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It is possible to improve water use in crude-oil extraction activities through assessing the water footprint?

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Content

It is possible to improve water use in crude-oil extraction activities through assessing the water footprint?

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Abstract. Water covers about 70% of the Earth's surface. From the total of water on the planet, freshwater is estimated to be about 3%, from which two-thirds are frozen or unavailable for use. Worldwide, about 19% of the water extracted from groundwater resources is used in the production industry. The highest consumers of freshwater are industries related to hydrocarbons (Oil & Gas and crude-oil), metal, food processing, agricultural and manufacturing. The extraction of conventional crude-oil requires significant amounts of water. To better understand how much fresh water is used in this activity, indicators such as the water footprint can be applied in order to seek improvements. The water used during crude-oil operations is not necessarily (physically) present on certain parts of the extraction process, but are an important part of the whole activity either directly or indirectly. Hence, the water footprint can give interesting insights about water use in the whole operation. This indicator provides strategic information on the use and consumption of water which can motivate companies to make economically conscious decisions in benefit of hydrological systems affected by industry. The estimation of the water footprint in companies of the Oil & Gas sector seeks to provide key information for decision making regarding this resource and a to find an eco-friendlier operation. In the present study, the analysis of the water footprint indicator for oil extraction during 2018, in a certain drilling rig was carried out according to the ISO 14046:2014 norm, in order to understand better the use and consumption of water and to explore opportunities for improvement. One alternative to reduce water use during operation is the 'dewatering method', as an alternative to reduce water use as it extracts excess water from crude-oil, alternative proposed in the present work.

Keywords: water footprint; water scarcity; oil industry; drilling rig; environmental sustainability; crude-oil and water; water use and hydrocarbons.

1. Introduction

1.1. Background

Water scarcity has become an environmental challenge, it is known that there are about 2.5 to 3% freshwater resources worldwide, from that amount, almost 70% is on glaciers, 29% have difficult access and less than 1% is available by human consumption (National Congress of the Environment, 2014). Theoretically from that 1% of freshwater, 69% is used by agriculture, 12% used for the urban municipal consume and 19% used by the industry and production of energy (Fund for Communication and Environmental Education, 2018). It is projected that between 2000 and 2050, universal water abstractions from groundwater and surface water will increase by 55%, corresponding to a growing water demand from manufacturing and oil-gas generation (Gerbens-Leenes, 2017) . Hence, it is important to analyze and manage water inventories. One alternative is by improving the use of exploitation of water through the processes of production of goods or services in order to understand better the current scenario and to seek out improvements. Some indicators such as the Water Footprint (WF) have been proved to support efforts to understand better water use (National Congress of the Environment, 2014).

Most human activities, particularly those related to industry need to use water at some point, it is a key element of development. The problem with water is that, to make it completely sustainable might be difficult to achieve. The reality is that resources, for example, oil as an energy resource, have numerous alternatives of clean energy as solar or wind energy, but water has no other alternative, it is an inimitable resource (Bergesen, 2017). Worldwide, about 19% of the freshwater used in the industry is used in activities such as oil & gas extraction, metal, wood, food processing, agriculture, and manufacturing. In the Oil & Gas industry, water is crucial for the operations of companies related to hydrocarbon extraction (Hoekstra & Chapagain, 2007).

The objective of this research is to contrast the close relationship with the use and consumption of water in a drilling rig field during a year, in terms of water volume per unit of mass. The water footprint of this industry is hypothetically large but never quantified before. In general, the oil & gas industry does not contemplate its supply chain water use and limit its scope to its own operations (Caro & Vargas, 2015). The present study focuses on the oil & gas industry as being one of the areas directly related to the development and economic growth worldwide due to its importance in energy production. The principal way to change the management and application of water strategies in this sector involves competent and accountable strategies in the use of water. One interesting indicator to asses water use is the Water Footprint (WF). The WF can assess the amount of water being used to generate a product or offer a service, representing the efficiency of the consumption of water used throughout the operations of a full production process (Ferrer M, 2018).

Hydraulic fracking is used by the oil and gas industry to boost hydrocarbon production since 1947 (Dara Kospa, Lulofs, Asdak, & Rahim, 2017). An important amount of water is used in drilling rigs to elaborate a 'slickwater', which, is a type of frack fluid combination of water, chemicals, and sand injected into the drilling pipe to allow better conditions during perforation and the consequent oil extraction. The composition of slickwater contains between 98% to 99.5% of water and sand, and between 0.5% to 2% of chemical additives, which are used to stop the growth of microorganisms, prevent well casing corrosion, increase the rate at which the fluid is injected, and the most important reduce pressure , this depends on the type of slickwater to be injected according to the geological features near the area being fractured (Barati, 2014).

Besides the application of water previously mentioned, the consume of water in a drilling oil field also considers the daily consumption of water by the staff in charge to operate the drilling rig, those activities; daily shower, 3 times of brushing teeth, laundry, washing fruits and vegetables to ensures products are cleaned up to 100%, amount of drinking water, represents an important amount of water used by the staff of a drilling rig to keep doing their activities guaranteeing their health-related of water consumed (Department of Water, 2013).

The present study assesses whether the concept and application of the WF for oil extraction can support the sustainable development of the area where the drilling rig is located in relation to water use. The analysis allows a better understanding of the amount of water required to offer a year of hydrocarbon extraction services.

1.2. Objectives of the study

1.2.1. General Objective

To estimate the WF in the operation of a drilling rig located in Ecuador during 2018 and generate a water optimization proposal to reduce water use and its environmental impact.

1.2.2. Specific objectives

- Quantitatively compare the grey water footprint of the drilling field according to the current regulations due to finding points of contamination throughout the process.
- Determine freshwater sources of recharge and discharge of the system where the activities of the workers and the drilling field intervene.
- Find opportunities for improvement in water use during operating processes at the drilling rig.

1.3. Latin American oil market

For more than a century, Latin America has been an indispensable part of the worlds' oil demand. The region supplied oil to the allies during World War II and served as a constant source of fuel for the growing economies of the newly industrialized world. In the last two decades, the countries of the region have begun to allow their oil companies more operational independence and have established clearer rules for non-public investment in the oil sector (Mateo & García, 2014) so the industry must adjust to the new challenges and take advantage of all opportunities for improvement from a sustainable point of view with the environment, reducing costs and uses of water.

Oil extraction companies need to adapt to this new condition, understanding that it is not a transitory issue but a permanent feature of the market. The price of oil has fallen during the years 2007 to 2013, forcing oil companies to find new alternatives to reduce costs during the next years, the most eco-responsible way to start increasing revenue is generating sustainability strategies in order to be responsible with the use and consumption of water (Mateo & García, 2014).

2. Literature review

2.1. Water Scarcity and Study Area

The inexorable population and economic growth worldwide, has taken into an inevitable rise in demand for food, energy, goods, and services. This results in freshwater scarcity at an alarming rate around the globe (da Silva et al., 2016). Companies need to constantly create or manufacture new products and services to supply demand, which impacts in water resources as it is needed for almost all production activities at some point. Further development results in a direct increase in the demand for water to grow food, supply industries and to meet the needs of urban and rural populations, forcing an increase of freshwater shortage in many parts of the world (Hoekstra, Mekonnen, Chapagain, Mathews, & Richter, 2012). The industry faces an important environmental challenge, where, strategic water management is required for the provision of basic water services and an equitable distribution, while satisfying the needs for inclusive economic growth without threatening the integrity of aquatic ecosystems (Department of Water Affairs & Forestry, 2013).

The water scarcity is alarming governments, global organizations, industries, and communities who are becoming concerned about the future availability and sustainability of water supplies. It is important to adopt strategies for adequate water management in harmony with the environment and with people needs (Hoekstra et al., 2012). The Oil & Gas industry is installing every time more crude-oil rigs throughout the Latin-American region to exploit the resource. This increase necessarily requires more freshwater to execute the extraction of crude-oil. In particular, most of the rigs located in the Ecuadorian Amazon are facing water challenges since the amount of fresh water is limited in the area (Caro & Vargas, 2015) and because of their closeness to vulnerable ecologic areas. Annex A presents more information regarding the area of the studied rig.

The Ecuadorian Amazon receives several environmental impacts during all steps in the operation of crude-oil extraction. During the exploration phase, there is deforestation for soil and geology studies as well as road construction. In addition, the explosions done to carry out seismic tests affect biodiversity, causing disruptions in wildlife life cycles. Contamination of soil and water, as well as water use, start from the day the drilling-rig camp is installed throughout operation until close up of the site. The extraction of water is done from several sources, including nearby rivers or groundwater. Also, there is contamination from chemicals to groundwater resources if waste water is not correctly handled (Caro & Vargas, 2015). For more information about sub-basin and hydrographic concessions see Annex B.

The present study focuses on a crude-oil drilling field situated in a particular jungle-area that lacks from fresh water from pipelines in the province of Orellana of the Ecuadorian Amazon basin. The nearest population, Coca city is located at 34.8kms. The only way to supply the drilling field with water is by using water tankers from the city of Coca, provided by private companies (Bernal, 2019). Annex A details the zone where the Coca city is located. Principal characteristics of the drilling rig of study in Table 1.

Table 1. Characteristics of the drilling rig

Characteristic	**Description / Value**
Type of direction	Controlled directionality perforation
Model	Maverick T1000
Drawworks rating	2.300 hp
Load rating	4.438,212 N
Mud pump model	Cameron CMP-1600
Max. input horsepower	1.600 hp
Max. pressure	7.500 psi
Number of clúster tanks	4

2.2. Water Footprint (WF) indicator

During the last twenty years, investigators have developed metrics and indicators to help characterize, map and track the use and consumption of water in the industry worldwide (Hoekstra et al., 2012) with the idea to understand better the amount of water truly used in human activities. The water Footprint (WF) is an interesting indicator developed to visualize the volume of water used along an entire supply chain in the manufacturing of a product or during the generation of a service (Aldaya, 2014).

The concept of WF responds to the use of direct or indirect water. This is particularly interesting since all the volume of water is not physically present in the good or service, but has been an important or the process to reach a final product (Chukalla, Krol, & Hoekstra, 2015). The WF indicator provides strategic information on the use and consumption of water. With this indicator, companies can understand better their water use and make economically conscious decisions in benefit of water-resources. It is important to consider all the factors that may influence water use along a supply chain (Hoekstra et al., 2012).

Depending on the type of good or service, 3 types of water footprint indicators are considered: blue, green and grey water footprints (Kospa, 2014). The blue WF consists of the volume of freshwater used for the operational processes, typically provided by rivers, lakes, and groundwater used along the supply chain (Zhang, Hoekstra, & Mathews, 2013). The green WF considers the amount of rainwater used in operational processes; however, this type of WF is not applied in this research. According to Gerbens-Leenes, the grey WF refers to the amount of freshwater needed to assimilate pollutants to meet water quality standards in a specific process.

The ISO 14046: 2014 water footprint standard has a methodological approach based on ALC Analysis of the life cycle of a product (or service), process or organization. This considers the direct and indirect uses of water throughout the supply chain and its corresponding and potential impacts. The present investigation aligns its objectives to this methodology since water footprint is not only represented in terms of volumes of water consumed and contaminated, but in relation to the impact on water resources (ISO,14046).

3. Methodology

3.1. Goal and scope

3.1.1. Goal of the study

The main goal of the study is to measure the WF during a year of operation of a rig extracting crude-oil in the Ecuadorian Amazon basin. It was necessary the identification of water recharge and discharge points along the entire supply chain of the drilling rig, considering its whole operation. The methodology selected to estimate the WF was the ISO 14046:2014. The measurement of the water footprint of the annual operations of a drilling rig contemplates three important aspects.

3.1.2. Scope of the study

- Analysis of the processes involving water use in a crude-oil drilling facility (rig) during an operational year

- Quantification of the water footprint indicator through the analysis of the blue and grey water footprint components involved in the crude-oil extraction process
- Identification of opportunities for water reduction and optimization in the rig

3.1.2.1 Specific requirements for Water Footprint calculations

Through application of the ISO 14046:2014 the study collects information of direct and indirect freshwater sources (Zhang et al., 2013) used during drill operations during 2018. The available information provided by the drilling company includes databases of freshwaters acquisitions. See Annex C for more information about the process of a purchase freshwater order.

3.1.2.2. Water inflow and outflow in a drilling rig

The ISO 14046:2014 standard recommends to limit the system where the water footprint is to be estimated in order to identify key elements. The present study includes the recharge and discharge points seen in Figure 1.

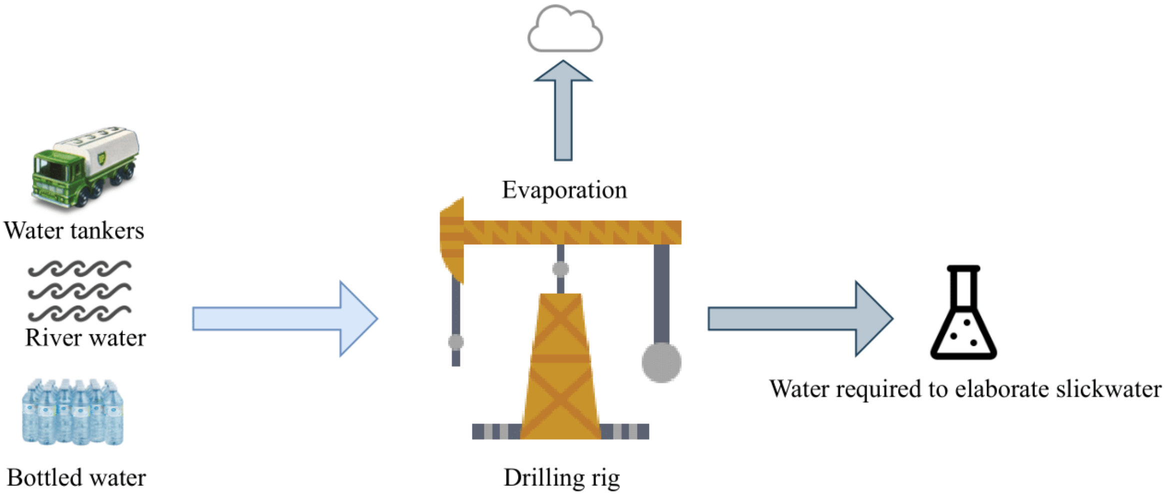

Figure 1. Water footprint System of study (drilling rig and staff).

3.2. Water Footprint calculations

3.2.1. Blue WF

According to the ISO 14046:2014, any assumption must be clearly defined since it will be a limitation of the study in terms of information. The following expression is used to calculate blue WF, according to the ISO 14046:2014 (Hoekstra et al., 2012).

$$[1]\ WF_{proc,blue} = BlueWater\ Evaporation + BlueWater\ Incorporation + Lost\ Return\ Flow\ \left[\frac{vol}{time}\right]$$

Where,

$BlueWater\ Evaporation$: Refers to freshwater evaporated throughout the activities in the process of operation

$BlueWater\ Incorporation$: Refers to freshwater entering the system throughout the activities in the process of operation

$Lost\ Return\ Flow$: Refers to the water that cannot re-enter the system and must be discharged from a source.

3.2.2. Grey WF

The grey WF indicator is given by the following expression (Hoekstra et al., 2012):

$$[2]\ WF_{proc,grey} = \frac{L}{Cmax - Cnat}\left[\frac{vol}{time}\right]$$

Where,

L: volume of water that is required to dilute pollutants among the process.

$Cmax$: the ambient water quality standard of the pollutant

$Cnat$: natural background concentration in the receiving water body

The C_{max} in the water is in relation to the total suspended solids (TSS/m^3) and was determined in relation to the current environmental regulations in the *Technical Standard for the discharge of liquids* found in Annex D (UICN, 2018). The maximum allowed discharge of TSS is 70 (UICN, 2018).

The Grey WF in this study refers to the process of compound of ¨slickwater¨ (see Figure 2), which consists of incorporating several chemicals as disinfectants, surfactants, thickeners, hydrochloric acid and, corrosion inhibitors to a mix of water-sand composition (Rivas Ibáñez, Molina Ruíz, Román Sánchez, & Casas López, 2017). This is the principal use of freshwater in the rig to assimilate chemicals during the extraction process.

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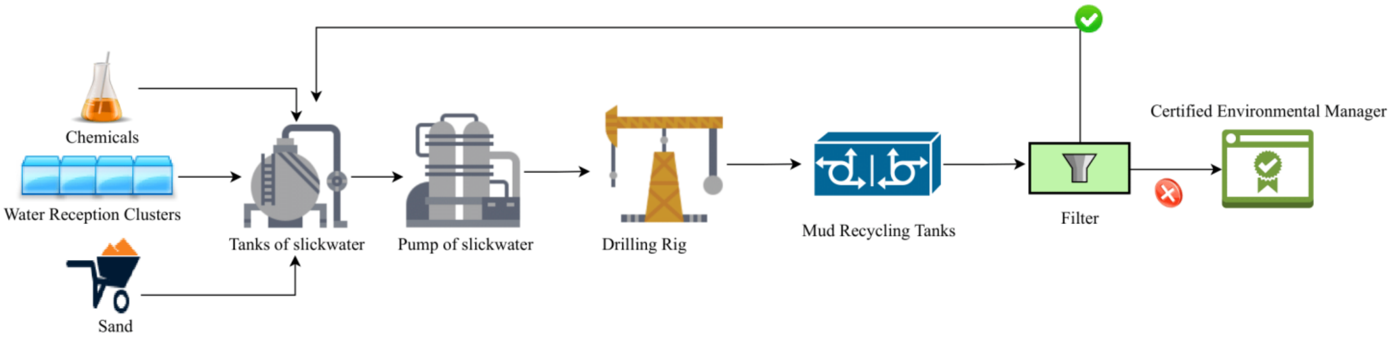


Figure 2. Slickwater process

3.2.3. Green WF

This variable is not considered in the present study as it relates to water resources, such as rainwater, but, the non-consumptive part of water withdrawals (Naranjo-Merino, Ortíz-Rodriguez, & Villamizar-G, 2017). Hence, the rig operation does not use this type of water.

3.2.4. Data validation

Hydric balances were done to guarantee the quality of the information. It is necessary to validate the information to be sure that the data is coherent between the inflow and outflow of the drilling rig (Bernal, 2019).

3.2.5. Data requirements

The water resources involved in the calculations of the WF were:

- Quantities of freshwater use (inputs and outputs)
- Type of charge or discharge water points in the system
- The resource type of water used in the process (e.g. river water, tanker)
- Water quality specifications (e.g. chemicals, biological components)
- Important aspects of water used (e.g. residence time, time of use, discharge method)

4. Data collection

Eight weeks of study were required to understand the flow of water through the process of extracting crude-oil in the drilling rig, as well as the activities of the base camp personnel which require water use. Water is used in the process in different steps as described in Figure 3, depending on the analysis, it is used until it is very contaminated and subsequently disposed of by various environmental managers. The points with direct water use correspond to those associated with the management of large water volumes to extract crude oil:

- Water reception clusters: areas (4 available) where water is temporarily stored for later provision to the rig operations.
- Steam generation systems: equipment that converts water to steam to be injected into the producing wells, reducing the crude-oil viscosity to ease its extraction.
- Treatment and Pumping Modules (TPM): operational areas handling the "slickwater" and where mixtures of the production fluid with chemicals are made.
- Drilling rig: injection of ‘slickwater’ into the drill.

- Wastewater treatment plant: collects process water from all filters systems to remove hydrocarbons and contaminants, through physical and chemical processes to recirculate water to the drilling rig.

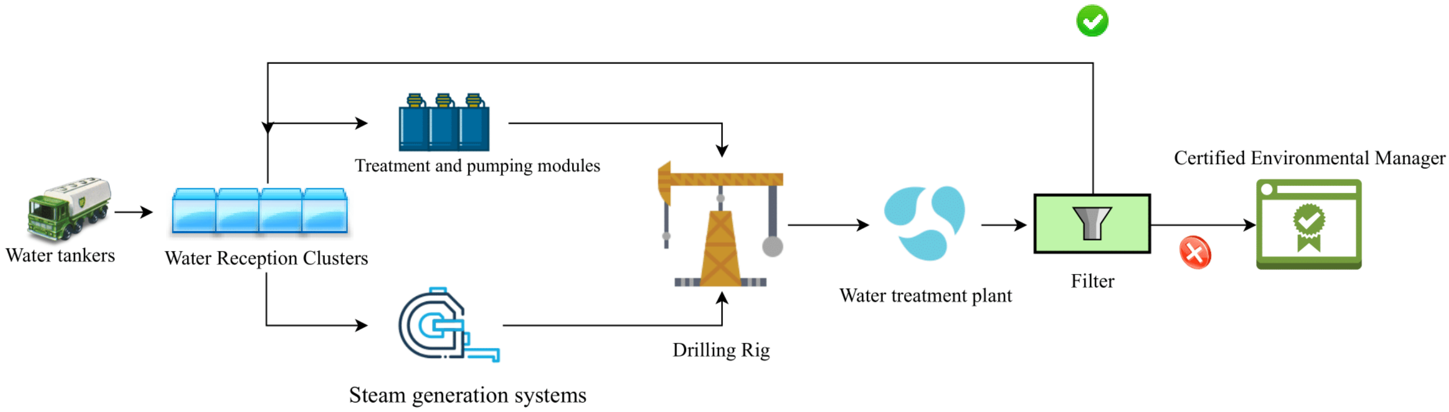


Figure 3. Waterflow inputs and outputs throughout the extraction process

4.1. Blue Water Evaporation

Evaporation happens during the steam generation process (with temperatures from 120°C to 156°C depending on operation requirements). The rest of the information has been unified from the Environmental Department.

Table 1. Data Collection

Water Temperature [°C]	Relative Humidity [%]	Air Temperature [°C]	Wind Velocity [km/h]
120°C	53	28°C	1,08

5. Results

5.1. Blue Water Footprint

After analyzing the database of purchase orders of freshwater throughout the entire study period the blue WF indicator is evaluated according to the equation [1] based on its variables: a) Blue Water Evaporation, b) Blue Water Incorporation, and c) Lost Return Flow.

5.1.1. River water

Table 2 summarizes the records of water pumped from the nearest river into the drilling field during 2018.

Table 2. River water throughout 2018

Month	**Freshwater [m^3]/yr**
January	4.813,03
February	4.306,90
March	4.508,15

April	5.821,19
May	7.811,08
June	7.564,98
July	6.512,54
August	6.256,59
September	6.771,31
October	7.662,18
November	8.011,29
December	5.047,33
TOTAL	**75.086,57**

5.1.2. Tanker freshwater

Table 3 summarizes he results of freshwater supplied by tankers during 2018 is 3133,97 m^3 and the detail is presented in Table 3.

Table 3. Freshwater supplied by tanker

Month	**Freshwater [m^3]/yr**
January	240,73
February	269,52
March	243,93
April	274,12
May	244,18
June	274,14
July	248,56
August	262,51
September	266,61
October	281,97
November	267,02
December	260,68
TOTAL	**3.133,97**

5.1.3. Water for human use and consumption

Bottled water is used for all human uses (e.g. food, cooking, bath, drinking, etc.), summarized in Table 4.

Table 4. *Bottled water consumption during 2018 at the rig*

Month	**Freshwater [m^3]/yr**
January	17,3
February	114,8
March	16,54
April	20,91
May	14,84
June	9,56

July	9,93
August	9,31
September	9,81
October	7,83
November	10,79
December	9,09
TOTAL	**250,71**

5.1.4. Total Blue Water Footprint

The calculated blue WF was 188786,27 m^3 of freshwater for 2018. This quantity of water is equivalent to 75 Olympic pools (1 Olympic Pool = 2500m^3).

Table 5. Blue Water Footprint results

Description	Freshwater [m^3]/yr
Blue Water Incorporation	78.471,25
Blue Water Evaporation	67.922,10
Lost Return Flow	47.281,55
Total Blue Water Footprint	**193.674,90**

For more information on the enclosed Grey WF, see in Annex E.

5.2 Grey Water Footprint

Table 6 summarizes the records of water needed to assimilate all the chemicals to elaborate slickwater during 2018

Table 6. Grey Water Footprint results 2018

Month	Freshwater
January	115,83
February	96,60
March	88,40
April	88,76
May	127,98
June	122,78
July	128,09
August	56,61
September	112,69
October	105,32
November	82,63
December	211,73
TOTAL	**1.337,42**

5.2.1. Total Grey Water Footprint

The analysis determined an estimated grey WF was 1337,42m^3 of freshwater per year to assimilate all the chemicals during the elaboration of slickwater. This quantity of freshwater is equivalent to half of the Olympic pool (1 Olympic Pool = 2500m^3).

Table 7. Grey Water Footprint results

Description	Quantity
L pollutand load	52.828,09
Cmax	70,00
Cnat	30,50
Grey Water Footprint	1.337,42

For more information on the enclosed Grey WF, see in Annex F.

5.3. Total Water footprint

The total WF offers a better idea together, these two components with a complete picture of the use of water by the nearest source of freshwater consumed, the network of the City of Coca, either as river water, by tank truck and freshwater required for the assimilation of contaminants. The only sure thing is that the freshwater does not belong to that place but to the nearest city and based on the result in the Table, we can see that it is considerable.

Table 8. Total WF by month 2018

Month	Blue WF	Gray WF	Total WF
January	31.836,88	115,83	31.952,71
February	32.465,43	96,60	32.562,03
March	32.427,93	88,40	32.516,33
April	12.982,19	88,76	13.070,95
May	12.848,90	127,98	12.976,88
June	9.453,50	122,78	9.576,28
July	9.334,12	128,09	9.462,21
August	11.983,90	56,61	12.040,51
September	13.992,80	112,69	14.105,49
October	7.138,65	105,32	7.243,97
November	9.847,93	82,63	9.930,56
December	9.362,67	211,73	9.574,40
TOTAL	**193.674,90**	**1.337,42**	**195.012,32**

6. Alternatives for reducing water use

6.1 Crude-oil dewatering with High-speed centrifuges

The studied rig shows a high use of water; hence, the present work seeks to propose alternatives to reduce water consumption and/or to improve water quality. One alternative is to use the technique called 'dewatering'. This technique uses a centrifugal separator, which spins at high-speeds to remove water from crude-oil (Johnson, Lun, Mohammed, & Hilal, 2020). This technique could allow the handling of contaminated water otherwise left untreated (grey WF). The recovered water could be later sent into the wastewater treatment plant to remove remains of hydrocarbons and contaminants. The dewatering method could be an interesting approach in this case due to the characteristics of the drilling rig described in section 2.1. In the Figure 4 is the process proposed step by step during extraction of crude oil.

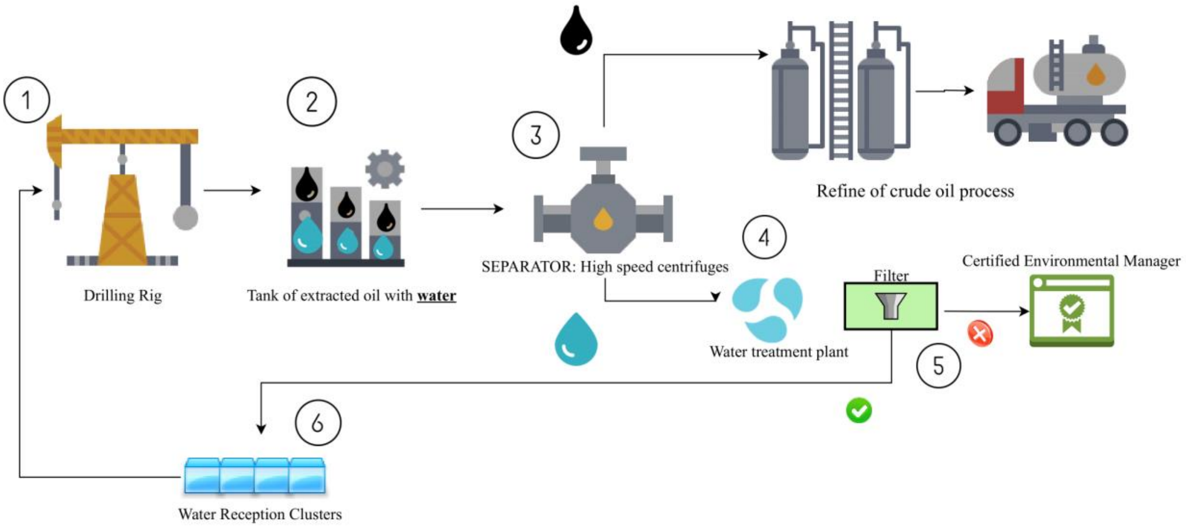


Figure 4. Dewatering process with High-speed centrifuges

6.2 Benefits of the Dewatering technique

6.2.1. Economic perspective

By using this technique, the requirement to have tankers to provide fresh water can be reduced, reducing at the same time the costs and logistics involved. The dewatering method could save an approximated of 3 deliveries of water tank per month (Bernal, 2019), that means an estimated cost reduction of $14.196,00. Table 8 shows the estimated savings if the data analyzed for the present study is considered and assuming an scenario here the mentioned technique was used.

Table 8. Estimated reducing costs of deliveries in freshwater by tankers for 2018

	Analyzed process		**With dewatering**	
Month	Deliveries	Cost	Estimated deliveries	Estimated Cost
January	13	$ 3.844,75	9	$ 2.661,75
February	14	$ 4.140,50	10	$ 2.957,50
March	13	$ 3.844,75	9	$ 2.661,75
April	14	$ 4.140,50	10	$ 2.957,50
May	13	$ 3.844,75	9	$ 2.661,75
June	14	$ 4.140,50	10	$ 2.957,50

July	13	$ 3.844,75	9	$ 2.661,75
August	14	$ 4.140,50	10	$ 2.957,50
September	14	$ 4.140,50	10	$ 2.957,50
October	15	$ 4.436,25	11	$ 3.253,25
November	14	$ 4.140,50	10	$ 2.957,50
December	14	$ 4.140,50	10	$ 2.957,50
TOTAL	165	**$ 48.798,75**	117	**$ 34.602,75**

6.2.1. Environmental perspective

If the amount of water is reduced, the impact on water resources is also improved. Table 9 presents a detailed analysis of the potential amount of water saved. The benefit of the environment is significant for two reasons, the consumption of freshwater from nearby villages will be reduced and the water that was previously wasted in the crude oil extraction process will be used with zero-waste.

Table 9. Estimated reducing of freshwater consumption by tankers

		Actual process		Dewatering implementation
Month	**Deliveries**	**Freshwater (m3)**	**Estimated deliveries**	**Estimated Freshwater (m3)**
January	13	240,73	9	166,66
February	14	269,52	10	192,51
March	13	243,93	9	168,87
April	14	274,12	10	195,80
May	13	244,18	9	169,05
June	14	274,14	10	195,81
July	13	248,56	9	172,08
August	14	262,51	10	187,51
September	14	266,61	10	190,44
October	15	281,97	11	206,78
November	14	267,02	10	190,73
December	14	260,68	10	186,20
TOTAL	165	**3.133,97**	117	**2.222,44**

The dewatering method could represent 911,53 m^3 of freshwater savings during an operation year of extraction of crude-oil. If a rig is considered to have an average time of operation of 3 years, the amounts of water saved are approximal 2734,59 m^3.

7. Conclusions

The total WF of one year of extraction crude-oil service was calculated in 195.012,32 m^3 of freshwater, from this value, 1.337,42 m^3 of water was required to assimilate the chemicals to generate 'slickwater' (grey water footprint). Around 61% of the blue WF has been used during the first quarter of operation of the year 2018, this due to the difficulties of a drilling assembly in the first months of operations, in order to improve that amount of water the dewatering method is proposed.

The largest component of freshwater used in the calculation of the blue WF is from river water sources by using 75.086.57 m^3 of water per year, compromising water in the area, these rivers are complex ecosystems with several types of fish and other aquatic life forms.

The gray WF depends on the quality of the water in its quantity of TSS that comes after its treatment in the water treatment plant, the contamination due to the hydrogen potential is not significant in relation to The water used to assimilate the chemicals and make the drilling gel or slickwater and currently approves the current Ecuadorian regulation, does not compromise the contamination of groundwater in the area.

In the long-term, the population of the City of Coca (41.730 people approx.) can be affected by the amount of freshwater that supplies this type of operations in the region.

7. Discussion

The water consumption for this drilling field of this company is very high as the calculations show. This is important since the drilling rig is in a region of the Ecuadorian Amazon where one of the largest very dense rainforests in Latin America is found. Therefore, water management should focus on the reduction in use of water during drill operations.

The present study can serve as a starting point for deeper analyses of the legal gaps that exist in the sustainable use of water law for crude-oil extraction operations. Nowadays, companies use water without limit or price restriction, but if price increase as consequence of consumption, companies would need to choose a more sustainable alternative to the use of water.

8. References

Allison, E. (2018). *Water in the Oil and Gas Industry*. [online] American Geosciences Institute. Available at: https://www.americangeosciences.org/critical-issues/factsheet/pe/water-oil-gas-industry [Accessed 13 Mar. 2019].

Barati, R. (2014). A Review of Fracturing Fluid Systems Used For Hydraulic Fracturing of Oil and Gas Wells. *ResearchGate*.

Bernal, F. (11 de April de 2019). Water consumption ina drilling rig. (R. Chango, Entrevistador)

Caro, A. F., & Vargas, L. A. (2015). Huella Hídrica En La Producción De Crudo Pesado En Campo Moriche – Puerto Boyacá – Departamento De Boyacá. *Universidad de*

Manizales – Caldas - Artículo de Investigación Científica y Tecnológica, 380.

Chukalla, A. D., Krol, M. S., & Hoekstra, A. Y. (2015). Green and blue water footprint reduction in irrigated agriculture: Effect of irrigation techniques, irrigation strategies and mulching. *Hydrology and Earth System Sciences*, *19*(12), 4877–4891. https://doi.org/10.5194/hess-19-4877-2015

da Silva, V. de P. R., de Oliveira, S. D., Hoekstra, A. Y., Neto, J. D., Campos, J. H. B. C., Braga, C. C., … de Holanda, R. M. (2016). Water footprint and virtual water trade of brazil. *Water (Switzerland)*, *8*(11), 1–12. https://doi.org/10.3390/w8110517

Dapartment of Water Affairs & Forestry. (2013). Water for an Equitable and Sustainable Future. *National Water Resource Strategy*, *NWRS2*, 201. Retrieved from http://www.dwa.gov.za/nwrs/LinkClick.aspx?fileticket=CIwWyptzLRk=&tabid=91&mid=496

Dara Kospa, H. S., Lulofs, K. R. D., Asdak, C., & Rahim, S. E. (2017). Strategies to Reduce Water Footprint in Palm Oil Production: A Case of PTP Mitra Ogan, Baturaja, South Sumatra. *MATEC Web of Conferences*, *97*, 01122. https://doi.org/10.1051/matecconf/20179701122

Gerbens-Leenes, P. W. (2017). The Consequences of Inaction,. *OECD Paris Francia*.

Johnson, D., Lun, A. W., Mohammed, A. W., & Hilal, N. (2020). Separation and Puri fi cation Technology Dewatering of POME digestate using lignosulfonate driven forward osmosis. *Separation and Purification Technology*, *235*(July 2019), 116151. https://doi.org/10.1016/j.seppur.2019.116151

Mateo, J. P., & García, S. (2014). El sector petrolero en Ecuador. 2000-2010. *Problemas Del Desarrollo*, *45*(177), 113–139. https://doi.org/10.1016/S0301-7036(14)70865-X

Naranjo-Merino, C. A., Ortíz-Rodriguez, O. O., & Villamizar-G, R. A. (2017). Assessing green and blue water footprints in the supply chain of cocoa production: A case study in the Northeast of Colombia. *Sustainability (Switzerland)*, *10*(1). https://doi.org/10.3390/su10010038

Pino, E. A. (s.f.). *Provincia de Orellana.* Enciclopedia del Ecuador, Ciudad del Coca.

Rivas Ibáñez, G., Molina Ruíz, J. M., Román Sánchez, M. I., & Casas López, J. L. (2017). A corporate water footprint case study: The production of Gazpacho, a chilled vegetable soup. *Water Resources and Industry*, *17*(July 2016), 34–42. https://doi.org/10.1016/j.wri.2017.04.001

UICN. (2018). *Guía de monitoreo participativo de la calidad de agua*.

Zhang, G. P., Hoekstra, A. Y., & Mathews, R. E. (2013). Water Footprint Assessment (WFA) for better water governance and sustainable development. *Water Resources and Industry*, *1–2*, 1–6. https://doi.org/10.1016/j.wri.2013.06.004

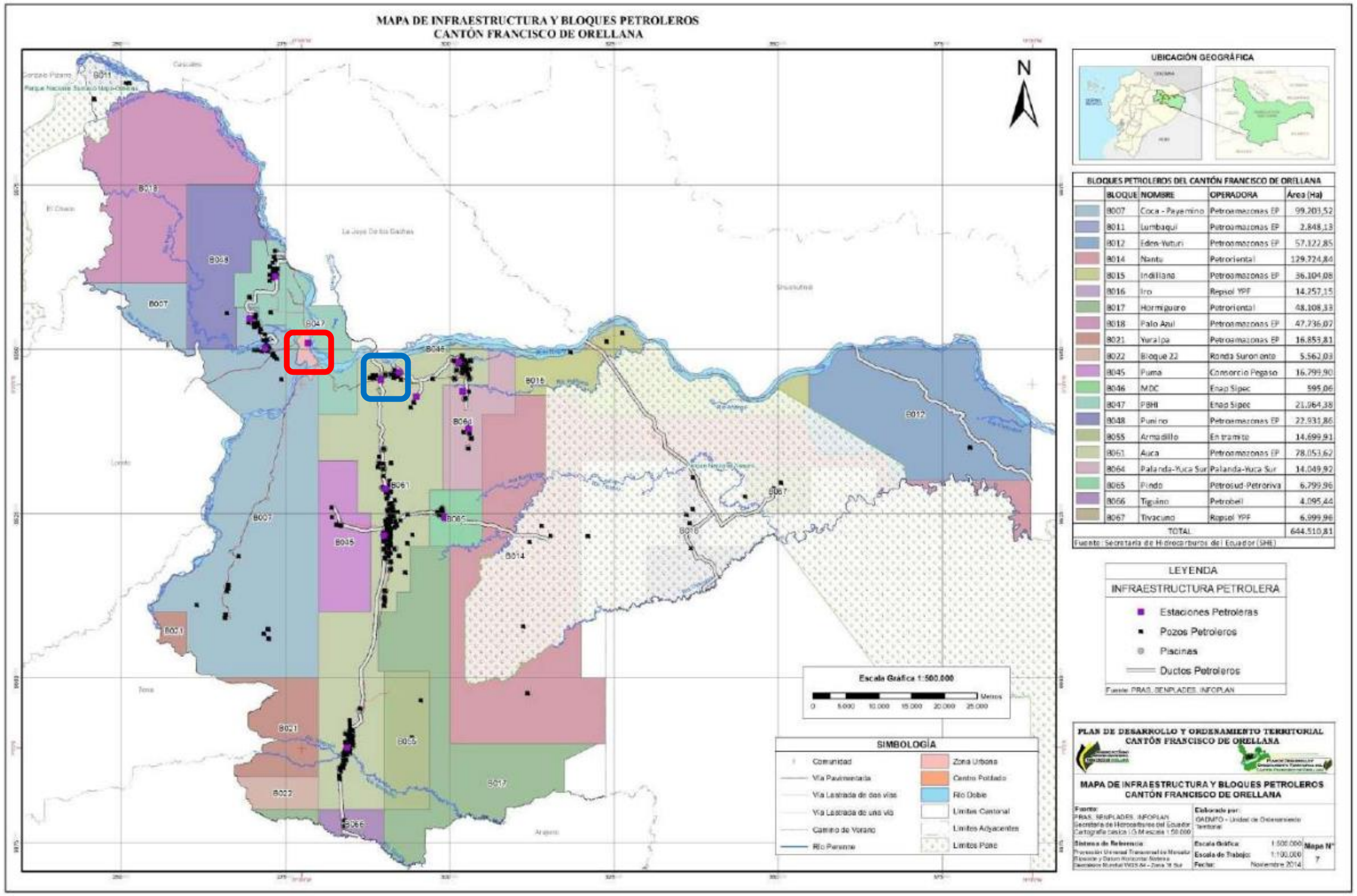
14046, ISO. (2014). Environmental Management Water footprint Principles, requirements, and guidelines. ISO

9. Annex

Annex A: MAP OF DRILLING RIGS LOCATED AT SAN FRANCISCO DE ORELLANA PROVIDENCE (In red Coca City, blue approximal location of drilling rig)

Source: Plan de Desarrollo y Ordenamiento Territorial Cantón San Francisco de Orellana 2014-2019

(San Francisco de Orellana Canton Development and Territorial Planning Plan 2014-2019)



BLOQUES PETROLEROS DEL CANTÓN FRANCISCO DE ORELLANA

BLOQUE	NOMBRE	OPERADORA	Área (Ha)
B007	Coca - Payamino	Petroamazonas EP	99.203,52
B011	Lumbaqui	Petroamazonas EP	2.848,13
B012	Eden-Yuturi	Petroamazonas EP	57.122,85
B014	Nantu	Petroriental	129.724,84
B015	Indillana	Petroamazonas EP	36.104,08
B016	Iro	Repsol YPF	14.257,15
B017	Hormiguero	Petroriental	48.108,33
B018	Palo Azul	Petroamazonas EP	47.736,07
B021	Yuralpa	Petroamazonas EP	16.853,81
B022	Bloque 22	Ronda Suroriente	5.562,03
B045	Puma	Consorcio Pegaso	16.799,90
B046	MDC	Enap Sipec	595,06
B047	PBHI	Enap Sipec	21.964,38
B048	Punino	Petroamazonas EP	22.931,86
B055	Armadillo	En tramite	14.699,91
B061	Auca	Petroamazonas EP	78.053,62
B064	Palanda-Yuca Sur	Palanda-Yuca Sur	14.049,92
B065	Pindo	Petrosud-Petroriva	6.799,96
B066	Tiguino	Petrobell	4.095,44
B067	Tivacuno	Repsol YPF	6.999,96
TOTAL			644.510,81

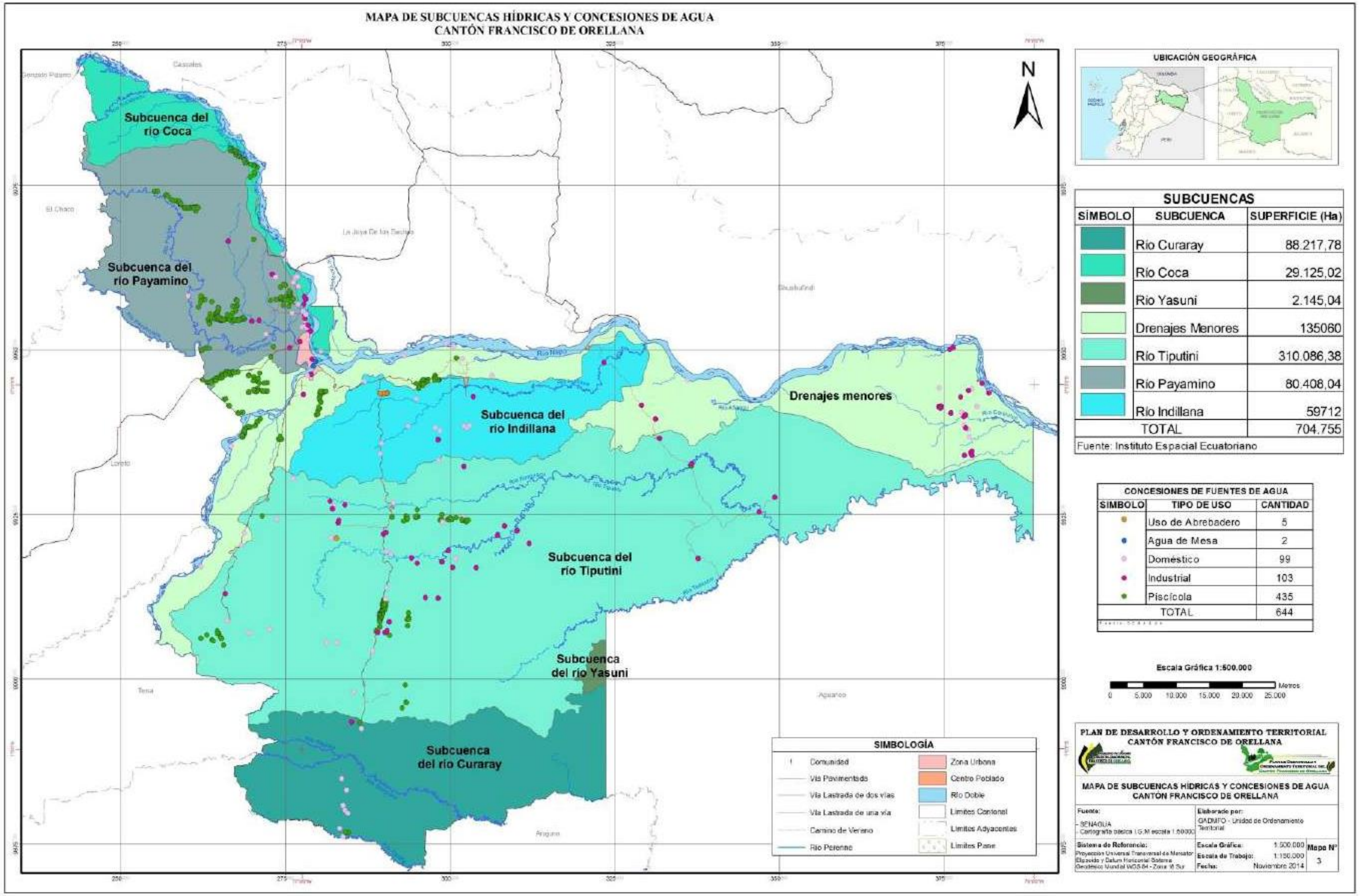
Fuente: Secretaría de Hidrocarburos del Ecuador (SHE)

Note: Due to terms of confidentiality, the exact location of the rig cannot be shown.

Annex B: MAP OF WATER SUB-BASIN AND HYDROGRAPHIC CONCESSIONS

Source: Plan de Desarrollo y Ordenamiento Territorial Cantón San Francisco de Orellana 2014-2019

(San Francisco de Orellana Canton Development and Territorial Plan 2014-2019)



SUBCUENCAS		
SÍMBOLO	SUBCUENCA	SUPERFICIE (Ha)
▨	Río Curaray	88.217,78
▨	Río Coca	29.125,02
▨	Río Yasuni	2.145,04
▨	Drenajes Menores	135060
▨	Río Tiputini	310.086,38
▨	Río Payamino	80.408,04
▨	Río Indillana	59712
TOTAL		704.755

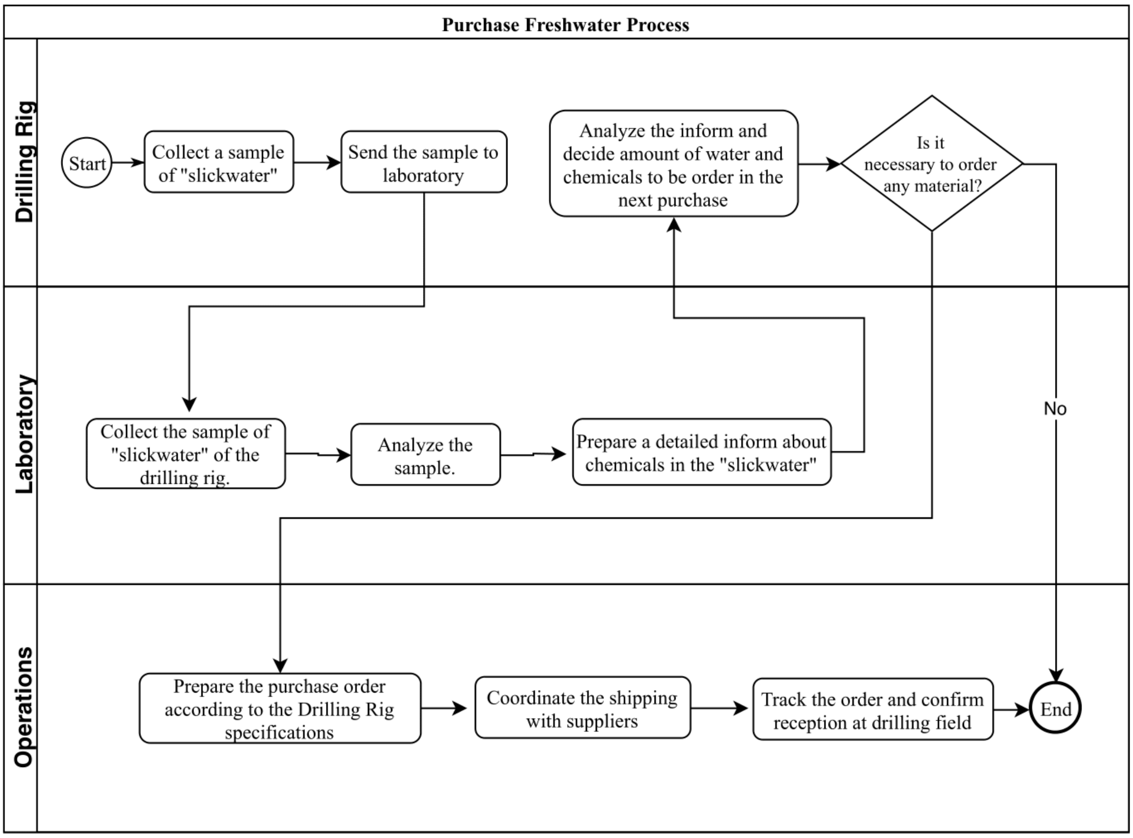
Fuente: Instituto Espacial Ecuatoriano

CONCESIONES DE FUENTES DE AGUA		
SIMBOLO	TIPO DE USO	CANTIDAD
●	Uso de Abrebadero	5
●	Agua de Mesa	2
●	Doméstico	99
●	Industrial	103
●	Piscícola	435
TOTAL		644

Fuente: - SENAGUA - Cartografía básica I.G.M escala 1:50000	Elaborado por: GADMFO - Unidad de Ordenamiento Territorial
Sistema de Referencia: Proyección Universal Transversal de Mercator Elipsoide y Datum Horizontal Sistema Geodésico Mundial WGS-84 - Zona 18 Sur	Escala Gráfica: 1:500.000 Escala de Trabajo: 1:150.000 Fecha: Noviembre 2014
Mapa N°	3

Note: Due to terms of confidentiality, the exact location of the rig cannot be shown.

Annex C. Process of Purchase of Freshwater requirements



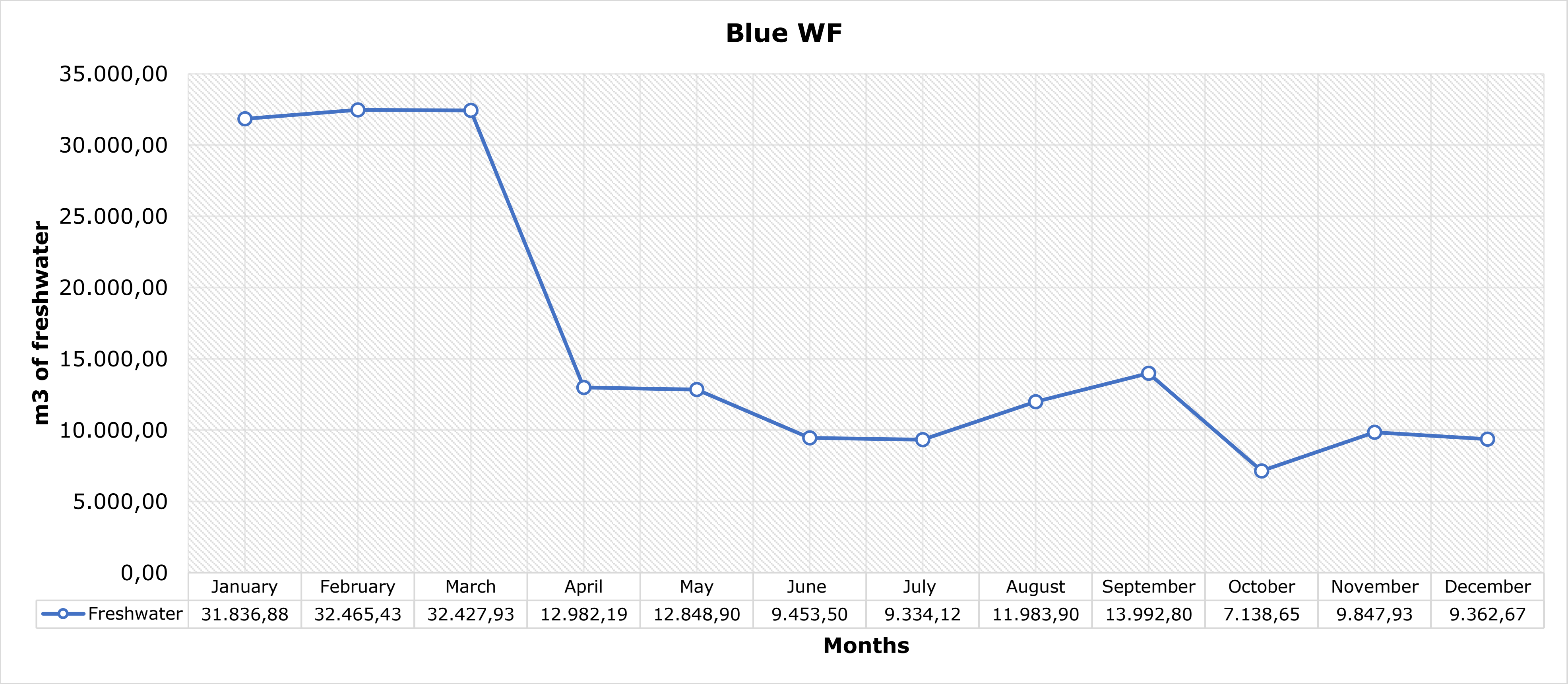
Annex D. NORMA DE CALIDAD AMBIENTAL Y DESCARGA DE EFLUENTES

Estándares técnicos para la descarga de líquidos

(Technical Standard for the discharge of liquids)

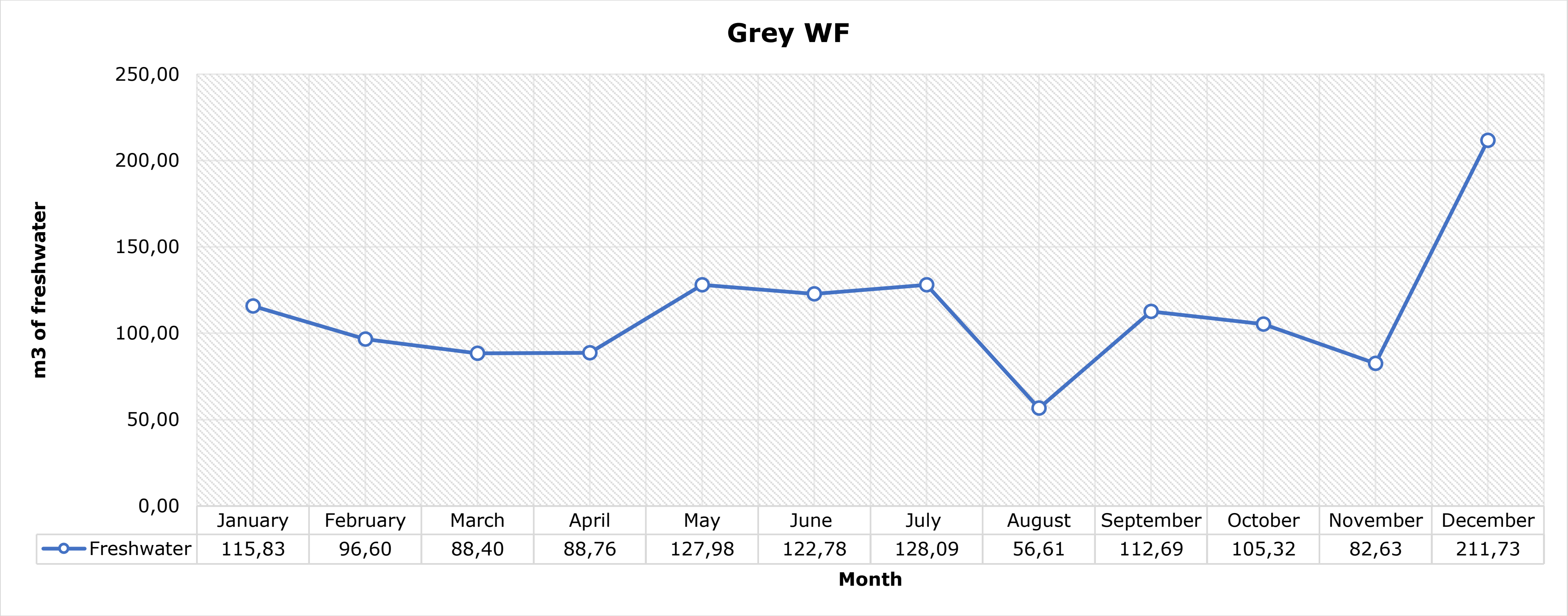
Parameters	**Unit**	**Maximum Limit**
Bifelino	ug/l	0,0005
Fluoruro	mg/l	1,5
Hierro	ug/l	1
Mercurio	mg/l	0,001
Nitrato	mg/l	10
Olor y sabor	-	Es permitido olor y sabor por tratamiento convencional
Plata	mg/l	0,05
Plomo	mg/l	0,05
Potencial de hidrógeno	pH	6-9
Selenio	mg/l	0,01
Temperatura	C	400C condición natural
Zinc	mg/l	5

ANNEX E. Result of total water footprint during 2018



	January	February	March	April	May	June	July	August	September	October	November	December
Freshwater	31.836,88	32.465,43	32.427,93	12.982,19	12.848,90	9.453,50	9.334,12	11.983,90	13.992,80	7.138,65	9.847,93	9.362,67

ANNEX F. Result of total grey footprint during 2018



	January	February	March	April	May	June	July	August	September	October	November	December
Freshwater	115,83	96,60	88,40	88,76	127,98	122,78	128,09	56,61	112,69	105,32	82,63	211,73