Total Dissolved Solids in Reclaimed Water

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More than half of human water demands can be met with recycled non-potable water, which opens up the possibilities for many water consumption reduction strategies. Recycled sources include HVAC condensate, rooftop storm water, gray (wash) water, and local sewage treatment plant effluent. Some of these are relatively clean, requiring only antimicrobial treatment, while others require filtration or removal of organic contaminants.

Levels of total dissolved solids (TDS) are often overlooked in these non-potable sources, resulting in challenges for end-uses such as cooling tower makeup and irrigation. Excessive levels of TDS can result in corrosion, fouling and scale in cooling towers and in toilet fixtures, and mortality to irrigated plants.

While some non-potable water sources, such as harvested storm water run-off and HVAC condensate, have very low TDS, other sources, such as treated sewage effluent (TSE) and recovered wash water can have quite high TDS. In areas with "hard" potable water supplies, TDS in the incoming city water may approach the acceptable upper limits for cooling tower makeup, before chlorides, nitrates, bicarbonates and sulfate salts are added by human use. Successful use of recycled water sources for non-potable water demands requires management of TDS from those widely varying sources.

Cooling tower water consumption is affected by the TDS level in the makeup water. Conventional limits for TDS in basin water range from 1,000 to 1,500 ppm, consistent with a conductivity of 2400 μS/cm. Cooling tower blowdown wastes water from the basin, removing dissolved solids to maintain the desired maximum TDS concentration.

Blowdown rates may sometimes be fixed to control maximum levels of certain impurities present in the makeup water rather than maintaining a TDS upper limit. The ratio of cooling tower makeup flow to blowdown flow is called the cooling tower cycles of concentration (COC). The maximum allowable COC is usually the ratio of the maximum allowable basin TDS to the makeup water TDS.

With conductivity or other concentration measurement sensors, blowdown rate can be controlled dynamically to maintain the desired TDS in the cooling tower basin. For conventional cooling tower water treatment protocols, higher levels of makeup water TDS result in higher rates of blowdown. Two strategies to reduce cooling tower water consumption are:

- Provide makeup water from low TDS water sources, maximizing the cycles of concentration for the makeup water.
- Use treatment protocols that enable basin TDS levels to exceed conventional levels.

TDS in Potable Water Sources

TDS in potable water is generally less than 500 mg/L, a recognized threshold above which excessive hardness, unappetizing taste, scaling and corrosion may occur. The range of TDS for potable water supplies can be from as low as 30 mg/L in streams running through igneous rock

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TABLE 1 Ion and water mass balance for building sewage effluent.

Fixture Type (Standard)	Flow Rate	Usage Time	Flow (L)	Uses/ Person	Percent of Population	Total Flow (L)
WC Men	1.6 gpf		6.048	2	50	6
WC Women	1.6 gpf		6.048	4	50	12.1
Urinals	1 gpf		3.78	2	50	3.8
Lavatories	0.5 gpm	15 sec	0.473	4	100	1.9
Calculated Daily Sewage Generation						23.8 L/Person
Statistical Daily Consumption (Based On Regression Equation) With 80% to Sewage						51.0 L/Person
Ion Excretion Per Person	Building Fraction		Building Ion	Sewage Flow Per Day		Effluent TDS Rise
72.8 g/day	33%		24.024 g	40.8 L/Person		588.8 mg/L

formations to as high as 1100 mg/L for streams running through sedimentary rock or from limestone aquifer wells.

In northern climates, TDS in streams may be elevated by road de-icing chemicals, and in agricultural areas, run-off from fields may elevate levels of nitrates and phosphates in lakes and rivers. The most common chemical constituents of TDS in city water supplies are calcium, sodium, potassium, phosphates, nitrates, carbonates and chlorides. In some regions, particularly arid areas of the southwestern United States, natural dissolved solids leached from sedimentary rock raise the TDS of potable water supplies to as high as 650 mg/L.[2]

While elevated TDS levels create minor issues for the homeowner, including soap scum, fixture corrosion and scaling, it presents significant problems for cooling tower users and elevates sewage treatment plant discharge TDS to levels that present hazards to discharge area flora and fauna. Upstream discharge of high TDS sewage treatment plant effluent into rivers used as potable water supply increases TDS levels for downstream cities. In dry climates, elevated TDS levels in surface water sources used for agricultural irrigation can result in reduced crop yields and long-term "poisoning" of the crop land.

High effluent TDS, to date, is a relatively undocumented by-product of maximizing water conservation. The inorganic solutes that are excreted or disposed of in the normal course of human use of buildings do not decrease even though conservation efforts reduce water flow. Therefore, conservation results in higher levels of concentration of these contaminants in the sewage and in the sewer treatment plant effluent. These higher levels of concentration present significant problems for recycling wastewater for non-potable uses in buildings.

TDS in Non-Potable Water Sources

As mentioned previously, some non-potable sources are quite low in dissolved solids. Rainwater and HVAC condensate are essentially distilled water, but may pick up some contaminants in the process of harvesting.

Other non-potable sources start with the TDS of the potable water supply and then add whatever contaminants that may result from their primary use in the building. The most common and cost effective forms of wastewater treatment have little or no impact on dissolved solids.

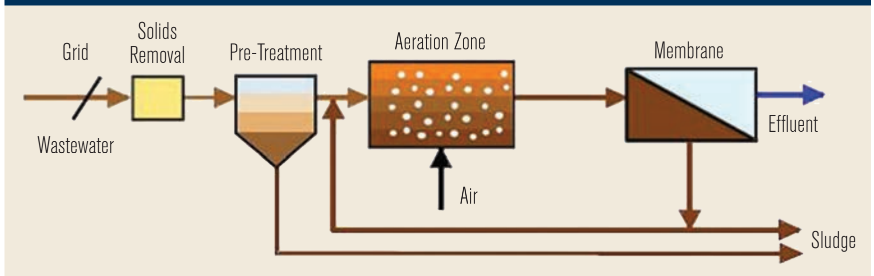
The average human excretes 72.8 g (2.6 ounce) of cations and anions (salts) each day, which, for most building types, constitutes the primary source of dissolved solids in wastewater.[3] While there may be other sources of dissolved solids in an office building, such as water softeners or detergents, the above figure represents a minimum contribution that might be expected. For an average office building, with the assumption that the toilet fixtures in the building receive approximately one-third of the daily salt excretions of the occupants and with the standard building code requirements for water use, the increase in TDS in wastewater from toilet fixtures would be more than 1200 mg/L, as shown in *Table 1*. Clearly the calculated fixture flows shown in the table do not capture the entire water use per person even in as simple an occupancy as an office building.

A statistical study of 49 offices in various U.S. locations revealed that the marginal increase in water use is approximately 51 L per day (13.5 gallons per day) per additional building occupant, with all other factors, such as cooling tower use and irrigation held constant.[4] Assuming that about 80% of total personal water use becomes part of the sewage flow stream, the resulting increase in TDS places the effluent at the margins of usability.

Managing TDS in Building Water Effluent

Water entering a building generally leaves it in one of three ways, as sewage discharge; as water vapor from humidifiers, evaporative coolers and cooling towers, or into the ground as irrigation. Dissolved solids entering the building water stream, either in the incoming potable water, or added to the water as part of the building function leave the building only through the sewage discharge and irrigation. As noted previously, flow reduction of potable water through conservation results in higher levels of TDS in sewage discharge.

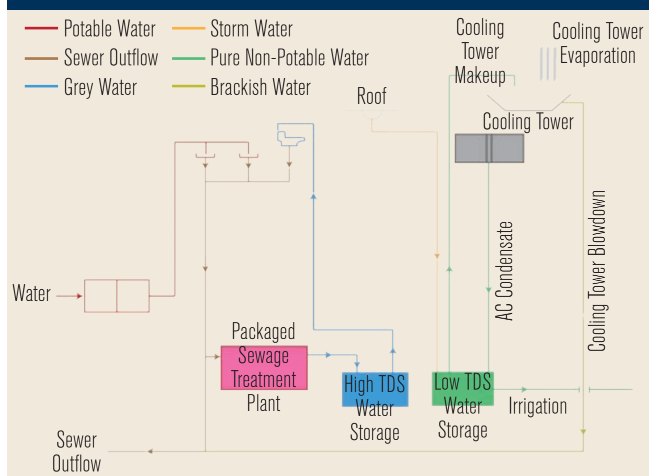
FIGURE 1 Membrane bio-reactor sewage treatment plant flow diagram.



Local packaged sewage treatment plants have been installed to provide recycled water or non-potable uses. Typical space-conserving sewage treatment technologies include membrane bio-reactors and multi-reactor-phytoremediation systems. Sewage is subjected to tertiary treatment in the building and is then recycled for specific non-human contact end-uses, including irrigation and cooling tower makeup.

Typical sewage treatment plant technologies, while effective at removing organic contaminants and particulates from wastewater, remove very little of the dissolved inorganic contaminants. Some "natural" wastewater treatment protocols use halophytic plant species to absorb and concentrate inorganic solutes, but their biomass must be regularly harvested to maintain the desired removal rate of dissolved solids.[5] Space requirements and maintenance costs for this technology make it unsuitable for most building applications. The most common packaged sewage treatment technology, because of its compact size, reliability and low maintenance requirements, is the membrane bio-reactor, illustrated in *Figure 1*.

FIGURE 2 Flow diagram for low TDS cooling tower makeup.



Dealing with High TDS in Building Wastewater

Three strategies were identified for using high TDS wastewater to achieve extraordinary reductions in potable water use. All strategies use local wastewater treatment and harvest the treated sewage effluent (TSE) for non-potable uses, but differ in how that effluent is used.

The first strategy recycles treated sewage effluent for flushing and discharges the remainder as a medium-high TDS stream to the city sewer system. The second option uses reverse osmosis-purified locally treated sewage for both cooling tower makeup and irrigation, requiring discharge of a very concentrated reverse osmosis brine to a suitable sink. Discharge of high TDS wastewater to the municipal sewage stream may be unacceptable or unlawful because of the impact of the treated sewage effluent on TDS in rivers and streams.

The third option uses treated sewage effluent for cooling tower makeup, but relies on a structured water treatment protocol to deal with issues of corrosion, scaling and biological growth.

Low TDS Cooling Tower Makeup

The first strategy reserves HVAC condensate and harvested storm water for cooling tower makeup with the blowdown rate controlled to maintain conventional upper limits of basin TDS. A portion of the sewage water generated by the building is treated and the effluent used for flushing while the remainder is discharged to the municipal sewer.

This strategy is appropriate to humid or high-rainfall climates, where condensate and storm water recovery can meet the preponderance of cooling tower makeup and irrigation requirements. For these projects, storm water recovered from the roof, typically, would be reserved for cooling tower makeup because of its relative lack of contamination, while irrigation requirements would be met with strategies that recover and retain site run-off. Cooling tower water is subjected to standard treatment protocols for microbiological and corrosion control. *Figure 2* (Page 30) is a flow diagram for this strategy.

The mass balance for the flushing component of this strategy is shown in *Table 2,* with an assumption that water efficient fixtures reduce the statistically derived flow per person by 20% and that 80% of consumed water goes to sanitary sewage.

The level of effluent TDS is unsuitable for either cooling tower makeup and problematic for irrigation.[6] As a result, no advantage results from sizing the sewage treatment plan larger than the requirement for flushing water. Treated sewage effluent should be monitored periodically for total ammonia concentration, because levels above 20 mg/L may result in accelerated corrosion of copper plumbing piping and fixtures.

TABLE 2 TDS rise for sewage system using recycled treated sewage effluent (TSE) for flushing.

Fixture Type (Water Conserving)	Flow Rate	Usage Time	Flow (L)	Uses/ Person	Persons	Total Flow (L)
WC Men	1.4 gpf		5.292	2	1,000	10,584
WC Women	1.4 gpf		5.292	4	1,000	21,168
Urinals	0.125 gpf		0.473	2	1,000	945
Calculated Daily Flushing Consumption						32,697 L
Statistical Daily Consumption (Based on Regression Equation Less 20%)						81,600 L
Potable Water Usage with All Flushing by Recycled Water						48,903 L
Sewage Flow Per Person/Day (80% of Potable Water to sewer)						19.6 L
Ion Excretion Per Person		Building Fraction	Building Ion	Sewage Flow Per Day		Effluent TDS Rise
72.8 g/day		33%	24.024 g	19.6 L/person		1228.1 mg/L

TABLE 3 Ion and water mass balance for reverse osmosis treatment of treated sewage effluent.

Ion Excretion Per Person	Building Fraction	Building Ion	Sewage Flow Per Day	Effluent TDS Rise
72.8 g/day	33%	24 g	19.6 L/person	1228.1 mg/L
			Annual Flow (L)	Actual TDS
Potable Water Usage			17,693,392	200.0 mg/L
Sewage Effluent to Reverse Osmosis			9,972,886	1428.2 mg/L
Recovered Purified Water–80% of Sewage Flow			7,978,309	50.0 mg/L
Waste Brine Stream–20%			1,994,577	6940.7 mg/L

Reverse Osmosis Treatment of Treated Sewage

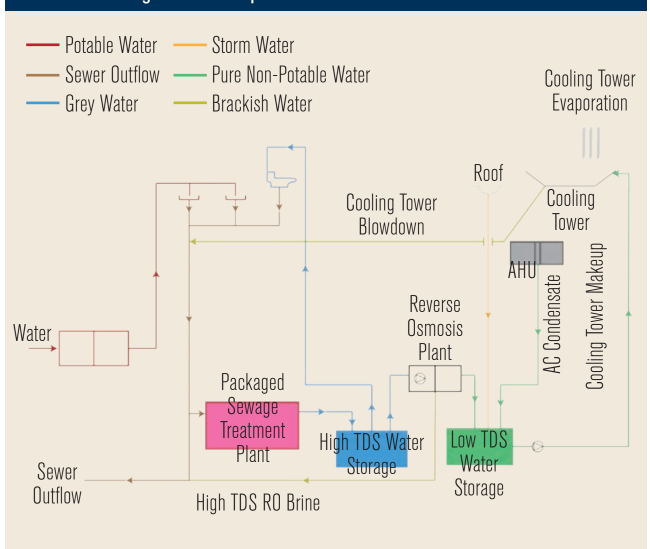
Reverse osmosis (RO) is a commonly used technique for creating relatively pure water by concentrating solutes into a separate smaller wastewater stream. In buildings, it can be used to extract pure water from locally treated sewage effluent, from cooling tower blowdown, or from other high TDS non-potable water sources.

For relatively low TDS (less than 5000 mg/L), the energy required to produce pure water is less than 1 kWh/m^3.[7] Based upon current electricity and water rates in New York City, the cost of water recovered by this method is about 25% of the cost, assuming no sewer surcharge, of water purchased from the city.[8]

A by-product of this process is a highly concentrated (approximately five times the concentration of the source) brine effluent stream that must be disposed in some environmentally safe manner. One technique is to use evaporation ponds to convert the brine to a solid mineral product that can be buried or recycled for its salt content. *Table 3* is a mass balance for this strategy.

Packaged low concentration reverse osmosis systems are available for an installed cost of between $5 and $10 per gallon of product per day of capacity. The system portrayed in *Figure 3* is a portion of the treated sewage effluent for flushing, and the remainder of the effluent is subjected to RO treatment for either cooling tower makeup or irrigation.

FIGURE 3 Reverse osmosis treatment of treated sewage effluent of irrigation and cooling tower makeup.



High TDS Cooling Tower Makeup

This strategy uses recent strategies developed for industrial cooling tower water treatment to use relatively high TDS makeup water and potentially eliminate high TDS blowdown disposal problems.[9,10] The goal is to achieve "zero blowdown" or "zero liquid discharge" through the use of water treatments that allow very high TDS levels, low blowdown rates, and, therefore, high cycles of concentration. Use of recycled sewage treatment effluent, furthermore, may expose metallic surfaces to elevated concentrations of highly-corrosive ammonium ions due to incomplete treatment of this human waste by-product.[11] Pursuit of this goal involves a number of interdependent and synergistic strategies, including:

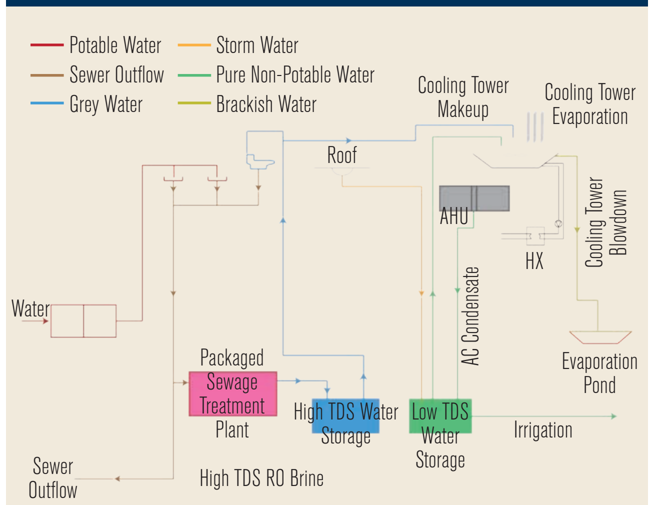
1. High efficiency softening replaces calcium and magnesium ions with sodium ions, greatly increasing the solubility of the dissolved materials and minimizing both carbonate and silicate scaling on cooling tower surfaces.
2. Deposition control strategies including dispersant surfactant and terpolymer treatments and sidestream filtration.
3. Basin water pH maintained above 9.0, to facilitate conversion of ammonium ions to gaseous ammonia that is volatilized by the elevated basin water temperature, and to minimize silicate scale.[12]
4. Azole corrosion inhibition chemistry protects copper and bronze surfaces from residual ammonium ion corrosion.[13]
5. Sodium silicate corrosion inhibitor chemistry protects metallic surfaces through the formation of thin silicate films on these surfaces.[14]
6. Very high TDS (above 50,000 ppm)[15] or bromination controls microbial growth.
7. Adjust cooling tower flow rate to accommodate lower specific heat of high TDS water.
8. Isolate cooling tower water from central plant using heat exchanger and avoid aluminum for surfaces in contact with cooling tower water.[16]

The combination of these water treatment strategies, however, enables cooling towers to operate at high TDS levels, to use high TDS makeup water and to reduce blowdown flow to a rate that can be disposed of in small evaporation ponds. Clearly, these strategies require sophisticated technology and diligent maintenance, but multiple studies demonstrate that potential water savings outweigh chemical treatment costs.[17,18]

TABLE 4 Ion and water mass balance for high TDS cooling tower makeup strategy.

Ion Excretion Per Person	Building Fraction	Building Ion	Sewage Flow Per Day	Effluent TDS 200 mg/L Source
72.8 g/day	33%	24.024 g	19.6 L/person	1428.1 mg/L
			Annual Flow (L)	Actual TDS
Cooling Tower Makeup			9,115,386	1428.1 mg/L
Cooling Tower Blowdown (1% of Makeup)			91,154	142,814.6 mg/L

FIGURE 4 Zero liquid discharge cooling tower makeup system.



Comprehensive cooling tower treatment programs incorporating the above strategies, primarily oriented toward industrial users, are currently available from multiple vendors. *Table 4* shows the mass balance for one of these very low blowdown systems (COC = 100) showing the very high level of TDS achieved and the relatively small amount of contaminated blowdown that must be disposed. Blowdown flow will be reduced by drift, but drift must be tightly controlled to protect exterior structures from the staining and corrosive effects of the cooling tower water.

Figure 4 is a diagram of this system. Note that a heat exchanger is inserted between the cooling tower and the chiller plant, to isolate potential service problems from high TDS water.

The result of using this integrated water treatment strategy is that low-quality, high-TDS, ammonium-rich water, usually produced by conventional wastewater treatment technologies, can be used for cooling tower makeup, without danger of corrosion or scaling. The outflow from the sewage treatment plant can be recycled both for toilet flushing and cooling tower makeup, even though the reduction of potable water flow through the system will raise the TDS of the sewage treatment plant effluent. The flushing requirement can also be supplemented with harvested storm water and HVAC condensate, reducing the TDS of the flushing water. Residual harvested rainwater and HVAC condensate in humid or rainy climates can be used for irrigation, exterior housekeeping, car washing or other non-potable end uses. Cooling tower blowdown flow, furthermore, is reduced to less than 1% of makeup requirements, enabling this highly corrosive brine to be disposed through the use of an evaporation pond, thus avoiding pollution of surface waters with high-TDS discharge.

Conclusion

Designers, addressing worldwide potable water shortages, are pursuing ever more aggressive water conservation strategies and using harvested non-potable water resources for non-potable end-uses. As shown in this article, the levels of TDS in sewage and treated sewage effluent, resulting from reduced total water flow in water efficient buildings, are likely too high for some of the intended end-uses.

Three options for using high-TDS local sewage treatment effluent to provide a substantial non-potable resource were discussed here. The first option uses the treated sewage effluent only for flushing, reserving harvested low-TDS water resources for cooling tower makeup. The second option uses reverse osmosis (RO) to remove dissolved solids from the treated sewage effluent for cooling tower makeup. The third option used a sophisticated cooling tower water treatment system to allow high TDS levels in the cooling tower basin without corrosion or scaling.

The second and third options have some level of additional first and operating cost compared with the first option. These options were analyzed for a prototype 35 000 m^2 (376,700 ft^2) office building with 2,000 workers in a temperate climate. The studies assumed that condensate was recovered with efficiency based upon the total flow generated per month (greater efficiency with greater flow), and that storm water run-off was recovered from the roof at a maximum of 80% recovery.

Table 5 shows that greater water conservation can be achieved with greater sophistication of the harvesting technologies. Option 3 achieves the highest savings, but that option requires sophisticated water treatment and controls to avoid corrosion and scaling, and requires disposal, using an evaporation basin, of highly concentrated brine, too toxic for introduction to city sewers or disposal in surface water. Note that while Option 3 discharges very little water to the city sewer system, approximately 91 000 L (24,000 gallons) per year of concentrated cooling tower blowdown must be evaporated.

An overall conclusion that can be drawn from this study is that very high levels of water conservation can be achieved, but conservation strategies for these higher levels of savings require more sophisticated engineering analysis than simple monthly water balance calculations. The impact of TDS levels in recycled water sources must be considered for non-potable uses.

The TDS level in building effluent streams entering district sewage treatment plants and ultimately surface water features is also a major concern in a large part of the world, especially in areas already suffering from water shortage. Building systems that mitigate dissolved solids not only enable optimal re-use of non-potable water assets, but also reduce the building's impact on the local hydrologic ecology.

TABLE 5 Potable water consumption for three alternative non-potable water harvesting strategies.

Total Building Non-Potable Flows		Non-Potable Flows by Option		
		Option 1	Option 2	Option 3
Total Harvested Storm Water	1,538,000 L	1,538,000 L	1,538,000 L	1,538,000 L
Total Harvested HVAC Condensate	759,539 L	759,539 L	759,539 L	759,539 L
Total Harvested Low TDS Non-Potable Water	2,297,539 L	2,297,539 L	2,297,539 L	2,297,539 L
Total Sewage Flow (80% of Misc. + Flushing)	14,378,635 L	14,378,635 L	14,378,635 L	14,378,635 L
Total Harvestable TSE (80% Recovery)	11,502,908 L	11,502,908 L	11,502,908 L	11,502,908 L
Total RO Product from Harvested TSE	9,202,326 L	–	7,978,309 L	0 L
End-Use Total Annual Requirements		Potable Requirement for End-Uses		
Total Flushing Water	8,305,038 L	–	5,013,028 L	1,955,214 L
Total Cooling Tower Makeup	10,474,398 L	8,176,858 L	198,549 L	49,712 L
Misc. Potable Water	12,421,362 L	12,421,362 L	12,421,362 L	12,421,362 L
Total Building Water Requirement	31,200,798 L	20,598,220 L	17,632,940 L	14,426,288 L
Total Effluent Flow (Sewer or Pond)	20,337,007 L	6,595,230 L	3,629,949 L	234,702 L

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