IPIECA

Water

2014

www.ipieca.org

Efficiency in water use

Guidance document for the upstream onshore oil and gas industry





The global oil and gas industry association for environmental and social issues

5th Floor, 209–215 Blackfriars Road, London SE1 8NL, United Kingdom
Telephone: +44 (0)20 7633 2388   Facsimile: +44 (0)20 7633 2389
E-mail: info@ipieca.org Internet: www.ipieca.org

Efficiency in water use

Guidance document for the
upstream onshore oil and gas industry

Acknowledgements

This document was prepared by the IPIECA Water Working Group.
IPIECA gratefully acknowledges the assistance of James Assem, the principal author, and other colleagues at WorleyParsons in its preparation.

Contents

Executive summary

This document presents a systematic process for identifying and assessing potential measures to improve water efficiency. Improving the efficiency of water use in onshore upstream oil and gas activities involves identifying and measuring water uses, understanding the risks associated with various source and disposal pathways, and managing water effectively to maximize the economic, social and environmental well-being associated with the resource. Improving water use efficiency by incorporating the principles of water stewardship, integrated water resource management and risk assessment is an ongoing process that should take place throughout the life of an operation.

This document provides good practice guidance for water management in upstream onshore oil and gas facilities. It complements existing water management guides, and references them in the text where applicable. The document is relevant for both new and existing operations, applies to fresh, brackish and saline water, and addresses the technical aspects of using water efficiently while meeting an oil or gas operation's water requirements.

The document is aimed at Health, Safety and Environment (HSE) professionals and practitioners, as well as external stakeholders. Of particular interest to HSE professionals will be the information on where water efficiency opportunities are likely to be found, and the associated decisions that will need to be made when implementing water efficiency measures. The document also aims to provide HSE professionals with an approach to initiating internal discussions with engineers and decision makers, and external discussions with regulators and stakeholders. For external stakeholders, the document explains how water is used and managed, and highlights the opportunities and constraints associated with water management and efforts to improve water efficiency.

The practical information and principles detailed in this guidance document are intended to complement the need for full compliance with all applicable laws and regulations. The document is not intended to be prescriptive, nor does it set an industry standard; rather, it offers a set of underlying principles and describes how they can be put into practice by implementing practical measures.

The document is composed of five key sections. The *Introduction* outlines the IPIECA Water Management Framework, introduces the document's context and scope, and presents a series of guiding principles together with a description of the overall process.

The section on *Water uses* looks at a first step in the overall process. This involves determining both water uses and returns in conventional oil and gas production, in enhanced oil recovery, and also in unconventional production (i.e. oil sands, shale/tight oil and gas, and coal bed methane).

The third section explores the identification of water efficiency opportunities. It frames the process for managing the demand for water, and

presents some of the risks that need to be considered. A hierarchical approach ('reduce, replace, reuse, recycle') for implementing water efficiency is also described. This section examines, within the context of a drainage basin, how collective action can offer additional options when planning for water efficiency. Accounting for water across an operation is the starting point in identifying where opportunities for efficiency exist. The selection of efficient water management systems needs an understanding of where water is coming from and where it is going, its respective quality, and how these factors may change with time. The non-technical risks and their influences on the operation also need to be understood and incorporated at the planning stage as these can influence the design of the water management system.

The fourth section details the process for *Appraising water efficiency opportunities*. This process requires consideration of a wide range of factors—both technical and non-technical—including water treatment methods, energy requirements, and land-use, social, cultural, environmental and regulatory issues. This section also focuses on the potential benefits and disadvantages that require consideration when appraising the opportunities for water efficiency improvements. Many factors influence the appraisal and selection of water efficiency measures, and the guide explains that a complex decision-making process will need to be applied. The section also describes non-monetary and monetary techniques for appraising the available options; use of these techniques enables a comprehensive range of influential factors to be taken into account in the decision-making process.

The final part of this guidance document, explores the importance of selecting appropriate indices to define and quantify improvements in water efficiency. It emphasizes the need to factor the index selection process into the overall approach to water efficiency, to ensure that accurate and appropriate data are collected.

The content of this document is the result of extensive consultation with, and valuable input by, IPIECA members. It contains a number of case studies which demonstrate the use of good practice in the oil and gas industry, and which will be added to over time and published on the IPIECA website (www.ipieca.org).

Introduction

Water management is an essential component of oil and gas operations. Although the global volume of fresh water used by the oil and gas industry is considerably lower than in the agriculture, power and some other sectors (AQUASTAT: FAO, 2012), the oil and gas industry can be a significant user of fresh water at the local and regional scale. Oil and gas operations may also involve the handling and management of large volumes of produced water, wastewater and rainfall run-off. The efficient use of water is a key aspect that has to be considered as part of the water management process and is the focus of this document.

IPIECA Water Management Framework

To promote and facilitate implementation of good practice in water management among its members, IPIECA has developed the *Water Management Framework* (IPIECA, 2013). The objective of the Framework is to provide:

- a template for integrated water resource management, addressing multidisciplinary aspects over the life of oil and gas operations;
- a strategic direction for IPIECA and its members linked to potentially changing priorities as industrial management practices develop;
- a structured industry approach, outlining necessary steps to meet current and future water management practices;
- an outline of available or pending guidance and tools—available or required—to implement good water management practices across oil and gas operations, of which this guidance document is one component; and
- a platform for the industry to develop its own strategies, and to consult and communicate water management activities and achievements to external stakeholders, including communities, regulators and governments, trade associations and non-governmental organizations (NGOs).

Context of the document

This document supports IPIECA's *Water Management Framework* by providing good practice guidance for water management at onshore upstream oil and gas facilities. It is intended to inform an external audience on how water is used and managed, and on the constraints that exist. It also provides guidance to HSE professionals and practitioners on where opportunities for water efficiency may occur, and on the decisions that need to be made when considering the available options. It aims to provide these professionals with the information needed to enable them to enter into discussions both internally with engineers and decision makers, and externally with regulators and stakeholders.

This guidance document does not aim to present a single prescriptive approach, nor is it intended as a standard for the oil and gas industry; rather, it presents a set of underlying principles and explains how these can be used as the basis for implementing a series of practical steps. The content has been shaped through consultation with, and agreement by, IPIECA members on the overall objectives, focus, target readership, input sources and technical content so as to maximize its utility and benefit. Over time, IPIECA members will be preparing detailed case studies to complement this guidance and demonstrate how good practice has been achieved. The case studies will be published on the IPIECA website (www.ipieca.org).

This document complements the IPIECA guidance document entitled *Identifying and assessing water sources* (IPIECA, 2014).

Scope of the document

This document provides guidance on good practice in optimizing water use for upstream onshore oil and gas operations. It is applicable to both new and existing operations, and applies to fresh, brackish and saline water, although the main focus is on the use of fresh water.

The scope addresses the technical aspects of optimizing water use in terms of meeting an operation's water requirements. Although the focus is on the efficient use of water, this is often linked to the need for an assessment of the suitability of available sources of water, and thus the wider environmental and social context.

Guiding principles

The process of optimizing water use centres on the concept of water stewardship and consideration of the principles of integrated water resource management (IWRM). Optimizing water use involves identifying and measuring the different uses of water, understanding the risks associated with various source and disposal pathways, and managing water efficiently to maximize economic, social and environmental well-being associated with the resource. The process of optimizing water use is recognized as being iterative—it is a continuous process that will need to be developed throughout the life of the operation.

These principles do not replace, but are intended to complement the need for full compliance with all applicable laws and regulations, which itself is assumed to be the baseline minimum requirement.

Water stewardship

Water stewardship is one of the key principles that underpin good practice in water management. It is defined by the Alliance of Water Stewardship (AWS, 2014) as 'the use of water that is socially equitable, environmentally sustainable and economically beneficial, achieved through a stakeholder-inclusive process …' Four aspects capture the intent of water stewardship:

- **Water governance:** addresses how water is governed and managed both internally within an operation and externally within the wider drainage basin. It covers the issues of rights, regulations, permits, licences, plans and policies to ensure that water is managed equitably as a resource for all users within the catchment, with a strong emphasis on stakeholder engagement.
- **Sustainable water balance:** addresses the amount and timing of water use, including abstractions, consumption and discharges, and whether the volumes involved are sustainable relative to renewable water supplies.
- **Water quality:** addresses the physical, chemical and biological properties of water, to determine whether the water quality within the site and drainage basin meets local water quality regulation, and is fit for the requirements of the ecosystem services present and for any human need or purpose.
- **Important water-related areas:** addresses the spatial aspects of water at the site and within the wider drainage basin, and concerns the health of environmental, social, cultural or economic benefits derived from the catchment.

The term 'sustainable' is referenced above and has been widely used in recent years for a wide variety of planning activities, often with no definition provided. The need for 'sustainable development' or 'sustainable use of resources' may have different meanings depending on the perspective of the user. In this document, the definition provided in the Brundtland Report (WCED, 1987) has been adopted, as follows:

> *'A system that is sustainable should meet the needs of the present without compromising the ability of future generations to meet their own needs.'*

Integrated water resource management

Similar to water stewardship, IWRM promotes the coordinated development and management of water, land and related resources (e.g. energy consumption, greenhouse gas emissions) with a view to maximizing economic and social welfare while protecting the environment (GWP, 2013). The underlying principle of IWRM is that water is a shared resource and that many of its uses are interdependent. In the assessment of any given water resource for use in an operation, consideration should therefore be given to the impacts of its use on other users, the impact of other users on the operation, and its importance in terms of biodiversity and ecosystem services.

Measurement

Efficient water management requires an understanding of an operation's water use and the collection of reliable, good quality data across its water infrastructure. These data facilitate the evaluation of water use efficiency, which enables continuous improvements to be made. It is also important to record the quality of the different water streams to provide an understanding of the options for sustainable management.

Risk assessment

The risks associated with water use in oil and gas operations may be financial, environmental, social or political. These risks should be identified in the early stages of a project, and assessed on an ongoing basis given that, as the project evolves, its associated risks may change.

Continuous improvement

The management of water should include a process of continuous improvement throughout the life of an oil and gas operation. A greater level of detail is often required during the design phase of a project, as development proceeds through the feasibility stage through to the final design. During the subsequent operational phases, updated plans can be implemented to optimize the use of water, minimize the associated risks, and take account of changes in the operating environment and/or changes in the operational regime.

Water efficiency hierarchy

Water efficiency is somewhat analogous to the 'waste hierarchy', a process used to protect the environment and conserve resources. Initially, priority is given to the identification of activities or processes that can reduce water use. If further efficiency measures are necessary, the next step is to assess the feasibility of using an alternative water supply, and to identify activities or processes in which water can be re-used and/or recycled.

The waste hierarchy is summarized as follows:

Reduce: lowering the consumptive use of a process or activity.

Replace: removal of the need for, or partial or full substitution of fresh water by, a different resource.

Re-use: use of water for the same or alternative process without treatment, or with minimal treatment.

Recycling: bringing water back into use through treatment to improve water quality.

The distinctions between the different measures in the water efficiency hierarchy can depend on overlapping technical factors. In the case of re-use and recycling, the degree of treatment and the number of re-use cycles complicates water accounting that attempts to track or measure recycling and re-use. (See *Water accounting* on page 20.)

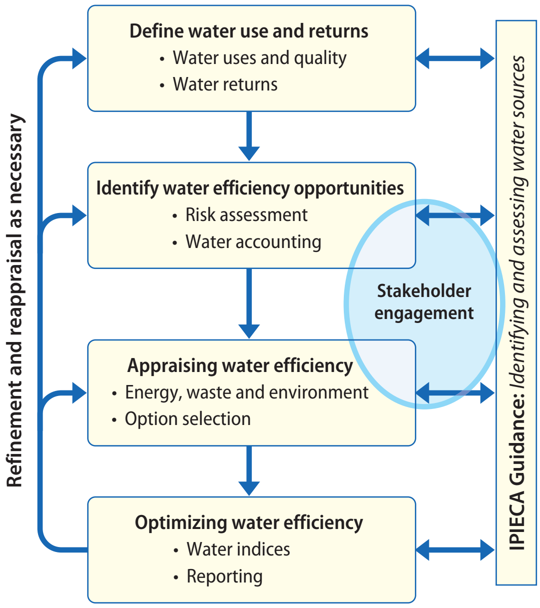
The overall process

The approach to identifying and implementing water efficiency opportunities at a local scale typically follows a sequence such as:

- identifying water uses and return flows;
- identifying the links between water uses, transportation means, stores, return flows and treatment approaches;
- identifying the opportunities and risks;
- appraisal of the options;
- making choices; and
- feedback.

The main steps in the water efficiency options and appraisal process presented in this guidance document follow this sequence and are shown in Figure 1. These steps are not intended to be prescriptive, as every operation is different and requires a customized approach. However, the process described here is logical, incorporates all the key principles outlined above, and when suitably implemented will meet the guiding principles outlined on pages 4–5.

Figure 1 *Outline water efficiency and options appraisal process*



Details of the process that can be applied for each of the steps are presented in the following sections of this document. This process can be implemented iteratively so that the implications of decisions are fully understood and appraised, and adjusted as the risk profile and/or available technology changes.

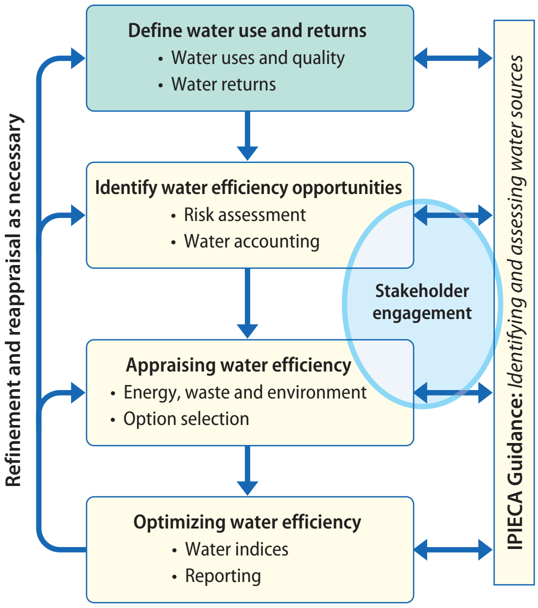
The implications of water efficiency measures on water resources should be considered at all stages of the operation. The approach and level of assessment will vary depending on location, community concerns, regulatory regime and operation specifics.

The implications of the decision process on the available water resources need consideration at each step of the process. The IPIECA guidance document entitled, *Identifying and assessing water sources* (IPIECA, 2014) should be consulted at the appropriate time, and it should be recognized that the outcomes of the water resource assessment may alter with time, and/or influence the water efficiency options and selection.

Water uses

This section presents typical water uses, quality requirements and water returns for the different oil and gas resource types.

Figure 2 *Efficiency in water use—defining water uses and returns*



Before identifying water efficiency opportunities, an operation's water uses and return flows (water that has either been used and is returned to the system, effluent, or a by-product of a process) should be understood. The type of hydrocarbon resource being developed and the maturity of the development will determine how water is used and managed, the requirements for water quality, and the scope for water efficiency within the operation.

This section presents typical water uses (summarized in Box 1), quality requirements, and water returns for the different oil and gas resource types.

To allow comparison between different resource types, generalized categories of water quality are employed; these are presented in Table 1. The quality has been defined based on

Box 1 *Generalized categories of water and their quality*

Water uses	
Personnel supply	• drinking, personal hygiene, food preparation • laundry, toilet flushing and cleaning
Construction and commissioning	• concrete batching, dust control, road surfacing • hydro-testing pipelines
Exploration and drilling	• drilling fluids, well linings (cement/grout) • well stimulation fluids and well flushing
Production	• development and extraction of resource from the reservoir
Process and operations	• boiler feed, pump seals, firewater, wash down, cooling water, resource refining and desalters
Returned water	
Wastewater	• 'black water' sewage effluent • 'grey water' hand basins, showers, baths, laundries and kitchens • industrial effluent and drainage
Produced water	• water that has come from the hydrocarbon reservoir
Flowback water	• water that is introduced to increase the permeability of the hydrocarbon reservoirs (hydraulic fracturing) and which then returns to the surface
Process water	• including blowdown, i.e. condensed water from coolers, dehydration, etc.

Table 1 *Generalized categories of water and their quality*

Category	Quality (TDS) mg.l^{-1}
Fresh water	<2,000
Slightly brackish	<4,000
Brackish	<15,000
Saline	>15,000
Brine	>40,000

the total dissolved solids (TDS) content as a proxy for overall water quality. Other water quality parameters may also be appropriate for classification.

Common uses and returns

The following definitions represent common uses of water by operations, and the associated water returns that can be realized.

Personnel

The workforces involved in construction, drilling and operating a facility require water for drinking, cooking, personal hygiene, laundry, toilet flushing, cleaning facilities, and heating, ventilation and air conditioning. The quantity of water required to fulfil these functions varies according to the environmental setting, but is typically between 180 and 300 litres per person per day. Potable water is generally required to meet these functions due to the consumptive element.

The return water associated with personnel supply are wastewaters, such as sewage effluent (black water) and grey water from hand basins, showers, baths, laundries and kitchens. The composition, and hence the quality, of the black or grey water can vary according to the environmental setting, which may alter due to different diets and chemical usage. The quantity of return water will also vary with the environmental setting but can be in the order of 80% of the supply volume.

Construction and commissioning

The typical uses of water during construction include dust suppression, washing down fleet vehicles, road preparation, concrete batching for foundations and buildings / infrastructure, integrity testing (hydrotesting) of pipelines and pipework during the commissioning process, and, in some instances, to create snow / ice for roads, bridges and well pads in areas where temperatures remain below freezing for extended periods of time (e.g. Alaska, northern Canada). The quantity of water required will be dependent on the size of the operation's facilities and the scale of the hydrocarbon resource being developed. The quality of water needed will range from slightly brackish, which is used for tasks such as dust suppression, to fresh water which is used for tasks such as hydrotesting (to minimize corrosion and maximize the effectiveness of the chemical additives).

Water used in construction activities is generally lost to the environment or bound within the product (e.g. concrete); in both cases this limits the generation of return water. Water used for hydrotesting becomes return water once it has passed through the pipework. The quality is altered due to the addition of chemicals and other contaminants introduced during the commissioning process.

Drilling and well completion

Drilling and completing an exploration or production well requires water for the drilling mud, development of the well, well completions (e.g. cement grout to hold the casing in place), and maintenance of the drilling rigs. The quantity and quality of water required will depend on the length of drilling and shallow geological conditions. These requirements can also change within a single well at different stages of the drilling process, although typically the quality required is that of fresh water.

Mud (including return water) from the drilling process is captured in mudpits/tanks. It contains additives to aid the drilling process, as well as drill cuttings (fragments of rock created by the activity) brought to the surface in the return water. Once the cuttings are removed, the mud is typically recirculated until the well has reached

Figure 3 *The flow of water-based drilling mud in exploration appraisal, development and production wells (not to scale)*

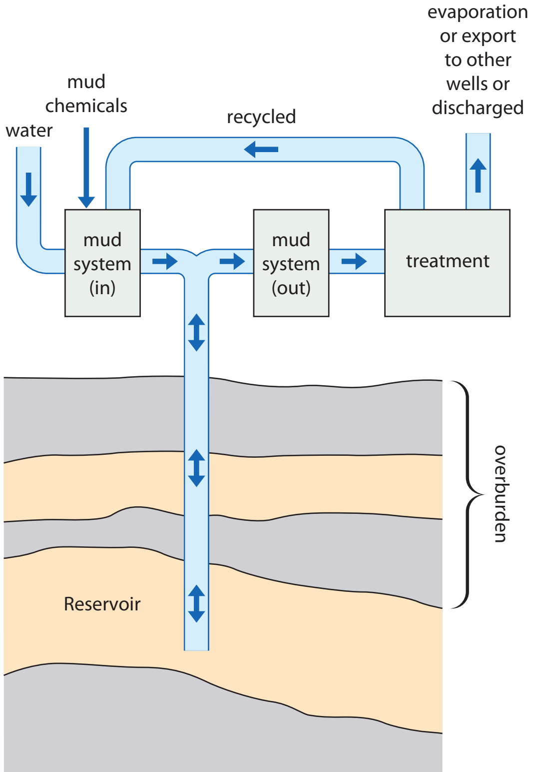


Figure 3 illustrates how water and chemicals are mixed to create mud, which circulates down the well and then back up to the surface. Cuttings are removed at the surface, and the mud is treated prior to recycling back to the original well, or for reuse in other wells. The volume of mud must be sufficient to fill the entire well bore (BP, 2013).

its target depth. Aside from water in the mud, few other return waters are associated with drilling as the water is either bound within the cement or lost to the environment.

Process and operations

Water is used for upstream processing of produced hydrocarbon streams prior to export. For example, it is used in desalters to strip out soluble contaminants from the product stream, within process pump seals (including the circulation pumps), for cooling water, and for steam generation for use in turbines.

For many facilities a large volume of water is associated with steam generation and cooling as well as utility water (such as fire water).

Return water flows commonly encountered from the processing stages include hydrocarbon dew-point condensation, blow-down water and condenser water from the boilers, along with cooling water, which can be re-circulated.

Produced water

Water trapped within the pore spaces of rocks when they are formed is referred to as connate water. Produced water is the term used to describe connate water extracted at the same time as the hydrocarbon resource.

Produced water is normally saline with a high temperature by nature of its long residence time in the rocks and its depth. The co-residence with the resource can also result in the produced water being saturated with hydrocarbons in both free and dissolved phases. In addition it may contain chemicals used in the extraction process, heavy metals in solution, and naturally-occurring radioactive material (NORM).

The following sections include a further discussion of produced water in relation to the extraction of different resource types.

Conventional production

A conventional hydrocarbon reservoir undergoes several phases of recovery, which reflect the pressures and formation conditions. In the primary production stage, natural mechanisms (e.g. formation pressure) result in the movement of the resource within a reservoir to the extraction point as it is forced to the surface. This requires little additional production support and, therefore, little water use above that needed for well drilling and the support of the workforce.

As the recovery process matures, the formation pressure becomes insufficient to sustain economic rates of recovery. Additional methods are therefore required to extract the resource at the surface, termed secondary or tertiary recovery. These recovery methods manipulate the reservoir pressures and fluid mobility to help bring the resource to the surface, and may employ fluids or gases.

Conventional gas production

Gas in conventional reservoirs is under natural pressure. It expands on release of the pressure (for example due to the drilling of a well) and flows naturally up the production well. No additional stimulus is required.

Beyond well drilling, water is mainly used in conventional gas production for gas processing. During this stage, water forms the basis of chemical solutions used to strip impurities, such as water vapour, hydrogen sulphide and carbon dioxide, from the gas. It is also used for cooling and steam generation, particularly when the gas is liquefied for export.

As gas field production matures the proportion of impurities in the gas may rise, requiring further processing to remove them. The quality of water required for gas processing varies depending on the end use. For example, fresh water is needed for steam generation, while saline is required for cooling.

Water vapour (produced water) is present within the gas; small amounts of water are also recovered as part of gas processing (dehydration). This water is not saline but may contain hydrocarbon contaminants.

Conventional oil production

The primary recovery stage (Figure 4) usually has sufficient natural pressure to force the resource into the production well. However, the reservoir pressure lowers as a result of production,

Figure 4 *Water use during the primary oil production phase (not to scale)*

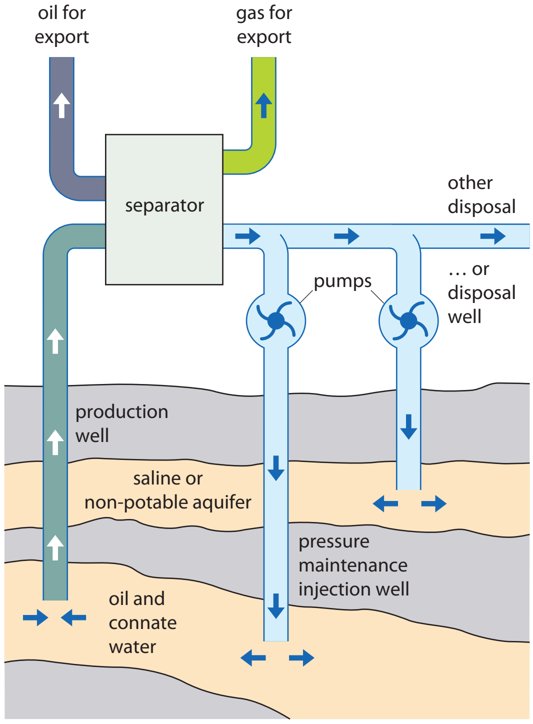
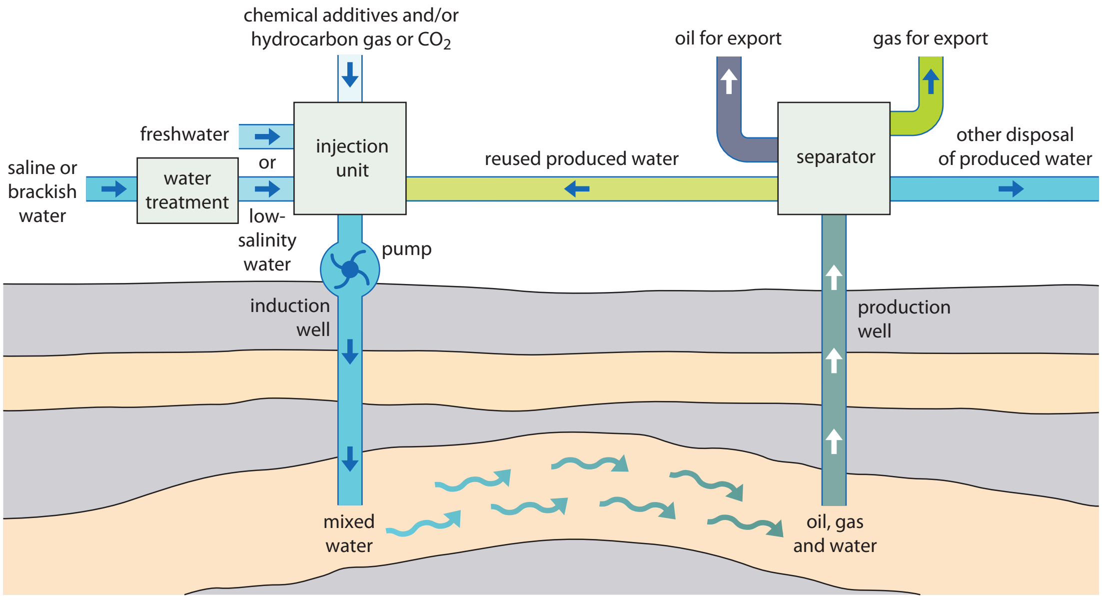


Figure 4 illustrates the primary production process where reservoir fluids, oil, gas and connate water reach the surface through the production well and enter a separator. From the separator, the gas and oil are piped for export and the produced water is either pumped back into the reservoir, through the injection well (shown here with injection directly into the oil zone to maintain pressure), injected into non-potable aquifers for disposal or piped to other disposal facilities (BP, 2013).

requiring injection of external fluids to maintain the pressure, and to displace the hydrocarbons and move them towards the production wells. This process is termed secondary recovery.

Secondary recovery methods (Figure 5) can involve injection of gas into the pore space of the reservoir and/or water, usually into the production zone, known as waterflood. As the production process matures, greater injection rates are required to recover the resource and, particularly in the case of waterflood, the amount of water produced at the production well increases. The ratio of water to resource recovered (the water cut)

Figure 5 *Water use during the secondary oil production phase (not to scale)*



Oil, gas and water reach the surface through the production well (shown on the right of the diagram) and enter the separator. Oil and gas are exported and the produced water is either pumped off for treatment and disposal, or piped to the injection unit for combination with fresh water and/or treated saline or brackish water. Hydrocarbon gases and/or CO_2 can also be combined in this unit to further facilitate oil recovery (see the section on Enhanced oil recovery, *below). The combined fluid is injected under pressure into the reservoir.*

may range from 1:1 in the early stages of waterflood and can increase to 11:1 or higher as the production matures (BP, 2013). Eventually, considerable volumes of injected fluid are recovered at the production wells and it becomes uneconomic to continue production. At this point the secondary recovery stage reaches its limit.

Water mixed with the produced oil stream (produced water) can be separated and used as the injection fluid. An additional water source may also be required to replace the resource recovered from the reservoir.

Saline water can be used for pressure maintenance or waterflood (typically TDS concentrations >30,000 $mg.l^{-1}$ are acceptable). A low-level treatment is usually required to remove suspended, dissolved and biological components that could create a risk of blocking or clogging pore spaces in the reservoir during injection.

Management of the produced water is a key component in conventional production. The properties of produced water are described on page 9. These properties can be altered by the use of corrosion inhibitors and emulsifiers in the primary and secondary stages of conventional oil production. Depending upon reservoir formation conditions, the produced water may be strongly mineralized and/or elevated in temperature, and may contain some hydrocarbons or low levels of NORM. The quality of produced water can also deteriorate as production matures and the quantity increases.

Enhanced oil recovery

Enhanced oil recovery (EOR) uses techniques to alter the fluid properties, displace or dislodge the resource (desorption and dissolution), and prolong the productive life of reservoirs. The technique applied is dependent on the characteristics of the reservoir, such as the temperature, pressure, depth, permeability and fluid properties, and the residual oil and water saturations.

EOR was originally employed to increase the productive life of a reservoir (hence its alternative name of tertiary recovery), but is now also being used as a technique that is initiated at the commencement of some new reservoir developments to maximize product recovery.

Techniques commonly employed in EOR are:

- **Thermal recovery** such as steamflood or in-situ combustion techniques: steamflood involves boilers at the surface heating water to generate steam for injection into the reservoir. This lowers the viscosity of the hydrocarbon, promoting its migration to extraction points. In-situ combustion involves ignition of hydrocarbons within the reservoir to volatilize lighter fractions (and water) and increase mobility, allowing collection at extraction points.
- **Miscible injection:** uses carbon dioxide or hydrocarbon injection to lighten the oil resource and increase its mobility to the production well.
- **Chemical flooding:** uses water mixed with polymers and gels injected into the reservoir to promote desorption and migration of hydrocarbons to the extraction point.

Steam generation and chemical flooding can require the use of fresh water to prevent scale and corrosion, and to allow chemical solutions to operate effectively.

As with primary and secondary recovery, management of produced water is a key component of EOR. The chemical properties of produced water are similar, but may also include any chemicals used as part of the EOR production process.

Unconventional production

Unconventional production refers to the extraction of hydrocarbon resources with low mobility and/or those present in low permeability geological formations. The techniques employed to recover these resources differ from conventional production. Unconventional resources are typically drilled with a horizontal and vertical component.

Oil sands

Oil sands are a mixture of sand, water, clay and bitumen. The bitumen is typically too viscous to flow or be pumped without being diluted and heated. There are two different methods of producing oil from oil sands depending on their depth: oil sands near to the surface can be recovered through open-pit mining techniques; oil sands located deeper underground require specialized in-situ extraction techniques.

After the bitumen has been recovered additional processing is required to convert the resource into synthetic crude oil.

Open-pit mining

Open-pit mining is similar to other conventional mining operations where large excavators are used to dig the oil sands out of the earth and deposit them into trucks. The trucks transport the oil sands to processing facilities where warm water is added to separate out the bitumen. The recovered product (bitumen slurry) is then sent for upgrading into synthetic crude oil, with the tailings (residual sand and fluids) sent to a holding pond.

Water is also used for cooling equipment, sand washing and dust suppression during mining.

Oil sands mining operations require water of slightly brackish quality (TDS concentrations of less than 4,000 $mg.l^{-1}$) and low in concentration of divalent ions such as calcium.

Water is often recovered from the tailings pond for reuse within the mining process (and in some instances for nearby in-situ recovery). Water retention occurs within the tailings pond. The volumes of retained water are dependent on the quantity of fines present and their rate of settlement and consolidation within the tailings pond. Chemical processes such as precipitation and ionic exchange also occur within the tailings pond and can result in recovered water being low in divalent ion concentrations.

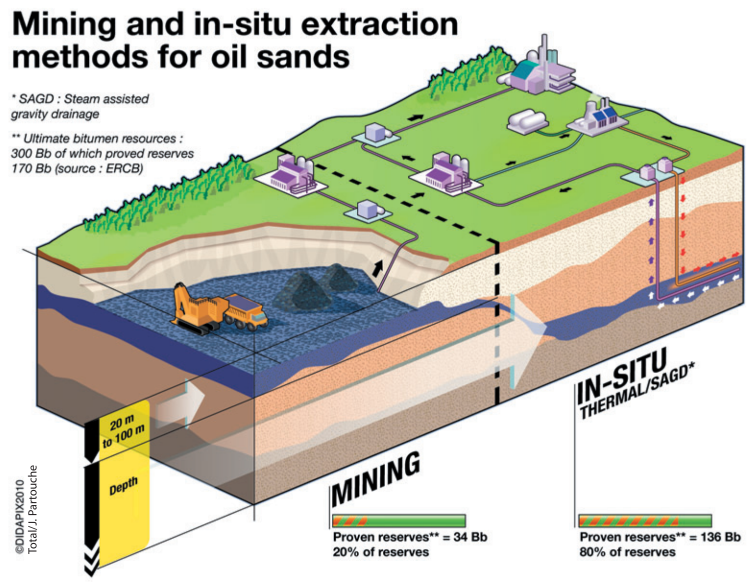
In-situ recovery

Several methods of in-situ oil sands production are used where the resource is located at depths that are too deep for open-pit mining. The most common methods are steam-assisted gravity drainage and cyclic steam stimulation. The purpose of these methods is to lower the viscosity of the bitumen so it can be pumped to the surface through production wells. The water employed in this operation is used primarily to generate steam.

Steam generation for in-situ operations generally requires a quality of water with TDS concentrations of <100 mg.l^{-1} as well as low hardness to prevent corrosion and scaling of steam generation technology. Consequently, a form of treatment is required before water can be used.

In Alberta, Canada it has been reported that approximately 80%–95% of the water used for the in-situ extraction of oil sands is recovered and recycled (Alberta Energy, 2013). Losses of water occur via oil displacement or void filling in the reservoir, via entrainment into the recovered resource, in waste products (e.g. salts) or from venting to the atmosphere. Additional quantities of water may be required to replace these losses and are typically provided from groundwater aquifers.

Figure 6 *Schematic of oil sands mining and in-situ extraction*



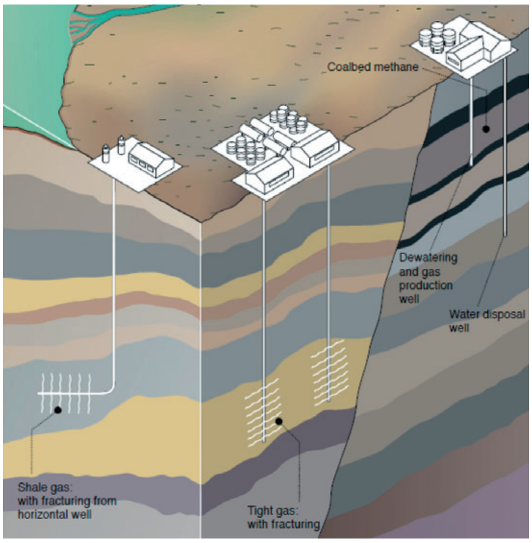
Shale/tight oil and gas

The low permeability of these host reservoirs means that stimulation techniques (such as hydraulic fracturing) are normally required for the economic production of the gas or oil resource. Water can be used as a medium for the hydraulic fracturing process. Other hydraulic fracturing systems use fluids such as oil, propane or methanol in combination with gases such as nitrogen and carbon dioxide.

The subsurface conditions present in the reservoir formation dictate the type of hydraulic fracturing fluids employed, due to the types of additives that can be used within them. In general, three types of hydraulic fracturing fluids are used within the production process: gel-based fluids; surfactant-based foams; and 'slick' water (where the viscosity is lower than standard water):

- gel-based hydraulic fracturing fluids are typically used where there is a high liquid content (oil and/or gas) in the formation and because they are able to carry higher concentrations of coarser-grained proppant

Figure 7 *Schematic illustration of unconventional natural gas extraction facilities*



From left to right: shale gas production using hydraulic fracturing from a horizontal well; tight gas production from a sandstone reservoir using fracturing from vertical wells; coalbed methane (CBM) production using a vertical well to de-water the coal seam; and a deep injection well for water disposal. This illustration is not to scale and is purely representational. (Source: BP, 2013)

into fractures. Gel-based hydraulic fracturing fluid may require a good quality base water for its make-up, although developments in chemical additives are making it possible to utilize lower-quality waters in some cases.

- Surfactant-based foams are used as hydraulic fracturing fluids. The application of these foams is depth-dependent. They can generally tolerate a lower water quality than gel-based hydraulic fracturing fluids, although the water used is generally required to be free of hydrocarbons.
- Slick water hydraulic fracturing fluids are more suited to formations where there is low fluid content. They carry a lower proportion of fine-grained proppant. These fluids can tolerate a lower quality of water (salt and hardness tolerant) in their formulation.

The quantity of water required varies depending on subsurface conditions, the type of well (vertical or horizontal), and the type of hydraulic fracturing fluid employed.

Following hydraulic fracturing, the water that returns consists predominantly of hydraulic fracturing fluids returning to the surface (flowback water). After this, the water is a mix of flowback and produced water, with the proportion of produced water increasing as the volume of returned water declines. Flowback water volumes are typically between 10% and 40% of the initial fluid volume used but can be as much as 75% depending on the formation (Tyndall Centre, 2011; API, 2010; Accenture, 2012). Flowback water tends to return over the first 30 days of the life of the well, after which the water that returns consists predominantly of produced water returned with the oil or gas resource. The volume of produced water varies depending on the characteristics of the reservoir formation, but for gas resources it can be in the range of 1 to 4 m^3 per MMCF of gas (Chesapeake Energy, 2011). The quality of flowback water depends on the original hydraulic fracturing fluid composition, the additives used, and the length of time the fracturing fluid remains in the reservoir prior to well clean-up. The quality of the produced water is dependent on the conditions of the formation, but is usually strongly mineralized with a high temperature. It can also contain NORM, again depending on the formation conditions.

More detail on water use in shale oil and gas operations can be found in a publication published jointly by the International Association of Oil & Gas Producers and IPIECA, entitled *Good practice guidelines for the development of shale oil and gas* (OGP-IPIECA, 2013).

Coal bed methane

Coal bed methane (CBM), termed coal seam gas (CSG) in Australia, is the production of gas from coal seams. The gas is naturally bonded (adsorbed) to the coal and trapped within fractures in the seam. Dewatering of the coal seam, where required, allows the gas to be released and to flow into the production well. Both water and gas are extracted from the same wells. Hydraulic fracturing can be used to increase the production of gas, by increasing the

number of pathways through which the gas flows to reach the production wells. Water is used as a medium for the hydraulic fracturing process.

The quality and quantity of produced water is determined by the conditions of the formation and the degree of hydraulic connectivity between the reservoir and the overlying and underlying water-bearing units. Good connectivity and replenishment can result in better quality but higher volumes of produced water. A lower connectivity can result in a brackish or saline quality of produced water with a lower overall abstracted volume. While the quantity of water abstracted can still be large in the early stages of production (during dewatering), it reduces with time.

Summary of water uses

Table 2 on pages 16–17 summarizes the volumes of water used and the water quality typically required for various tasks associated with the production of different oil and gas resources.

It should be noted, however, that the volumes of water used will vary significantly depending on the type and size of the hydrocarbon resource being developed, the existing infrastructure (if substantial new infrastructure is required, water will be required for construction and workforce supply) and the geological conditions. The table also describes the factors that influence changes in the demand for water over the lifetime of an operation, which in turn affect the water efficiency measures that may be implemented.

Table 2 *Summary of water uses, quality and return flows for different categories of tasks in oil and gas operations*

Sector	Water use	Volume range	Quality requirement (TDS[1], $mg.l^{-1}$)	Water returns	Water demand changes with time
Water uses common across the oil and gas resource types	Personnel	0.18–0.35 $m^3.p^{-1}.d^{-1}$	<600	Black water Grey water	Volumes generally higher during construction when there is a larger number of personnel and lower during operation.
	Exploration and drilling	200–4,000 m^3 per well	<4,000	Drilling fluid recirculation pits	Volumes depend on the length of the well. Total quantities used in an operation will depend on the drilling programme and can be higher in the initial phase of an operation before remaining more constant during production.
	Construction commissioning	0.45–0.55 m^3 per m^3 concrete 1,000-3,000 $m^3.d^{-1}$	<2,000 to >15,000	Concrete wash water Hydrotest water	Hydrotest volumes are dependent on the pipe lengths and diameter. Concrete volumes on the size of the facility. Quantities are generally higher during construction of a facility.
	Process and operations	100-500 $m^3.d^{-1}$	<2,000 to <15,000	Firefighting water Drainage water Condenser water Dehydration water	Volumes are dependent on the equipment used and facility size, but generally quantities remain constant during operation of the facility.
Conventional gas	Production	9,000–>50,000 $m^3.d^{-1}$	>30,000	Scrubbing water	Volumes can remain constant for long periods of time, but are likely to increase as production matures and concentrations of impurities in the gas increase.
Conventional oil	Production (primary)	100–17,000 $m^3.d^{-1}$	>30,000	Produced water	Volumes vary on field size and oil production rates and generally increase with time to maintain pressure.
	Production (secondary)	10,000–>50,000 $m^3.d^{-1}$	>30,000	Produced water	Volumes vary on field size and oil production rates and generally increase with time to maintain pressure.
Enhanced oil Recovery	Production	10,000–>50,000 $m^3.d^{-1}$	<2,000 to <15,000	Produced water	Volumes vary on field size production techniques but generally remain constant during the production period.

[1] TDS = total dissolved solids

continued …

Table 2 Summary of water uses, quality and return flows for different categories of tasks in oil and gas operations (continued)

Sector	Water use	Volume range	Quality requirement (TDS, $mg.l^{-1}$)	Water returns	Water demand changes with time
Oil sands (open pit mining)	Production	10,000–>50,000 $m^3.d^{-1}$	<4,000	Tailings	Volumes vary on field size, but total quantities are on average constant during the production period, but may undergo seasonal variations.
Oil sands (in-situ)	Production	3,000–25,000 $m^3.d^{-1}$	<100	Condensed water	Volumes vary on field size and oil production rates. The quantity on average are constant although variations occur during the production period depending on losses and gains from entrainment in the formation.
Shale/tight oil and gas	Production	3,785–59,000 m^3 per well	<2,000 to 30,000	Flowback water Produced water	Volumes depend on the drilling programme and can be higher in the start-up phase of an operation before generally remaining constant during production.
Coal bed methane	Production	189–1,500 m^3 per well		Flowback water Produced water	Volumes depend on the drilling programme and can be higher in the initial phase of an operation.

References

AEA (2012). *Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe*. AEA Technology plc. Report to the European Commission, DG Environment. Ref. ED57281, Issue No. 17c.

Alberta Energy (2013). *Alberta's Oil Sands: The Facts*. Government of Alberta, Ministry of Energy. www.energy.alberta.ca/OilSands/791.asp#Water Usage Accessed August 2014.

AWM (2012). The proceedings of the Advanced Water Management Conference, 2012.

BP (2013). *Water in the energy industry: An introduction*. BP International Ltd.

BRGM (2011). *Maîtrise des impacts et risques liés à l'exploitation des hydrocarbures de roche-mère : enjeux, verrous et pistes de recherche: Rapport Final*. Bureau de Recherche Géologiques et Minières, report ref. BRGM/RP-60312-FR. September 2011.

CAPP (2013). *About Canada's Oil*. Canadian Association of Petroleum Producers, June 2013.

Frac Focus www.fracfocus.org

King (2012). *Hydraulic Fracturing 101: What Every Representative, Environmentalist, Regulator, Reporter, Investor, University Researcher, Neighbor and Engineer Should Know About Estimating Frac Risk and Improving Frac Performance in Unconventional Gas and Oil Wells*. Society of Petroleum Engineers, Conference Paper. Document ID SPE-152596-MS.

NRC (2010). *Management and Effects of Coalbed Methane Produced Water in the Western United States*. National Research Council of the National Academies.

NYSDEC (2011). *Supplementary Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Programme*. New York State Department of Environmental Conservation, New York, USA.

Secretary of Energy Advisory Board (2011). *Shale Gas Production Subcommittee: Ninety Day Report*. Report to the US Department of Energy.

Texas Water Development Board (2007). *Assessment of Groundwater Use in the Northern Trinity Aquifer Due To Urban Growth and Barnett Shale Development.*

Tyndall Centre for Climate Change Research (2011). *Shale gas: a provisional assessment of climate change and environmental impacts*. January 2011.

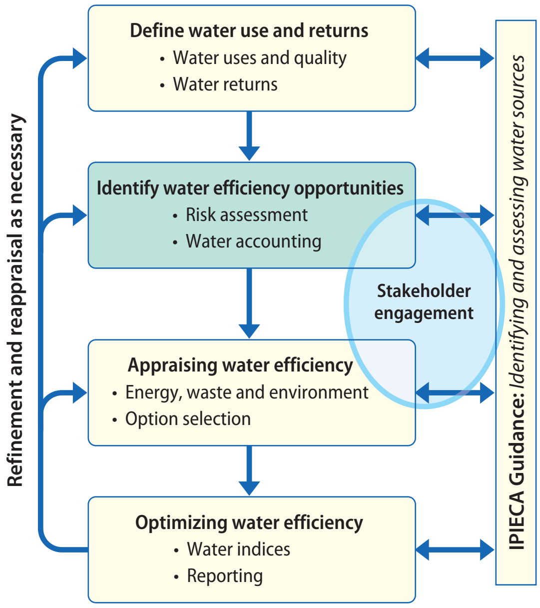
US DOE (2009). *Modern Shale Gas Development in the United States: A Primer*. Prepared by the Ground Water Protection Council for the United States Department of Energy, April 2009.

US EPA (2011). *Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*. United States Environmental Protection Agency, Office of Research and Development. November 2011.

Identifying water efficiency opportunities

This section presents the challenges and risks involved in identifying and managing water efficiency opportunities.

Figure 8 *Efficiency in water use—identifying and managing water efficiency opportunities*



The previous stage of the process identified the operation's expected water uses and the range of quality required as well as the associated water returns. Identifying water efficiency opportunities requires an understanding of the links between these water uses across an operation, how the uses may change over time, and the risks associated with using and disposing of the water. This section frames the process for managing the demand for water, and presents some of the risks that could potentially influence the choice of efficiency measures. The benefits of accounting for water use across an operation are also presented, as this can enhance the potential for identifying water efficiency opportunities.

Demand management

The principles set out on pages 4–5, including the water efficiency hierarchy ('reduce, replace, reuse and recycle') can be applied when managing the water demand. The following tiered questions can be used when identifying efficient water uses:

- Is the water use required or can it be removed?
- Can the water use be substituted?
- Can measures be put in place to lower the amount of water used?
- Can return water from a task be used, or re-employed elsewhere without treatment?
- Is it technically and economically feasible to return water for reuse following treatment?

Generally, the environmental as well as economic benefits decrease as one descends through the water efficiency hierarchy, although replacement of fluid media may result in higher economic and/or environmental disbenefit. Evaluation of the benefits associated with each option is an important component of the water efficiency appraisal, and is further discussed in the section on *Appraising water efficiency opportunities* on page 30.

Collaborative water management initiatives, often termed collective approaches, are being promoted by a number of organizations such as the CEO Water Mandate (CEO, 2013). A number of different initiatives are being developed, underpinned by a shift in attitudes that has led to greater consideration of the potential beneficial resource value and opportunities provided by the efficient use of wastewater and returned water. The concept recognizes that one operation's waste water might be another operation's supply water.

Risk assessment

Risk can be considered as a combined estimate of potential importance (severity) and the likelihood of either the harm or the benefit occurring. Some risks associated with potential harm may also provide opportunities by way of management and mitigation measures. For example, recognition of water stress should create a focus on achieving high levels of water conservation and efficiency. This in turn can often lead to further benefits associated with long-term cost, energy or waste reduction. The process of identifying opportunities for water efficiency needs to take account of the risks associated with the following factors:

- availability of suitable water (quantity and quality) over the life of an operation;
- regulatory constraints with respect to water withdrawal, consumption and disposal;
- social aspects including local reputation, local activism, availability of suitable water for human needs and local food supply; and
- water-related environmental aspects in the area of influence of the operation.

Water risk assessment tools

Water risk assessment tools are available that can help to screen for water risks and identify areas of water stress in the vicinity of a proposed operation. (Refer to the IPIECA guides, *Identifying and assessing water sources* (IPIECA, 2014) and *Review of water risk tools* (IPIECA, 2014a) for a comprehensive list of water risk assessment tools.) Some of these tools, such as the World Resources Institute *Aqueduct*™ Water Risk Atlas and the IPIECA *Global Water Tool© for Oil and Gas*, provide a broad screening level assessment to identify areas of higher water risk that may require a more detailed, local level approach. Additional, and in some cases complimentary tools, such as the Global Environmental Management Initiative (GEMI®) *Local Water Tool™ for Oil and Gas*, have also been developed to help understand comparative water risks at the local level.

These tools enable risks associated with water allocations to be planned for and assessed, and opportunities associated with water management to be identified. Using this information, the risks to operations can be reviewed in priority areas facing water stress, and water management and efficiency plans may be defined accordingly.

Water availability

The amount of effort put into identifying and implementing water efficiency improvements will usually be a function of the water availability in the operation's area of influence. When the availability of water is constrained, understanding and quantifying the risks associated with water use can be critical to the operation's viability, and significant resources may need to be assigned to meet these objectives.

The interaction between oil and gas operations, stakeholders, and changes in water balance and catchment conditions, including collective risks and uncertainties (for example through changing hydrological patterns) is fundamental to understanding the internal water reuse, recycling or water conservation strategies and goals that should be pursued. Further details on assessing water availability are provided in *Identifying and assessing water sources* (IPIECA, 2014).

Regulation

The local, national and international regulations that apply to an existing operation, or to new operations, are an important risk to consider when designing or upgrading a water management system. Some jurisdictions may be prescriptive down to the level of specific water efficiency measures and processes employed on an operation.

Regulatory regimes can cap the quantity of water abstracted, and may specify recycle and discharge requirements. These regulations will present associated risks and constraints that will need to be considered when planning the water management system. Early engagement and understanding of the regulatory environment is therefore important for defining the constraints on the water management system and likely water efficiency requirements.

Social, cultural and environmental considerations

Stakeholders may consider some water-related aspects to be important for the ecosystem services that they provide, or for cultural, spiritual, recreational, economic or biodiversity values. Their views and any issues and concerns they might have about potential impacts of the proposed operation may impose constraints on the water management system. Consultation should be undertaken early and often. IPIECA's *Ecosystem services guidance: Biodiversity and ecosystem services guide and checklists* (IPIECA, 2011) and *Ecosystem services checklists* (IPIECA, 2011a) can assist in managing this risk.

Wastewater streams being reused or recycled for other consumptive tasks can raise cultural sensitivities in certain areas. The sources of water used within certain tasks, and the potential options for reuse, may need to be considered in light of these cultural issues as part of the overall water management system.

Other considerations

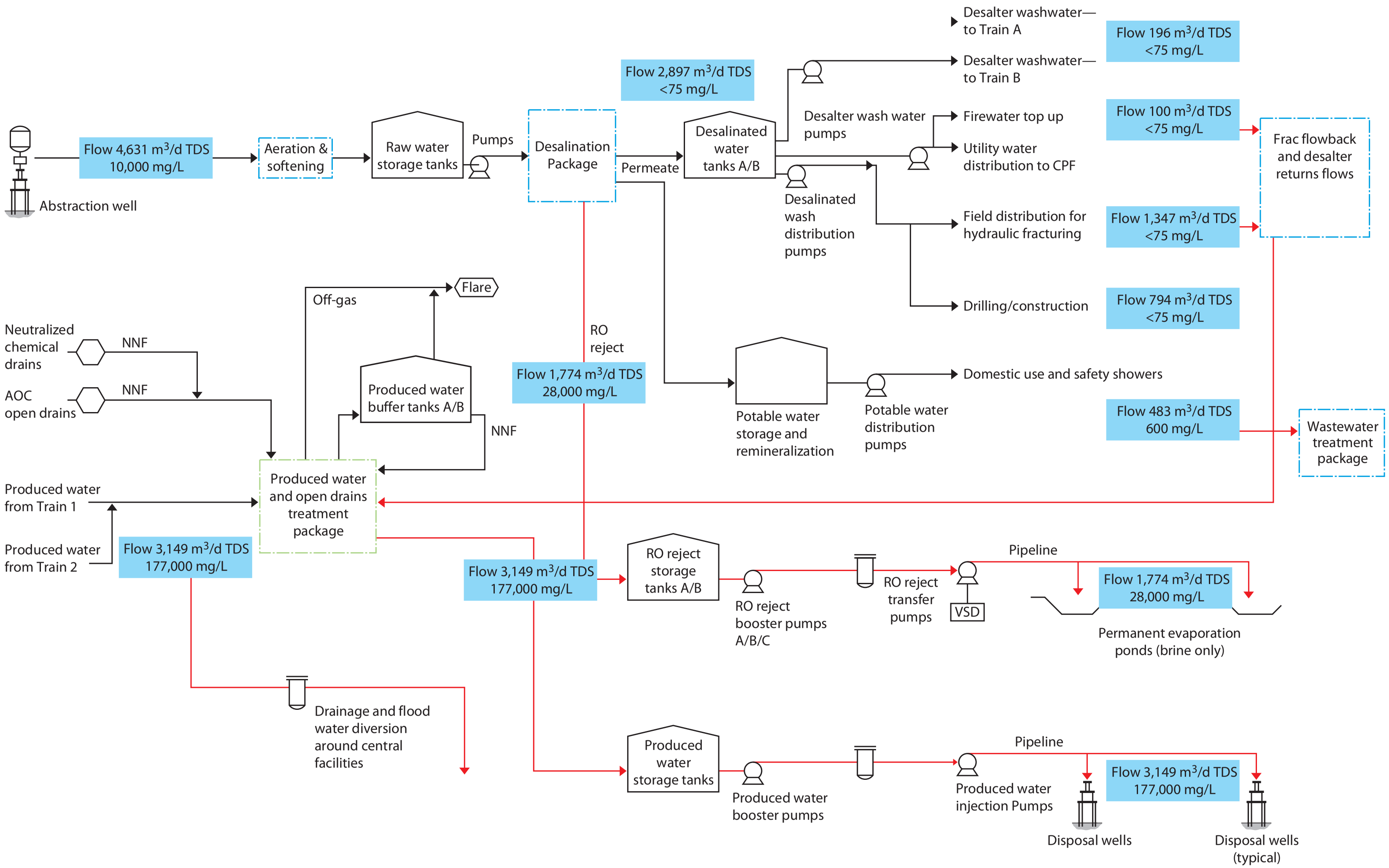
The potential future demands on the local hydrological system, e.g. through agricultural, industrial or urban development, or as a result of external factors such as climate change, may have a impact on the availability of water within an operation's area of influence. This could pose a risk to the long-term supply of water and may need to be factored in to the water management system. IPIECA's guidance on *Identifying and assessing water sources* (IPIECA, 2014) provides further details on assessing potential future changes to water resource availability and should be consulted where this risk is identified.

Water accounting

Water accounting provides quantification of the movement of water through an operation, based on its sources and destinations. It should account for all relevant water flows, including elements such as on-site drainage, which may be a potential source for another part of the operation. The accounting includes the characteristics of water quality, inflows, storage and outflows. This detailed 'water balance' model helps to identify which of the different water quality streams are suitable for use, and provides a basis for identifying water efficiency opportunities. The water balance can be represented by schematic diagram (see Figure 9 on page 21) and/or presented in tabular form.

The water balance is for a single point in time. However, the water flows are dynamic during the life of an operation, and an understanding of

Figure 9 *Schematic diagram of water accounting*



the changes in demand and returns is also required to identify efficiency opportunities. Reviewing these dynamic requirements also informs project planning through establishing:

- the availability of water resources, infrastructure and supporting utilities to support a proposed efficiency measure; and
- where water-using activities may have peak demands which coincide, and which could require management through programming.

The water balance can also serve as a quality assurance tool. Performing a water audit at regular intervals, or whenever there is a major change in process or equipment, can verify the water balance and allow assessment of unaccounted losses (leakage) or gains, verify equipment performance, and identify unnecessary water usage.

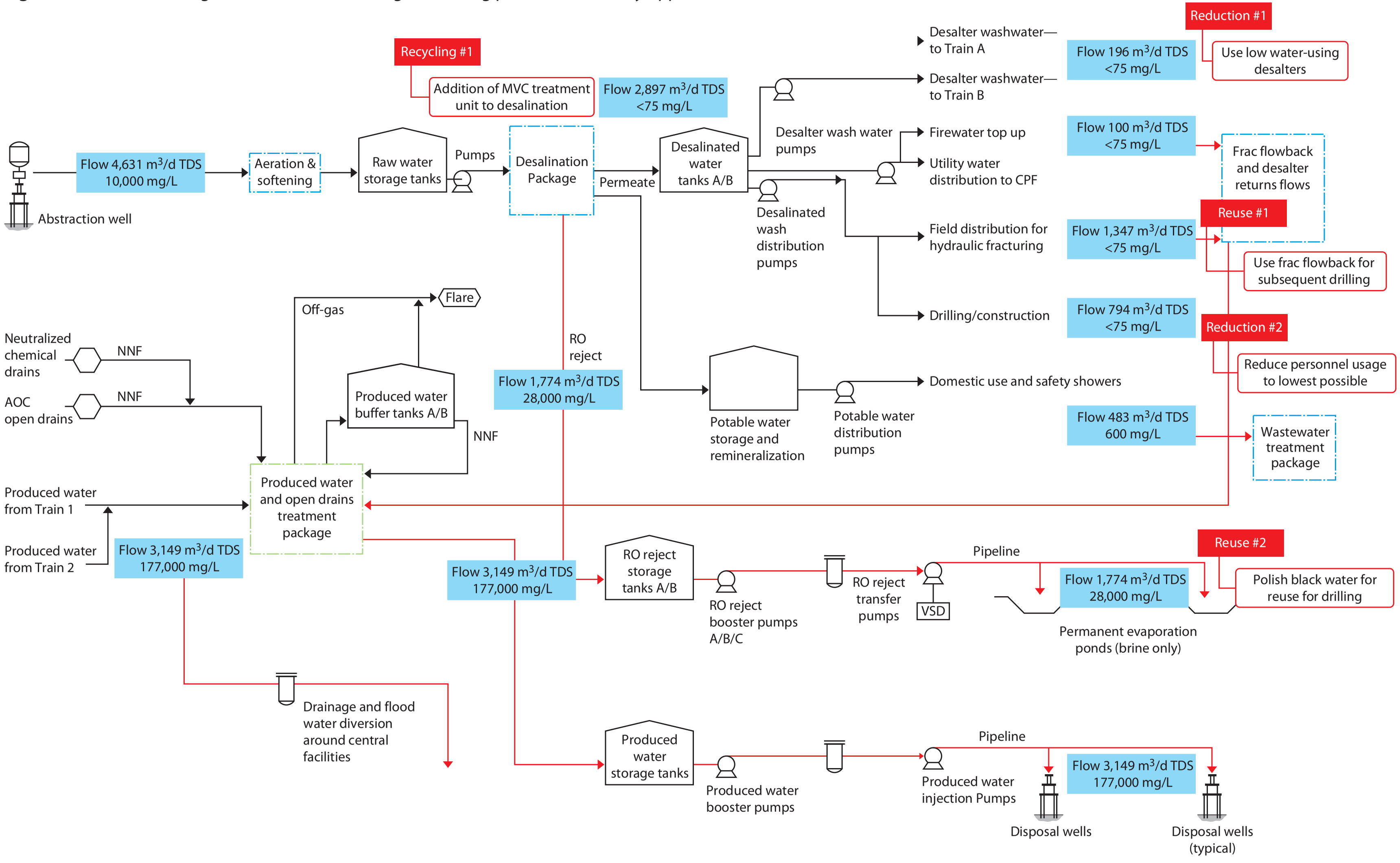
The water balance allows key water flows across an operation to be identified. Effective ongoing management of the water system requires these flows to be monitored and measured. The water balance allows identification of where the installation of metering and monitoring equipment may be most appropriate. A comprehensive system of metering and monitoring allows: greater control of the water management system; an understanding of the quantity of water that is reused/recycled; and the potential for efficiency gains. However, metering and monitoring of every water flow may not be appropriate or beneficial, and the overall requirements and objectives of the operation will need to be considered when selecting where, how and with what resolution to collect the data. It is recommended that, as a minimum, the input and output flows are metered and monitored.

The collected data need to be reviewed so that the performance of the water management system can be assessed, improvement goals set, and water efficiency options identified. The collection and review of reliable data on flow and quality enables effective water management decisions to be made as part of a water efficiency review.

Water efficiency opportunities

While planning the water management system, the assessment of water efficiency opportunities should be prioritized and screened. Applying the demand management principles (see pages 4–5) to the water uses and returns described in the section on *Water uses* (page 7–17) allows some initial water efficiency opportunities to be developed. These are summarized in Table 3 (pages 28–29) and described below but do not form an exhaustive list. Figure 10 provides a schematic illustration of identified efficiency opportunities. Many of these opportunities are already being employed across the oil and gas industry. However, some of them may not be appropriate in every case, and the risks and economics need to be appraised on a case-by-case basis before implementation, based on an assessment of the risks and opportunities, along with the other environmental, social and economic factors. This is further discussed in the section on *Appraising water efficiency opportunities* (page 30).

Figure 10 *Schematic diagram of water accounting illustrating potential efficiency opportunities (in red)*



Reduce

A reduction in water use is achieved by lowering the consumptive use of water in one or more processes. This can be accomplished by using operational controls, eliminating non-essential uses and identifying water uses that may be considered wasteful or extravagant.

Water use can also be reduced through equipment selection or adaptation of plant, such as changing the class of technology, or upgrading technology on existing operations at an appropriate time in the asset cycle.

Metering and monitoring of the water management system offers efficiency opportunities by enabling:

- better matching of supply and demand, potentially enabling a reduction in waste from uncoordinated abstraction and discharge; and
- detection of leakage and losses through the system.

Efficiency opportunities also exist in reducing an operation's volume of returned water.

Produced water forms a major component of the returned water volumes in most upstream oil and gas operations. Reducing the volume of produced water from the reservoir can enhance efficiency by reducing process requirements, downstream treatment and final effluent disposal volumes. A reduction in the volume of produced water can be obtained by down-hole segregation techniques. These can include mechanical (e.g. the selective cementing of perforations) or chemical (gels) to shut off/block high yielding water horizons (AWM, 2012).

Replace

This is defined as the partial or full substitution of fresh water by a different resource, i.e. a lower quality water resource or an alternative media.

Water availability generally defines whether replacement is feasible and appropriate. Utilizing a poorer quality of water (brackish or saline) is a common replacement option used by the oil and gas industry. However, it normally requires some form of treatment to make the

CASE STUDY: Noble Energy—Life-Cycle Water Management programme (Colorado, USA)

The Life-Cycle Water Management programme was created to improve water efficiency in the arid Western USA

In 2011 Noble Energy implemented a Life-Cycle Water Management programme for its operations in the Denver-Julesburg Basin in Colorado, United States. Noble considers its operations in this area as a core onshore US asset, representing a significant percentage of the company's water consumption at an estimated 8.5 million barrels per year. Recognizing this, Noble began implementing a comprehensive water management strategy that begins by targeting a reduction in the amount of water used from tributary stream systems. This system is designed to simultaneously reduce the quantity of water trucked to each site, while ensuring that the right amount of water is delivered to the right location at the right time. In this basin, this means constructing several strategically located storage ponds, pumps and pipelines as alternative means of water storage and delivery for sites. These central facilities help to reduce Noble's overall footprint as they serve multiple sites and reduce the number of truck trips needed to transport water. These strategically located water supply facilities reduce truck mileage by approximately 5 million miles per year in the region and yield an annual reduction of 58,000 tonnes of CO_2 emissions.

water usable. Replacement can, therefore, be more costly and can introduce additional environmental factors such as waste management and energy consumption.

The partial or full replacement of water by gases is also used extensively by the oil and gas industry. Gases, such as produced gas—a complex mixture typically dominated by methane and carbon dioxide—can be used to maintain pressure in reservoirs and enhance production rates, depending on reservoir characteristics and availability. The use of propane, methanol, or oil in combination with nitrogen or carbon dioxide may be a feasible replacement for water in hydraulic fracturing under certain circumstances.

Reuse

This is defined as the use of water that has already been used on one or multiple processes in the same or alternative processes, with or without treatment or with minimal treatment (e.g. filtration).

Produced water is reused for pressure maintenance or reservoir production (waterflood) routinely within the oil and gas industry.

CASE STUDY: ExxonMobil—water recycling in hydraulic fracturing (New Mexico, USA)

Recycling produced water to conserve fresh water resources

Overview

ExxonMobil partnered with a major service company to test the feasibility of recycling produced water rather than using fresh water during hydraulic fracturing of certain types of wells. (Produced water is that which comes to the surface along with the oil and gas.)

Results

An eight-well pilot project in the arid Delaware basin of New Mexico showed that the produced water could be recycled into a workable hydraulic fracturing fluid, conserving more than 1 million gallons of fresh water per well (equivalent to about 200 truck hauls).

Commentary on results

Produced water in the Delaware basin of New Mexico may contain salts and mineral solids in concentrations about eight times higher than seawater, even after initial treatment to remove the heavier contaminants. Water like this is generally considered to be waste and transported off-site or injected into deep disposal wells. Recycling the produced water into a substitute for the fresh water component of a hydraulic fracturing fluid could be an economic and environmentally-beneficial option—if the recycled produced water is available at the right times and in the right quantities near the drilling rig, and if the high concentration of salts and dissolved solids does not impair the fluid, the formation or the equipment.

ExxonMobil affiliate XTO Energy teamed up with a major oil field services company in 2012 to test this feasibility, first in a laboratory, and later in the real-world production setting of eight XTO wells near Carlsbad, New Mexico. The tests confirmed that the fluid used in these wells could successfully fracture the rock and carry sand into the fractures to hold them open, even when based on 100% produced water following minimal treatment. Although this may not be applicable in other basins (since feasibility depends on a combination of factors such as geology, proximity, logistics, scale of field development and water chemistry), the eight-well programme in the Delaware basin was able to recycle its produced water and conserve more than 8 million gallons of fresh water, in addition to saving money and reducing waste.

There are many opportunities for taking return water from one task and reusing it for another without the need for extensive treatment. Some examples within a facility's boundary include grey water use for toilet flushing, and cooling water for dust suppression and/or irrigation, among others. Collection and storage of rainwater within a facility boundary for reuse also offers water efficiency opportunities.

Where return water may not have been considered suitable for reuse within a different task, blending with other water streams may offer a further opportunity for reuse.

Recycle

Recycling is essentially the same as reuse, except that a greater level of treatment is required to make the water quality suitable for use. Technologies are available that can treat and recycle water for most requirements or desired end uses. Consequently there are multiple opportunities for recycling. However, as this involves some form of treatment, the associated economic and environmental costs must be taken into account; these are further discussed in the section on *Appraising water efficiency opportunities* (page 30).

It is not feasible to list all the available recycling opportunities across an operation, hence only the broad classes of returned water are summarized here:

- **Effluent streams:** some treatment processes generate effluent streams that can be captured and further recycled. For example, desalination reject water can be passed back through the treatment plant (double pass system) to increase the quantity of demineralized water from the original raw water withdrawn.
- **Commissioning:** hydrotest water is water used as part of the pipeline commissioning process. Capture and recycling of hydrotest water for subsequent commissioning activities could be a feasible water efficiency measure.
- **Drilling fluids:** water in the mudpits/tanks used for recirculation could be recovered and recycled to remove drill cuttings and polymer additives.
- **Produced and flowback water:** this can be recycled for use in the same or other tasks.
- **Process returns:** processing of the resource can include the removal of water. Opportunities for recycling may exist as part of these normal processing activities, such as recovery of water entrained within condensates and inhibitors such as mono-ethylene glycol

CASE STUDY: Shell—Wastewater treatment for hydraulic fracturing operations (Dawson Creek, Northeast British Columbia)

A new wastewater treatment plant enables Shell to achieve significant reductions in fresh water usage

Shell's Groundbirch natural gas venture in Northeast British Columbia requires significant volumes of water for its hydraulic fracturing operations. To ensure as little as possible is to be taken from the main water supply, Shell and the City of Dawson Creek jointly commissioned the building of a new wastewater treatment plant. With a capacity of 4,000 cubic metres a day, enough water for more than 12,000 Canadian households, the plant will treat wastewater currently released into the Dawson Creek. Wastewater is treated to a standard suitable for industrial and municipal uses and the local municipality could use the water for cleaning roads and watering sports fields.

Shell will pipe its share of the water from the treatment plant to its natural gas operations some 48 kilometres to the west of Dawson Creek where the company operates the Groundbirch gas field, reducing traffic and associated noise and dust. Currently, Shell is recycling approximately 75% of the water it produces. Shell's goal is to reduce and virtually eliminate the amount of fresh water it uses in drilling and completions.

or as part of the dehydration process to remove water from the resource stream.

- **Operational returns:** return waters from laboratory areas, drum washing facilities and drainage from plant areas can be recycled after removal of hydrocarbons and chemicals that may be present within these flows.

Recycling of water also provides additional sources of water for use by an operation. These additional supplies can replace and reduce overall water withdrawals.

Integrated water resource management (IWRM) and collective approaches

Collective approaches are aligned with integrated water resource management principles as water within the catchment or basin will be viewed as an interdependent system rather than a collection of self-contained individual operations. Collective approaches to water management require proactive efforts in collaboration, cooperation and compromise. The three general areas of collective water management are:

- transfers of water across businesses, industries and sectors;
- co-ownership and use of water treatment assets by multiple users; and
- watershed management, whereby water is returned to a natural water store (surface water body or aquifers) and managed according to its optimum beneficial use whilst keeping it within the basin.

Table 3 *Summary of some potential water efficiency opportunities*

Sector	Water use	Water returns	Efficiency opportunities
Water uses common across the oil and gas resource types	Personnel	Black water Grey water Rain water	**Reduction:** employ water saving fittings **Replace:** use of grey water or harvested rainwater for toilet flushing **Reuse:** use of grey water or harvested rainwater for toilet flushing; Harvested rainwater for site preparation, dust suppression, site wash down **Recycling:** use of treated grey water in drilling and well completions, construction
	Exploration and drilling	Drilling fluid recirculation pits	**Reduction:** employ drilling fluids that minimize water losses **Replace:** use treated grey water instead of fresh water **Recycling:** recover drilling fluids for use in subsequent drilling operations
	Construction commissioning Hydrotest water	Wash water Hydrotest water	**Reduce:** plant footprint and concrete quantities to reduce water for site preparation and consumptive use **Replace:** fresh water with poorer quality for dust suppression, commissioning and testing **Reuse:** hydrotest water for site preparation, dust suppression
	Process and operations	Firefighting water Drainage water Cooling water	**Reuse:** for site preparation, dust suppression, site wash down, irrigation water, boiler make-up water
Conventional gas	Exploration and production	Scrubbing water	**Reuse:** recirculate the water for further scrubbing
Conventional oil	Exploration and production (primary)	Produced water	**Replace:** employ gas instead of water for pressure maintenance **Reuse:** utilize produced water for pressure maintenance **Collective action:** use of produced water by third parties
	Exploration and production (secondary)	Produced water	**Replace:** employ gas instead of water for pressure maintenance **Reuse:** utilize produced water for pressure maintenance **Collective action:** use of produced water by third parties

continued …

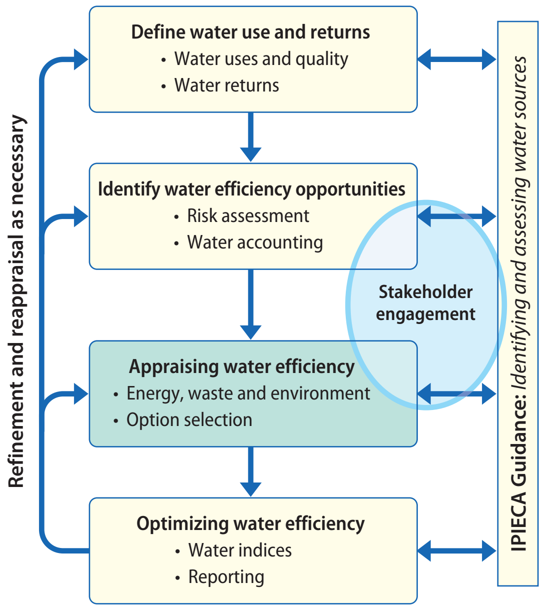
Table 3 Summary of some potential water efficiency opportunities (continued)

Sector	Water use	Water Returns	Efficiency Opportunities
Enhanced oil recovery	Exploration and production	Produced water	**Replace:** employ gas instead of water for pressure maintenance **Recycle:** utilize produced water for pressure maintenance **Collective action:** use of produced water by third parties
Oil sands (open pit mining)	Exploration and production	Tailings	**Recycle:** recover tailings water
Oil Sands (in-situ)	Exploration and production	Condensed water	**Recycle:** recover condensed water **Collective action:** reuse tailings water from nearby mining operation
Shale/tight oil and gas	Exploration and production	Flowback water Produced Water	**Replace:** employ propane instead of water **Reuse/recycle:** re-employ flowback and/or produced water for subsequent hydraulic fracturing
Coal bed methane	Exploration and production	Flowback water Produced water	**Replace:** employ propane instead of water **Reuse/recycle:** re-employ flowback and/or produced water for subsequent hydraulic fracturing **Collective approach:** centralized treatment facilities for handling produced water

Appraising water efficiency opportunities

This section outlines the need to appraise the technical, economic and environmental implications of the selected water management system

Figure 11 *Efficiency in water use—appraising water efficiency*



The previous section described the links in the water management system and explained where potential efficiency opportunities may exist. The efficiency opportunities need to be appraised to determine the technical implications and economic and environmental effects, both positive and negative, that may arise from the proposed water management system. The technical factors that inform the appraisal process are:

- treatment options and capability of the operators;
- energy requirements and available sources;
- waste products;
- social and environmental concerns;
- air emissions; and
- land-use requirements.

These factors, and the considerations that need to be made as part of the appraisal process, are outlined below. The efficiency opportunities can be explored using structured approaches; several methods are available for achieving this, two of which are the 'pinch analysis' and 'value improvement'.

- **Pinch analysis:** this is a methodology for reducing the amount of water used by different tasks, by first calculating the theoretical water efficiency based on quantity and quality, and then attempting to optimize the systems or process operating conditions to achieve this.
- **Value improvement:** value-improving practices (VIPs) are studies designed to reduce costs and risks. They are often undertaken at the early planning stages of a new operation, as well as at the later stages of development (e.g. pre-construction) or following commissioning. VIPs are also known under other names such as value engineering or value analysis studies. The VIP process typically involves a workshop with the relevant technical disciplines to rapidly screen and review a wide range of efficiency opportunities creating a priority of options to pursue for further appraisal.

Treatment

Water efficiency measures based on the 'replace', 'reuse' or 'recycle' options are likely to involve some form of water treatment or preparation before the water can be used for a particular task.

Replacement may introduce a poorer quality water influent stream that will need treatment. Reuse should not require significant treatment, other than filtration before the water can be reused, and recycling requires treatment of the water to bring it back into service for a better quality use.

Reduction in water use does not introduce new treatment processes to an operation, but can have an impact on the end treatment process. This is because the contaminant levels in effluent water can become increasingly more concentrated, reaching levels at which an appraisal of existing or planned treatment plant technology will be required to ensure that it is able to handle the waste stream effectively while meeting the output criteria.

The treatment technologies applied for the replacement, reuse or recycling of water will depend on the volume of water to be treated, its intended use and the quality required. In general, increasing contamination (salinity, oil content, etc.) in the influent water stream requires more complex treatment processes (along with an increase in capital investment costs and energy requirements) to achieve the desired water quality.

Multiple technologies exist for treating water and new technologies are constantly being developed. This guidance document does not detail all the treatment technologies available for use, but it highlights the general types of treatments and the considerations needed when selecting them as part of a water efficiency process.

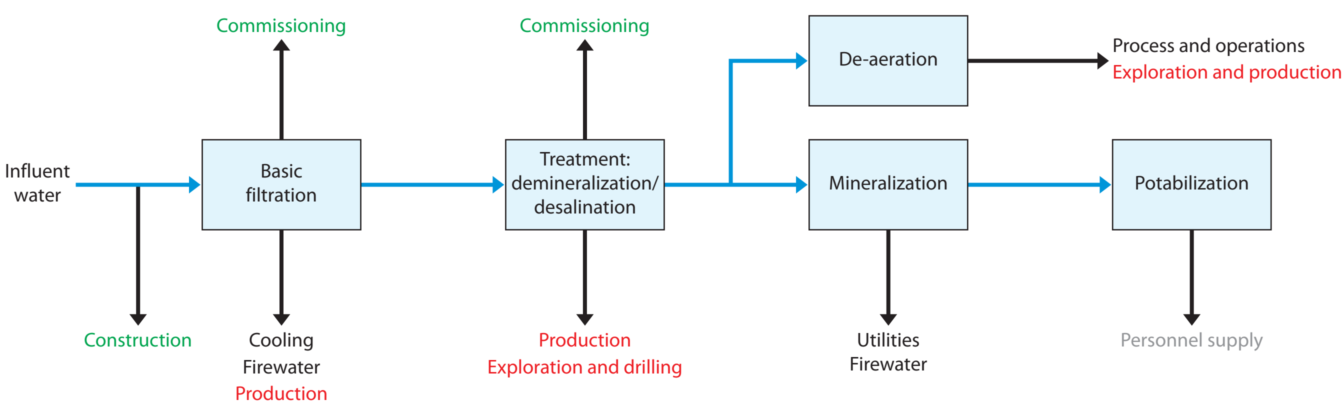
The typical treatment stages that may be considered as part of a water efficiency programme are:

- low-level treatment: pre-treatment and/or primary treatment for returned waters;
- filtration: the use of advanced membranes;
- demineralization and/or desalination of water;
- potabilization and/or polishing of effluents, which includes disinfection;
- wastewater (black/grey) treatment; and
- treatment of oily water.

Some of the main treatment technologies used within the oil and gas industry and their operating ranges are presented in Table 5 (pages 38–39) and further discussed below. Most treatment comprises some form of coupled system (treatment train) to optimize the performance of the process. A schematic treatment train for an upstream oil and gas operation is illustrated in Figure 12.

Water treatment systems tend to rely on achieving the best possible segregation of return water streams, so that a specific treatment method can be applied to an individual stream rather than treating all return water to the highest common treatment level. Furthermore, the mixing of different waters can create incompatibility issues due to dissolved mineral contents. This can result in precipitation in

Figure 12 *Schematic treatment train for upstream oil and gas water uses*



pipelines, water treatment processes and disposal wells. Compatibility modelling can indicate whether co-mingling of waste streams is beneficial, or may help to identify where it may impose constraints on reuse and/or recycling. Where mixing of water streams is proposed, early investigation of the compatibility of the waters should be considered as this may require changes to the water management system. Laboratory scale and/or pilot plant testing should also be considered to ensure a robust solution.

When appraising treatment technology as part of the water efficiency process, an important factor to consider is staff expertise in operating the equipment. Education and training of staff may be required to ensure that the equipment is operated in line with the efficiency goals of the operation.

Low-level treatment

Principally, low-level treatment comprises physical, chemical or mechanical conditioning of the water. Techniques applied include:
- basic filtration using screens and/or sand beds to remove solid materials;
- maceration to break up large solids; and
- settling processes, such as electrical or chemical coagulation where small particles are removed by processes that cause them to clump (coagulate) together.

Filtration

Membrane filtration techniques are advanced filtration methods which enable the removal of finer particles from the influent water. Classes of membrane filtration include primary, micro-, ultra- and nano-filtration, with each class of filter being capable of removing increasingly finer particles, respectively. The operation's requirements and setting will determine the applicability, feasibility, benefits and impacts of the various membrane filtration technologies.

Continual passing of return water through membranes can generate concentrated waste streams that will need to be disposed of. The lifetime of the membrane, and the scaling and regeneration requirements, will also need to be factored into the appraisal of the system as part of the efficiency process.

Demineralization and desalination

Demineralization and desalination both involve the removal of ions, such as cations of sodium, calcium, magnesium and potassium, and anions such as chloride, nitrate and sulphate, from the water. The different terminology applies to the quality of influent water. Demineralization refers to freshwater quality, and desalination to non-freshwater quality.

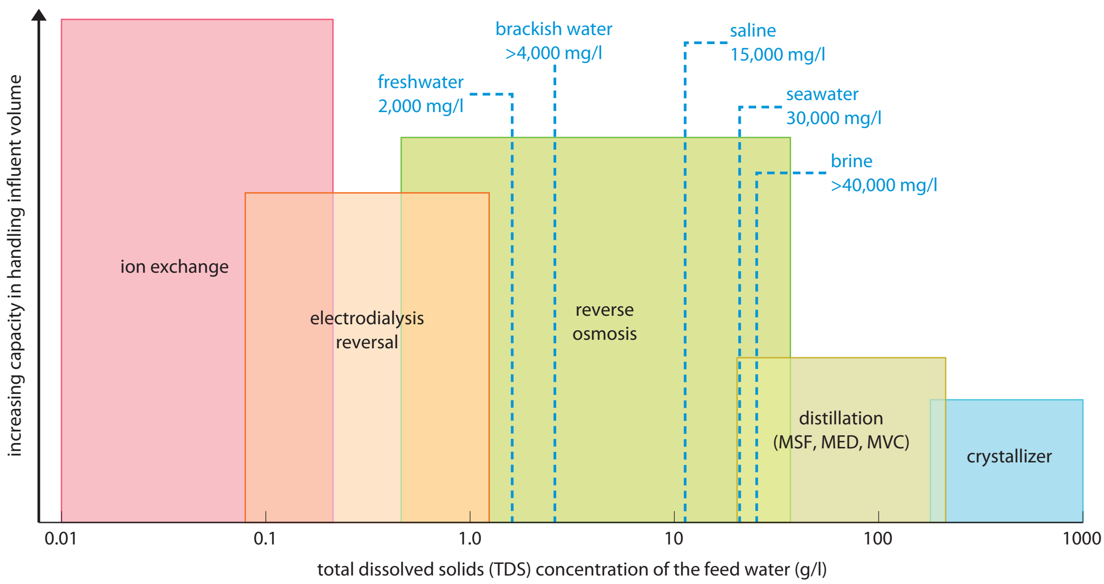
Demineralization of fresh water can be a requirement for certain end uses where scaling and corrosion are of particular concern, for example piping, equipment (e.g. boilers) or where clogging of pores in the reservoir formation is of concern if water is used for pressure maintenance. Removal of these ions can improve efficiency of the task by reducing the downtime for cleaning and maintenance.

Appraisal of the compatibility of a return water for recycling or reuse within processes that require a low ion content could remove the requirement for demineralization in some cases.

Ion exchange is one method of demineralization. It uses resins (a form of polymer) which adsorb the unwanted minerals in the water onto the resin surfaces. The process is reversible, and the ion exchanger can be regenerated using acid, alkaline or salt solutions.

Non-freshwater inputs can be treated to reduce salinity using ion exchange, membrane or distillation methods. The selection and application of the treatment technology is based on its ability to treat water with differing

Figure 13 *TDS concentration range at which different classes of desalination technology are effective*



chemical characteristics. Figure 13 shows the TDS concentration ranges at which different classes of technology are effective.

Membrane technology comprises electrodialysis reversal (EDR), reverse osmosis (RO) and distillation techniques:

- EDR treatment systems use electricity and a series of membranes to remove salts from the water.
- The RO process forces water through a membrane retaining other dissolved or suspended substances.
- Distillation uses heating and cooling on opposites sides of a membrane to separate water into vapour and liquid phases, resulting in distillation.

Distillation technologies consist of multi-stage flash (MSF) distillation, multiple-effect distillation (MED) and mechanical vapour compression (MVC). The underlying principle of these processes is to evaporate the water using heat (or power in the case of mechanical vapour compression) to create desalinated water. A comparison of advantages and disadvantages between the different desalination processes is included in Table 4.

A significant issue with desalination is the disposal of the concentrated waste stream (brine or salt) produced. Additional technologies, such as crystallizers and evaporators (ponds or wind aided) can be used to reduce the volume for disposal. Consideration will need to be given to the amount of solid waste produced by the evaporation of water in these processes. Disposal of the waste will need to be managed, and may also require significant energy input (see the section on *Waste* on page 41). Despite the deployment of additional technology, increasing the amount of water recovered from saline sources may reduce total operational costs. This can be achieved predominantly by reducing the volume of waste brine for disposal. (Refer to the sections on *Energy* and *Waste*, on pages 40 and 41, respectively).

Desalination is increasingly being applied within the oil and gas industry due to water availability constraints. The need to consider the use of desalination, and to appraise the associated

Table 4 *Advantages and disadvantages of different desalination treatment technologies*

Process	TDS input ($mg.l^{-1}$)	TDS output ($mg.l^{-1}$)	Water recovery	Advantages	Disadvantages	Energy consumption kWh/m^3
Electrodialysis reversal (EDR)	<12,000	140–600	85–94%	Low energy consumption High membrane life expectancy (7–10 years) Operates at low to moderate pressures Low investment cost	Currently can only treat brackish water Periodic cleaning of membranes required Leaks may occur in membrane stacks Bacterial contaminants not removed by system and post treatment required for potable water use Removes only charged ions with preferential removal of divalent ions	0.5–6.6
Reverse osmosis (RO)	<40,000	200–500	30–85%	Can treat saline water Low energy consumption Low investment cost No cooling water flow Simple operation and fast start-up High space/production capacity Removal of contaminants other than salts achieved Modular design Maintenance does not require entire plant to shutdown Higher recoveries are possible for multiple pass or waters with lower salinity	Higher costs for chemical and membrane replacement Vulnerable to influent water quality changes Adequate pretreatment a necessity Membranes susceptible to biofouling Mechanical failures due to high pressure operation possible Appropriately trained and qualified personnel recommended Low membrane life expectancy (5–7 years)	2–5.5

continued …

Table 4 Advantages and disadvantages of different desalination treatment technologies (continued)

Process	TDS Input ($mg.l^{-1}$)	TDS Output ($mg.l^{-1}$)	Water Recovery	Advantages	Disadvantages	Energy Consumption kWh/m^3
Multi-stage flash (MSF) distillation	<90,000	<50	50–90%	Lends itself to large capacity designs Proven, reliable technology with long operating life Flashing rather than boiling reduces incidence of scaling Minimal pretreatment of feed water required High quality product water Plant process and cost independent of salinity level Thermal energy can be sourced by combining with power generation	High investment cost High energy consumption Larger footprint required (land and material) High quality materials required as process is susceptible to corrosion Slow start-up rates Maintenance requires entire plant to be shut down Product water requires cooling and blending prior to being used for potable water needs	10–25.5
Multiple-effect distillation (MED)	<130,000	10	50–90%	Minimal pretreatment of feed water required Reliable process low maintenance Tolerates normal levels of suspended and biological matter Heat energy can be sourced by combining with power generation Very high quality product water	High energy consumption Medium investment cost High quality materials required as process is susceptible to corrosion	5.2–11
Mechanical vapour compression (MVC)	<250,000	10	50–98%	Developed process with low consumption of chemicals Low energy consumption Low scale and corrosion potential Low capital and operating costs Portable designs allow flexibility	Start-up requires auxiliary heating source to generate vapour Limited to smaller-sized plants High mechanical power requirement High maintenance requirement Medium investment cost	7–12

References

Turek, M. (2002). *Cost-effective electrodialytic seawater desalination.*

Awwa (2008). *Evaluation of Dynamic Energy Consumption of Advanced Water and Wastewater Treatment Technologies.* Awwa Research Foundation, Denver, USA.

additional technologies, is therefore a crucial element of the water efficiency process.

Potabilization

Treating water to achieve potable quality may require advanced filtration (membranes) to remove pathogens and/or fine solids. Water that has been produced by a desalination process is unsuitable for consumption and requires re-mineralization. Disinfection, typically using chlorine, ultraviolet irradiation or ozonation may also be required before distribution of the water for use.

When recycling water for potable use, consideration should be given to the risks from the carry-over of trace contaminants that may be present in the original return water influent stream.

Wastewater treatment

Following filtration, biological treatment processes can be applied. These processes use organisms to remove biological elements, pathogens and nutrients to further clarify the waste water. Depending on the end-use criteria, disinfection may be used as a third stage of treatment in order to reduce pathogen levels.

Waste water generated by industrial processes is not normally suited to biological treatment due to the organisms being incapable of processing the chemicals present. Blending water from industrial processes with black and grey return water may be sufficient to allow biological treatment. Alternative processes, such as advanced filtration systems, may need to be considered for the industrial effluent.

Waste water that contains high concentrations of contaminants as a result of the water efficiency measures may exceed the capability of the wastewater treatment process. Before attempting to treat black water, the treatment process should be evaluated to ensure that it is able to accommodate such high concentrations of waste; this is essential for preventing toxic shock to the biological treatment organisms and ensuring that the treatment technology remains capable of meeting the discharge criteria.

CASE STUDY: Hess and Target Logistics (crew camp provider)—treatment and use of crew camp processed waste water to enable its use as a fracturing fluid source water (Tioga, North Dakota)

Development and implementation of an economic treatment process for currently unusable waste water to render it usable for mixing fracturing fluid for Bakken wells

The key challenges are:

- finding an economic solution without compromising the quality of the fracturing fluid formulations; and
- conducting a successful field trial of the treatment process and subsequent fracturing fluid testing that requires coordination and agreement among five companies (Hess, Target Logistics, a water plant management company, an equipment vendor and a fracturing service provider).

A successful field pilot at the water treatment plant was completed. The processed waste water was shown to be effectively treated with the method employed, such that the treated water could be used to prepare two stable fracturing fluid formulations utilized by Hess in the Bakken. Laboratory fluid rheology and stability tests conducted by the fracturing service provider confirmed the effectiveness of the treatment in providing a non-potable water source.

The next step is to sign the necessary service contracts with the parties and move ahead with proposal and use of the treated, processed crew camp waste water in Hess fracturing operations.

Oily water treatment

Removal of oils is principally required for produced water and flowback return water, and is an early step in the process to prevent impacts on later treatment steps. A number of methods are available for removing the oil. The first step generally involves the use of an oil separation tank, followed by different technologies, such as gravitational techniques (separators) or flotation methods (dissolved air flotation, induced gas flotation, dissolved gas flotation). Filtration (coalescing) and walnut shell filters may also be used as a polishing step after free-phase oil has been separated from the water. The amount of oil requiring removal will determine the technique or techniques that are required.

Flowback water can also contain suspensions of unbroken polymer gel. The gel suspensions can be a major limitation to subsequent treatment steps as they can get caught in membranes and filters, creating blockages and allowing the carry-over of contaminants.

CASE STUDY: Total and Veolia Water—ultra-filtration of produced water using ceramic membranes (Gabon, Cap Lopez Oil Terminal)

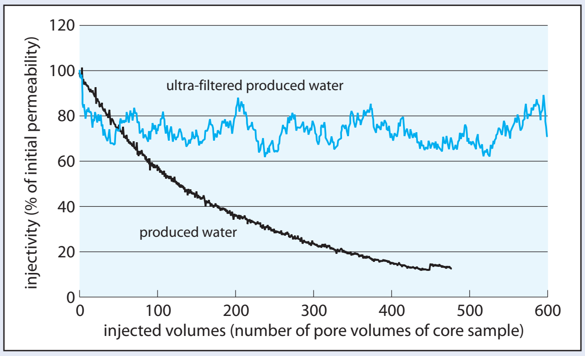
Development and application of ceramic membranes to improve produced water management and enhance produced water reinjection (PWRI) performance

It is estimated that three barrels of produced water are generated for one barrel of oil produced, growing over the life of fields and resulting in large quantities of produced water. The efficient management of water is key for the oil and gas activity while efforts are deployed to meet environmental regulations.

Water injection is needed to maintain reservoir pressure and enhance oil production. Produced water could be recycled for injection purposes with removal of particles and oil. Ultra-filtration with ceramic membranes can achieve this by removing particles up to one hundredth of a micron in size. The use of ceramic membranes is a first for Total and for the oil and gas industry. Research and pilot testing were needed to optimize the operating conditions before an industrial-scale water treatment pilot was installed.

Produced water

Produced water after ultra-filtration



Ceramic membranes successfully removed suspended solids and oil in water down to 10 mg per litre with a recovery rate of 90%. Testing showed that sustained re-injection of treated produced water was possible while re-injection of raw produced water results in loss of injectivity.

Table 5 *Summary of the main water treatment technologies currently used by the upstream onshore oil and gas industry*

	Low-level treatment	Membrane filtration	Potabilization	Ion exchange
Purpose	Primary treatment	Secondary treatment	Tertiary treatment	Demineralization and desalination
Process description	Screening, sand filtration, sludge removal and coarse suspended solids	Advanced filtration, softening, and selective removal of sulphate, ions and colloids	Disinfection and clarification BOD removal, nitrate phosphorus, bacteria and viruses removal of 6 log pathogens	Substitution and sorption of ions using resins/polymers
TSS[1] output (mg.l^{-1})	20	20	20	5
Max particle size removal (µm)	75	75	75	1
Divalent ion (Ca, Mg, Sr, Ba, SO_4) removal	<20%	<20%	50–90%	90%
Fe removal	<20%	20–90%	20–90%	90%
TDS[2] removal	-	-	20–90%	50–90%
Hardness removal	-	-	>75%	>75%
Oil as TPH[3] removal	-	70–80% oil removal	90% oil removal	-
BTEX removal	-	-	-	-
Advantages	Simple in operation, and requires low maintenance	Nearly all non-dissolved organic carbon removed	Low energy	Nearly 100% product water recovery, minimal energy use
Disadvantages	Requires large footprint Frequent replacement/ regeneration of sand filters required	Membranes may need frequent maintenance	Can require large chemical dosing	Sensitive to fouling from organic materials and suspended solids. Requires pretreatment.

[1] TSS = total suspended solids [2] TDS = total dissolved solids [3] TPH = total petroleum hydrocarbons

Notes:
This table is focused on treatment technologies related to water replacement, reuse and recycling; it is not focused on the treatment of process waters, waste waters and produced waters for environmental discharge or third-party use. Quoted values of TSS output and removal rates are typical levels only; there are string variations depending upon many factors including technology and quality of incoming water supply.

	Membrane desalination	Oil separation	Oil removal	Distillation	Crystallization
	Demineralization and desalination	De-oiling	De-oiling	Desalination (including high-salinity brines)	Complete distillation
	Membrane desalination using porous and non-porous media	Separators	Flotation	Thermal, evaporation, distillation and condensing cycles utilizing latent heat recovery	Vertical tube falling film evaporators, and seeded slurry brine
	5	50–200	<30	<5	<5
	1	-	-	1	1
	90%	-	-	99%	99%
	90%	-	-	99%	99%
	99%	-	-	99%	99%
	99%	-	-	99%	99%
	-	50–200 $mg.L^{-1}$	30–100 $mg.L^{-1}$	99.9%	99.9%
	-	80% removal	70–85% removal (dependent upon free and dispersed oil inlet concentrations)	Trace carry over	Trace carry over
	Refer to Table 4 High rejection (>99%) of larger divalent ions and metals and <90% of monovalent salts is expected Product water recovery is between 60% and 85%.	Low maintenance Less impacted by quality changes in feed water	Removes dissolved oil	Refer to Table 4 Established technology Higher quality product water produced Less impacted by quality changes in feed water	No liquid discharge
	Refer to Table 4 High maintenance	May not capture dissolved oil/fine oil particles Oil carry over can occur if skimming and sludge removal is not adequate High pH and heavier oil fractions lowers efficiency	Not ideal for influent water of with high temperatures High solids content in influent lowers efficiency	Refer to Table 4 Can require high energy input and high investment	High energy and investment cost Solid disposal required

Table 6 *Energy requirements across the water cycle (CEC, 2005)*

	Energy use (kWh/m^3)	
Water system component	**Low**	**High**
Supply and conveyance	0	3.2
Distribution	0.14	0.3
Waste water collection and treatment	0.22	0.9
Waste water discharge	0	0.1
Recycled water treatment and distribution for non-potable uses	0.1	0.3
Treatment for potable or good quality use	0.02	25.5

Energy

Energy is essential for water withdrawal, conveyance, treatment and disposal. A study by Powicki (2002) identified that electricity represents approximately 75% of the cost of municipal water processing and distribution.

Table 6 provides a summary of typical energy requirements across a water management system. A direct relationship exists between moving water and the energy input. The energy requirements for supply and conveyance components will vary significantly according to the environmental setting of an operation. Surface water supplies that can be gravity fed may require no energy input, or only low energy inputs, whereas long-distance pumping and increases in elevation are likely to require high energy inputs. Consequently, the link between water use and energy is critically important in the selection and appraisal of the water management system and the efficiency opportunities selected. The development of an energy balance alongside a water balance should be considered to appraise potential water efficiency measures and to identify opportunities for energy efficiency measures to be incorporated into the water management system.

The water-energy link also extends to indirect emissions from greenhouse gases resulting from the use of energy. This is frequently referred to as the water-energy-carbon nexus, which requires balancing as part of the water efficiency process.

If a replacement water source is located a long-distance away from the operation site, or at a lower elevation, the energy required to convey the supply can become considerable. Historically, some major industrial desalination projects have been completed involving distances of hundreds of kilometres. The use of poorer quality water generally requires more energy for treatment to achieve the required specification than that required for better quality water. Where gas is used for replacement, the transport and compression of the gases can also increase energy expenditures. Careful consideration should be given to the energy implications of replacement, to ensure that a real benefit is achieved.

A reduction in water use can lead to a beneficial reduction in energy consumption due to proportional reductions in conveyance, treatment and disposal.

Energy savings can also be realized if return water is reused rather than disposed of. In many cases, the deep disposal of some return waters into injection wells is considered the optimum solution. However, high-pressure pumping is required to overcome formation pressures, and this usually entails higher energy costs. Removal of this disposal route can therefore have benefits in terms of reduced energy requirement beyond those achieved through water recovery.

Attaining improved water quality through recycling requires treatment and conveyance of potentially large volumes of water, and significant amounts of energy can be used in this task. In general, increasing the amount of water treatment results in an increase in energy consumption (Brandt *et al*., 2012). Energy efficiency measures can be incorporated into the water management system to reduce the energy impact and should also be considered as part of the water efficiency appraisal process.

Multiple operators in an area may experience the same difficulties in accessing and supplying water of the right quality and amount. Cumulative energy requirements could be substantial. Applying a collective approach can achieve reductions in cumulative energy use where shared facilities can be operated, or where return water can be shared across operational boundaries. The additional pumping effort required for distribution still needs to be considered; for operations separated by large distances this could partially or completely offset benefits arising from a collective approach.

Waste

Understanding the wastes that can be produced by the proposed water efficiency measures can be fundamental to assessing the feasibility of an opportunity. Waste management can have implications, both positive and negative, for energy, economic, social and environmental factors. Planning for waste management therefore needs to be considered in the early stages of appraising the water efficiency opportunities.

Replacement with poorer quality water is likely to increase the need for treatment of the water before its use. Treatment processes generate their own waste by-products, such as effluent reject, sludges and solid wastes (e.g. salts). In certain instances the quantities of these waste by-products can be substantial and, depending on the source of the water, may contain hazardous compounds (such as NORM or hydrocarbons). Beneficial reuse of the waste by-products may be possible depending on the project setting. Effluent reject could be recycled in the first instance, prior to disposal. Salt may have a value to other industries (e.g. magnesium chloride-rich solutions have several important uses as a raw material for magnesium oxide and other magnesium containing chemicals) and sludges may have an agricultural end use. Figure 14 illustrates some of the potential benefits that can be realised from waste streams. The ability to store, handle, reuse or dispose of these waste by-products needs to be appraised. Any reuse of waste by-products should be evaluated thoroughly to assess the environmental consequences of their 'next' use.

A reduction in the volume of water used can have an impact on the end treatment process, as the concentration of wastes in influent water increases, possibly to the extent that it may not be technically feasible for the treatment plant to attempt to process it. Appraisal of the treatment plant will be required to determine the levels of waste in the return water that it is able to accommodate, while meeting the output criteria and handling requirements of the associated waste products.

The reuse of return waters for other applications reduces the need for disposal of the waste water. However, the concentration of wastes in the overall volume of return water may increase, and this will require appraisal of the treatment plant to determine whether it is able to accommodate the levels of waste in the return water.

The recycling process of treating water to achieve a progressively higher quality does not necessarily destroy contaminants but does tend to result in the creation of concentrated effluent streams. This effect of creating highly concentrated waste streams needs to be appraised to avoid the need for significant additional treatment and processing at the point of disposal, which could be counter-productive to the intended water efficiency initiative.

The waste by-products from a treatment process could be a valuable source/resource for another industry or operator in the area. An appraisal of the marketplace in the area surrounding the operations could help to identify a beneficial opportunity and contribute to a collective approach to the management of water.

Social and environmental

The principles of the IPIECA guidance on *Identifying and assessing water sources* (IPIECA, 2014) should be considered when replacing a water source with an alternative water supply. If the supply is some distance away, the social and environmental impacts from conveyance of the supply to the operation need to be considered, as do the effects of withdrawal.

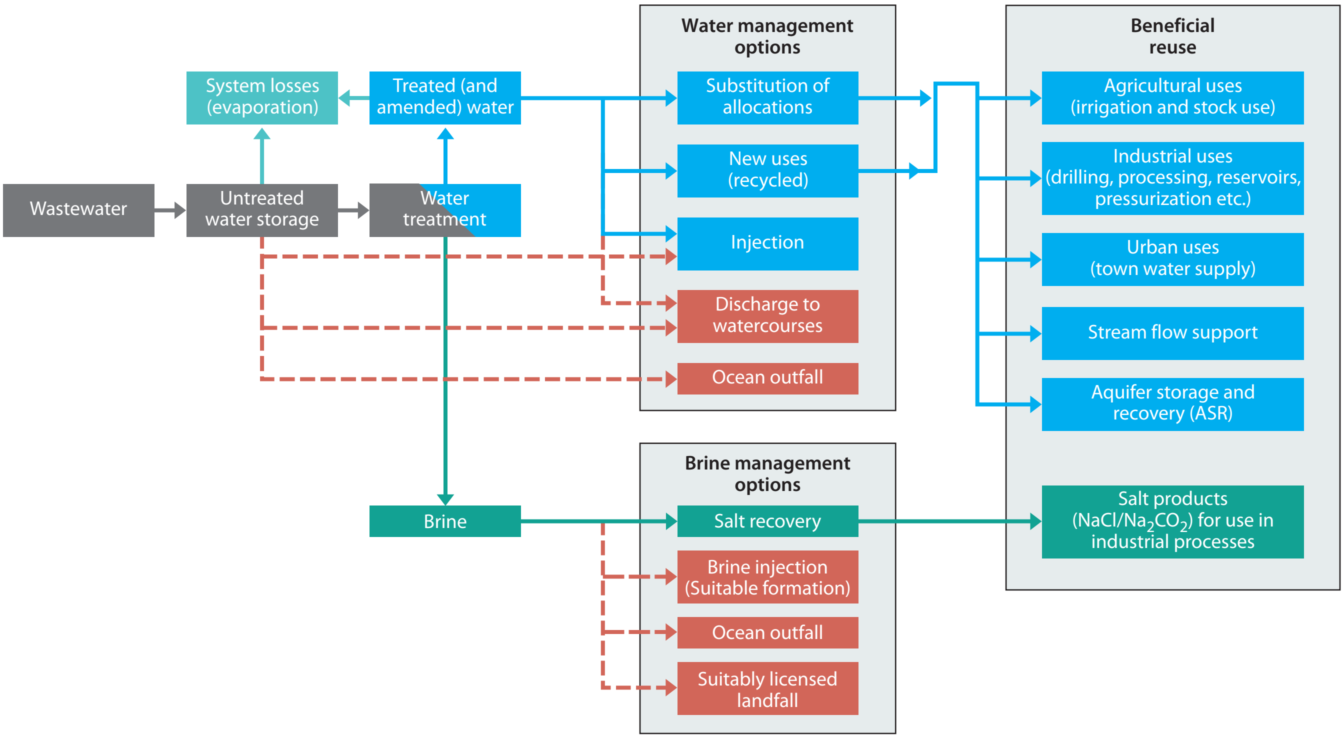
A reduction in water use is generally perceived to have positive benefits for the environment and community. Treatment facilities require fewer chemicals, and hence less truck movements and associated emissions to deliver them.

In existing operations, where disposal into water bodies that are of social and environmental importance has been occurring over a sustained period of time, any reduction in the disposal volumes may cause a change in the dynamic equilibrium of these water bodies and ecosystem services. Provision of a supply of treated water for local use, or the development of a local economy based around the by-products generated from the treatment process may have positive social effects but can also create a local dependence on the resource. Operations are transient and may not be sustained beyond the life of the resource; it is therefore essential that an appraisal of the environmental and social impacts that are dependent on the operation is undertaken to understand the long-term effects of water efficiency decisions. Stakeholder engagement will be an important part of this process and can assist in the decision making process. For further information on stakeholder engagement see *Identifying and assessing water sources* (IPIECA, 2014).

The reuse of returned water is generally perceived to have a positive environmental and social effect by reducing overall water withdrawal. However, as noted in the section on *Regulation* (page 19) it is unacceptable in many countries for certain return waters to be employed for personnel supply uses, even after recycling. An appraisal of the social and cultural sensitivities concerning the recycling of certain return waters may be required, as this can have implications for the overall water management system and may constrain other options for reuse, e.g. via blending / dilution, etc.

Taking a collective approach to water management can offer positive environmental and social effects through lowered water withdrawal requirements and discharges, as well as providing beneficial reuse for treated water. A series of potential wastewater management options under a collective approach is illustrated in Figure 14 on page 43.

Figure 14 *Conceptual water management options within a drainage basin*



Air emissions

Water efficiency measures can introduce both direct and indirect changes in air emissions. For example, a particular action or treatment process may result in a direct change in emissions (e.g. sulphur and nitrous oxides), whereas variations in power consumption lead to indirect changes in emissions, principally greenhouse gases. Indirect changes (see *Energy* on pages 40–41) and direct changes are described further below.

The use of gases to replace water in the production of resources is widely used by the oil and gas industry. The increased use of this technique is, in part, due to a greater understanding of the subsurface processes taking place in the reservoir. However, this technique can increase the acidity and 'souring' (hydrogen sulphide content) of the recovered resource. This increase in hydrogen sulphide requires its removal from the resource, which can potentially lead to increased emissions of sulphur dioxide to the air. Replacement of fresh water with poorer quality water may also have an effect on emissions (off-gases) through the requirement for treatment prior to use. Similarly, the treatments required for the recycling of return water will also lead to off-gas emissions.

The level of change in emissions is dependent on the technology being used. In certain settings, air emissions may be of concern to local populations, or they may be a risk to sensitive ecosystems; hence the selection of appropriate technology may be constrained by emissions criteria.

Operating a water transfer system on a drainage basin scale as part of a collective approach could reduce the influence of direct emissions by reducing the spatial extent of the sources.

Land use

Implementing water efficiency measures requires consideration of both the plant siting and footprint. The availability of land required to meet water efficiency requirements may be restricted. Facilities that cover large areas may be efficient in their water use but could still have environmental and social impacts, and may incur increased energy consumption from conveyance and other challenges inherent in operating a dispersed site.

The requirement to meet environmental obligations, such as maintaining animal migratory routes, protected habitats or flora species, may require a facility to be segregated. Where these obligations exist, the energy requirements for conveyance as well as plant layout may need to be considered as part of the water efficiency appraisal process.

Replacing the raw water stream with alternative supplies or fluid media may result in an increase in the amount of equipment required to make it useable, but also to store, handle or dispose of any waste by-products. For example, the use of gas as a medium for pressure maintenance and production can require additional surface facilities for sulphur removal from gas injection, while the use of deep wells for the disposal of effluent will require well pads and pipe runs. These all have the potential to expand the footprint of an operation.

A reduction in consumption can have a beneficial effect on the plant footprint as lower use can lead to smaller storage facilities and therefore reduced land requirements.

Balancing the supply of return water with the demand for its reuse may require extra space for additional pumping equipment and a potential need for separate pipe runs. These all have the potential to increase the site footprint. Metering and monitoring can assist in managing the supply and demand needs. Appraising the feasibility of storage requirements and durations, as well as the space for housing them, needs to be considered as part of the efficiency options review.

Where recycling of return water is an opportunity, an appraisal of the need for specific treatment plant may be required, along with the potential need for additional land to house both the plant and associated pipe network.

Where constraints exist with respect to the site footprint, a collective approach to water management systems through the sharing of facilities could offer a benefit. Where these facilities are located some distance from the operational site, the length of pipe runs and power supply (see *Energy* on pages 40–41) will need to be included in the appraisal process.

Options selection

The appraisal of an efficient water management system requires the consideration of technical, economic, environmental, social and regulatory requirements. An assessment of the options needs to consider the collective impacts, both positive and negative. Accordingly, some type of formal options appraisal is required to enable all the relevant factors to be summarized into a format that enables a transparent and auditable decision to be made about the water efficiency measures to be implemented. For more information on the options appraisal process see *Identifying and assessing water sources* (IPIECA, 2014). The approaches set out below are common to, or complement, those approaches and are expanded to include the water efficiency opportunities to be appraised.

There are several approaches to options appraisal that can be used depending on the planning needs, data availability and project phase. They range from qualitative to quantitative analysis and may use indicators that are benchmarked according to performance standards that are being followed by the project.

Appraisal techniques can be broadly divided into those that do not necessarily rely wholly or largely on monetary valuations, and those that do. The full costs and benefits of water efficiency measures may not be fully identifiable or realized unless an analysis of the overall economics (internal and external costs and benefits) is undertaken. However, non-monetary techniques help to narrow down the multiple options available for water efficiency measures prior to undertaking a monetized appraisal.

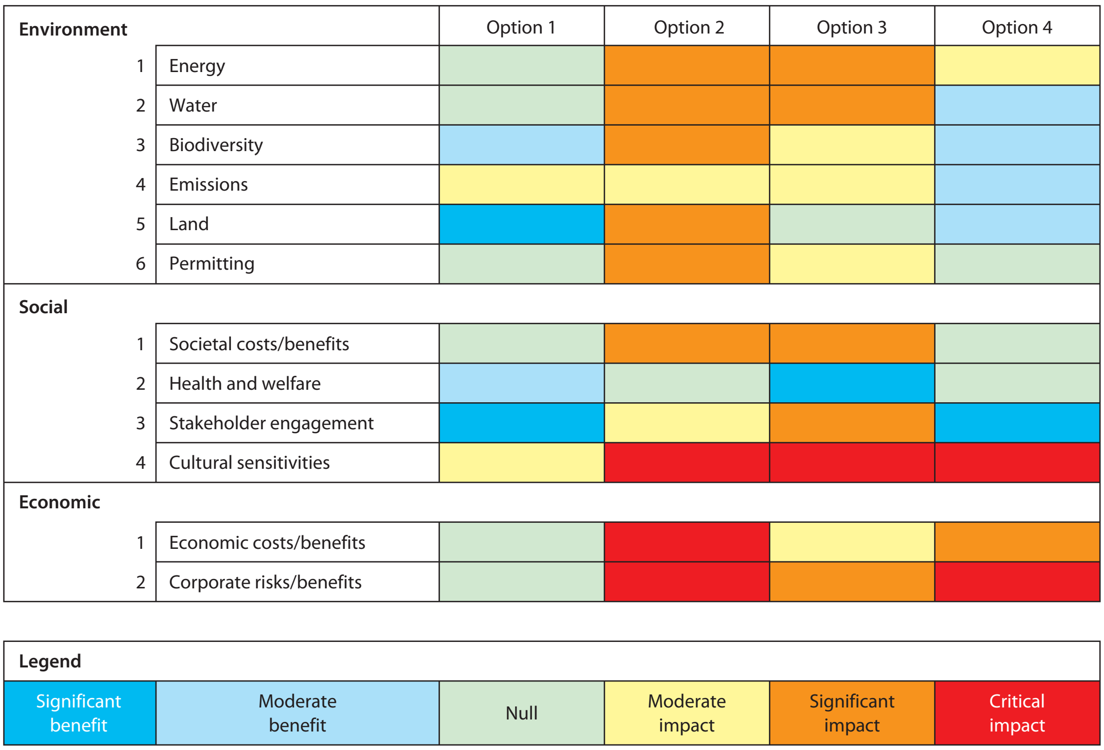
Non-monetary analysis

Multi-criteria analysis (MCA) is a general term that can be applied to a range of techniques that do not rely on monetary valuation and so can incorporate factors that may be quantified but not valued, or which can only be assessed in qualitative terms.

MCA techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable possibilities from unacceptable ones. There is the potential for significant impacts and costs associated with the selection of water efficiency measures, and it is therefore preferable to shortlist the options before undertaking a valuation exercise to reach an optimal outcome.

While a wide range of MCA variations have been developed, a standard feature is a 'performance matrix', in which each row describes an option and each column describes the performance of the option against a specified criterion. The criteria should be clearly specified, ideally measurable (at least semi-quantitatively) and, as far as possible, mutually independent. An example MCA matrix is shown in Figure 15.

Figure 15 *Example performance matrix for multi-criteria analysis*



In a basic form of MCA this performance matrix may be the final product of the analysis. The decision makers then have to assess the extent to which the objectives are met by the entries in the matrix, and ensure that there are no unjustified assumptions causing incorrect ranking of options.

Monetary analysis

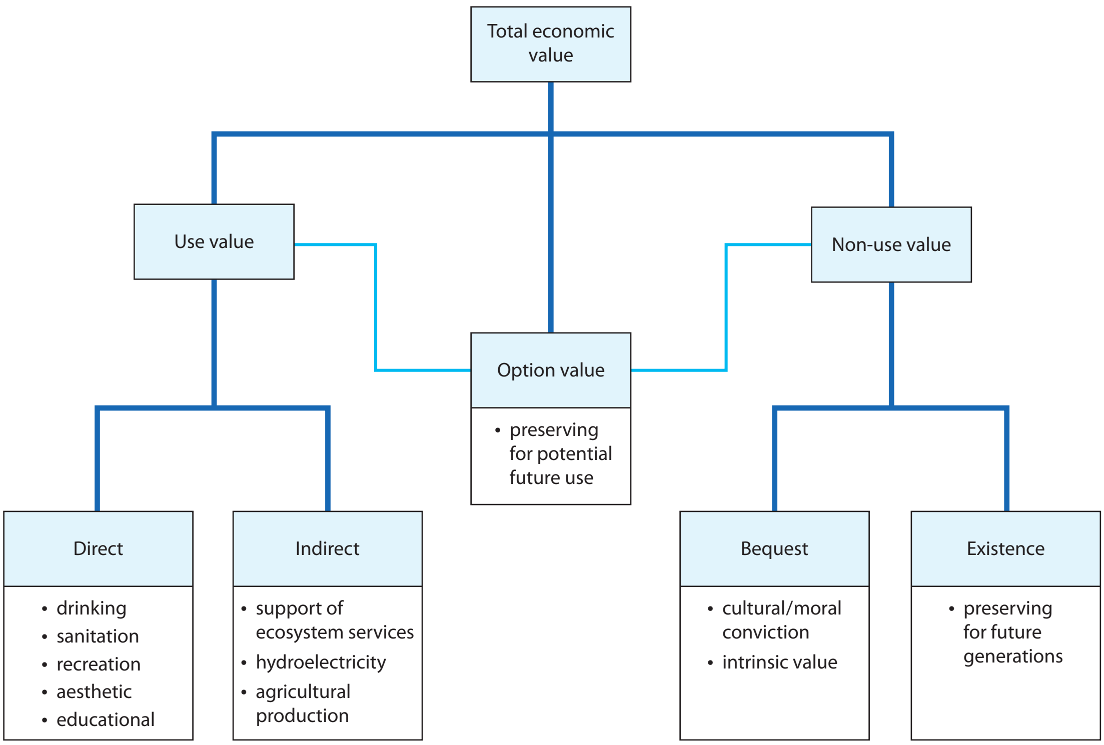
Potential efficiency measures are usually evaluated using monetized assessment techniques incorporating 'as low as reasonably practical' (ALARP) principles so that potential water efficiency gains can be weighed against other factors, such as carbon, energy, environmental and social impacts, rather than just the financial cost.

Estimating the value of water is a key component in appraising water efficiency measures, as the value is often less than the price that is paid.

However, water valuation can be a complex and controversial, process. This is because it is relatively straightforward to apply a monetary cost to fixed assets such as treatment systems, pumps, pipelines and operational expenses such as energy consumption, whereas water can provide several different societal benefits which have differing values. Determining monetary values for these benefits is usually the most problematic aspect of this process. These values may be derived using a well-developed economic theory of valuation based on willingness to pay or willingness to accept compensation for loss.

Economic modelling applies the concept of total economic value (TEV) as a framework for the valuation of water. One approach to implementing the TEV concept involves identifying different uses and services that a particular environmental product or service provides, and is the sum of use, non-use and option values, defined as follows:

Figure 16 *Representation of total economic value for water valuation*



- Use values relate to direct (e.g. consumptive) and indirect (e.g. ecosystem services) uses of water.
- Non-use values include the existence and bequest (preservation for future generations) of the water.
- Option value is the potential for future direct or indirect use.

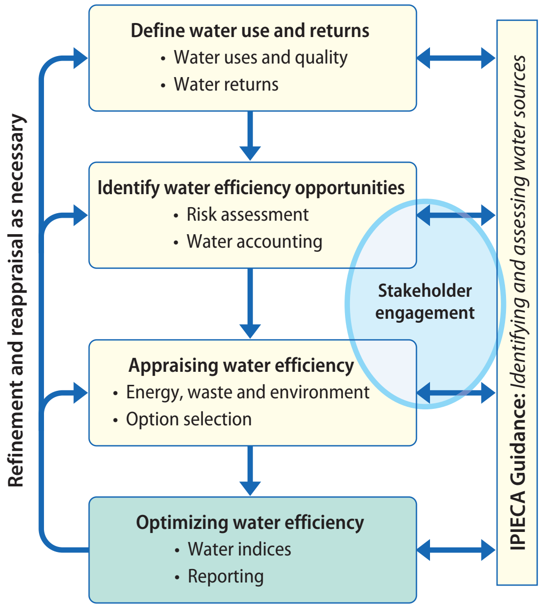
Figure 16 illustrates the TEV and its constituent parts for a water valuation. A guide to water valuation methods is provided in WBCSD, 2013. WBCSD have also prepared a companion guide covering ecosystem valuation.

It should be noted that the unit value assigned to the supply water is often a weak constraint on decision-making, as water is generally priced well below its market value as a social commodity. This can result in an underestimation of the benefits of increased water efficiency. For facilities and operations located in areas identified as being water-scarce, a practice that may be considered is to assign a conservative value for raw water to encourage facilities to find solutions beyond the local market price for water.

Optimizing water efficiency

This section outlines the importance of continuous optimization and improvement of water efficiency measures.

Figure 17 *Efficiency in water use— optimizing water efficiency*



The factors that need to be considered as part of the selection of the water efficiency measures appropriate to the operation have been set out in the previous sections, and an auditable decision process defined. The implementation of water efficiency measures requires continual review to demonstrate the value of the installed processes and enable continuous optimization and improvement to be identified. Selection of the appropriate index to define and quantify the water efficiency improvements at an operation is important. It will need to be considered as part of the overall approach to water efficiency to ensure that the correct data are collected.

Water use in upstream onshore oil and gas production was described in the section on *Water uses* (page 7), which showed that it is highly variable depending on reservoir type, maturity of the production process and formation conditions. Consequently, a comparison of water use between operations is not straightforward.

Standardized reporting in water management is important for understanding the performance of an operation, and can also provide a broad indicator, both for an organization and across the wider industry. Standardized reporting methods for the oil and gas industry are presented in the IPIECA guidance on voluntary sustainability reporting (IPIECA/OGP/API, 2010—update due for release in 2015). This sets out the standard indicators for reporting on water use as:

- E6: Fresh water—report quantity of fresh water withdrawn and/or consumed (the amount of fresh water withdrawn less fresh water returned) by oil and gas operations.
- E9: Discharges to water—quantify hydrocarbon discharges to a water environment.

Water indices

There are many approaches (water indices) for recording and reporting water efficiency and what may be appropriate for one industry or sector may not be appropriate for another. A summary of some of the available indices currently applied is provided.

Rate of return

The Global Reporting Initiative (GRI) Guideline indicator EN10 applies a water efficiency index based on the percentage of the total volume of water that is recycled and reused (rate of return). The indicator includes all return water that is used to meet water demand.

The GEMI® *Local Water Tool*™ (LWT™) *for Oil and Gas* uses the GRI EN10 format as one of its reporting options.

Water/product ratio

This index is based on the amount of water used per unit of production. Within the oil and gas industry this can be between water withdrawal or water consumption and a defined unit of production such as a barrel of oil. This water index allows comparison across the industry, where the size of hydrocarbon reservoirs being developed can vary significantly.

The IPIECA *Global Water Tool© for Oil and Gas* includes the water/product ratio as a metric in its reporting.

Water/energy intensity

This reporting index is a variation on the water/product ratio. Oil and gas production has definable calorific energy values. Reporting the amount of water used per energy unit (intensity) can provide a means of comparing water use across the broader power industry.

Water discharge

The 2013 CDP Water Disclosure and the GRI Indicator Protocol on Emissions, Effluents and Waste Aspects (EN21) both use water discharges (both planned and unplanned) as a water indices.

The GEMI® LWT™ uses a variation of the GRI EN21 as one of its reporting options. The variation incorporates the discharge of collected rainwater and domestic sewage, which are absent from GRI EN21.

Water footprint

The Water Footprint Network applies a water index based on 'the volume of fresh water appropriated to produce a product taking into account the volumes of water consumed and polluted in the different steps of the supply chain' (Hoekstra, 2011). It therefore considers both direct and indirect uses of water. The water footprint approach follows a method that has been adopted by UNESCO.

However, where supply chains are long and beyond a company's direct control it may be difficult to both collate the required information and to define the limits of the accounting. To assess the water efficiency or optimization of an operation, the data collection requirements for the water footprint approach can be substantial and may not be appropriate for the objectives.

References and further reading

Accenture (2012). *Water and Shale Gas Development: Leveraging the US experience in new shale developments*.

AEA (2012.) *Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe*. AEA Technology plc. Report to the European Commission, DG Environment. Ref. ED57281, Issue No. 17c.

Alberta Energy (2013). *Alberta's Oil Sands: The Facts*. Government of Alberta, Ministry of Energy. www.energy.alberta.ca/OilSands/791.asp#Water Usage Accessed August 2014.

API (2010). *Water Management Associated with Hydraulic Fracturing*. API Guidance Document HF2, First Edition, June 2010.

AQUASTAT (website). FAO's global water information system. Food and Agriculture Organization of the United Nations, Rome. www.fao.org/nr/water/aquastat/main/index.stm

Arthur, J. D., Langhus, B. G. and Patel, C. (2005). *Technical Summary of Oil & Gas Produced Water Treatment Technologies*. ALL Consulting LLC, March 2005.

AWM (2012). The proceedings of the Advanced Water Management Conference, 2012.

AWS (2014). *The AWS International Water Stewardship Standard, version 1.0.* Alliance for Water Stewardship, April 2014. http://www.allianceforwaterstewardship.org/become-a-water-steward.html#aws-standard

Awwa (2008). *Evaluation of Dynamic Energy Consumption of Advanced Water and Wastewater Treatment Technologies*. Awwa Research Foundation, Denver, USA.

BP (2013). *Water in the energy industry: An introduction*. BP International Ltd.

Brandt, M. J., Middleton, R. A. and Wang, S. (2012). *Energy Efficiency in the Water Industry: A Compendium of Best Practices and Case Studies—Global Report*.

BRGM (2011). *Maîtrise des impacts et risques liés à l'exploitation des hydrocarbures de roche-mère : enjeux, verrous et pistes de recherche: Rapport Final*. Bureau de Recherche Géologiques et Minières, report ref. BRGM/RP-60312-FR. September 2011.

CAPP (2013). *About Canada's Oil Sands*. Canadian Association of Petroleum Producers, June 2013. www.capp.ca/getdoc.aspx?DocId=228182&DT=NTV

Carbon Disclosure Project (CDP) (website). https://www.cdproject.net/en-US/WhatWeDo/Pages/government-policymakers-testimonials.aspx

CEC (2005). *2005 Integrated Energy Policy Report*. California Energy Commission, Integrated Energy Policy Report Committee, Final Report CEC-100-2005-007-CMF, November 2005. www.energy.ca.gov/2005_energypolicy

Chesapeake Energy (2011). *EPA Hydraulic Fracturing Study Technical Workshop #4: Water Resources Management*. March 2011.

CEO (2013). *Guide to Water-Related Collective Action*. CEO Water Mandate, September 2012. http://ceowatermandate.org/wp-content/uploads/2013/09/guide-to-water-related-ca-web-091213.pdf

Frac Focus: Chemical Disclosure Registry (website). www.fracfocus.org

Global Reporting Initiative (GRI). Details on EN10 Indicator Protocol. https://www.globalreporting.org/reporting/G3andg3-1/guidelines-online/G3Online/StandardDisclosures/Environmental/Pages/EN10IndicatorProtocol.aspx

GWP (2013). Global Water Partnership website: *What is IWRM?* (Integrated Water Resources Management). www.gwp.org/en/The-Challenge/What-is-IWRM

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. and Mekonnen, M. M. (2011). *The Water Footprint Assessment Manual: Setting the Global Standard*. Water Footprint Network. Earthscan, London and Washington D.C. ISBN 978-1-84971-279-8

IPIECA/OGP/API (2010). *Oil and gas industry guidance on voluntary sustainability reporting*. www.ipieca.org/publication/oil-and-gas-industry-guidance-voluntary-sustainability-reporting-2010-update (An updated edition of this document is scheduled for publication in 2015.)

IPIECA (2011). *Ecosystem services guidance: Biodiversity and ecosystem services guide and checklists*. www.ipieca.org/publication/ecosystem-services-guidance-biodiversity-and-ecosystem-services-guide

IPIECA (2011a). *Ecosystem services checklists*. www.ipieca.org/publication/ecosystem-services-guidance-biodiversity-and-ecosystem-services-checklists

IPIECA (2013). *Water Management Framework*. www.ipieca.org/water-management-framework

IPIECA (2014). *Identifying and assessing water sources*. www.ipieca.org/publication/identifying-and-assessing-water-sources

IPIECA (2014a). *Review of water risk tools*. www.ipieca.org/publication/review-water-risk-tools-guidance-document-oil-and-gas-industry

King, G. E. (2012). *Hydraulic Fracturing 101: What Every Representative, Environmentalist, Regulator, Reporter, Investor, University Researcher, Neighbor and Engineer Should Know About Estimating Frac Risk and Improving Frac Performance in Unconventional Gas and Oil Wells*. Society of Petroleum Engineers, Conference Paper. Document ID SPE-152596-MS.

NRC (2010). *Management and Effects of Coalbed Methane Produced Water in the Western United States*. National Research Council of the National Academies.

NYSDEC (2011). *Supplementary Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Programme*. New York State Department of Environmental Conservation, New York, USA.

OGP-IPIECA (2013). *Good practice guidelines for the development of shale oil and gas*. International Association of Oil & Gas Producers/IPIECA, December 2013. OGP report number 489.

Powicki, C. (2002). *The Water Imperative.* Electric Power Research Institute, EPRI Journal, July 2002.

Secretary of Energy Advisory Board (2011). *Shale Gas Production Subcommittee: Ninety Day Report*. Report to the US Department of Energy.

Texas Water Development Board (2007). *Assessment of Groundwater Use in the Northern Trinity Aquifer Due To Urban Growth and Barnett Shale Development.*

Turek, M. (2002). *Cost-effective electrodialytic seawater desalination.*

Tyndall Centre for Climate Change Research (2011). *Shale gas: a provisional assessment of climate change and environmental impacts*. January 2011.

US DOE (2009). *Modern Shale Gas Development in the United States: A Primer*. Prepared by the Ground Water Protection Council for the United States Department of Energy, April 2009.

US EPA (2011). *Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*. United States Environmental Protection Agency, Office of Research and Development. November 2011.

Water Footprint Network (website). www.waterfootprint.org

WBCSD (2013). *Business guide to water valuation: An introduction to concepts and techniques*. World Business Council for Sustainable Development, September 2013.

WCED (1987). *Our common future*. World Commission on Environment and Development. Oxford University Press, UK.

This page intentionally left blank

This page intentionally left blank

This page intentionally left blank

IPIECA is the global oil and gas industry association for environmental and social issues. It develops, shares and promotes good practices and knowledge to help the industry improve its environmental and social performance, and is the industry's principal channel of communication with the United Nations.

Through its member-led working groups and executive leadership, IPIECA brings together the collective expertise of oil and gas companies and associations. Its unique position within the industry enables its members to respond effectively to key environmental and social issues.

Members

Addax Petroleum	Husky Energy	Qatargas
Anadarko	INPEX	RasGas
Bashneft	KPC	Repsol
BG Group	Mærsk Oil	Santos
BP	Marathon Oil	Saudi Aramco
Chevron	Nexen	Shell
CNOOC	Noble Energy	SNH
ConocoPhillips	NOC Libya	Statoil
EDF	OMV	Talisman
eni	Petrobras	Total
ExxonMobil	Petronas	Tullow Oil
Hess	Petrotrin	Woodside Energy
Hunt Oil	PTT EP	

IPIECA also has an active global network of oil and gas industry association members.
Please refer to our website for a full list.

IPIECA
5th Floor, 209–215 Blackfriars Road, London SE1 8NL, United Kingdom
Telephone: +44 (0)20 7633 2388   Facsimile: +44 (0)20 7633 2389
E-mail: info@ipieca.org Internet: www.ipieca.org