

# A Case Study on Management of Coal Seam Gas By-Product Water

Mojibul Sajjad, Mohammad G. Rasul, Md. Sharif Imam Ibne Amir

**Abstract**—The rate of natural gas dissociation from the Coal Matrix depends on depressurization of reservoir through removing of the cleat water from the coal seam. These waters are similar to brine and aged of very long years. For improving the connectivity through fracking /fracturing, high pressure liquids are pumped off inside the coal body. A significant quantity of accumulated water, a combined mixture of cleat water and fracking fluids (back flow water) is pumped out through gas well. In Queensland, Australia Coal Seam Gas (CSG) industry is in booming state and estimated of 30,000 wells would be active for CSG production forecasting life span of 30 years. Integrated water management along with water softening programs is practiced for subsequent treatment and later on discharge to nearby surface water catchment. Water treatment is an important part of the CSG industry. A case study on a CSG site and review on the test results are discussed for assessing the Standards & Practices for management of CSG by-product water and their subsequent disposal activities. This study was directed toward (i) water management and softening process in Spring Gully CSG field, (ii) Comparative analysis on experimental study and standards and (iii) Disposal of the treated water. This study also aimed for alternative usages and their impact on vegetation, living species as well as long term effects.

**Keywords**—Coal Seam Gas (CSG), Cleat Water, Hydro-Fracking, Desalination, Reverse Osmosis.

## I. INTRODUCTION

COAL Seam Gas (CSG) is mainly of methane ( $\text{CH}_4$ ) that present in coal body as a Matrix form, dissolved in brine and some of them as free state within the cleats (natural fractures) & pores of the in situ coal [1]. The amount of natural gas present in the coal depends on type of coal and other factors. For unminable deep seated coal reserves, these natural gases are extracted through drilling wells up to the coal body and collected at well-head low pressure. The CSG extraction operation is very expensive and only very few amount of coal energy can be exploited ( $\approx 2\%$ ), but the gas is one of the most pure form of energy source with minimum Green House Gas emitter. The CSG operations are named as Coal Bed Methane (CBM) in other area of the world and are extensively underoperation in North America. The CSG well development and operational technologies are running in Australia following the Federal and State regulations which are compliance to global standard & practices. Huge amount of water are pumping off from the coal body. These waters are treated in the process plant and later on discharge to the surface water stream, used for alternative purposes depends on

situation. This water management became a challenge for the CSG industry especially the brine disposal issues. Continual technological development and efforts are adopted for improving the CSG water treatment and their subsequent usages. In this review paper a comprehensive case study was conducted through CSG site visit, collection of CSG water related data and monitoring of their practices. In the following sections an overview on CSG operation and water management issues are discussed.

## II. OVERVIEW ON COAL SEAM GAS

The development of the CSG industry is a prospecting energy source to Australia along with global perspectives through exporting liquefied natural gas (LNG). Huge range of proven CSG reserves (especially coals are not exploitable with conventional mining) in Australia and estimated around 33 TCF [2]. The coal basins of the Surat, Bowen and Galilee basins in Queensland and the Gunnedah, Gloucester and Sydney basins in New South Wales are the major CSG reservoirs. Massive activities are running in Australia for extracting Coal Seam Gas (CSG) at low well head pressure, accumulating with gathering pipelines to the step up compressor station, then transport to the Liquefied Natural Gas (LNG) plant for shipment. Huge amount of capital investment is required for drilling and production well development, upstream and downstream infrastructure facilities, operational facilities like as gathering pipe line network, gas clean up and separator, pressure step up compressor station, high pressure pipeline to the LNG plant at the port. In addition the produced water management and subsequent desalination by product handling became a vital concern for the entrepreneurs as well as national level.

The gas concentration within the coal body depends on various factors particularly geology of the coal formation. In Queensland the discovered reserves and geological survey report shows that the coal deposits of Bowen Basin, Surat Basin, Galilee Basin having potential prospect for CSG operation [3]. The ability of the gas to move through the coal formations depends on the type, number, size, orientation and connectivity of these voids and particularly, on the dimensions of the connections between the voids. Most of the gas in coal usually occurs adsorbed to the walls of the smaller voids. The gas extraction depends on mainly of permeability of the coal body. The permeability of Australian coals typically ranges from 1 to 10 milli Darcys (somewhere in USA, it is 35 milli Darcys) [4]. For extraction of in-situ CSG gases the following activity executed for gas exploitation as: (i) Production well drilling & commissioning, (ii) Stimulating activity like

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Hydraulic Fracking of coal seam for creating openings of fissures & fractures for connecting the gas deposit area to the production well. In addition placement of fracking agent (mainly sand) within the coal body (provisional), (iii) Inter linking the production well gas inlet port by means of horizontal bore hole loop and controlled blasting (provisional) and (iv) Depressurization of reservoir by pumping off cleat water of the coal body.

### III. GAS EXTRACTION AND BY-PRODUCT WATER

The gas production rate of a CSG field had attained in a stable state while major portion of the waters are extracted from the coal body. It is assumed that the declining phase of gas flow refers to minimization of water incoming rate; due to closing of openings of the coal body [5], [6]. The rate of produced water extraction varies with geological formation and hydrogeological characteristics of the coal seam. The water quantity decreases exponentially over time. The optimal gas production rate continues while the rate of produced water declines and pumping may discontinue within 10-20 years of initial pumping. In deeper coal seams, higher volume of water must be extracted for de-pressurization.

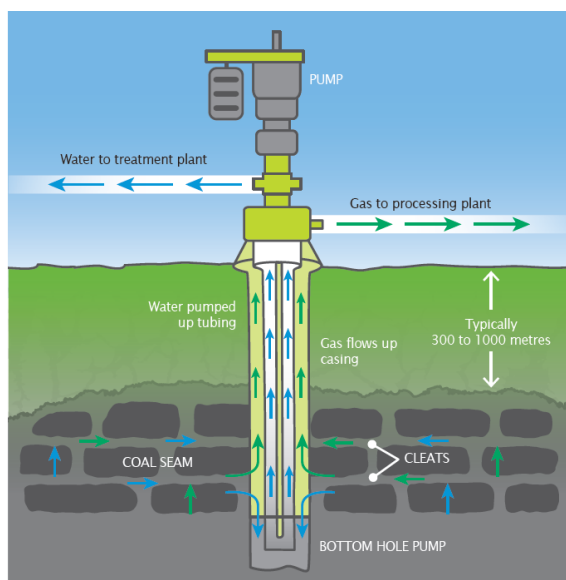


Fig. 1 Coal Seam Gas extraction process [7]

It is assumed that the weakly joined coal seams may have sufficient fissure/fractures which would facilitate inter connectivity between the wells and cleats. More over the nature of the coal (wet/dry) also an influencing factor depending on the location, deposits and the extended aquifer. The total water production from a well depends on the intensity of CSG wells in the CSG block. In Queensland the average water extraction rate from a CSG well is initially 0.2~0.8 ML/day and decreases over time. Further drilling and hydro fracking stimulation activities are executed on the basis of the economic return and geological prospecting. The work-over activity of the CSG well is carried out based on the well-

head production rate. This is a decision making phase for further extension or permanent sealing of the well.

### IV. COAL SEAM GAS WATER AND THEIR COMPOSITION

The water produced in CSG wells included natural minerals such as salts, metals, dissolved or dispersed oil compounds, dissolved gases and naturally occurring radioactive materials or additional chemicals used in well construction and maintenance or added to hydraulic fracturing liquids [8]. Mainly 2 (Two) types of water are generated in CSG wells are as:

- **Flow-Back Water:** The Flow-back water contains generally the associated water used for hydraulic fracturing and other processes involved in drilling, washing & cleaning of production wells.
- **Produced Water:** The produced water is the continual by-product came out along with gases. Produced water influenced with the properties like the saline aquatic depositional environment of geological formation and typically rich in cations such as  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Ba}^{2+}$ ,  $\text{Sr}^{2+}$  and  $\text{Fe}^{2+}$  and anions such as  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$ . From these marine origins, the chemistry of the water in the coal is modified by geological influences. The Produced water consists of generally as: (i) Formation Water: accumulated in the coal with oil and gas deposits. Sometimes these are treated as Cleat Water, having brackish properties and (ii) Seepage Water: is the flux of other groundwater sources into and out of the coal formation which depends on the geological formation, fracture, and faults exist within the surrounding capping rocks.

The composition of produced water varies according to the depositional environment of the coal, thermal maturity of the coal, and the flux of fresh water into the coal formation from surrounding formations. The depositional environment has either saltwater or fresh/brackish characteristics or changing major and trace element characteristics, which is presented in Fig. 2 [9]. These parameters also determine whether the methane generation pathway is dominated by thermogenic or biotic (sulfate-reducing) processes. The chemistry of the broader geology also affects the formation water.

### V. BY-PRODUCT WATER SOFTENING

Dewatering of coal seam releases the stress state and allows dissociation of the coal matrix. Gas production and life expectancy of a CSG block is a function of dewatering rate over several years. In Queensland, the average dewatering of a well is around 20,000 liters of water/day [10]. Extensive study conducted for CSG water treatment and subsequent management conducted throughout the world [11]-[14]. Water of suitable quality can be used for town water, aquaculture, recharging aquifers, wetlands, recreational lakes or at mining operations and power stations, and recent practice has been for poor quality water to be contained in storage ponds [12]. Queensland Government amended the Environmental Protection Act 1994 to limit construction of evaporation

ponds. Guidelines are set up for CSG water quality monitoring [15] and handling, inter-governmental initiatives are taken in Australia [16]. There are two main processes to treat CSG water as: (i) Desalination, (ii) Amendment through altering the balance of the water.

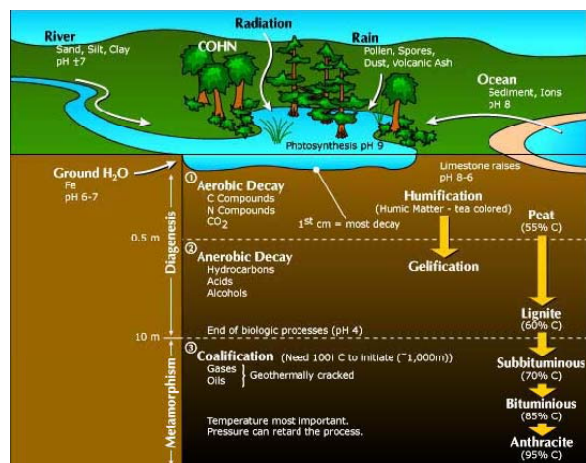


Fig. 2 The burial process and coal formation [9]

## VI. DESALINATION AND GENERATED SOLIDS IN CSG OPERATION

The water pumped out from the CGS wells is very salty and contains a range of naturally chemicals. It may also include heavy metals and radionuclides. The National Water Commission predicted that the CSG industry as a whole will extract more than 300 Giga liters of water each year with 31 million tonnes of waste salt over the next 30 years. Waste salt is referred to 'salt', 'saline effluent' and 'brine' from the source of Sodium Chloride (NaCl), Sodium Carbonate or Soda Ash ( $\text{Na}_2\text{CO}_3$ ) and Sodium Bi-Carbonate ( $\text{NaHCO}_3$ ).

## VII. HYDRO-FRACKING CHEMICAL AGENTS

Hydraulic fracking involves injection of sand/water slurry at high pressure into the coal seam to fracture the surrounding rock/coal seams for holding the fractures open, thus releasing of gas. A fracking agent added to water is BTEX (a combination of Benzene, Toluene, Ethyl Benzene and Xylene), which is harmful to living species and environmental pollutant. Other chemicals, however, may be used, such as sodium hypochlorite and hydrochloric acid, cellulose, acetic acid and disinfectants [17].

## VIII. MANAGEMENT OF PRODUCED WATER AND THEIR TREATMENT

Different water management strategies are practiced for treatment and subsequent usages of CSG produced water such as:

- (i) Re-injection of the produced water back into the suitable formation, typically below a relatively impermeable barrier at depth.

- (ii) Reusing for hydraulic fracturing operations or other industrial use.
- (iii) For livestock watering, crop irrigation or some other agricultural purpose.
- (iv) Discharge to the natural surface flow streams. The CSG produced water treatment depends on well sites and their purposes of use.

The treatment consider the issues like as; oil particles, suspended solids as well as the dissolved hydrocarbons, solids, alkalinity, disinfection and degasification issues. Following procedures and management strategies are general practices in the CSG industry as:

- (i) **Removing of Hydrocarbons:** Oil particles larger droplets sizes of  $40+ \mu\text{m}$  diameter are removed by skimming, gravity separators and corrugated plates. Droplets with a diameter of  $3\sim 25+ \mu\text{m}$  can be removed by filters, meshes, hydro cyclones and gas/air flotation. Finer droplets ( $0.01\sim 2 \mu\text{m}$  in diameter) can be removed by membrane filters and centrifuges.
- (ii) **Suspended Solids:** The suspended solids are removed by filtration or centrifuge mechanism. Micro and ultra-filtration are effective at removing suspended matter, including inorganics and hydrocarbon droplets. Nano-filtration is also an effective filtration method.
- (iii) **Dissolved Hydrocarbons:** Soluble organics/Analyte is removed from produced water by "sorption" methods. Membrane bioreactors are also used for complex mixture and situation.
- (iv) **Dissolved Solids:** Evaporation, distillation and membrane filtration techniques are adopted for removing dissolved solids. Ion exchange method like Reverse Osmosis (RO) is a proven methods and practicing for low concentration of total dissolved solids (TDS) of up to  $20,000 \text{ mg/L}$ . Ion exchange resins can be regenerated readily which is treated as cost effective. For higher concentrations, from  $40,000$  to  $100,000 \text{ mg/L}$ , thermal distillation and evaporation are effective. Electro-dialysis reversal method is also a proven technique for removing of dissolved solids.
- (v) **Alkalinity:** Produced waters are typically alkaline and various techniques are practiced like neutralization with addition of acids.
- (vi) **Disinfection:** Bacteria and algae within the produced water are removed with chemicals like as Ozone and Hydrogen peroxide for degrading organic matter. UV radiation is also effectively used for the same purposes.
- (vii) **Degasification:** Gases are removed from produced water by pressure reduction, ultrafiltration and heating.

## IX. THE REGULATORY FRAMEWORK IN AUSTRALIA

Water disposal is one of the most important considerations in the CSG industry. It is very costly to build water-handling facilities, drill disposal wells, and comply with numerous environmental regulations. Similar issues exist in coal mining and business for handling and disposal of the coal slurry. The components of coal slurry like carcinogenic compounds and heavy metals (like as Mercury, Arsenic, Lead, and Nickel) are

permanently stored in toxic waste facilities because they are hardly transformed into a biodegradable natural form. Similar issues are also arisen for disposal of brine generated by reverse osmosis, nano-filtration and ion exchange remains a key area of concern due to its high concentration of salts and other chemicals. The environmental protection standards are set through ANZECC aquatic ecosystem guidelines. The existing regulation of CSG mining in Queensland and New South Wales is extensive. In Queensland relevant acts are mainly: (i) The Environmental Protection Act 1994 (Qld), (ii) The Petroleum Act 1923 (Qld), (iii) The Petroleum and Gas (Production and Safety) Act 2004 (Qld), (iv) The Water Act 2000 (Qld) and (v) The Water Supply (Safety and Reliability) Act 2008 (Qld). In New South Wales the relevant legislation is: (i) The Petroleum (Onshore) Act 1991 (NSW), (ii) Environmental Planning and Assessment Act 1979 (NSW) and (iii) The Water Management Act (2000) (Qld). In addition, the Commonwealth provides some regulatory protection under The Environmental Protection and Biodiversity Conservation

Act 1999 (Cth) (EPBC). The water quality benchmarks and the monitoring guidelines are updated jointly by the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) and Australia and New Zealand Environment and Conservation Council (ANZECC) [15].

Generally a complete chemical analysis of a representative water sample is needed for further water management decision. There are three common techniques used for disposing of produced water in the CSG industry as: (i) *Subsurface Injection*: requires that a well be drilled or an existing well be worked over to accept produced fluids into an approved disposal zone. (ii) *Surface Evaporation*: uses active evaporation ponds and a spray/mist system to evaporate the produced water, (ii) *Stream Discharge*: requires an elaborate treating and monitoring system to ensure that chlorides, total dissolved solids, and other impurities are lowered to acceptable levels.

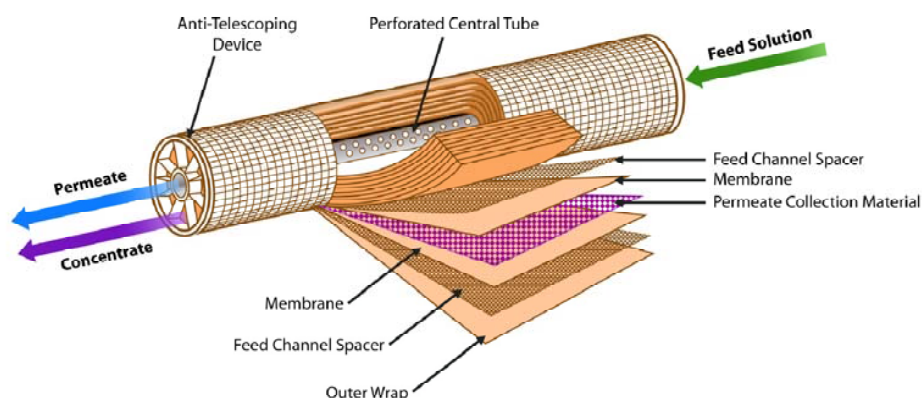


Fig. 3 A single R/O Element [20]

TABLE I  
TYPICAL TREATED AND UNTREATED CSG WATER QUALITY

Sl. No.	Analyte Description	Units	Untreated CSG	RO Permeate	Drinking Water Guidelines	Livestock Guidelines	Irrigation Guidelines
01	Conductivity (EC)	$\mu\text{S}/\text{cm}$	12,120	122	<746	2,985 ~7,462	<950#
02	TDS*	mg/L	8,120	82	< 500	2,000 ~ 5,000	< 12,000^
03	pH	-	9.2	9	6.5 ~ 8.5	6.5 ~ 8.5	< 636#
04	Chloride	mg/L	3850	32	< 250	-	< 8040^
05	Nitrate N (Calc)	mg/L	< 0.01	< 0.01	< 50	-	< 175#
06	Fluoride by ISE	mg/L	5.85	0.33	< 1.5	-	> 700^
07	Selenium as Se	mg/L	< 0.01	< 0.01	< 0.01	-	-
08	Sodium as Na	mg/L	3,000	39.5	< 180	-	-
09	Total Hardness as $\text{CaCO}_3$	mg/L	36	< 7	60–200	60–200	60–200
10	Iron , Fe	mg/L	0.225	< 0.005	< 0.30	-	< 0.2
11	Boron , B	mg/L	3.3	0.53	< 4	-	< 0.5
12	Barium ,Ba	mg/L	2.2	0.006	< 0.7	-	-
13	Manganese ,Mn	mg/L	0.037	< 0.001	< 0.10	-	< 0.2
14	Aluminum as Al	mg/L	0.495	< 0.01	< 0.20	-	-

Where only EC or only TDS is given, the other parameter is determined through relationship  $[\text{EC} \times 0.67 = \text{TDS in mg/L}]$ , # Threshold for most sensitive crops, ^ Threshold for most tolerant crops.

## X. CASE STUDY AND FINDINGS

The Spring Gully CSG sites are operating by Origin Energy, Asia-Pacific LNG, and Australia. A comprehensive field tour and data collection was conducted for engineering analysis and assessing the water management activities. The site is 80 km north to Roma, Queensland. The first well flow tested in 1998 and commercial production commenced in 2005 and around 110 operational wells were in operation and extension program targeted for 160 CSG wells. The CSG production rates vary significantly from well to well and ranging up to around 3TJ/day and the average rate is about 1.2TJ/day. The average water production for a well is initially 95.4kL and tapers down to 63.6kL after about 200 days and continues. Around 6 Mega Liter of CSG water came out from the field in that time. Their water management practice involves the treatment of CSG water with Reverse Osmosis, capacity of 9 (nine) Mega Liter. The treated water is released into a creek nearby [18]. CSG water quality varies by region but is typically brackish in quality (100-10,000 mg/L of TDS), sodic, and high in bi-carbonate, making it unsuitable for many uses without treatment. For comparison, it is mentioned here that the Brisbane (capital of Queensland) tap water is typically 240 mg/L and seawater, 35,000 mg/L. Quality standards for drinking water in Australia are set out by the Australian Drinking Water Guidelines [19]. The provision of treatment water bottling should be assessed extensive study and observation [20]. Quality standards for other applications of water such as irrigation and livestock are outlined in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality [21].

This study looked into alternative management options of CSG Water specifically potable, mining, and irrigation or farming application. There were 5 evaporation ponds and the treated and untreated water sampling collected for testing procedure as: (i) Conductivity testing of untreated CSG water (Pond 1 and Pond 2), (ii) Conductivity testing of treated CSG water and (iii) pH testing of treated CSG water. Their water treatment process consists of (i) Filtration for removing suspending particles (ii) Reverse Osmosis for desalination purposes. The treated water used for multipurpose economic usages and remaining is dispose to nearby Eurombah Creek. A typical *Reverse Osmosis* schematic is presented for understanding the desalination process in Fig. 3. The findings and discussion presented in this paper are intended to serve as a reference point for any future in-depth feasibility studies into the site's CSG Water management options.

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## REFERENCES

- [1] Connell, L.D., Couple Flow and Geomechanical Process during Gas Production from Coal Seams. *International Journal of Coal Geology*, 2009. 79: p. 18-28.
- [2] Australia, G., Coal Seam Gas fact Sheet, G. Australia, Editor. 2013: Australia.
- [3] Esterle, J. Introduction to Coal Geology for Gas Reservoir Characterization.
- [4] Jamshidi, M. and K. Jessen, Water Production in Enhanced Coalbed Methane Operations. *Journal of Petroleum Science and Engineering* 2012. 92–93: p. 56–64.
- [5] Walton, I. and J. McLennan, The Role of Natural Fractures in Shale Gas Production, in *The Role of Natural Fractures in Shale Gas Production*. Energy and Geoscience Institute, University of Utah, USA.
- [6] Connell, L., Predicting CSM Field Performance, Reservoir Simulation for Field Optimization and Production Forecasting.
- [7] What is Coal Seam Gas? 2012; Available from: [www.csiro.au](http://www.csiro.au).
- [8] Ward, C., R., Analysis and Significance of Mineral Matter in Coal Seams. *International Journal of Coal Geology* 2002. 50: p. 135- 168.
- [9] Burial Process and Coal Formation. Available from: <http://smc.uwo.edu/coal/swamp>.
- [10] Berger, K.C., Forecasting Coal Seam Gas Water Production in Queensland's Surat and Southern Bowen Basins - Summary. 2012.
- [11] Drewes, J.E., an Integrated Framework for Treatment and Management of Produced Water. 2011.
- [12] Plumlee, M.H.e.a., Coalbed Methane Produced Water Screening Tool for Treatment Technology and Beneficial use. *Journal of Unconventional Oil and Gas Resources* 2014. 5: p. 22-34.
- [13] MacLellan, G. and K. MacNeil Environmental Best Management Practices for Formation Water from Coal Bed Methane Exploration and Production Activities. 2008.
- [14] Guidelines for Water Reuse, in EPA/600/R-12/618, U.S.E.P. Agency, Editor. 2012, U.S. Agency for International Development: Washington DC.
- [15] Australian Guidelines for Water Quality Monitoring and Reporting, in *National Water Quality Management Strategy*. 2000.
- [16] Intergovernmental Agreement on a National Water Initiative, The Commonwealth of Australia and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and the Northern Territory., C.O.A.G.C. (2004), Editor. 2004: Australia.
- [17] APPEA. Fracking. 2011; <http://www.appea.com.au/industry/csg/fracking>.
- [18] Averina, A., Management of Coal Seam Gas (CSG) By-Product Water in Queensland, in *Faculty of Sciences, Engineering and Health*. 2007, Central Queensland University, Australia.
- [19] NHMRC, Australian Drinking Water Guidelines, as part of National Water Quality Management Strategy N.H.a.M.R. Council, Editor. 2004: Canberra.
- [20] Khan, S., Drinking Water Through Recycling: The benefits and Costs of Supplying Direct to the Distribution System. , in a report of a study by the Australian Academy of Technological Sciences and Engineering (ATSE). 2013: Australia.
- [21] ARMCANZ, A., Australian and New Zealand Guidelines for Fresh and Marine Water Quality, as part of National Water Quality Management Strategy, , Australia and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Editor. 2000, ANZECC & ARMCANZ: Canberra.