Unconventional Upstream Operations Engineering

Section 07 Water Collection and Disposal

Section Objectives

- Describe the scope of the issue
- Review disposal techniques and develop a basis for choosing among them

Scope

- Managing produced water is the subject of thousands of pages of regulations and millions of pages of legal decisions
- The intent of this presentation is to give you the feel for the magnitude of the subject, not prepare you to deal with its complexities—get help from environmental, regulatory/legal, and engineering professionals early in the process
- This presentation is not intended to provide engineering or legal advice on your specific problems, any recommended practices in it are subject to be poor advice for certain conditions
- The data and examples are focused on operations in a limited number of jurisdictions to provide examples of how things can work. A review of the requirements in any particular jurisdiction is required prior to committing resources to a project.

Introduction

- Even at today's product prices:
  - Wells remain economical with much higher LOE than in the past
  - A big part of the increased LOE is lifting and disposing of water
- More water is getting to the surface today than ever before
- The regulatory environment is getting more strict all of the time

Introduction

- According to the U.S. DOE
  - Non-CBM onshore water production in the US is 14 million bbl/day (2,230 ML)
  - Some estimates add about 1 million bbl/day (159 ML)of CBM water
  - Wild guesses put the Gas Shale water over 6 million bbl/day (954 ML)
  - Disposal costs average $0.80/bbl ($5/m^3)
  - Industry explicit and implicit costs of lifting and disposing of produced water is at least $10 billion/year in the U.S.
- All of these numbers are suspect since recording accurate water volumes is not a priority with either the producers or the regulators—produced water is a waste product that is seldom accurately tied to wellhead production
  - Operators that say they're doing a good job of measuring wellhead water volumes tend to never do a full-system material balance
  - No one has the obligation to reconcile reported wellhead water to reported injection or evaporated volume
  - Efforts to do that reconciliation have always met with dismal failure

Water Quality

Water Source	TDS (mg/L)
Rainfall	10
Pristine freshwater lakes and rivers	10 to 200
Amazon river	40
State water project deliveries	275
Lakes impacted by road salt	400
Agricultural impact on sensitive crops	500
Colorado River	700
California drinking water limit	1,000
Average seawater	35,000
Brines	>50,000
Groundwater	100 to >50,000

Water Quality

	EPA Safe Drinking Water Act Limits	Dawson River Queensland Limits	San Juan River Actual	Typical Coal
pH	6.5-8.5	6.5-9.0	8.5	7.8
Dissolved O_2 (mg/L)	No limit set	No Limit Set	11	0
Turbidity (FTU)	5	50 ppm TSS	3.5	3
TDS (mg/L)	500	220	250	10,000
Oil & Grease (mg/L)	ND	0	ND	50

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Water Gathering

- There is no ASME water gathering standard:
  - People apply ASME B31.4 (Oil pipelines) because it is a liquid
  - People apply ASME B31.8 (Gas transmission) because the line always has some amount of gas
  - Neither choice is wrong, it is best to document the reason for the choice you make
- Water gathering systems rarely (if ever) run full, so the pipe must be rated to withstand:
  - The hydrostatic head of the sum of all uphill distances
  - Added pressure to overcome friction losses
  - Added pressure to overcome disposal site inlet equipment pressure drops
- Pressure ratings lower than ANSI 300 (600 psig or 4100 kPa) are almost never the best choice
- Steel lines tend to have serious top-of-pipe corrosion issues
- The issues add up to spoolable composite pipes being the best choice in nearly every application

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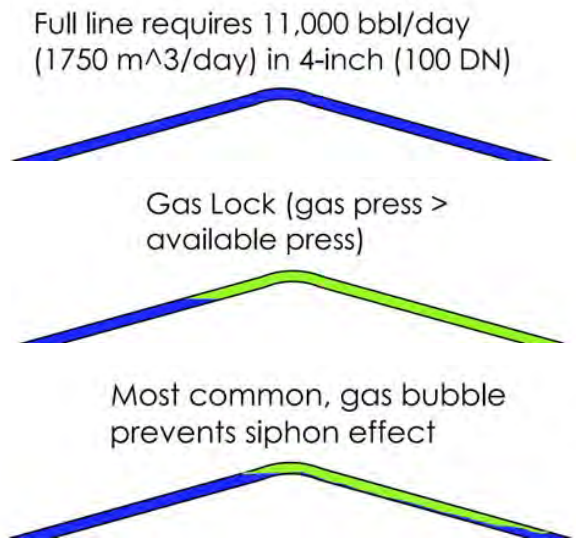
Removing gas from water systems

- If a line is full, the only elevations that matter are start and end point (intermediate hills irrelevant)
- With a partially full line every up hill portion adds to req'd pump discharge pressure
- High point vents
  - Purpose is to restore siphon
  - They can't do that because the lines are not full
  - They add cost, create a potential leak point, and a potential failure point for no added value
  - More effective to remove gas at disposal facilities



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Infrastructure for Accumulation Transport

	Trucking	Pipeline
Capital Cost	Very Low	High
Operating Cost	Very High	Very Low
Main Risk	Road accidents	Line Failure

- The trade off is never clear or obvious
- A hybrid system is often the best economics
  - Strategically placed water-transfer stations with pumps
  - Water is trucked to transfer station
  - Pipeline runs from transfer station to central location

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Transportation Example

- A company drills a new well:
  - Expected water production 200 bbl/day [32 m^3] can be piped with 2-inch pipe, requires 3 trucks/day)
  - 5 miles [8 km] from a transfer station
  - Trucking requires 3 days on-site storage (600 bbl or 95 m^3)
  - Their trucking costs average \$0.20/bbl/mile (\$2/m^3/km) or \$200/day
  - Pipelines cost \$35k/inch-mile (\$860/mm-km) or \$350k and no on-site storage
- Two companies do the same analysis
  - Company "A"—build pipeline (NPV(15) \$219 k, IRR 28%)
  - Company "B"—truck water (NPV(15) \$177 k, IRR 59%)

Transportation Example

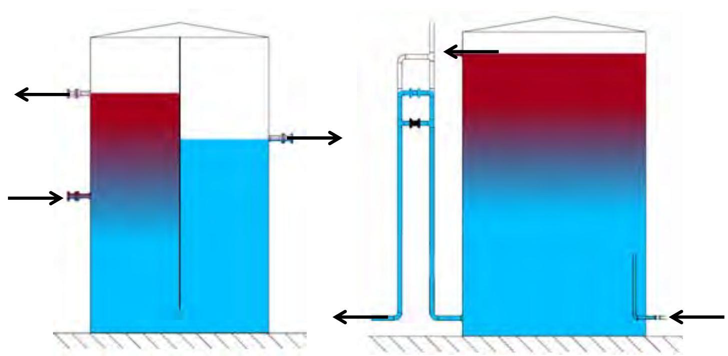
- Different jurisdictions have different rules for disposal, for example:
  - The U.S. state of Pennsylvania does not allow deep well injection of produced water (require evaporation or surface discharge)
  - The U.S. state of Ohio does allow deep well injection, but "foreign" water is subject to a tariff (\$0.20/bbl [\$1.26/m^3])
- Western Pennsylvania typical disposal costs
  - Trucking → \$6.00/bbl \$37.74/m^3
  - Disposal → \$2.30/bbl \$18.87/m^3
  - Tariff → \$0.20/bbl \$ 1.26/m^3
  - Total → \$8.50/bbl \$57.87/m^3
- At \$4/MCF, break even is at 470 bbl/MMSCF [2.64 m^3/kSCM]

Site-Entry Facilities

- Solids can be difficult for pumps and injection wells
  - Filters and strainers require monitoring
  - Filters designed for water tend to fail in oil and vice versa
- Oil causes a problem with any sort of produced water facilities
  - Surface discharge limited by regulation
  - Oil in downhole injection wells will shorten the injection life of the well
  - Oil in an evaporation pond will reduce evaporation rate and is a hazard for birds

Dealing with Oil

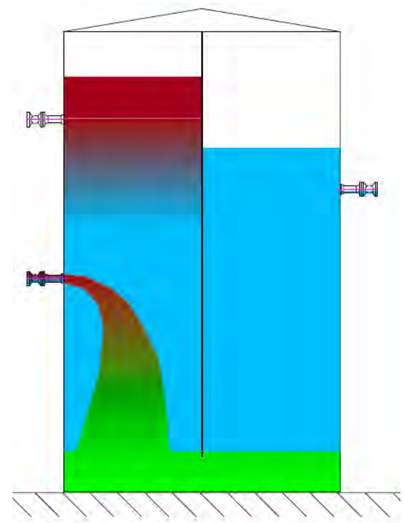
- Gun barrels are the typical solution to oil in gas fields



- When the fluids are exactly at design conditions:
  - Oil level is at the oil-outlet
  - Water level is at the water outlet
  - If a quart of liquid comes in, a quart must go out

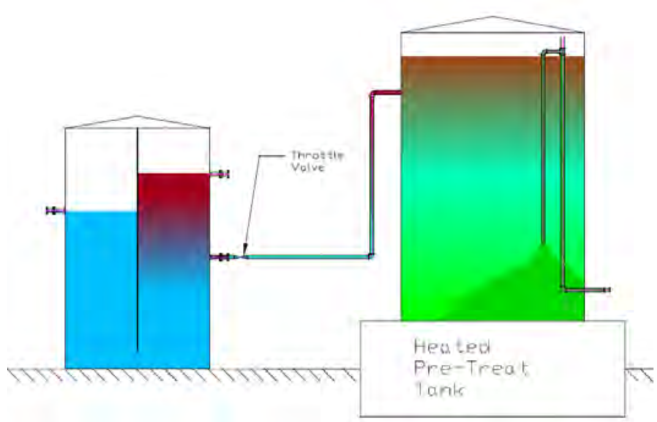
Gun Barrels

- Example design conditions
  - 160°F [71 C]
  - Water SG 0.96
  - Oil SG 0.75
- Fluid from truck
  - Fluid temp 35°F (1.67 C)
  - 78 bbl water [12.4 m^3], 1.07 SG
  - 2 bbl oil [0.32 m^3], 0.98 SG
  - Empty truck in 15 minutes (7,600 bbl/day or 12,080 m^3/day rate)
  - Incoming fluid drops like a stone
  - Treated fluid leaves
  - Oil finds its way to the water side



Gun Barrel

- Problem can be fixed by converting from batch to continuous:
  - Trucks unload into heated pre-treat tank
  - Throttle valve controls flow rate of warm liquid into gun barrel
  - Set throttle valve at about twice the normal daily in-flow rate

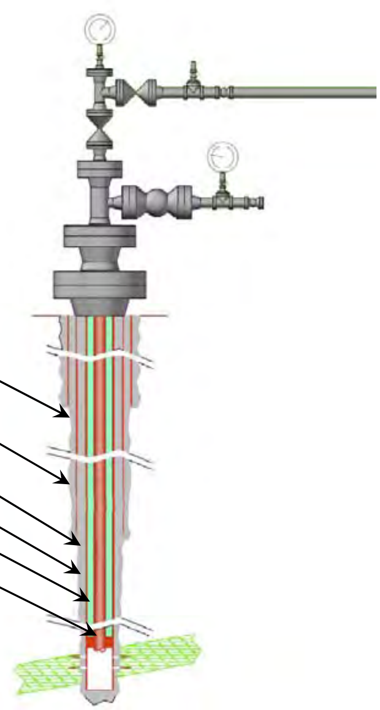


Deep Well Injection

- Purpose: permanent disposal of produced water into non-productive formations
- "Non-productive" means:
  - Not a source or a potential source for potable water
  - Not an economic source of hydrocarbons
- Typical limitations
  - Surface injection pressure plus hydrostatic pressure must be less than the fracture gradient of target formation
  - Methods to insure both tubing and casing mechanical integrity are installed, adequate, and verifiable
  - Total injected volume is limited by permit

Deep Well Injection
Protect Aquifers

- Accomplished by barriers:
  - Cement sheath
  - Surface casing
  - Cement sheath
  - Production Casing
  - Annulus Fluid
  - Tubing

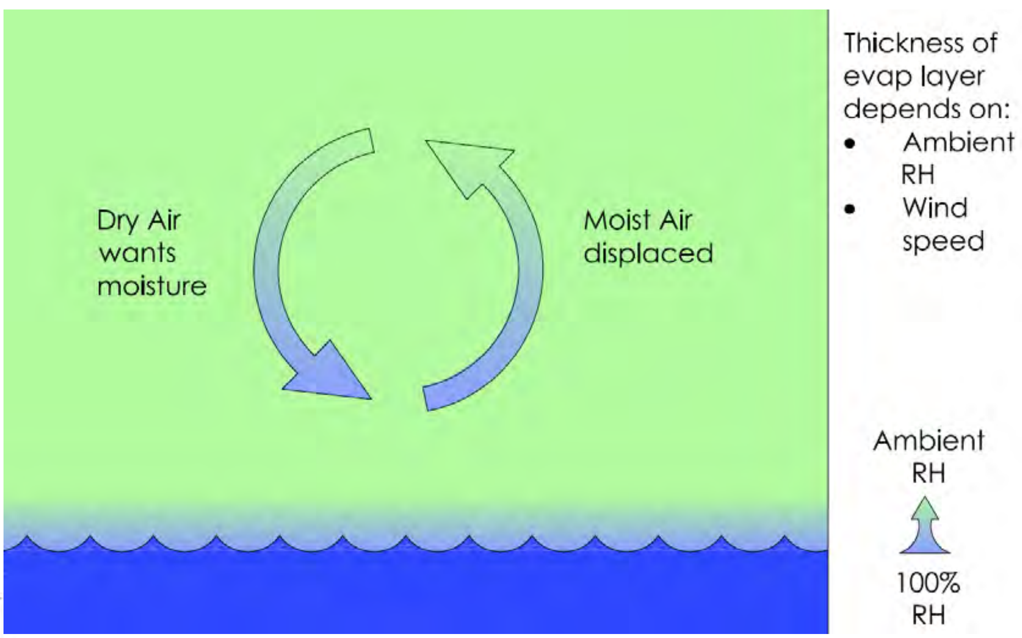


- Annulus Fluid
  - Not hazardous to ground water
  - Increasing pressure → tubing leak
  - Decreasing pressure → casing leak

Equipment Needed for Deep Well Injection

- Tanks – it is a good idea to have about 1-2 days of storage
- Filtration – most successful injection operations filter the water to about 25 microns
- Pumps
  - Charge pump – required for long-term operation of plunger injection-pumps (not needed for progressing cavity or multi-stage centrifugal injection pumps).
  - Injection pump – needs to be able to pump the daily volume into the permitted injection pressure
- Automation
  - Need to be able to stop the process if injection pressure approaches permit limit or tank level gets too low

Evaporation



Rate of evaporation

- The nominal average daily solar energy is something around 1360 W/m^2 (all forms)
- Latent heat of vaporization of water is 2250 W-s/gm
- Simplified evaporation rate:

$$EvaporationRate = \frac{Solar_{irradence}}{Heat_{latent} \cdot \rho_{water}} = \left(\frac{1360 \frac{W}{m^2}}{\left(2260 \frac{W \cdot \sec}{gm}\right) \cdot 1000 \frac{kg}{m^3}} \right) = 0.0520 \frac{m^3}{m^2 \cdot day} = 0.0304 \frac{bbl}{ft^2 \cdot day}$$

- This simplified equation understates required pond size at most latitudes, but is a useful order of magnitude determination

Pond Size

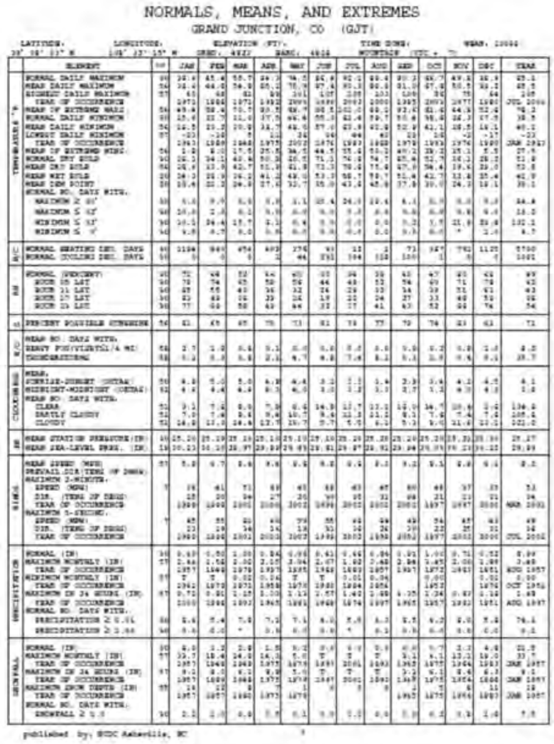
- Generally use the PenPan equation to get evaporation rate

$$E_0 = \left(0.015 - 0.00042 \cdot T_m + z \cdot 10^{-6}\right)\left(0.8 \cdot R_s - 40\right) + 2.5 \cdot F \cdot u\left(T_m - T_D\right)$$

- The terms of this equation are:
  - E_0 = Evaporation rate (mm/day)
  - F = A factor that accounts for the change in air density with changes in elevation $F = 1.0 - 1.7 \times 10^{-5} \cdot Z$
  - R_s = Solar irradiance (W/m^2) $R_s = 10.8 \cdot T_m + 153$
  - T_D = Mean dew point temperature (°C)
  - T_m = Mean daily temperature (°C)
  - u = Wind velocity at 2 meters above surface (m/s)
  - z = Elevation above sea level (m)

Page 1 of NOAA Data

- Lots of data
  - It includes average temp, rainfall, dew points, etc. for every month
  - It also includes minimums and maximums for each term
- Only comes in paper format and the only way I've ever been able to get it from .pdf to .xls is by retyping it, but it is the best source of this data for every location on earth



Pond Size

- Go to NOAA and get climatological data
- With NOAA data and the PenPan equation you can estimate
  - average net evaporation (i.e., evaporation minus precipitation),
  - evaporation in the worst year (min temps and max precipitation)
  - evaporation in the best year (max temp, min precipitation)
- Determine the pond size needed for the expected inflow during the worst months of the worst year
- Add a safety factor for a worst of the worst year

Extra Considerations

- For 10,000 TDS water
  - Every barrel evaporated will leave 3.5 lb (1.58 kg) of solids in the pond
  - Specific volume of solids is around 0.01001 ft^3/lb (625 cm^3/kg)
  - When the pond fills up with solids it will have to be drained to muck out
- My preference is to design two ponds, each sized for full expected inflow and average conditions
  - Flow into one pond
  - Suck out of inflow pond and spray over other pond
  - When pond fills with solids, turn sprayer over inflow pond and muck out other pond
- Aeration equipment may be needed to control odors

Spray Heads

- The best information on evaporation from sprayers comes from people doing irrigation
  - They avoid sprayers that break water drops up very small
  - They use sprayers that put out large drops
  - With large drops, evaporation is a surface function
  - With small drops, evaporation is a volume function
- For evaporation ponds it is good to use spray heads that cut the drops to less than 50 microns
  - Increases buoyancy so drops stay in the air longer
  - Allows bulk temperature to participate in evaporation
  - Overspray becomes a larger issue

Bottom Line on Pond Size

- Bird Netting cuts evaporation
- Wind fencing cuts evaporation
- Aerators increase evaporation at moderate and high ambient temperatures
- Well-designed spray heads significantly increase evaporation in all temperatures
- The net result is probably close to natural evaporation from an uncovered pond in an “average” year

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Break

10:00

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Beneficial Use Challenges

In many Western states water rights law can be extremely complicated and contentious. Operators may be reluctant to pursue beneficial uses because once they have made the investment to clean and use the water, their rights may be challenged.

Even if the challenge is unsuccessful, the cost and uncertainty associated with litigation may make the pursuit of beneficial produced-water use unattractive. Another legal concern is the potential for unknown future liability. While there are no known problems with using treated produced water, the specter of liability issues arising in the future still looms. Other industries have faced huge liabilities from products once thought to be benign. In addition, the possibility exists for lawsuits to be filed alleging problems where none exist. Whether these fears are founded or not, these are very real concerns that limit the beneficial uses of produced water.

National Energy Technology Laboratory, Program Facts

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Beneficial Use Risk Example

- Lawsuit *Vance v. State of Colorado*
- Plaintiff sued the State claiming:
  - In situ water must be removed from well before CBM can be produced
  - Therefore, all CBM water production is "beneficial use" instead of a waste product
  - Plaintiff won because the State preferred to lose (industry was not allowed to participate)
- Therefore:
  - CBM wells in Colorado now must be permitted as both gas wells and water wells
  - CBM operators are required to acquire (purchase) water rights
  - It is unclear whether this will extend to requiring royalty payments on produced water or not, but additional lawsuits are expected

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Beneficial Use

- Reuse
- Treatment
- Surface Discharge to rivers
- Irrigation
- Stock/wildlife watering
- New uses
- Case Study

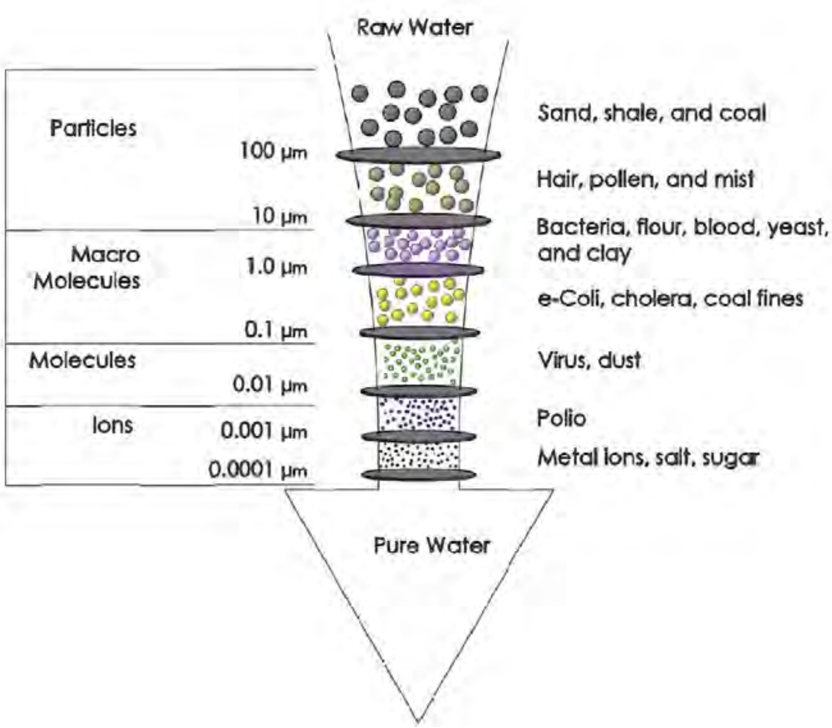
Reuse

- Untreated produced water can be used in operations
  - Drilling fluids
  - Frac water
  - Hydrotest water
  - Dust control on roads
- Often permits are required before you can reuse produced water (and it can be difficult to find who to ask)

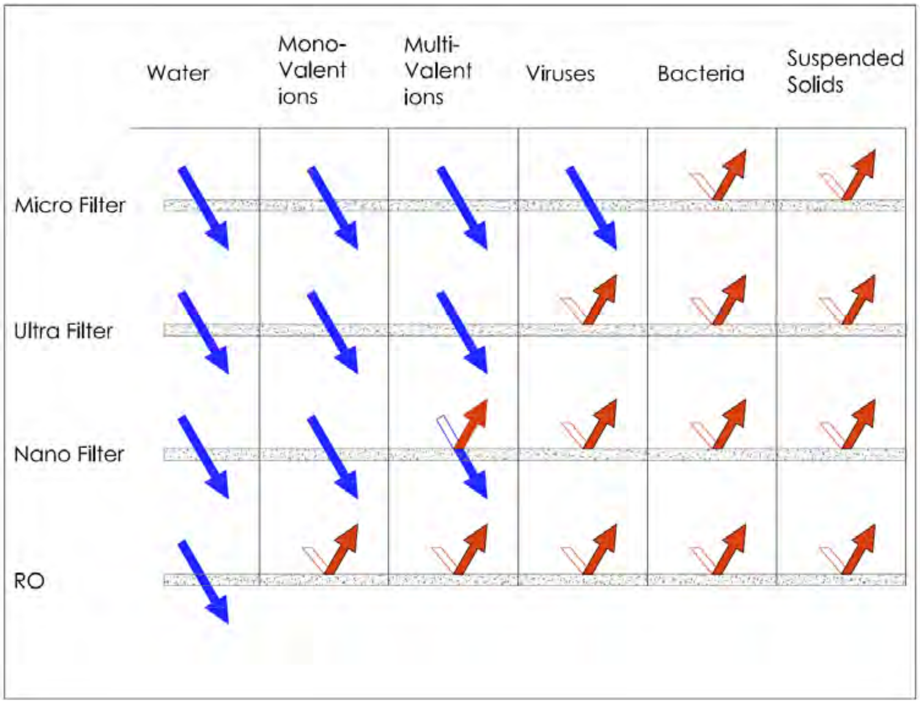
Treatment

- In most basins virtually all water must be treated before it is useable for most beneficial use options
- Reverse Osmosis (RO) is the most common treatment method used in Industry
  – Can concentrate solids into 10-20% of volume (i.e., 100 bbl of 7,800 TDS water can become 90 bbl of 900 TDS water and 10 bbl of 91,900 TDS brine
  – The brine is typically disposed of in a deep well, but an evap pond can be used
  – Has failed repeatedly in Oil & Gas due to complex filtering requirements—basically an entire water treatment plant is required upstream of the RO plant

Filtration



Desalination – Removing contaminants



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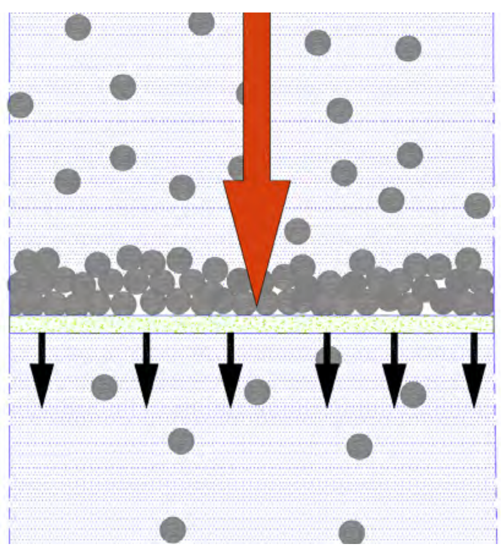
Conventional Filtration

- Flow perpendicular to filter surface
- Contaminants retained on the filter surface
- 100% of the feed water passes the media
- The media must be backwashed (i.e. taken offline) or filter replaced
- Microfiltration / Ultrafiltration / media filtration / cartridge filtration



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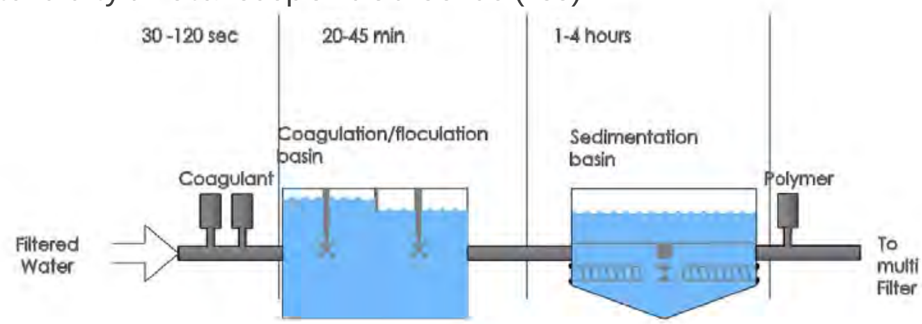
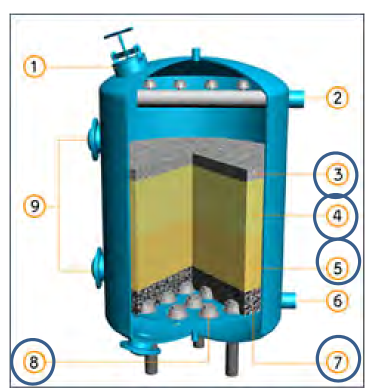
Coagulation, floculation, and sedimentation

- High performance "Clarifying" system (i.e. removing difficult to settle fine solids) combining
  - Chemical Coagulation (added chemicals attach to solids to form micro-flocs, not visible with the naked eye)
  - Flocculation allows micro-flocs to aggregate into large clumps (visible with the naked eye)
  - Sedimentation allows clumps to settle out of the flow
- Highly robust, capable of handling high variations in turbidity / Total Suspended Solids (TSS)



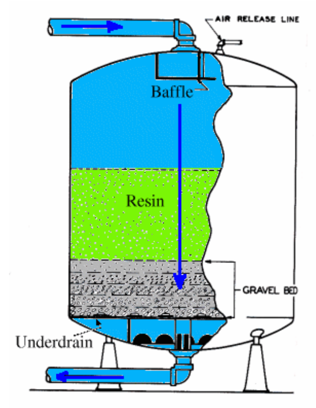
Multi-Media Filtration (MMF)

- Removes carried over suspended solids
- Small coagulant dose to remove any remaining Fe/Mn
- Anthracite layer for large particles (3)
- Filter sand to remove finer particles (4) and (5)
- Garnet sand and gravel support layer for fine polishing (7)
- Filter is periodically backwashed in sequence with clarified water and air scour
- Backwash is directed to Open Drain and back to the Balance Pond (8)

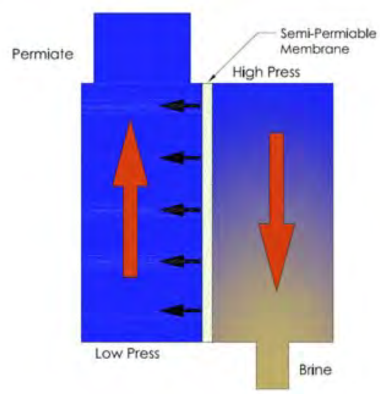


Ion Exchange Softening Process

- Remove hardness to safeguard RO and boost recovery
- Remove trace heavy metals Fe/Mn carry over
- Exchange monovalent cation (Na+) adsorbed on the resin with divalent cation (Ca^{2+}, Mg^{2+}, Sr^{2+}, Ba^{2+}) in the feed water
- Another safeguard for suspended solids polishing
- Must be regenerated with:
  - Sulphuric acid → regenerate resin into hydrogen form
  - Hydrochloric acid → regenerate hydrogen form
  - Caustic soda → convert resin back to sodium form
- After softening only limiting factor for RO recovery is silica



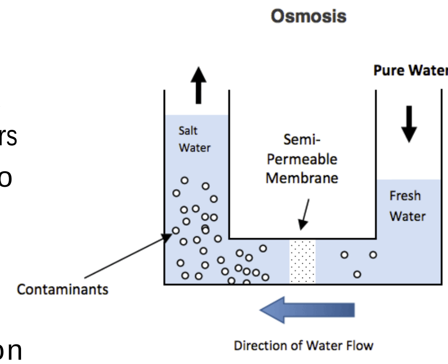
Cross Flow Filtration



- Nano filtration and RO
- Flow tangential to membrane (inflow is parallel to outflow)
- Portion of feed water is filtered and becomes permeate
- Portion of feed water containing brine stream is wasted
- Eventually micro contaminants must be removed from surface of membrane via Clean in Place (CIP)

Osmosis

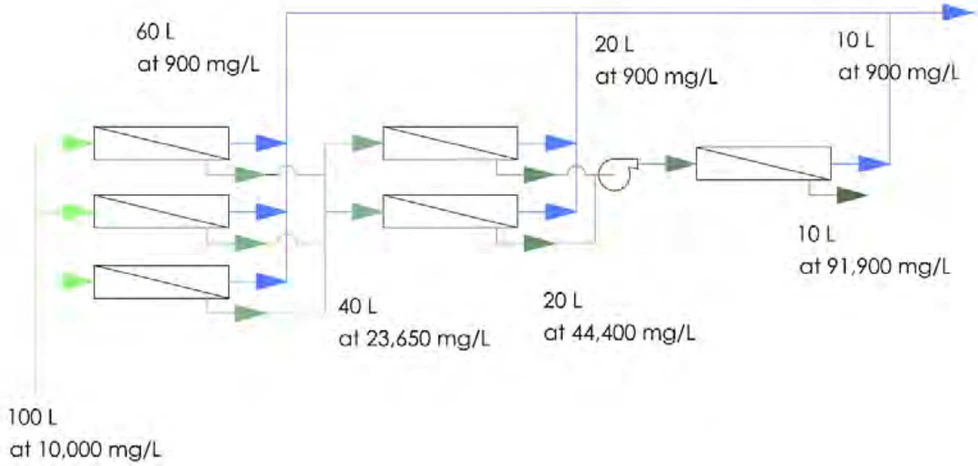
- A weaker solution will tend to migrate through a semi permeable membrane towards a stronger solution through "ozmotic pressure"
  - Semi permeable membrane → a substance that will allow some atoms and molecules through, but not others
  - Ozmotic pressure→ Nature will tend to dilute a concentrated mixture. Two concentrations at the same pressure will tend to flow from low concentration to high concentration until pressure in the high concentration builds up enough to stop the flow. The pressure required to stop the flow is Ozmotic Pressure



Reverse Osmosis

- Appling a pressure greater than Ozmotic Pressure to the concentrated side of a semi-permeable membrane will drive flow of solute to the clean side
- Principally removing salt and metal ions
- 0.45 micron cartridge filters provide last line of RO defense
- Three stage system is typically used

RO Recovery



Alternate Treatment

- Distilling
  - Water is boiled and the steam is condensed
  - Can concentrate further than RO
  - It takes a lot of energy, manpower, and capital
  - It only makes economic sense if the steam can be used to do useful work
- Manmade Wetlands
  - Can be an effective way to purify a large volume of water
  - Be sure you understand all of the ramifications prior to starting
  - Can create an obligation to maintain the wetlands in perpetuity

Alternate Treatment Freeze/Thaw Evaporation

- "Purer" water will freeze before less pure water
- Over time the ice on a pond will be nearly pure
- The rub is how to remove the ice to someplace where it won't recontaminate
- Amoco did a study on this in 1996-97 and it works well in the San Juan Basin in winter. They:
  - Started with 8,000 bbl of 12,800 TDS water
  - 60 days of operation
  - Yielded 6,400 bbl of 1,010 TDS
  - 1,600 bbl of 44,900 TDS
  - They removed the ice by picking up the grating with two track hoes and moving outside the berm and shaking the ice off the grid into the dirt

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Surface Discharge

- Produced water discharged to surface water must have a permit
  - Must be a same temperature as river
  - Must have approximately the same composition as river
  - Regulators have been burned many times, permits are difficult to obtain
- Additional tests such as "fish kill" may be required on water that otherwise meets guidelines
- This is often an expensive option, but sometimes it is the only option
- Preparing water for surface discharge can cost $3-5/bbl

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Livestock/Wildlife Watering

TDS (mg/L)	Stock Watering Comments
<1,000	Excellent for all stock
1,000-2,999	Very Satisfactory, may cause mild diarrhea in animals until acclimated
3,000-4,999	Satisfactory, may be refused by animals not used to it
5,000-6,999	Avoid use for pregnant or lactating animals
7,000-10,000	Avoid use with very young or very old stock
>10,000	Unsatisfactory for all classes of animal

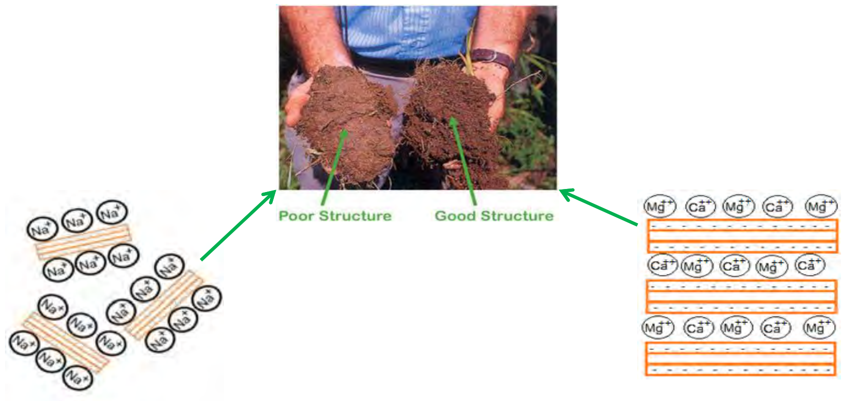
Irrigation

TDS	μS/cm	Irrigation Comments
<175	<273	Excellent
175-525	273-820	Good
525-1,400	820-2,187	Permissible
1,400-2,100	2,187-3,281	Doubtful
>2,100	>3,281	Unsuitable

- Produced water tends to be:
  - CBM water → 1,500 – 15,000 mg/L
  - Shale gas → 600-150,000 mg/L
  - Tight gas → 10,000-100,000 mg/L

Sodium Absorption Ratio – SAR

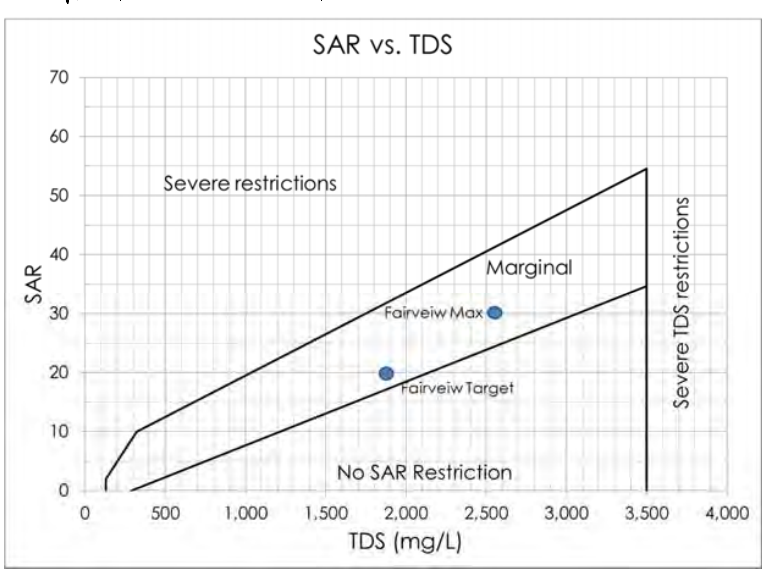
- Sodicity of produced water can induce soil dispersion caused by the exchange of Na^+ in the water with Ca_2^+ and Mg_2^+ in the clay fraction of the soil
- Converts granular structure to hard/compact structure



Irrigation

- Sodium Absorption Ratio (SAR) is defined as:

$$SAR = \frac{[Na^+]}{\sqrt{\frac{1}{2}\left([Ca^{2+}]+[Mg^{2+}]\right)}}$$



New Uses

- Large-scale industrial cooling
- Small-scale industrial cooling
  - Swamp cooler
  - Water cooled equipment

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Power Plant Cooling

- An 1,800 MW (gross) power plant evaporates 500,000 bbl/day or 15,000 gpm [80 ML/day or 57 m^3/min] of river water in cooling towers
- They have conducted feasibility studies of replacing 50,000 bbl/day [8 ML/day] with produced water.
- The project is still under consideration, but some enthusiasm was dampened when the drought broke in 2004 followed by 2005's record-high rainfall

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Small Scale Cooling

- Swamp coolers have proven very effective in arid regions
- A swamp cooler for a compressor has real potential
  - Air is cooled to about 20°F [11 C] below ambient
  - Air is saturated with water vapor (further increasing heat transfer)
  - Can add significant hp for compression
- Biggest concern is that solids might get onto cooling surfaces and foul them
- Mist pads do clog quickly, but choice of pads helps a lot (some pads deal with solids better than others)

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Water Cooling

- Replacing the standard air cooler on a compressor with a plate and tube heat exchanger can transfer a large quantity of heat into an evaporation pond
- This heat transfer will improve the performance of the compressor
- The heat in the pond will accelerate evaporation
- This will work,
  - There are many thousands of water-cooled compressors in other places
  - The idea is foreign to Oil & Gas and is meeting a lot of resistance

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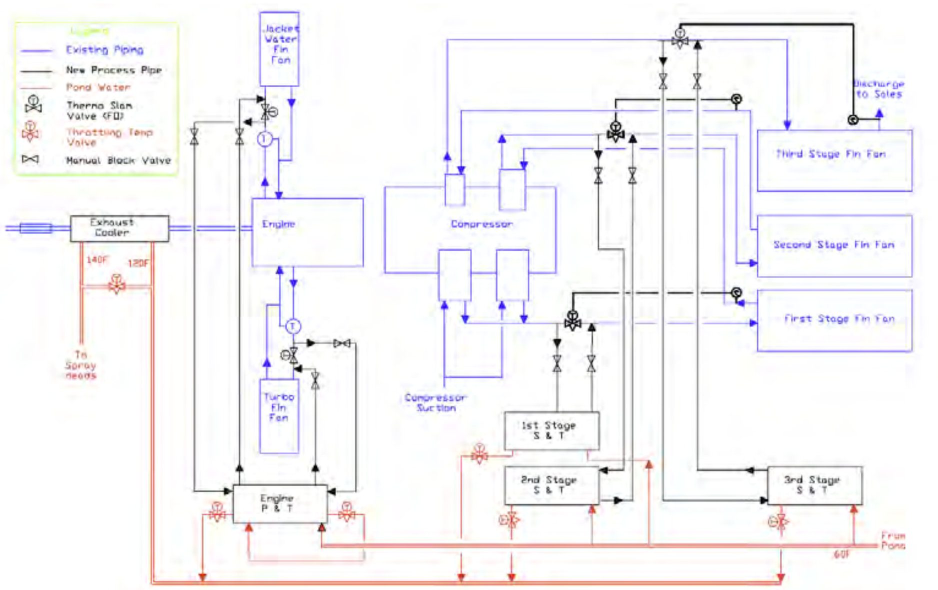
Small scale cooling



Break

10:00

CASE STUDY

Santos, Ltd., Queensland GLNG

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GLNG Development

- The company is developing coal seam gas from the Bowen Basin (Comet Ridge area)
- Field is being developed to supply feed gas to an LNG project
- Well production
  - 0.1-16 MMSCF/day of gas (800 MSCF/day or 800 GJ average)
  - 50-2,000 bbl/day of water (300 bbl/MMSCF or 48 kL/GJ average)
- Anticipate 3,000 wells
- Current production from Fairview field (Roma, Arcadia Valley, and Scotia are currently in Apprasial)
  - 1.3 BSCF/day [1.3 PJ/day]
  - 400,000 bbl/day [64,000 m^3/day]

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Overriding Principles

- Business Requirements → 95/5 Rule
  - Water management must not constrain gas production 95% of the time
  - When water management does constrain gas production
    - Water production must not be constrained more than 20%
    - Gas production must not be constrained more than 2%
- Environmental/Social requirements
  - Maintain license to operate
  - Be a valued member of the community
  - Absolutely avoid a legacy of enduring environmental damage

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Associated Water Reuse and Disposal Hierarchy

Preferred and non-preferred approaches from the ***regulators stand-point***

1. Fresh Water Aquifer Injection
2. Beneficial Use
3. Disposal to Surface Water
4. Disposal Via Evaporation Dams

Brine and Solid Salt Management Options

1. Salt Recovery
2. Inject Brine Underground
3. Pipe Brine to Marine Waters
4. Solid Salt to Land-Based Disposal Facility

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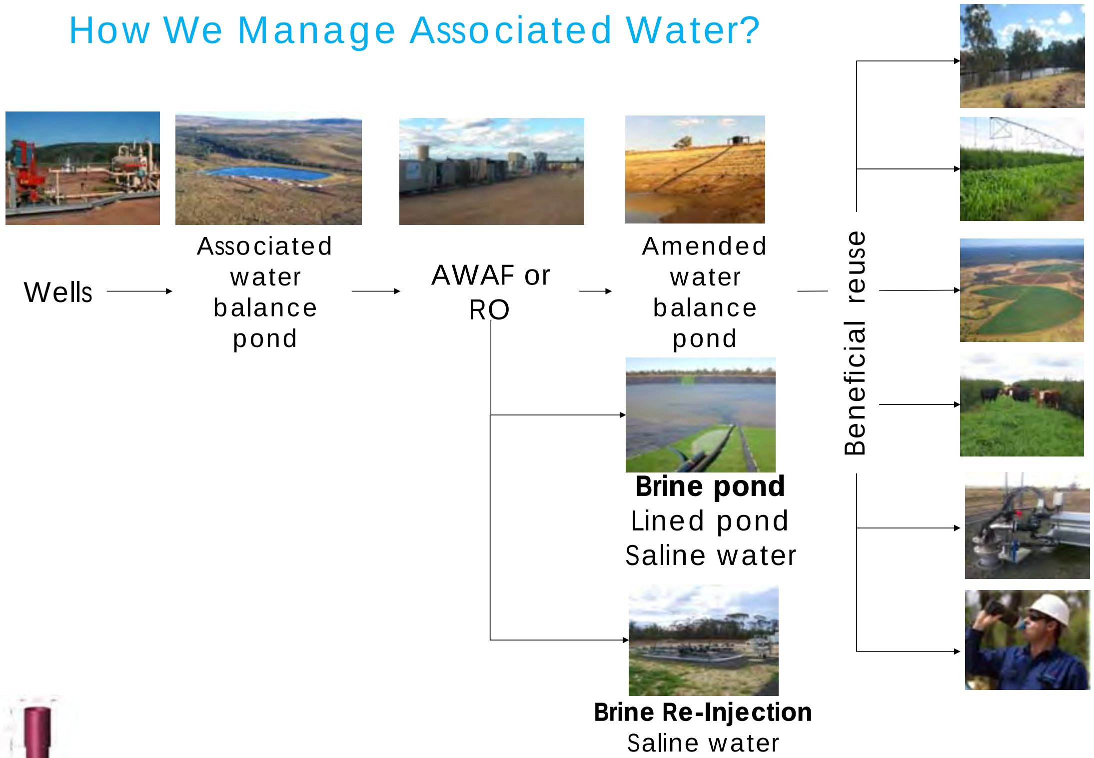
How We Manage Associated Water?



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Managed Aquifer Recharge (MAR)

- Highest acceptability by regulators
- Still very difficult to actually get permits
  - Consequences of an upset are devastating
  - Regulators want to keep risk of upset as low as possible
- Regulators manage risk by
  - Strict limits on water quality (plus strict monitoring requirements)
  - Strict limits on injection rate and total injected quantity
  - Not being very quick to approve new projects
- This option is very high on everyone’s list, but permits are not yet forthcoming

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Beneficial Reuse – Irrigation

Luecaena

- Fast-growing crop that has been used as feedstock in Australia since 1921 and has the potential to substantially increase beef production in Queensland.
- Leucaena has been established under **pivot irrigators** in the south-east of the Fairview field.

Chinchilla White Gum

- Chosen as the first tree species to be **drip-irrigated** using produced water.
- This white bark species grows naturally around Chinchilla and has demonstrated a survival rate above the industry average.
- The trees grow to one metre in diameter and up to 40 metres tall.
- It is a particularly hardy species that produces a rich red timber, suitable for a variety of uses.

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Chinchilla White Gum

- Irrigating 1.2 million trees uses 80,000 bbl/day (12.7 ML/day or about 3 gal/day/tree or 11.3 L/day/tree)
- Trees mature into a commercial hardwood in 12 years
- As the field-development proceeds, additional plots have been planted to handle new water
- Rumors contend that since the Chinchilla White Gum is an endangered species, exporting the hardwood (it is in high demand as flooring material) will be prohibited by Endangered Species regulations—just a rumor at this point

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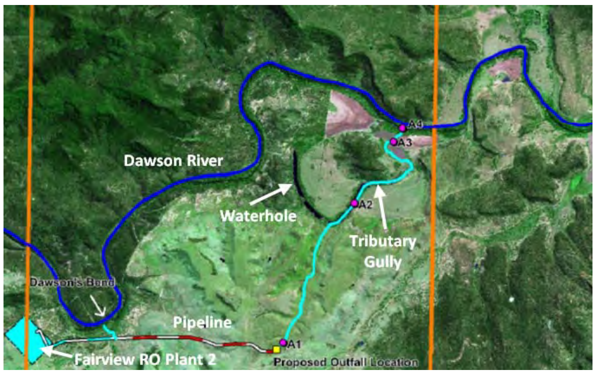
Discharge to Surface Waters

- Low on the reuse hierarchy but necessary due to irrigation demands already maximised and aquifer recharge not feasible in Fairview
- Provides greater flexibility and is less constrained by seasonal factors than irrigation
- Subject to:
  - Intensive hydrological and water quality impact studies
  - Evaluation of mixing zones, near field and far field effects
  - Ecotoxicology and ecological risk assessment
  - Cumulative impact assessment capturing all activities in Fitzroy Basin



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Other Options

- Other options currently used
  - Construction
  - Dust Suppression (Only low TDS)
  - Potable water at HUB sites following disinfection (i.e. via Ultraviolet (UV) and addition of free chlorine)
- Considered and unfeasible uses
  - Mining industry e.g. coal processing
  - Oil & Gas e.g. fresh water fracking, flooding
  - Industrial use
  - Power stations
  - Reinjection into depleted coal seams
  - Aquaculture
  - Direct potable reuse to town drinking water supply

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Options in Use

Coal Seam Water Management Option	Fairview CSG Field	Roma CSG Field	Arcadia Valley CSG Field	Scotia
Agriculture: Irrigation	√	√	√	√
Dust suppression / construction	√	√	√	√
Agriculture: livestock watering	√	√	√	
Release to surface water	√	√		
Managed Aquifer Recharge (MAR)		√		√

Response to Upsets

- First Response
  - Increase the use of coal seam locally, for example for dust suppression and irrigation
- Second Response
  - Move coal seam water downstream to the next water management pond
- Third Response
  - Move coal seam water to flexible options like discharge to surface water
- Fourth Response
  - Use contingency measures in Operating plans
- Fifth Response
  - Reduce flow from wells where water production is high compared to gas production
- Sixth Response
  - Shut in wells with high water and low gas

Storage Ponds

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Fairview AWAF3 Irrigation Water Quality Objectives

Constituent	Unit	Minimum	Target	Maximum
Electrical Conductivity(EC)	µS/cm	-	3,000	4,000
Total Dissolved Solids (TDS)	mg/L	-	2,000	2,650
pH	-	5.0	-	8.6
Sodium Adsorption Ratio (SAR)	-	10	20	30
Langelier Saturation Index (LSI)	-	-	-	No limit
Bicarbonate Alkalinity	mg/L as $CaCO_3$	-	-	500
Carbonate Alkalinity	mg/L as $CaCO_3$	-	-	70
Hydroxide Alkalinity	mg/L as $CaCO_3$	-	-	No limit
Chloride	mg/L	-	-	3.0
Free Chlorine Residual	mg/L	2	2	5
Fluoride	mg/L	-	-	3.0
Calcium	mg/L	-	-	No limit
Magnesium	mg/L	-	-	No limit
Potassium	mg/L	-	-	No limit
Sodium	mg/L	-	-	800
Boron	mg/L	-	-	15

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Brine Treatment / Disposal

Order of Decreasing DEHP Preference	
Option	Outcome of Initial Screening
Salt Recovery	Not Taken Forward Order of magnitude more expensive than other options
Inject brine underground	Taken Forward for further assessment
Pipe brine to marine waters	Not Taken Forward 400 km pipeline is uneconomic and environmentally unacceptable
Solid salt to land-based disposal facility	Taken Forward for Further Assessment

Base Case Evaporation & Crystallisation	Preferred Case Injection
• Technology is proven and available • Technology is scalable • Known and reasonable costs • Achievable in timeframe required; • Local landfill reduces risks from trucking	• Favoured by DEHP and the community over evaporation and crystallization • Cost-effective and currently implemented in the Fairview • Low engineering risk

Conclusions

- Produced water is a large and growing problem
- All solutions are expensive and all have drawbacks:
  - Deep-well injection requires considerable manpower and wells don't have a predictable life
  - Evaporation ponds require a lot of space and overspray of concentrated solids can be a problem
  - Beneficial use options can have unintended consequences
- Any option should be reviewed by an environmental/ regulatory specialist early in the process—the rules, laws, and regulations are very complex and often contradictory.

Symbol	Name	fps	mks
c_p	Specific heat at constant pressure	BTU/(lbm*R)	J/(gm*K)
c_v	Specific heat at constant volume	BTU/(lbm*R)	J/(gm*K)
dP	Differential pressure	psi	kPa
f_f	Fanning friction factor (f_m/4)	fraction	fraction
f_m	Moody friction factor	fraction	fraction
g	Acceleration of gravity	32.174 ft/s^2	9.81 m/s^2
g_c	Conversion from mass to force at the surface of the earth	32.174 (ft*lbm)/(s^2*lbf)	
ID	Inside Diameter	in	mm
k	Adiabatic constant	fraction	fraction
N	Normal. Used with mks volume units to indicate that the volume is referenced to "standard" conditions		
P	Pressure	psia	kPa(a)
q	Volume Flow Rate	MSCF/day gpm	Nm^3/day L/min
Q	Rate of heat transfer	BTU/s	J/s
R_{air}	Gas Constant for Air ($\bar{R}$ /MW_{air})	53.353 ft*lbf/(lbm*R)	287.1 m^2/(K*s^2)
R_{gas}	Gas Constant for a specific mixture of gases ($\bar{R}$/MW_{gas}=R_{air}/SG_{gas})	ft*lbf/(lbm*R)	m^2/(K*s^2)
$\bar{R}$	Universal Gas constant	1545 ft*lbf/(mole*R)	8314 m^2/(K*s^2)
R_e	Reynolds number	fraction	fraction
SG	Specific Gravity relative to a reference fluid (MW_{gas}/MW_{air} or ρ_{liquid}/ρ_{water})	fraction	fraction
T	Temperature	R	K
VI	Volume Index on a flooded screw compressor	fraction	fraction
W	Work done by compressor	hp	kW
$\vec{v}$	Velocity	ft/s	m/s
Z	Compressibility	fraction	fraction
ε	Absolute pipe roughness	ft	m
η	Efficiency	fraction	fraction

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ρ	Density	lbm/ft^3	kg/m^3
$\dot{m}$	Mass flow rate	lbm/s	kg/s

Subscripts:	
air	Parameter is specific to air
ASL	Above sea level
atm	Atmospheric
avg	Average
bot	Conditions at the bottom of a fluid column
choked	Conditions referenced to sonic velocity
eff	Effective
gas	Parameter is specific to an identified gas mixture
i	Initial conditions
ideal	Conditions for an ideal gas (i.e., one who's compressibility is approximately equal to 1.0)
liquid	Parameter is specific to an identified liquid mixture
max	Maximum
min	Minimum
real	Conditions for a real gas (i.e., one who's compressibility is a function of gas density)
res	Reservoir
static	Static as in pressure above a column of fluid
std	Standard Conditions
top	Conditions at the top of a fluid column
volumetric	Relating to volume
1	Upstream conditions
2	Downstream conditions

