Supplementary Material

The Water Footprint of Heavy Oil Extraction in Colombia: A Case Study

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1. List of acronyms/glossary

API: American Petroleum Institute: an organization which sets unit standards in the oil and gas industry.
API gravity: The relative density of a hydrocarbon based on a scale of degrees by the API
B7: 7% biodiesel blended with 93% petroleum diesel
BOD_5: Biological oxygen demand in 5 days
BSW: Water cuttings and sediments
COD: Chemical oxygen demand
cP: centiPoise (viscosity unit of measurement)
CSS: Cyclic steam stimulation
EHT: Thermal-electrostatic treatment
EOR: Enhanced oil recovery
FKWO: Free water knock-out
GDP: Gross domestic product
IACAL: Potential changes in water quality (Índice de alteración potencial de la calidad del agua)
IARC: Non-returned water to the water basin index (índice de agua que no retorna a la cuenca)
IDEAM: Colombian Institute of Hydrology, Meteorology and Environmental Studies (Instituto de Hidrología, Meteorología y Estudios Ambientales)
IPHE: Ecosystem water stress (índice de presiones hídricas a los ecosistemas)
IVH: Water vulnerability index (índice de vulnerabilidad hídrica)
NSW-2014: 2014 Colombian National Water Study
PVC: Polyvinyl chloride
SIAR: Produced wastewater treatment plant
SR: Secondary recovery
TSS: Total suspended solids
USD: United states dollars
WF: Water footprint

2. Background on the Middle Magdalena, Colombia

The Middle Magdalena hydrographic area is the portion of the Magdalena water basin situated in a valley that lies between the Eastern and Central mountain chains of the Andes. It extends 386 km and covers 32,000 km^2, which corresponds to 22.5 percent of the total Colombian land surface and includes the following Colombian departments, Huila, Tolima, Cundinamarca, Caldas, Boyacá, Antioquia, Santander, Bolívar, Cesar, Magdalena and Atlántico. The Middle Magdalena can in turn be broken down into 21 sub-hydrographic zones. The region is tropical

and is exposed to a bimodal hydrological regime. It is also home to an abundance of lotic (fauna and flora) and terrestrial species. Unfortunately, this richness is threatened by erosion, water abstraction and contamination [1]. In terms of hydrology, the most significant parameters of both the Middle Magdalena and the sub-zone where the company operates, are presented in Tables S.1, S.2 and S.3.

Table S1. Surface water parameters for the Middle Magdalena [2].

Area (km^2)	Flow		Total Supply		Runoff		Precipitation
	Average Year (m^3/s)	Dry Year (m^3/s)	Average Year (10^6 m^3)	Dry Year (10^6 m^3)	Average Year (mm/year)	Dry Year (mm/year)	Average Year (mm/year)
59701	2667	1232	84112	38839	1409	651	3095

Table S2. Subterranean water parameters for the Middle Magdalena [2].

Aquifer Type	Saturated Thickness (m)	Water Conductivity (m/d)	Water Transmissivity (m^2/d)	Storage Coefficient (adimensional)	Specific Storage (L/s/m)	Area (km^2)
Unconfined, semi-confined to confined, karst	80 a > 800	0.2 a 2	80 a 280	4×10^{-4} a 1×10^{-3}	0 a 2.0	24496

Table S3. Parameters for the subzone of the Middle Magdalena, where the company of the case study operates [2].

Parameter		Value
Area (km^2)		2311
Flow	Average year (m^3/s)	112
	Dry year (m^3/s)	83
Total supply	Average year (10^6 m^3)	3522
	Dry year (10^6 m^3)	2611
Available Supply	Average year (mm/year)	1826
	Dry Year (mm/year)	1353
Runoff	Average Year (mm/year)	1312
	Dry Year (mm/year)	927
Precipitation	Average year (mm/year)	2072
BOD_5 (t/year)		611
TSS (t/year)		1218
IVH	Risk category	Low
IARC	Value	0.001
	Risk category	Very low
IPHE	Value	0.817
	Risk category	Very high
IACAL	Risk category	Low

3. Heavy Oil Extraction Processes

The following are the main facilities at the three oil fields (with the exception of the vapor production facilities which are only found at two), which affect the local surface and subterranean water availability:

- **Extraction: production clusters:** Each of these has the following wellheads of different types: production, test, gas recuperation, stimulation fluid recuperation and vapor injection.
- **Vapor production:** These facilities are involved in the intake and purification of freshwater, as well as vapor injection, which facilitates heavy crude extraction. The cyclic injection of vapor is applied to the wells in different stages. The vapor is first injected and then steam/water condenses, which heats the viscous oil. This process facilitates crude pumping. For the CSS operations, it is necessary to first collect and treat water via coagulation, flocculation, membrane filtration and softening so that it may be injected as vapor into the subsoil. In terms of technology, the oil fields have two options when it comes to vapor generation. One option is fixed and generates 50,000 lbs/h. The second option is portable and has a generating capacity of half the first. The steam generated is then transported to the point of injection.
- **Collection, pumping and transference plants:** these facilities collect the fluid that is transported by the production lines to where crude is treated. They also are involved in the mechanical separation of the annular natural gas flow from that of the crude. The system regulates fluid pressure (a controlled process whereby the fluid is pumped to a module). Additionally, these facilities have the following elements: annular gas recuperation system, stimulating fluid recuperation system and test separators. The gas on entry to the intermediate station passes through a separation condenser drum. It is then sent to the treatment module and pump, where it is used as a fuel for the generators.
- **Treatment and pumping Modules:** they receive and handle oil production. Here crude oil is mixed with chemicals (demulsifier and emulsion breaker). They have water separators, referred to as free water knock-out (FKWO) whereby, via gravity and heat, free water molecules present in the fluid are separated (approximately 50% of the water present in the fluid is separated, as is the gas). Once the crude has been separated, it is sent to thermal-electrostatic treatment installations, referred to as EHT. It is then analyzed for water cuttings and sediments (BSW) using a measuring device which determines whether or not the dehydrated crude meets the water cut and sediment quality requirements, as set by clients (BSW < 0.05%). Should it meet them, the crude is sent through pipelines that feed into storage tanks. A meter checks the crude prior to entry.
- **Residual Water Treatment Plants:** There are three types. The first is the wastewater treatment plant which is located in the treatment and pumping module (referred to as SIAR). Here the water that has passed through the FKWO separators and the thermo-electric treatment facilities is received. The plant's function is to remove, mechanically and chemically, any contaminants present in the production water so it can be sent to the injection wells. It is composed by the following elements: primary separation system, skim tank, secondary separation tank, flotation cell, tertiary separation tank, walnut shell filter, solid extraction pool, filtered water injection system and other types of control mechanisms. The second type of water treatment is that of domestic wastewater. It is treated in septic tanks and is taken to infiltration fields. The process is not "dilute and disperse". The third type is sub-contracted. Any industrial residual wastewater derived from drilling or well servicing is treated, transported and sprayed on the company's oil field roads to reduce dust and suspended particulate matter from causing health/environmental problems.
- **Administrative and camp facilities:** Although water is predominantly used for industrial processes, oil production requires auxiliary support for those working on the site and for the running of company operations. This set of facilities includes offices, internet servers, kitchens and restrooms.

- **Auxiliary industrial processes:** the water used in drilling and well servicing and construction/maintenance of site infrastructure (roads, the well foundations and other earthworks, buildings).

References

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2. IDEAM. *Estudio Nacional del Agua 2014*; Instituto de Hidrología, Meteorología y Estudios Ambientales—IDEAM: Bogotá, DC, Colombia, 2015.