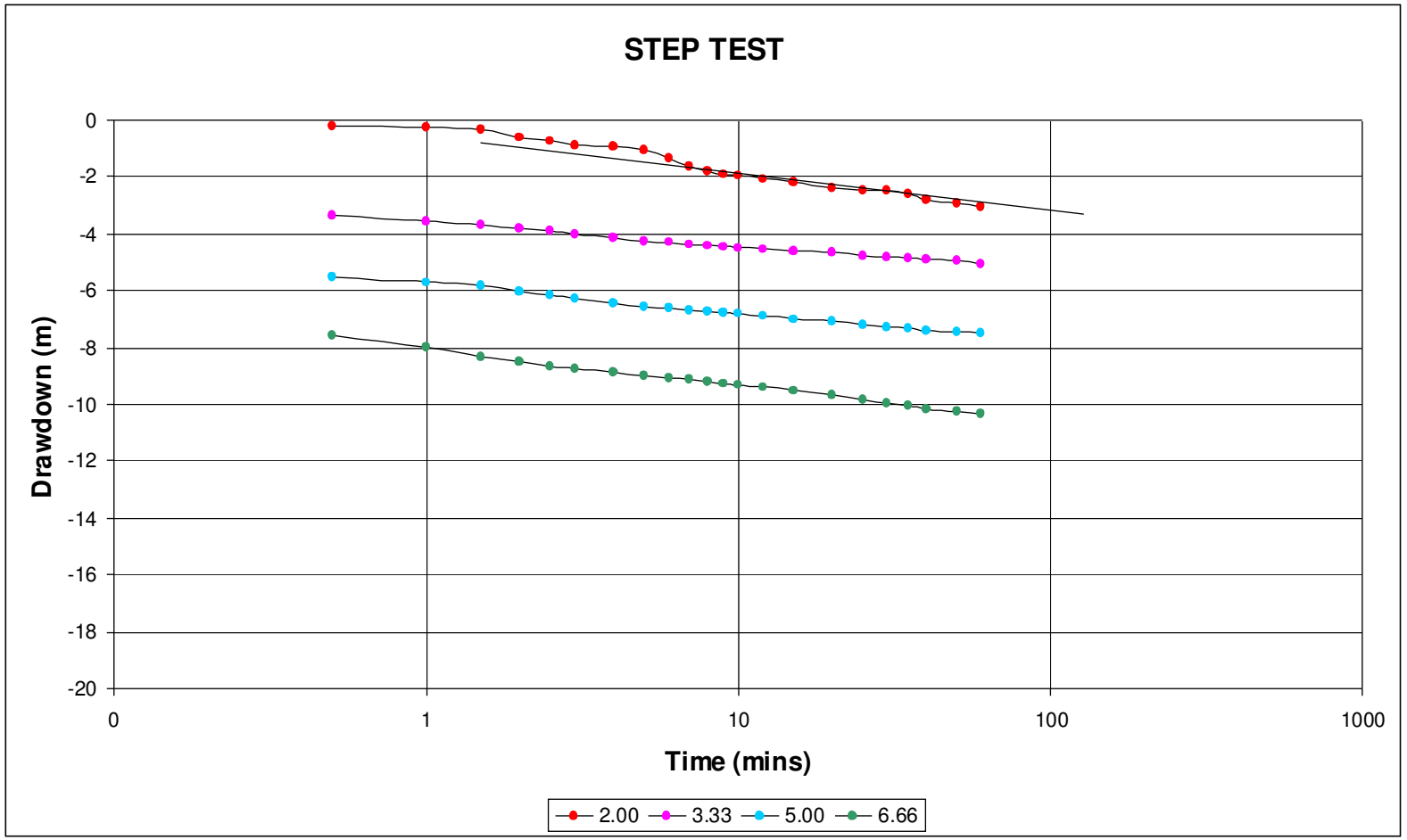


TESTING (Yield - Quantity)

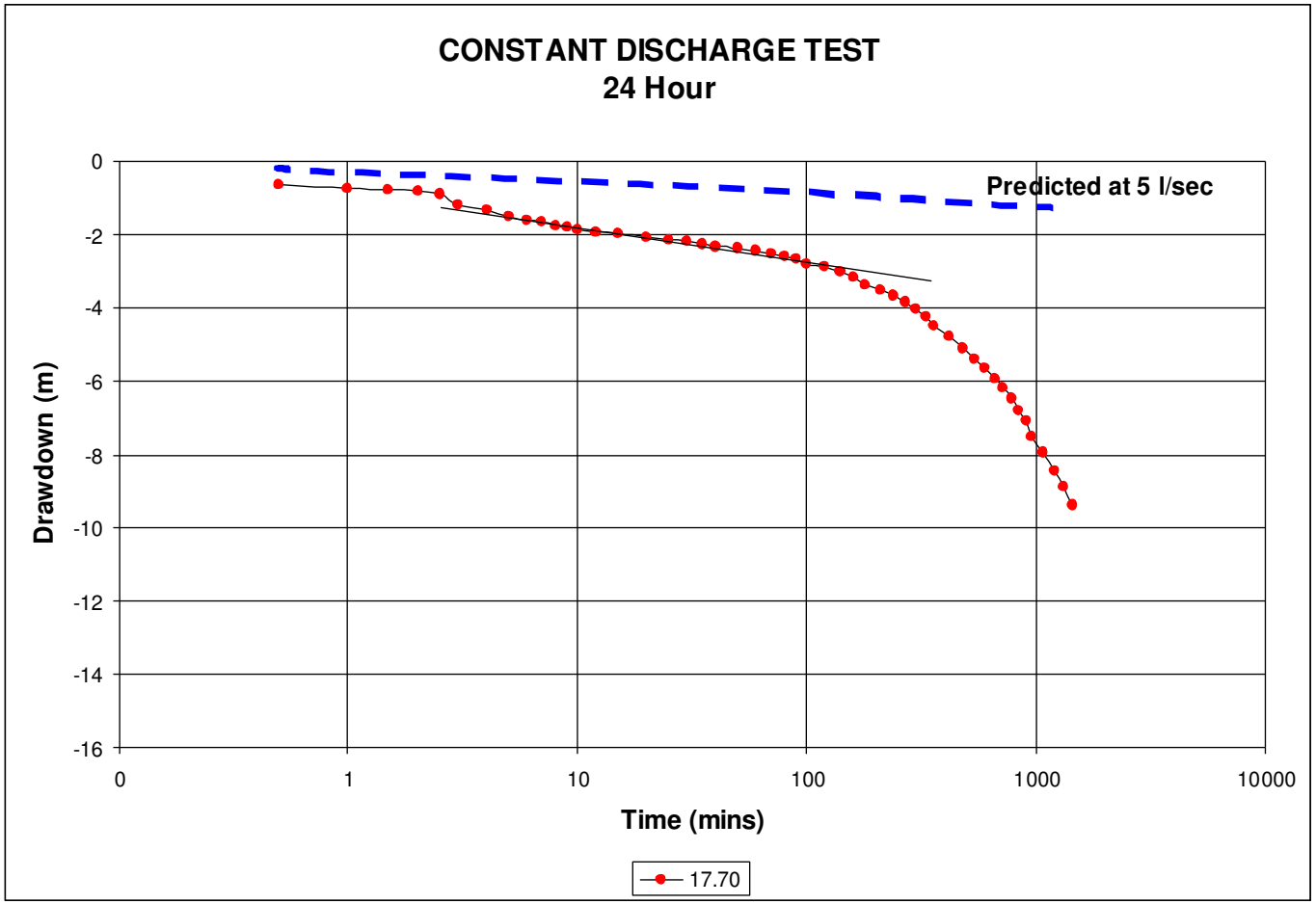
- Boreholes must be tested before equipping the source. This will include the yield and chemical testing of the source,
- Testing should be done according to the DWAF guideline document and contractors must test with a positive displacement pump and a drive unit capable of increasing the pump revolutions (variable speed, thus variable yields, kept constant for a certain period),
- Correct test results and reporting (when consulting is done) will supply valuable information regarding the source and include the following:
    - Data collected will include the depth, water level, casing depths, equipment and verified co-ordinates,
    - Measuring the depth before installing the test pump and after removal thereof will indicate possible collapsing,
    - The maximum yield of water entering the source (blow yield during drilling) can be obtained,
    - The depth of water strikes (if not known) can be derived (interpreted) from the data,
    - Timeframes wherein dirty water was pumped during the test will indicate possible construction problems, such as incorrect placing of casing, insufficient “gravel pack” etc.
    - A safe daily abstraction can be calculated for correct test data. (Recommended abstraction),
    - The recommendation for each borehole will include a calculated installation depth of the pump and will reduce the new equipment and maintenance cost (Many pumps are installed unnecessarily deeper than the fractured zones and will not supply more water), ensure lower operating cost (smaller motors, pipes, pumps etc. can be utilized for shallower installation depths and lower correct abstraction yields), recommended pumping rates will ensure water level fluctuations are limited (better protection on pump friction, less motor ampere differences and therefore lower maintenance cost,
    - Using available data will save money – limit funds spent on duplication of existing results.

Test Pumping in progress

Step Test Data



Longer Duration Tests



Water Chemistry (Quality)

- The chemical analysis of water should always be noted as part of the recommendation submitted for that source,
- Poor (Class-3) or dangerous (Class-4) water quality is often due to high quantities of Nitrates, Fluorides, TH (Total Hardness) and / or EC/TDS (Total dissolved salts).
  - **Nitrate –** Nitrates are produced by the decay of plant, animal and human waste. Pollution of water with Nitrates is typical found wherever intensive land use activities take place.
    - High Nitrates has the potential to cause tiredness and failure to thrive. In extreme cases cyanosis and difficulty in breathing in bottle fed infants under the age of one year may occur.
    - Nitrate, or Nitrite as such, do not have any taste, colour or smell.
  - **Fluoride –** This is the most electro-negative element and readily forms complexes with many metals. Fluoride is however needed in trace quantities during tooth formation to harden the tooth enamel.
    - Chronic intake of high Fluoride levels can damage the skeleton, causing a hardening of the bones and making them brittle.
    - Fluoride has no taste, colour or smell and cannot be detected aesthetically.
  - **TH –** The TH in rainwater is very low (little Calcium & Magnesium) and in some groundwater sources the TH may be very high where soluble Calcium and Magnesium minerals are present.
    - Some TH in water is beneficial to health as it contributes to the need for essential elements Calcium and Magnesium but excessive TH should be avoided by sensitive groups
    - Elevated TH impairs the lathering of soap, it also affects the taste of water especially for brewing tea or coffee and scaling problems in pipes or hot water appliances will occur
  - **EC/TDS –** The electrical conductivity (EC) is a measurement of the ease with which water conducts electricity. The EC of water indicates what the total dissolved salt (TDS) contents of the water is.
    - Rainwater has a low EC and after falling on the earth, rainwater picks up salts on its way to the ocean or the groundwater table and the amount depends on the geology and the extent of evaporation. High EC levels may include laxative effects and disturbances of the salt and water balances in humans (especially infants).
    - High EC / TDS values will impart a salty taste to the water and values above 300mS/m will not slake thirst,

Water quality classification

QUALITY OF DOMESTIC WATER SUPPLIES - VOLUME 1: ASSESSMENT GUIDE

CHEMISTRY CLASSIFICATION

CLASS	Ph	TDS	Elec. Cond.	Total Hardness T.H.	Calcium Ca	Magnesium Mg	Chloride Cl	Sulphate SO4	Nitrate NO3	Sodium Na	Potassium K	Flouride F
Class 0	5.00-9.50	<450	<70	0-200	0-80	<30-70	<100	<100-200	<6	<100	<25	<0.7
Class 1	4.50-5.00 9.50-10.00	450-1000	70-150	200-300	80-150	70-100	100-200	200-400	6-10	100-200	25-50	0.7-1.00
Class 2	4-4.50 10-10.50	1000-2400	150-370	300-600	150-300	100-200	200-600	400-600	10-20	200-400	50-100	1.00-1.50
Class 3	3.00-4.00 10.50-11	2400-3400	370-520	>600	>300	200-400	600-1200	600-1000	20-40	400-1000	100-500	1.50-3.50
Class 4	<3->11	>3400	>520			>400	>1200	>1000	>40	>1000	>500	>3.50

CLASS	Faecal Coliforms	Total Coliforms	Turbidity NTU	Arsenic As	Cadmium Cd	Copper Cu	Iron Fe	Manganese Mn	Zinc Zn			
Class 0	0	0	<0.1	<0.010	<0.003	0-0.5	<0.01	<0.05	<3			
Class 1	0-1	0-10	0.1-1	0.01-0.05	0.003-0.005	0.5-1.0	0.01-0.2	0.05-0.1	3-5			
Class 2	1-10	10-100	1-20*	0.05-0.2	0.005-0.020	1.0-2.0	0.2-2.0	0.1-1.0	5-10			
Class 3	10-100	100-1000	20-50*	0.2-2.0	0.020-0.050	2.0-15.0	2.0-10.0	1.0-5.0	10-20			
Class 4	>100	>1000	>50*	>2.0	>0.050	>15	>10.0	5.0->10.0	>20			

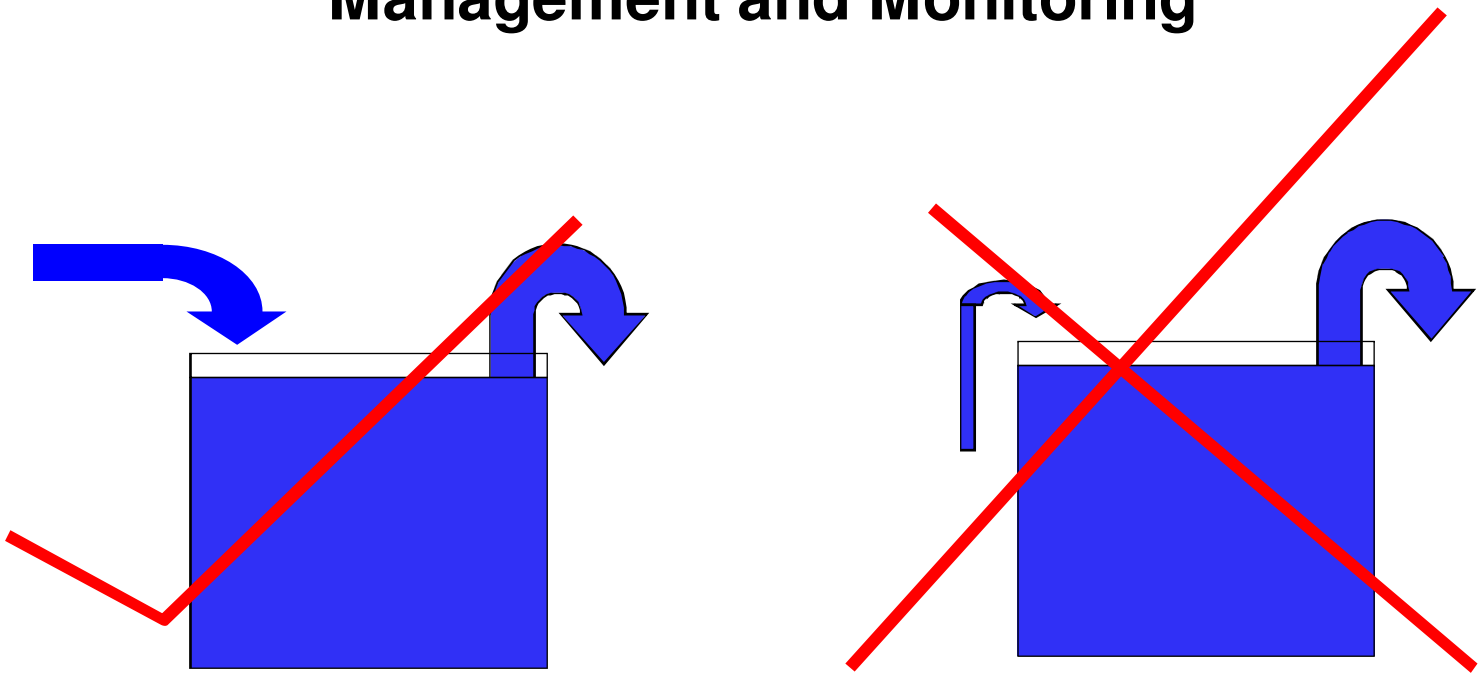
Class 1	Good water quality-suitable for use, rare instances of negative effects.
Class 2	Marginal water quality-conditionally acceptable. Negative effects may occur in some sensitive groups.
Class 3	Poor water quality-unsuitable for use without treatment. Chronic effects may occur.
Class 4	Dangerous water quality-totally unsuitable for use. Acure effects may occur.

Equipment / Pumping schedules / Reliability

- **Motorized Diesel / Electrical (Including submersible) installations**:
  - The 8 to 12-hour recommended abstraction rate should be used to design the equipment, especially should power not be available or no power planned to become available within a year,
  - When the 24-hour recommended abstraction is utilized for designing equipment powered by a diesel source, the daily abstracted volume will be less than 40% of the available volume but the borehole will never be over pumped, even when power becomes available,
  - When an electrical power source is available, electrical equipment should be considered and the 24-hour recommendation used for designing the equipment,
  - Diesel powered borehole equipment is more expensive, operating cost is higher, has a higher maintenance component and requires more reliable operator to start and stop the machine but can control the pumping schedules as long as diesel is available. When the diesel tank is empty the problem can be solved within a few hours through buying, but with electricity you rely on the supplier thereof (ESCOM etc.)
  - Electrically powered borehole equipment is more effective, can automatically control the water supply via reliable electronic components but should the power supplier (ESCOM) cut off the supply or does not deliver, communities could be without water without much to do about the situation – will wait for the power to be available again,
  - Submersible pump equipment is reliable, cheaper, low in O&M cost and is easier to protect against theft.
- **Hand pump installations**:
  - Although water supply from a hand pump is low yielding, time consuming and labour intensive, it is still the most reliable source of water supply and requires little maintenance and no operational cost,
- **Wind and solar installations**:
  - These are the two most underrated power sources when it comes to water supply from boreholes, especially windy and sunny South Africa.
  - Wind and solar technology has improved within the last two years and although the initial purchase cost is high (especially higher for good yielding boreholes) the operating cost and maintenance is low,
  - Many low yielding boreholes are available (unequipped) and even a low yielding borehole (0.1 x 24-hours) can supply more than 8 000 litres per day and can assist in the total water demand required for a community.

Sustainable use of a resource

Management and Monitoring

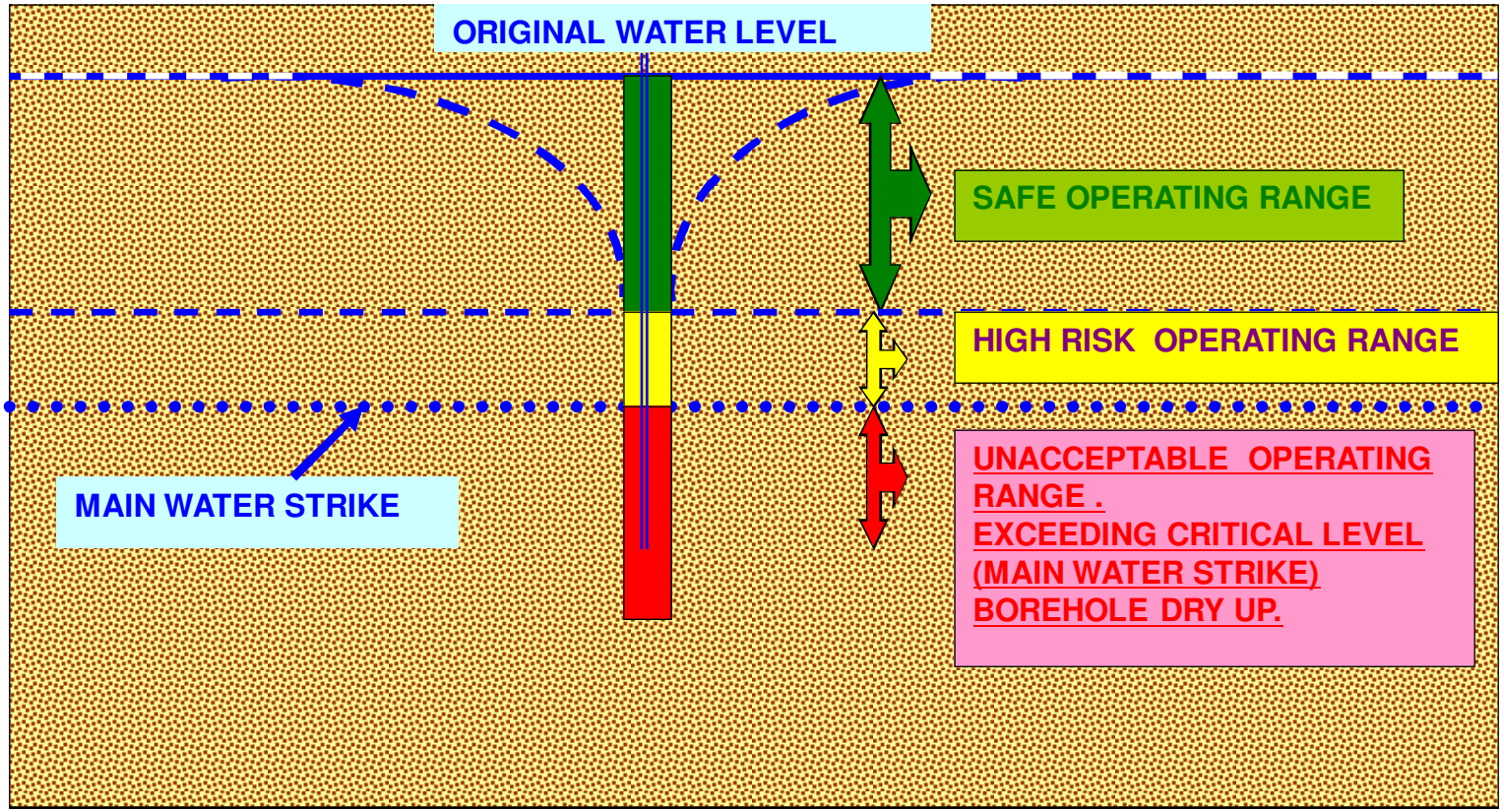


INFLOW EQUALS OR EXCEED OUTFLOW

OUTFLOW EXCEEDS INFLOW

CAN NOT SUSTAINABLY TAKE OUT MORE THAN IS PUT IN FROM ANY RESOURCE !!!

Sustainable abstraction from a borehole



Factors leading to over abstraction

- Poor understanding of groundwater
- Growing need/demand
- Under designed or/and outdated infrastructure such as reservoirs & pipelines
- Varying water use patterns

Management options: not site specific

TRAIN PERSONNEL

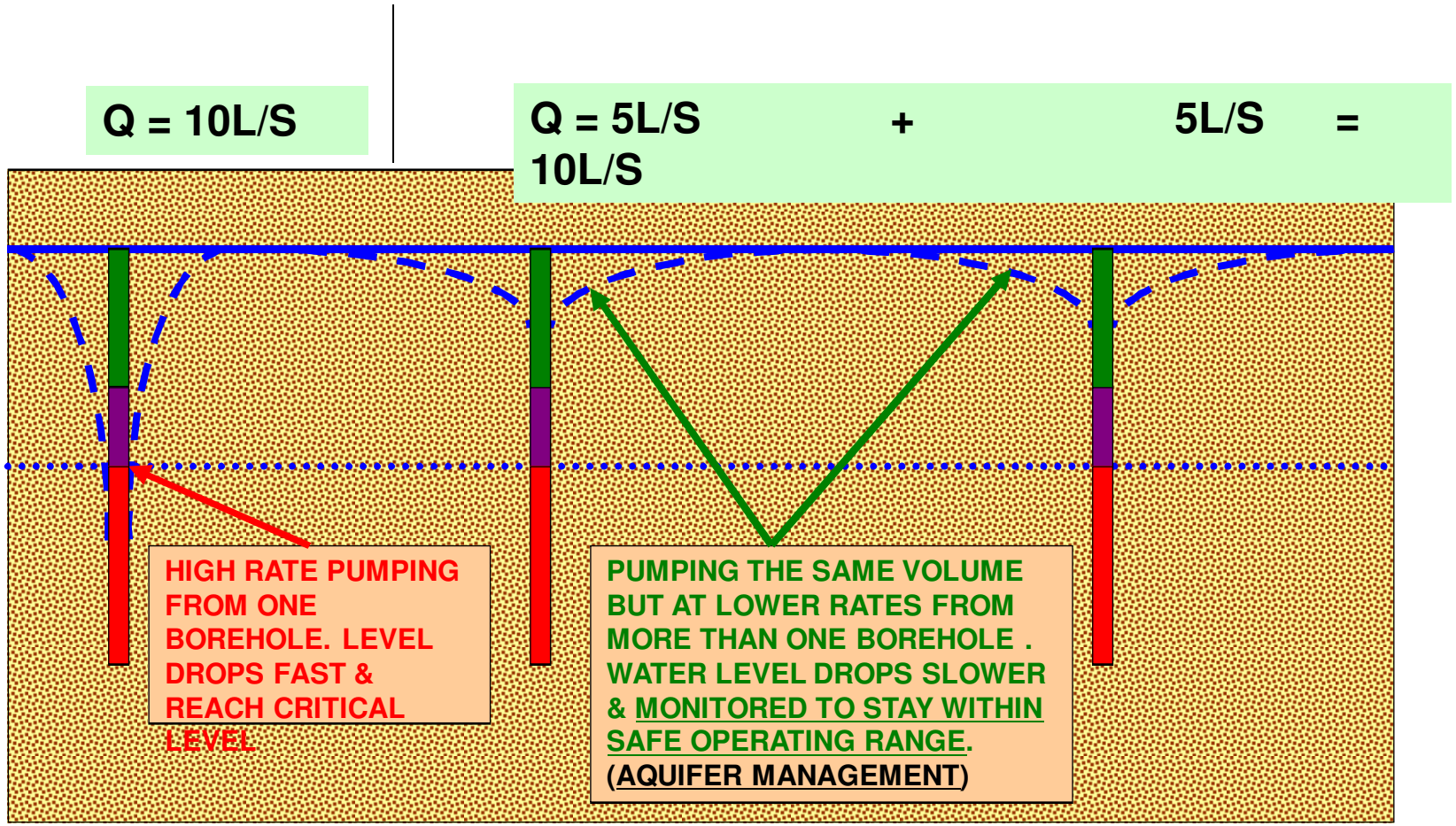
APPLY THE KNOWLEDGE & MANAGE

CREATE AWARENESS

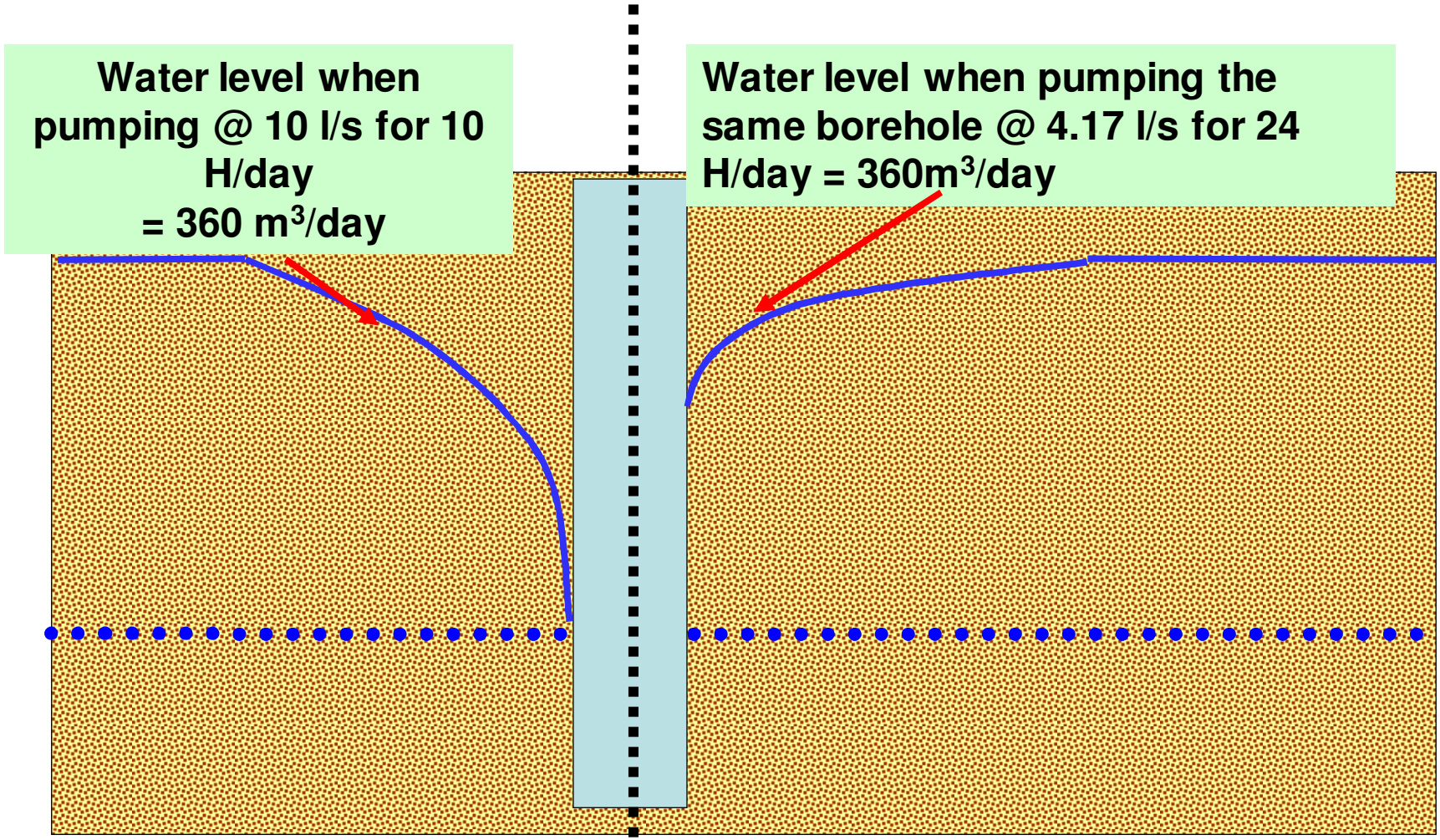
Management options (site specific)

- Wellfield design & Layout (use of more boreholes)
- Adjusting pumping times and yields (24 Hour cycle @ lower yields)
- Increasing storage capacity (Larger or more reservoirs)- Avoid pumping into reticulation.
- Maintenance & upgrading (detect & prevent leakage or wasting of water)

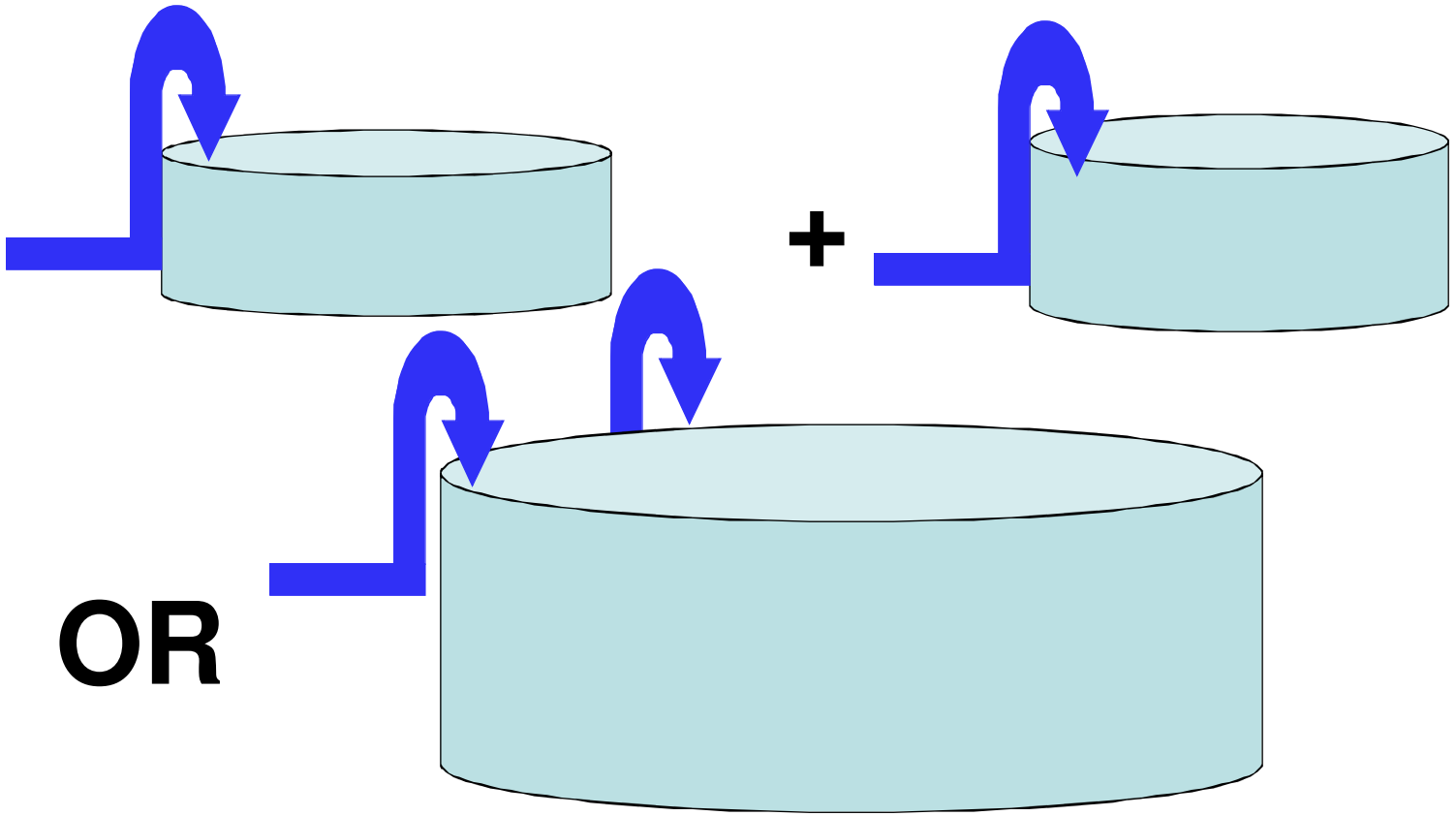
Wellfield Design



Adjusting pumping times & yields

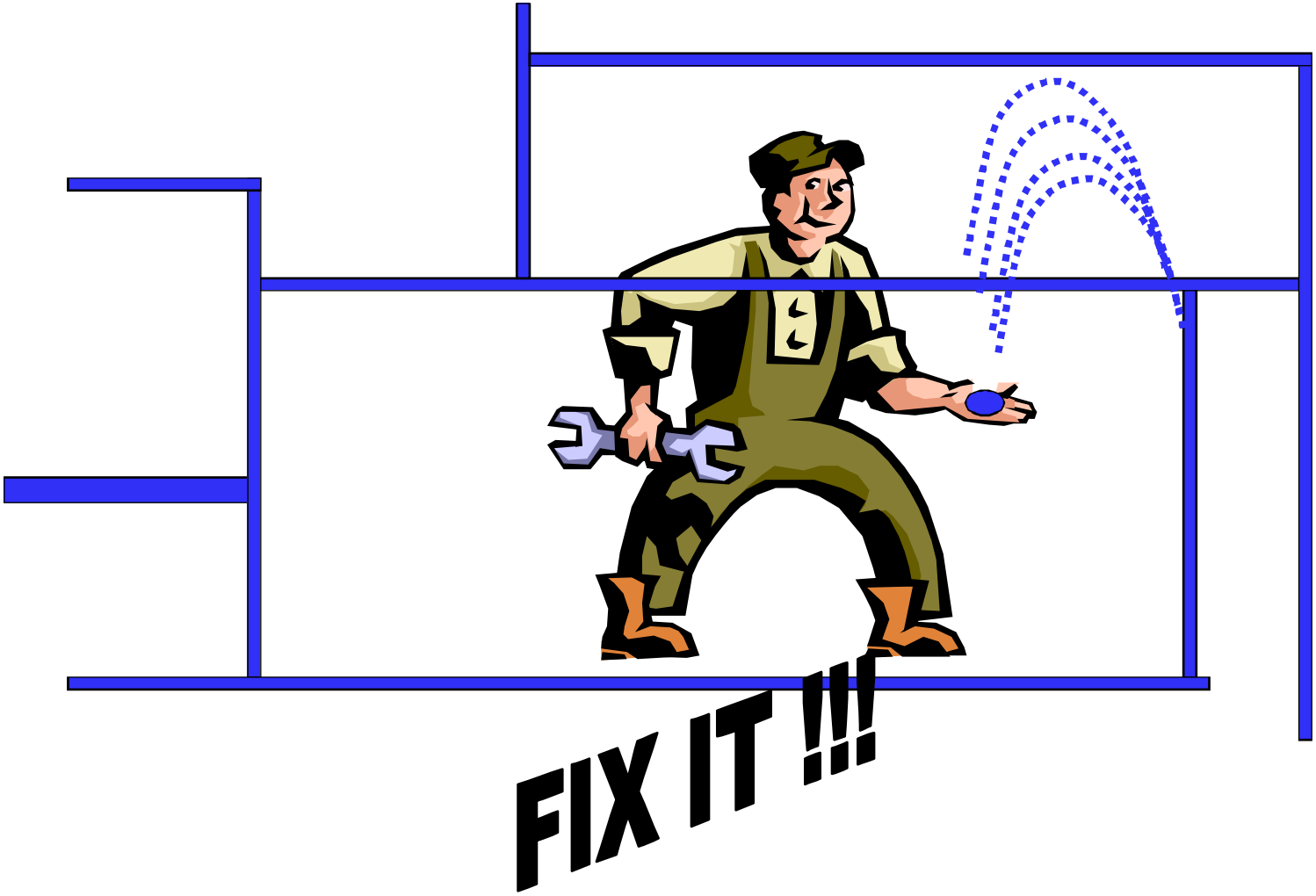


Increasing storage capacity



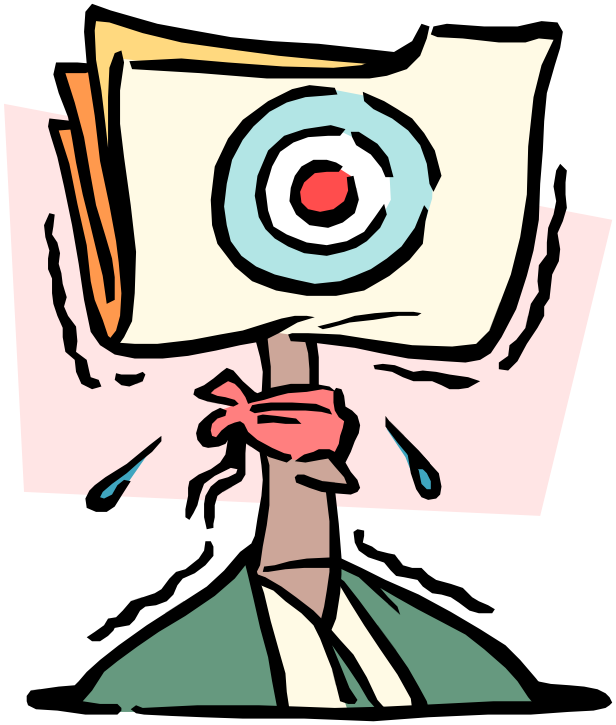
Use extended pumping times or/and periods of low demand (Night time, rainy/cool weather to build reserves.

Maintenance & Upgrading



The rewards

OR ?



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