Water Utilization and Conservation Practices

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Abstract: Water is an increasingly scarce commodity which contributes to the growing pressure of a globalized economy. Over the past 10 years with reduction in surface water resources and a continuing growing population, it is necessary to secure water supplies and ensure long term sustainable management of water resources. The total water requirement of India for various activities around the year 2050 has been estimated to be 1450km^3/annum. This review paper explores explanations on the various water application in different sectors and measures to conserve water so as to reduce the quantity of wastewater discharged. Various treatment options have also been discussed. Water balance chart, water audit and industrial ecology are few concepts which helps in identifying sources and sinks of water in an industry. Opportunities for water recycling in high tech industries appeared to be technically feasible and efforts need to be taken to invest on water use efficiency and treatment techniques and investigation on various reuse purposes
Keywords: Sustainable management, Water balance chart, Water audit, Industrial ecology

I. INTRODUCTION

Water is a vital compound, which assists in all the metabolic activities within a living organisms and also acts a medium for transport of nutrients and completing the biogeochemical cycle in earth. It is used for various anthropogenic activities such as unindustrialized (Agricultural, municipal etc.), industrial (all process based industries) and it is also utilized naturally by ecosystem in its own pathway. In present scenario, the greatest challenges faced in any country globally is Water availability, accessibility and its subsistence. Naturally, the available fresh water which is accessible and used is not evenly distributed because of the climatic conditions. Hence, water scarcity is inevitable in many regions due less availability and population [12]. Another important criteria to be considered in the current situation of water consumption are standard of living. The rise in living standards increases the water consumption directly or indirectly. The process of consumption water can be explored and understood by knowing the footprints of water for a particular product. These products can be a finished products from agriculture or industrial processes. Never decreasing water demand due to various factors (population, standard of living etc.,) and less availability of water is posing an impact over sustainable development [7]. Pollution and over exploitation of surface water resources, demands to secure water supplies and ensure long term sustainable management of water resources [13].

The present conditions of available water resources of are being examined in the context for meeting the future demands of population and ambition to become a developed nation [11]. According to the estimates, the total water requirement of India for various activities by the year 2050 will be around 1450 km^3/annum, which is more than three folds compared with the present demand of ~500 km^3/annum. The Water stress can also impact on income of major tourism destination [14]. Currently 40% of the world's population live in areas of water scarcity and an estimated 50% will be affected by 2025. GRACE (Gravity Recovery and Climate Experiment) is a NASA program in which satellites provide information about Earth's freshwater resources from outer space. These satellites also track changes in the Earth's gravitational field which are indicative of water movement - both above and below the surface. Global water use has grown twice the rate of population growth over last 100 years.

Global water scarcity is expected to increase due to the growing population, economic development, water intensive energy production, dietary changes and climate change. Generally, water availability of more than 1700m^3/person/year is considered acceptable, while below this level it is considered as water scarce region. In areas with less than 1000m^3/person/year, the lack of water limits human activities and business operations, while less than 500m^3/person/year is viewed as a main constraint to human life [12]. Per capita water availability v/s population growth is shown in Figure 1.

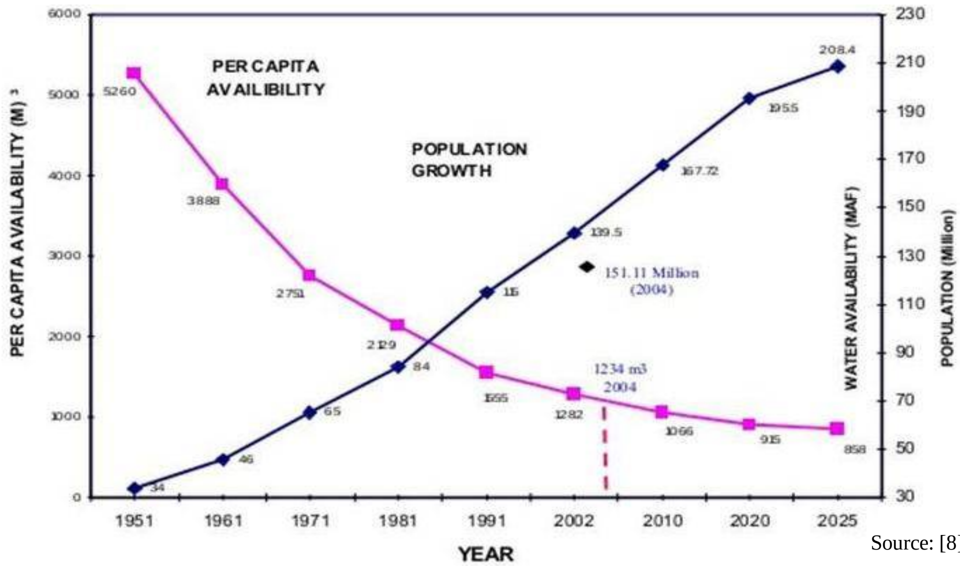

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Figure 1: Per capita water availability v/s population growth

According to UNESCO (2009), recent trends show that world's population is growing by about 80 million people per year, which is directly proportional to increase in freshwater demand of about 60 million cum a year. Also by 2030 the number of urban dwellers is expected to be about 1.8 million more than in 2005 and to constitute about 60% of world's population making the improvement of urban water infrastructure a particularly critical issue [13]. Water use can be differentiated as blue (water withdrawn), green (soil moisture) and grey water (polluted water that returns into the water systems) [7].

Industries need to manage water depending on process requirements, the type of impacts and the condition of watershed in which they operate [12]. Watershed is the area of land (catchment area) that captures rain and snow and then stores, filters, seeps or drains this water into a common water body. Its area and the volume of water that drains from it relates directly to the size and flow of the primary stream or water body. Important volumes of water can be reused if investments are done in wastewater treatment plant to give opportunity for recycling wastewater [7]. In the year 2013, a survey of 500 companies reported that more than 90% have water management plans in place and 63% have set water reduction targets for their direct operations. Increasingly, companies realize that their water practices may have impacts that reach into local communities and surrounding ecosystems. Water availability and water risk assessments are difficult endeavors due to the level of local data required to make detailed evaluations of a company's water related challenges. Many water indices such as Falkenmark Index and water stress index are available. These focus maximum on fixed human water requirements and water availability, renewable water supply and annual demand for water, environmental water requirements, life cycle assessment and/or water foot printing [12].

Water footprint concept was developed and designed to estimate total water use in business operation. Water footprint assessment applied to business or organization can be defined as total volume of freshwater that is used directly or indirectly to run and support a business to produce product and serves and is expressed in terms of volume of freshwater use per year. It can facilitate business and other water use and needs for improved water management. Water footprint assessment applied to business or organization can be defined as total volume of freshwater that is used directly or indirectly to run and support a business to produce product and services and is expressed in terms of volume of freshwater use per year. Internal water footprint can be defined as volume of water use from domestic water resources to produce goods and services for inhabitants of the region. It is the difference of the total water volume used from domestic water resources in national economy and the volume of virtual water export to other countries. External water footprint is the volume of water used in other regions to produce goods and services imported and consumed by the inhabitants of that region. By adding together the blue, green and grey water component total water footprint is obtained [7]. Also various global water assessment tools such as Global Water Tool (GWT), India Water Tool (IWT), Aqueduct Water Risk Atlas Tool (Aqueduct), Water Risk Filter (WRF) etc have been developed to help understand the complexity of water availability. These tools can provide companies with useful and relevant information to guide their decision-making [12]. AWWA Water Loss Control Committee's free water audit software package can be used to compile a water audit and evaluate water loss. It is a water audit tool designed to quantify and track water losses associated with water distribution systems and identify areas for improved efficiency and cost recovery. It provides a top-down summary water audit format.

In India, around 2100 textile units, (Small scale industries) (SSI) are operating and the average water consumption is 200 m^3/d. These industries accentuate the water scarcity problem by their high water consumption and wide variety of pollutants discharge. It is argued that due to considerations of gestation period and capital requirement, wastewater renovation and recycling as water conservation measures must receive priority in addition to rain water harvesting, etc [11].

II. WATER UTILITY

As a "science of sustainability", industrial ecology can provide effective and efficient measures for industrial activity to reduce the environmental impact and realize coordinated development with the environment. According to industrial ecology, in a regional industrial ecosystem, an individual company needs to go beyond its own boundary and consider its own development from a larger viewpoint. In this way industries are interlinked with each other through cooperation which could resolve the problem of reducing and utilizing wastes, which would be difficult for an individual industry to resolve. In this way, resources could be more efficiently utilized and the whole industrial system could achieve coordinated development between economy and environment. Water is an important material of an industrial ecosystem which could be efficiently used through cooperation between companies. Industrial ecology suggests principles on water utilization for an industrial ecosystem which can be generalized as shown in Table 1 [10]. Water is an important resource in the industry as it functions as an essential element of processes and products, a means of heat transfer and a medium for waste transportation as shown in Table 2 [3].

It is used in production processes, process utilities and for a range of other miscellaneous purposes. Production processes utilize water either as a cleaning agent, contaminant diluter or as a part of the final product, whilst process utilities such as cooling towers and boilers utilize water for steam production and to make up water loss due to evaporation [1]. Traditionally, water has been considered an abundant, cheap resource with limited economic concerns over the volumes of water used. However, world is facing the ongoing risk of water shortages, particularly given the uncertain impacts of climate change. Globally, industry uses approximately 20% of the freshwater extracted by humans, around twice as much as is used for domestic purposes and if this water is not contained within products, it exits industrial process as wastewater [3]. Employee sanitation and general plant cleaning usually constitute water used for other miscellaneous purposes. Since water is vital to many manufacturing processes and activities, its efficient use should be a priority in order to ensure that water scarcity and increasing water tariffs will have minimal effects on production. Water supplied to an industry as per norms and average annual water consumption is shown in Table 3.

Table 1: The principles suggested by industrial ecology on water utilization for an industrial ecosystem

Unit	Raw water	Recycle water	Wastewater generation	Water losses	Wastewater discharge
Boiler	95	25	2	118	-
Process	35	25	58	2	-
Sanitary	5	-	4	1	4
Washing	-	20	20	-	-
Ash Quenching	-	4	-	-	-
Total (m^3/d)	135	74	84	121	4
Water in			Water out		
Raw water + recycle water			Wastewater generation + water losses + wastewater discharge		
135+74			84+121+4		
209 m^3/d			209 m^3/d		

Table 2: Water balance for unit operations

Industrial Sector	Annual water consumption in million m^3	Rate of water supply in m^3 as per norms per ton production
Pulp and Paper	905.8	250
Textile	829.8	200
Steel	516.6	20
Sugar	194.9	2
Fertilizer	73.5	15

Table 3: Water supply and utilization in various industrial sectors

Principles	Meaning
Water cascading	The step-wise use of water according to different water quality requirements of different water demands between companies
Wastewater utilized as production material	Treated or untreated wastewater is used as raw materials for making products
Wastewater reuse	Wastewater is used again after being treated
Water substitution	"Scarce" water should be substituted with "plentiful" water of a special region. In this way, the quantity of scarce water could be saved and serviceable time could be extended
Wastewater treatment facility sharing	Several neighboring companies jointly construct a wastewater treatment facility and utilize it, through which costs of wastewater treatment facilities constructed by individual companies can be saved

A water audit is carried out to measure the quantity and quality of water inputs and outputs within a defined boundary, consisting of a single process or set of processes assumed to be operating at a steady-state. One of the most useful outcome of water audit is the creation of water flow diagram-an easy to understand representation of usually complex process systems [1]. It includes design in both production and secondary use levels. The purpose of water network design is to maximize water generation and reuse water into the industrial processes. To be effective, water resource management should not only look into theoretical optimization values, but also to investigate practical, behavior and strategically issues for holistic approaches. To better understand water flows within the water system boundary, a water auditing technique using water balance chart needs to be implemented. The charts are survey-based flow diagrams for identification of process flow, water and wastewater streams and possible water recycling routes within a defined boundary. The use of water flow balance charts may suggest abnormal water usage which cannot be identified during normal operations and then be used to identify water saving opportunity within processes [9].
The initial step of any water audit is to investigate the known overall water inputs and outputs of the system under examination. It shows where water enters and leaves the process, and where it is used within the process. Generally an auditor will determine prior to an audit what level of discrepancy between inputs and outputs they are willing to accept. This tolerance is referred to as closure and is calculated from Equation 1:

$$Closure: ((\sum Water\ input - \sum Water\ output)/(\sum Water\ input)) < Predetermined\ tolerance \quad (1)$$

Often closure cannot be obtained, generally indicating that significant water losses are occurring throughout the system. The method of water auditing then allows for investigation of where these losses are occurring throughout the system through analyzing water volumes utilized by individual process units. However, it is important to note that even where closure is obtained, this only indicates the relationship between inputs and outputs of the entire system; it does not immediately indicate the relationship between inputs and outputs of the entire system; it does not immediately indicate that the process is using water optimally [2].
The water balance chart can be divided into three major water usages within the system as shown in Figure 2, including water consumption for domestic uses (WD), secondary uses (WS) and process

uses (WP) which add up to total tap water consumption. Water use at domestic level usually refers to water usage related to human activities such as food processing and cleaning (e.g. wash hands and flush toilets). Secondary water usages in a plant normally are employed for cooling tower and air scrubber operations. Besides, the chart also includes most of the common water recycling approaches, namely recycling of reject or effluent and cascade rinse water. The data from water flow balance sheet can be used for different statistical analysis (i.e. descriptive and multivariate statistical analysis) for further water recycling strategy evaluations [10]. Apart from industrial use, commercial water use is also a significant component of overall urban water demand. Water audits of commercial office buildings have revealed that non-potable applications, in particular for toilet flushing and cooling tower blowdown, accounts for between 50% and 90% of total building demand. The influence of office buildings on the urban form of cities means there is need to incorporate this sector in seeking more sustainable development [5].

I. WATER CONSERVATION STRATEGIES

As water supply increases and treatment costs increase, there will be increasing pressure on the chemical or process industries to reduce water consumption. There are many types of technologies/ methodologies available to save freshwater and reduce wastewater generation [6].

Commitment to reliable environmental management practices and implementing cleaner production strategies will lead to minimal use of chemicals, water and energy. Cleaner production can lead to pollution prevention and cleaner technologies. It can be defined as “decreasing risks on human and environment by continuous application of integrated and preventive environment strategy on products and processes and can be achieved through good housekeeping process and/or equipment modification, input material substitution, on/off site recycling and reuse, changes in products/services/processes and/or technologies [7]. Membrane processes have been the technology of choice to provide recyclable water through treatment of lower quality resources. The application of ultrafiltration (UF) and reverse osmosis (RO) units produces treated effluent with quality meeting the requirements for recycle as boiler feed water make-up [11]. They have been shown to be applicable to a wide variety of wastewaters generated by industries such as food, beverage, car manufacturing, metal plating, tannery, carpet manufacturing, textile and glass manufacturing. Since industrial wastewater characteristics are quite diverse, the use of membrane filtration processes for water reclamation is preferred over conventional water treatment technologies since they can deliver more consistent permeate water qualities despite the variations in the quality of feed water. They are also more energy efficient and have smaller footprints compared to conventional water treatment technologies [1]. Disposal of RO rejects can be carried out in an environmentally acceptable manner through careful planning. Evaporation systems for disposal rejects can also be used. Evaporation can be carried out by adding heat to liquid, the latent heat supplied being the latent heat of vaporization. Low pressure steam can be used as heating medium [11].

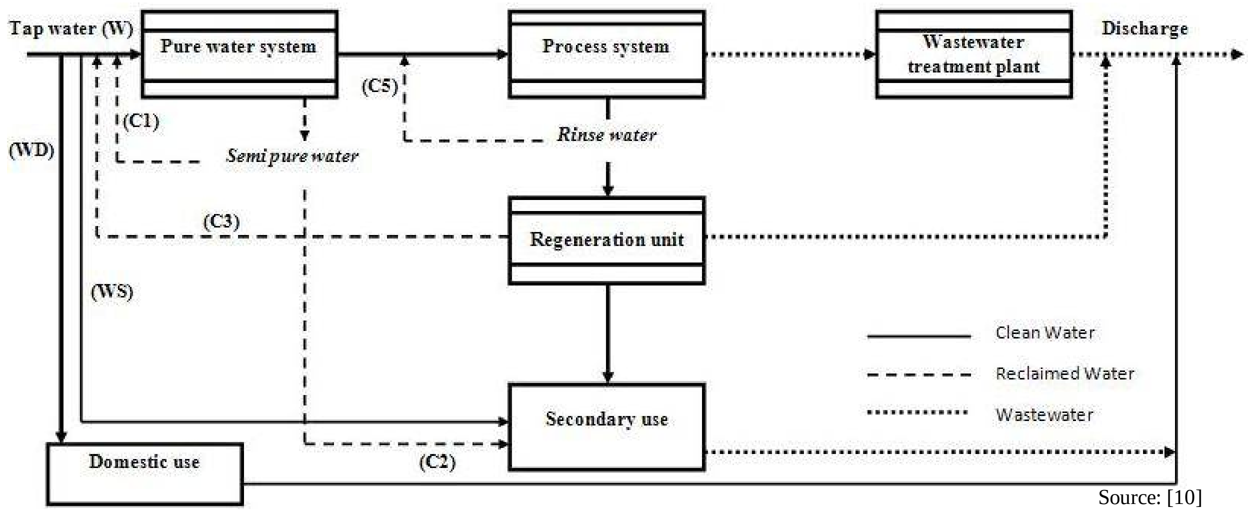
High-tech industries, which generally refer to those producing microelectronics, communication and display devices, green energy related appliances (e.g. solar panels) and biotechnology products, typically involve rinsing and cleaning procedures in the production lines that use extensive amount of ultra-pure water to avoid contamination caused deficits in their products. Aside from water usage in production lines, water use in their secondary system (i.e. cooling tower and air scrubber) for environmental control is also high, as the environment in cleanrooms is required to be maintained at high standards (i.e., moderate temperature and low airborne molecular contamination). The water being used in the secondary system may not need to meet the ultra-pure water criteria, however, low concentrations in TOC as well as conductivity are expected to avoid fouling and corrosion problems under normal operations.

Cooling water contributes to one of the largest industrial demand for water and as such it is the predominant industrial water reuse point either for cooling towers or cooling ponds. Moreover, parts of the effluent can possibly be diverted back to domestic water system for indirect potable reuse as toilet flushing and garden irrigation. Reuse of reclaimed water for non-potable purpose may be the most environmental beneficial option as the water does not need to meet the quality requirements for potable water and the treatment for water reclamation are usually less energy and resource intensive [9].

In Australia, agencies have encouraged the adoption of stubble farming systems to achieve both private on-farm and public off-farm benefits. Benefits of stubble farming systems include reduction in sediment load and suspended particles (turbidity) through reduction in hillslope erosion and retention of water in the landscape. Vegetation is critical for maintaining the local water cycle through suppression of surfaces temperatures, in turn preventing drying, run-off and ultimately increased erosion. In general, water quality and quantity is expected to reflect land use management but the relationship is confounded by natural variation at larger scale [4]. Commercial buildings contribute significantly to the ecological footprint of urban areas. So there is the need to consider opportunities for improved sustainability in this setting through more efficient use of water, energy and materials. Groundwater controls are often needed both during the construction of high rise buildings and during their operating life to manage the impact of groundwater inflows on the stability of soils [5].

For various domestic purposes drinking water quality is not required for several of inside areas including laundry, toilet and outdoor areas. Water conservation strategies such as recovery and reuse of rain water and grey water for non-drinking purposes at household levels have gained prominence in recent years. Alternative water supplies such as grey water and rainwater can be used. Rain water and grey water samples should be collected for typical physical, chemical and biological water quality parameters like *Escherichia coli*, total coliform and other parameters like pH, EC, TDS, turbidity, DO, TN, TP, BOD and COD. Water consumption can be reduced by supplementing rain water to areas such as toilet, laundry and kitchen and installing water saving devices and appliances and especially drought tolerant garden design. Slight increase in total coliform MPN indicates the presence of blue green algae and nonpathogenic organisms. Greywater can be recycled by simply diverting washing machine wastewater with a hose or diversion system or constructing greywater recycling system. Greywater can be used for garden watering mostly as surface irrigation [13].

Three indices are developed for evaluation of water use performance for a plant, namely, process recovery rate (PR), total plant recovery rate (TR) and total plant discharge rate (TD). The recovery rates are defined as total reclaimed water over total water demand (i.e. available for using) and higher recovery rate represents improved water use efficiency. On the other hand, the discharge rate is defined as total discharged water over total water demand and it is expected to have the rate as lower as possible so that less contaminated water will be discharged to the environment. In countries where water supply and discharge is charged, increase in water recovery rates not only reduces the cost for water supply but also lowers the discharge fee.



Source: [10]

Figure 2: Simplified water flow chart for water-use performance

The water use performances of PR, TR and TD are expressed as the following formulas based on the streams illustrated in the simplified water flow chart in Figure 2:

$$Process\ recovery\ rate\ (PR) = \frac{C_1+C_2+C_3+C_4+C_5}{WP} \quad (2)$$

$$Total\ plant\ recovery\ rate\ (PR) = \frac{C_1+C_2+C_3+C_4+C_5}{W+C_1+C_2+C_3+C_4+C_5} \quad (3)$$

$$Total\ plant\ discharge\ rate\ (TD) = \frac{D}{W} \quad (4)$$

In the equations C_1, C_2, C_3, C_4 and C_5 stand for reject or effluent recycle back to pure water production system, reject or effluent recycle for secondary water use, rinse water from process system recycle back to pure water production system after the regeneration unit, rinse water send to secondary water use after the regeneration unit and rinse water direct reuse in process system respectively. W signifies total tap water consumption, whereas WP only represents the water consumption for processes and D is the summation of total discharge. In order to identify most successful water use efficiency plants equation 5 is assigned. The most water use efficient plant has 3 points whereas the least one has 0 points.

$$Water\ use\ performance\ score = \sum R_{i,}\ i = PR, TR, TD \quad (5)$$

Process recovery rate (PR) and total plant recovery rate (TR) increase as daily water demand increases. This suggests that plants with higher water demand may have more opportunities for water recovery within its system boundary. Cooling water contributes to one of the largest industrial demand for water and as such it is the predominant industrial water reuse point either for cooling towers or cooling ponds. Moreover, parts of the effluent can possibly be diverted back to domestic water system for indirect potable reuse as toilet flushing and garden irrigation. Reuse of reclaimed water for non-potable purpose may be the most environmental beneficial option as the water does not need to meet the quality requirements for potable water and the treatment for water reclamation are usually less energy and resource intensive [9].

When dealing with multiple-contaminant problems, the design methodology for single contaminant cannot be used anymore. In multiple contaminant system, the key contaminant of each unit is different which is related to the water source to the unit. Due to the complexity, the design for water networks with single contaminant based on internal mains cannot be extended to that of multiple-contaminant systems. The road map is to identify the limitations of the single contaminant approach to multiple contaminant systems. The next step is to investigate whether feasibility of reusing water leaving one water using operation within another operation with respect to secondary contaminant is possible or not. Consider a set of *i* water-using processes involving a set of *J* contaminants. The problem formulation starts by defining for each process the limiting water flow rate f_i, the inlet concentration limits C_{in} and outlet concentration limits C_{out}

$$C_{i,in} = \{C_{i1,IN}, C_{i2,IN}, C_{i3,IN} \ldots\ldots\ldots\ldots C_{iJ,IN}\} \quad (6)$$

$$C_{i,out} = \{C_{i1,out}, C_{i2,out}, C_{i3,out} \ldots\ldots\ldots\ldots C_{iJ,out}\} \quad (7)$$

Where $C_{iJ,IN}$ and $C_{iJ,out}$ are the inlet and outlet concentration limits of process *i* with respect to contaminant J. For two contaminants A, B the water supply line gives the proportional mass transfer relationship as:

$$\frac{C_{iA,n} - C_{iB,n}}{C_{iA,out} - C_{iB,in}} = \frac{C_{iB,n} - C_{iB,n}}{C_{iB,out} - C_{iB,in}} \quad (8)$$

In order to maintain the feasibility of reuse of water from one operation to another operation, sometimes it is necessary to perform *inlet concentration shift* of contaminant. The next step is to investigate the feasibility of reusing the water from the outlet of operation *i* within operation *j*. Reference concentration can be determined using equation (9) [6]:

$$\frac{C_{j,n} - C_{j,in}}{C_{j,out} - C_{j,in}} = \frac{C_{j,A,n} - C_{j,A,n}}{C_{j,A,out} - C_{j,A,in}} \quad (9)$$

ZLD is more likely to be achieved by following the water minimization hierarchy (WMH), where water use should focus on, in decreasing priority:

- Source elimination: Remove water requirements
- Source reduction: Reduce water requirements
- Reuse water: Reuse water directly without treatment
- Regenerate water: Reuse water following treatment (also known as recycling)
- Use fresh water: When the use of ‘new’ water cannot be avoided.

By considering inputs, outputs and water quality, ZLD is more likely to be achieved than by focusing on minimizing wastewater outputs alone. Wherever possible, data from the flow meters need to be analyzed and where flow meters are not available it has to estimated using proxy data (for example, rainfall from the nearby weather station) or calculated based upon known relationships (for example, evaporation from the cooling towers).In general, a small difference between inputs and outputs indicates sound knowledge of flows on site and demonstrates that when flows are not metered, estimates can still be made on the basis of proxy data and known relationships [2].

1V. CONCLUSIONS

Besides structural aspects, cleaner production has been widely regarded as a vital measure of preventing pollution at the source and achieving efficiency. End-of-pipe treatment technologies can be divided into 4 categories according to their differential pollution control effects: (1) primary physical and chemical treatment, (2) traditional biological treatment aimed at ammonia nitrogen removal. (3) Advanced biological treatment aimed at both ammonia nitrogen and total nitrogen removal and (4) tertiary deep treatment. The role of alternative local water sources in reducing demand for imported potable water and reducing the environmental impact of urban development has received considerable attention in the residential sector from both researchers and policy makers. Slurry can be dewatered on a vacuum belt filter or decanter. Decanter removes more water but requires strict pH adjustment to the iso-electrical point of the substance. By using multi stage hydro cyclones all soluble materials and fine cell residues are removed in a water saving process. Water auditing can thus contribute to sustainable water use, with the ideal outcome of zero liquid discharge (ZLD). Identifying opportunities for water use efficiency usually involves the deployment of different water management strategies such as water audit, process integration and use of advanced water treatment technologies. Water management strategies provide useful insights into possible process changes that may lead to an increase in water use efficiency and eventually water savings. Opportunities for water recycling in high tech industries appears to be technically feasible and efforts need to be taken to invest on water use efficiency and novel treatment techniques and investigation on various reuse purposes.

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