Water Recycle as a Sustainability Tool for Industrial Plants

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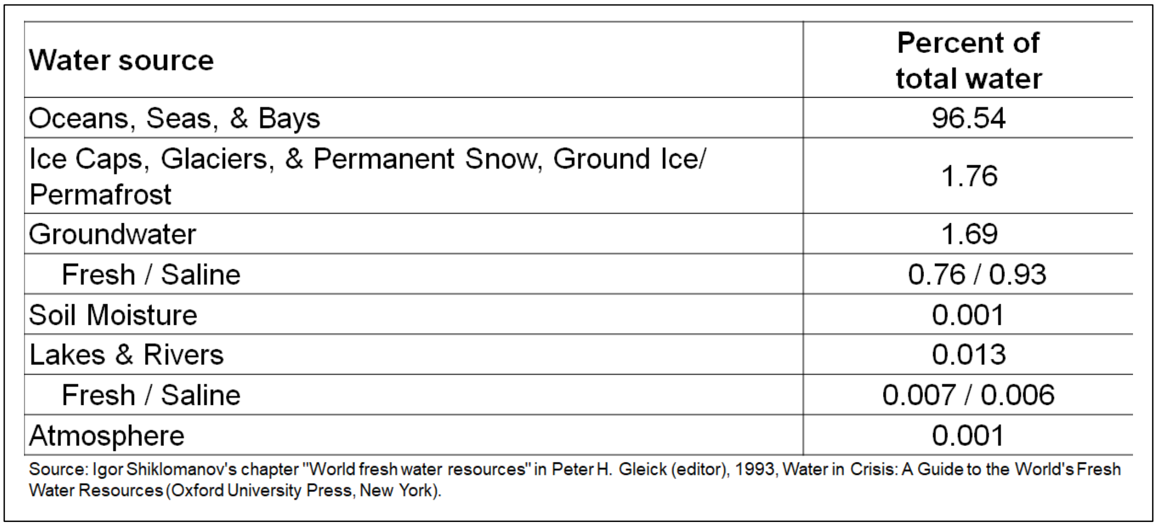
ABSTRACT

Water scarcity is becoming an issue in many parts of the world and the ability to maximize water utilization is a key part of sustainable operations. Given the heavy industrial reliance on evaporative cooling systems to reject heat, these systems are a critical component for most plants. In this paper we will discuss the options for minimizing water consumption based upon the principles of minimization, recycling and reuse. Three different approaches will be discussed and illustrated using case histories of actual plants and what was learned from them.

INTRODUCTION

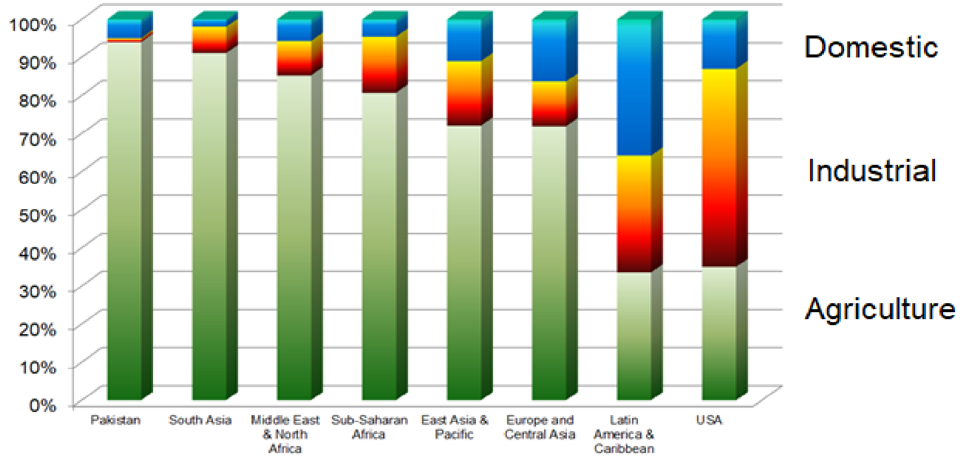
While there are a variety of different water sources, fresh water is the preferred source since it requires the least treatment for domestic, industrial or agricultural usage. However, the amount of available fresh water is limited and represents less than 0.8% of the total water available.



Water source	Percent of total water
Oceans, Seas, & Bays	96.54
Ice Caps, Glaciers, & Permanent Snow, Ground Ice/ Permafrost	1.76
Groundwater	1.69
Fresh / Saline	0.76 / 0.93
Soil Moisture	0.001
Lakes & Rivers	0.013
Fresh / Saline	0.007 / 0.006
Atmosphere	0.001

Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources (Oxford University Press, New York).

Not only is the amount of fresh water limited, but availability is not uniform, and it varies considerably by geography. Competition for water by different segments makes it a very valuable commodity, and these competing demands will increase in the future.



Source: World Development Indicators (all except USA)
Pakistan: FAO Water Report – Aquastat (2011)
*Data comes from Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2014, Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405, 56 p., http://dx.doi.org/10.3133/cir1405.

The previous graphic shows the share of fresh water use by section in the 2010 – 2014 time period. Understandably, countries with large populations and varying rainfall can see the majority of the fresh water being used to support agriculture. Domestic water consumption is expected to increase in regions where living standards are rising, and this will put additional pressure on water resources.

Water conservation is typically driven by local availability and demand. For example, in southern California, industry is being encouraged to use reclaimed sewage water (Title 22 water) as their primary water source. While treated, this water supply generally still contains elevated levels of phosphorus, chloride and other ions compared to surface waters. Australia is not water rich in areas where most of the population is located. This has driven the move to use reclaimed water (treated sewage water) for water features and also for agricultural use (agricultural irrigation in the Melbourne area).

The combination of populations being in low rainfall areas and growing human demands means that industrial plants are experiencing constraints on their ability to access fresh waters. However, this is not limited to just regions with little or no water – even areas with abundant water supplies are facing restrictions on using fresh water. Northern Alberta (Canada) has considerable fresh water but regulations for oil extraction plants require that no fresh water be used (they are allowed to use reclaimed water and brackish well waters). The overall result is a trend towards using lower quality water (and reclaimed water) for industrial applications.

This global movement towards restrictions on water usage means that industry must increasingly innovate the way it uses water. Water conservation issues that have been restricted to high volume process users (pulp and paper mills, steel mills etc.) are now extending to more moderate consumers such as open evaporative cooling systems.

Utility users in industrial plants include both boilers and cooling systems. Compared to boilers, evaporative cooling loops require two to ten times as much water and are typically the main consumer. While aerial cooling can reduce the load on cooling water systems, the lower efficiency and increased electrical consumption means that aerial cooling is restricted to a much narrower range of conditions. Given the heavy industrial reliance on evaporative cooling systems to reject heat, these systems are a critical component for most plants.

Pretreatment for boilers is such that the final water is of a very high purity, with contaminants reduced to a fraction of a ppm. However, for cooling systems, pretreatment is more rudimentary and is normally limited to filtration either alone or in conjunction with clarification. As a result, water used as make-up to cooling systems will have almost all of the impurities that would be present in the source water.

The use of lower quality water as make-up to cooling systems means that the level of corrosive ions (chloride) and nutrients (phosphate, organic carbon, ammonia) are higher, which makes maintaining system reliability more of a challenge.

In some cases using water from within the plant, rather than sourcing it externally offers benefits in terms of water quality and the overall environmental impact. In this paper we will discuss the options for minimizing water consumption based upon the principles of minimization, recycling and reuse. Three different approaches will be discussed and illustrated using case histories of actual plants and what was learned from them:

i) Wastewater re-use in a food processing plant.
ii) Water diversion in a gas processing plant.
iii) Water cascading in a fertilizer plant.

In each of these cases, the cooling tower was the ultimate water consumer.

WASTEWATER RE-USE – FOOD PROCESSING PLANT

The ice cream manufacturing plant is located in a town with a limited potable water supply and with an effluent treatment plant that is approaching its maximum capacity. This plant is a large ice cream plant in Canada and wanted to expand the facility. This meant adding cooling capacity which would raise the water usage.

The town was faced with the choice of either supplying the extra water and the increased sewage treatment posed by the expansion or using this capacity to service new residential customers. Since the cost of expanding the municipal waste treatment plant would be high and the tax revenue from residential users is more beneficial, the town told the plant that there would be significant surcharges for any additional water or sewage usage demand.

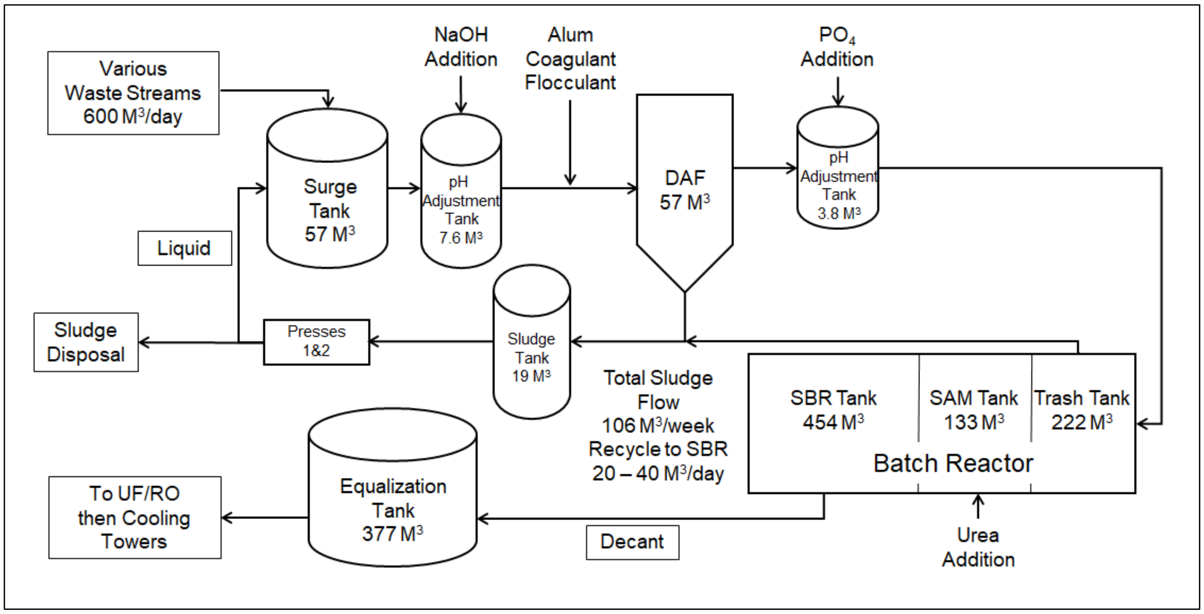
By re-using their existing wastewater, the plant could both proceed with the expansion and not make large demands on the town. This would allow further residential construction, with no increase in the town's water treatment plant. This would allow the town to increase its tax revenue and the plant received credit for being both environmentally sustainable and helping the community.

Since the plant had its own effluent treatment system that had been used to pre-treat the water prior to discharge to the municipal system, the plan was to upgrade it. By enhancing the effluent system, already in operation, and expanding it, the goal was to make it suitable as cooling tower make-up. In order to manage the risks of the project, it was done in three stages:

i) Sampling of effluent from the plant's internal effluent treatment system was conducted to determine the typical water quality with respect to organic loading (sugar, milk solids, fat, etc.) as well as inorganic constituents (phosphate, chloride, sodium, hardness, etc.). The orthophosphate and chloride levels in the wastewater were high and were taken into account in modelling that was done on the water chemistry. This model was presented to the plant management and served as a basis for our recommendations in terms of what mechanical and chemical treatment options could be considered.

ii) The decision was made to go with UF and RO after the biological treatment to bring the water to the quality needed. Since the plant could not risk problems with their systems and did not want to invest the $300K for the new treatment system without confirmation that it would produce the required water quality, a pilot system was obtained for trial purposes. During the trial period a number of parameters were evaluated, including permeate quality and the cleaning frequency of the membranes. Over the month-long evaluation period it was found that the combination of UF/RO met all the requirements and that fouling of the UF was well within acceptable limits.

iii) Once the pilot plant work was assessed, the decision was made by the plant to install a UF/RO to treat the effluent from their primary treatment system (DAF/SBR). The goal was to produce 245 M^3/day of permeate from each of the two RO trains with a target recovery rate of 70%. The recovery rate was set to minimize the potential for fouling by calcium phosphate.



Rather than discharging the treated effluent to the town, it was put through the UF/RO to improve the quality.

ROI (Return on Investment)
With capital costs of $300K and the avoidance of additional discharge surcharges of $400K (related to any plant expansion), the payback on the system was 9 months. In addition, this change allowed the plant to increase production without the need to take additional water from the municipal supply.

ROE (Return on Environment)
However, there are a number of other benefits to the plant from this project:

i) In excess of 65% of the plant effluent is now diverted from discharge to the town and instead is used as make-up to the multiple cooling systems in the plant. This in turn lowered their water costs since this displaced an equivalent amount of water that was used for the cooling system.

ii) By lowering the amount of water required for the plant and the discharge volume, it allowed the town to permit further residential expansion without the need to spend any capital to expand their water treatment plants. The reduction in water consumption/discharge equates to:

   - 324 residential units (family of 4) based on typical potable water demand.
   - 169 residential units (family of 4) based on typical sewage discharge flows.

iii) This was promoted by the plant as evidence of their commitment to the community and the sustainable nature of their business model.

The system has been in operation for six years and continues to perform well and to design specifications.

WATER DIVERSION – GAS PROCESSING PLANT

This sour gas treatment plant in Canada disposed of wastewater from the plant site via deep well injection. While there were no restrictions upon the amount of water taken from the river, the plant wanted to lower their environmental footprint and looked at the different options.

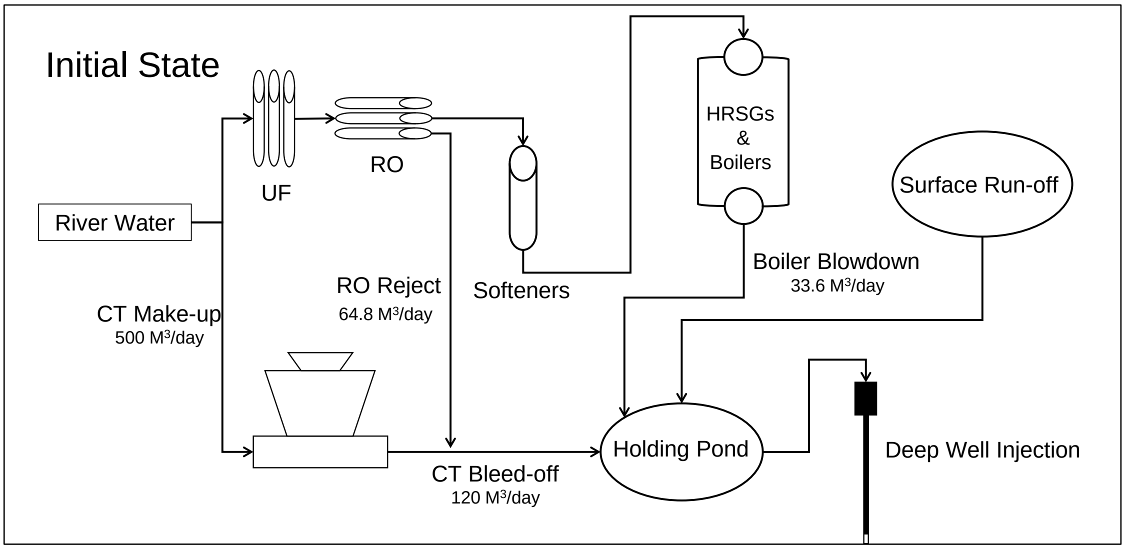
The wastewater from the plant went to a deep well injection system that disposed of the water deep below the surface. The water that was disposed of included the following streams:

i) Surface run-off – rain water collected from around the plant.
ii) RO reject – the concentrated discharge from the boiler pre-treatment system.
iii) Boiler blowdown – the wastewater from the boilers.
iv) Cooling tower bleed-off – the water removed from the cooling system.

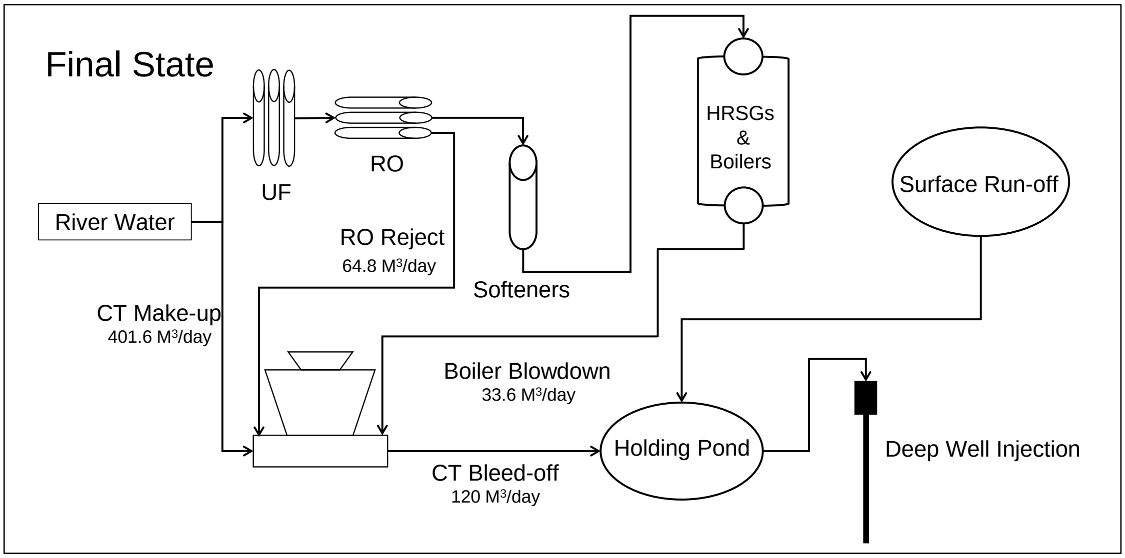
While the injection well was in good condition and it was handling all the water flows, it was decided that ways to reduce the amount of water being disposed of should be checked. The project was broken down into two phases:

i) Initially the RO reject was directed to the cooling system.
ii) In the second phase, boiler blowdown was also diverted to the cooling system.

Both of these changes resulted in the cooling water chemistry changing as the RO reject had a high salt concentration and the boiler blowdown was highly alkaline and contained phosphate. Modelling of the cooling water chemistry was conducted to assess the potential issues that these changes might cause and to determine what changes would be needed to ensure that system reliability was not affected.



When the system was fully implemented there were both savings to the total plant water intake as well as discharge to the deep well injection system. This is illustrated in the next diagram.



The benefits to the plant included:

i) Make-up from the river was lowered by ≈25%.
ii) Deep well injection dropped by ≈40%.

There were changes made to the cooling system automation and the treatment program was modified slightly. After more than 12 months of operation, corrosion and scaling rates have continued to show excellent control. The ROI was less than 12 months for the automation.

WATER CASCADING – FERTILIZER PLANT

A major fertilizer complex plant in Asia instituted a novel approach of cascading bleed-off from one cooling system to another. Chloride limits in the fertilizer plant restricted the number of cycles of concentration in order to minimize the risk of SCC (stress corrosion cracking). Plants containing stainless steel heat exchanger tubes are limited by the grade present, but typical limits to avoid SCC damage are:

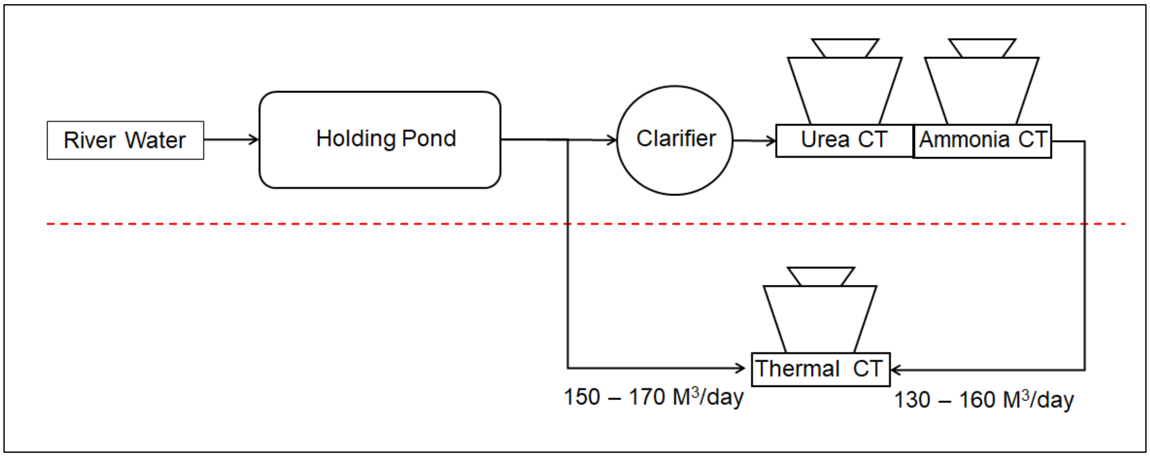
- 304 / 304L 175 – 200 ppm chloride (at 60°C) and FAH <0.5 ppm
- 316 / 316L 300 – 400 ppm chloride (at 60°C) and FAH <0.5 ppm

(FAH = free available halogen)

Depending upon the make-up water composition, duration of chlorine dosing and the cycles of concentration, the chloride contribution from hypochlorite, or chlorine gas, will represent 25 – 50% of the total chlorides measured in the cooling water.

While there were limits in the fertilizer plant, the thermal plant (electricity generation), could tolerate higher levels of chloride, making it an ideal receiver for water from the fertilizer plant.

The following simplified schematic shows how the system operates with water cascading from one cooling system to another.



By taking the discharge from the fertilizer plant and using it as make-up to the power plant cooling system, it was possible to further increase the cycles of concentration. Modelling of the water chemistry showed that with relatively minor adjustments, that this change could be accommodated with no negative impact on system performance.

	Urea CT	**Ammonia CT**	**Thermal Plant CT**
Chloride Limit	150 ppm	250 ppm	≈500 ppm (≈550 ppm with Cl from hypo)
Cycles of Concentration (based upon Mg)	1.3	2.04	Before ≈5 After ≈3.5

The cycles in the thermal plant cooling system were lowered to ensure that the program was working well. However, the longer-term goal is to target a value above 4 and ideally back to the initial level of 5.

The water balance at the plant is summarized in the following table.

	Ammonia + Urea CTs	**Thermal CT**
Initial State		
River Make-up	960 M^3/hr	240 – 250 M^3/hr
Bleed-off	300 M^3/hr	30 – 40 M^3/hr
Final State		
River Make-up	960 M^3/hr	150 – 170 M^3/hr
Bleed-off as Make-Up		130 – 160 M^3/hr
Discharge	140 – 160 M^3/hr	60 – 80 M^3/hr

By cascading the water in this manner, limits with respect to chlorides are observed while at the same time the best use of the water obtained. This allows for a 7% reduction in water consumption and a 35% reduction in bleed-off. As the system is further optimized, chemical consumption (compared to the base case) will be reduced.

CONCLUSIONS

These three case histories illustrate that while the drivers in each case were different it was possible to lower water consumption without any loss of system reliability or integrity. At the same time, using less water brought economic as well as community benefits.

Excellent tools exist to allow modelling of the current and future water chemistry, which allows most of the potential problems that could occur to be considered and addressed. For instance, the phosphate level in the water going to the RO system at the food processing plant required an RO anti-scalant that could function under higher stress conditions. In the case of the deep-well injection, the boiler blowdown required more acid feed to the cooling system and the treatment product was reformulated to adjust for the phosphate contributed by the boiler blowdown.

By combining an understanding of the water chemistry with the key objectives, it is possible to conserve water and have a more sustainable operation.