Chapter 4
Sefficiency (Sustainable Efficiency)

There is a fundamental difference between descriptive and performance indicators of a water use system. The former responds to the question “What is happening?” (e.g., what are the WPIs in a WUS), and the latter focuses on the questions, such as “Does it matter? Are we reaching targets?” (EEA 2015). A target is “a goal to be achieved” (Merriam-Webster Dictionary 2019), and highly important in water management as explained in the previous chapter on the theory presented in this book (FIW5c). For example, ET is part of the description of a WUS (Table 2.1) and by itself value-neutral, because there is no independent target for ET in a locality. As such, decreasing ET in water scarce regions may be a valid option but the real question is the amount of consumption reduction that brings about sustainable development. To answer this and many other questions in water management, we need to use efficiency as a performance indicator with 100 (i.e., in %) as its ideal target. To appreciate efficiency, first let us understand its concept, which is the main reason for its wide usage:

- “Efficiency is thus not a goal in itself. It is not something we want for its own sake, but rather because it helps us attain more of the things we value” (Stone 2012).
- “Resource efficiency means using the Earth’s limited resources in a sustainable manner while minimising impacts on the environment. It allows us to create more with less and to deliver greater value with less input” (European Commission 2019).

These two explanations of the concept of efficiency clearly establish its central significance, particularly under water scarcity. It also becomes clear that efficiency should promote sustainability and as will be seen in Chap. 5, it should be an integral part of equity. After understanding the concept, the key question is how to quantify it for a WUS based on the theory presented in this book. Sefficiency developed in...
this chapter fulfils this requirement and if followed properly produces sustainable solutions.

Sefficiency includes economic, environmental and social concerns in its formulation, which makes it a sustainable efficiency indicator for the management of a WUS. However, “sustainability is not a scientific concept, but rather a social goal. It implies an ethic. Public value judgments must be made about which demands and wants should be satisfied today and what changes should be made to ensure a legacy for the future. Different individuals have different points of view, and it is the combined wisdom of everyone’s opinions that will shape what society may consider sustainable” (Loucks 2002). This needs transparency and the involvement of all the stakeholders (see Sect. 3.2), because to become sustainable is complex. The quote also refers to “public value judgments”, which should be scientifically bounded (Sect. 1.2) as much as possible in order to produce solutions that are more robust for the integrated three Pillars. “In addressing the priority problem the task is that of reducing and not of eliminating entirely the reliance on intuitive judgments” (Rawls 1999). Even though our “priority problem” is different, but the statement also applies to Sefficiency, meaning that it reduces and constraints value judgments significantly.

Before continuing to the proof of Sefficiency, let us present a non-exhaustive list of its possible benefits:

- Enables transparency through the fixed structure of the WUS
- Enables stakeholders involvement for each WPI and its quality and benefit Pillars
- Minimizes the risks of water scarcity
- Adapts to uncertainty (e.g., climate change, population)
- Lessens impact of severe conditions (e.g., drought)
- Protects environment
- Reduces new infrastructure
- Saves energy
- Decreases cost
- Rationalizes investments
- Supports economic growth
- Creates jobs
- Improves cost effectiveness of water service
- Allocates water better
- Enhances conditions for recreation.

### 4.1 Proof of Sefficiency Indicators

In general, there exists both input and output efficiencies for any system (Coelli et al. 2005) in order to reveal the complexity of its structure and behaviour. Sefficiency equations compute the performance of a WUS from the supply and demand sides (FIW5c). The former is relative to inflow and the latter to consumption, which is a very important part of outflow (FIW2). This proof is based on Haie and Keller
(Macro, Meso, and Micro-Efficiencies in Water Resources Management: A New Framework Using Water Balance 2012) and Haie (Sefficiency (Sustainable efficiency): a Systemic Framework for Advancing Water Security 2013). To start, let us be comprehensive and write the water balance in terms of these two perspectives.

The generic WUS depicted in Fig. 2.1 is composed of Inflow and Outflow with negligible change in storage (FIW1a), which according to the principle of water balance (Inflow = Outflow) can be written as Eq. (4.1):

\[(V_1 + OS + PP) - (ET + NR + V_2 + RP) = 0\] (4.1)

For variable definitions refer to Chap. 2 or the Abbreviations and Symbols in the beginning of this book. Water balance of a WUS can also be presented in terms of consumptive and non-consumptive flows (Table 2.2) as in Eq. (4.2):

\[(V_1 + OS + PP - V_2 - RP) - (ET + NR) = 0\] (4.2)

In order to write an alternative arrangement of water balance that embodies the above two equations and keeps their forms (inflow and consumptive), the binary index \(ic\) is introduced, which gives Eq. (4.3):

\[
\begin{align*}
(V_1 + OS + PP) & - (1 - ic)(V_2 + RP) \\
- [(ET + NR) + ic(V_2 + RP)] &= 0, \quad ic = \{0, 1\}
\end{align*}
\] (4.3)

Note that if \(ic = 0\) (i.e., consumptive type), Eq. (4.3) becomes Eq. (4.2), and if \(ic = 1\) (i.e., inflow type), we get Eq. (4.1). However, water balance equations are descriptive and do not give any information regarding the performance of a WUS. At this point, we need to introduce the other two Pillars of water management, i.e., quality and benefit attributes into Eq. (4.3) as shown in Eq. (4.4):

\[
\begin{align*}
\left\{ [(V_1 + OS + PP) - (1 - ic)(V_2 + RP)] - \\
-[(ET + NR) + ic(V_2 + RP)] \right\}_s &= \Lambda, \quad ic = \{0, 1\}
\end{align*}
\] (4.4)

Subscript ‘s’ stands for the useful part of all the WPTs and their corresponding WPIs within the curly brackets. This means that \(X_s = W_sX * X\), with X being a WPI, \(X_s\) its useful part, and \(W_sX\) its Usefulness Criterion, which is presented in Eq. 2.1. For example, if \(X = ET\), then its useful part is \(X_s = ET = W_{sET} * ET\).

Because X is greater than or equal to \(X_s\) and the usefulness of the inflow is more than or equal to the outflow, a non-negative undesirable (Sect. 2.5) factor called Lambda, \(\Lambda\), is inserted in the right hand side of the equation to maintain the equality. The undesirables of a WPI are non-beneficial and pollution and consequently a fundamental aim of water management is to minimize them. It should be noted that Eq. (4.3) is a special case of the Eq. (4.4), with \(W_{bX} = W_{qX} = 1\) (unitary Usefulness Criterion) leading to \(\Lambda = 0\), which indicates that there are no undesirables. In a
real WUS, these conditions never happen but the idea of good water management is to maximize $W_{bX}$ and $W_{qX}$. This is to get the highest benefit with lowest pollution possible in a learning environment specific to the WUS under analysis, which in turn minimizes the undesirables. In other words, the basic idea is to \[ \text{Min (} \Lambda \text{)}, \] which can be written as Eq. (4.5):

$$
\min \left\{ \frac{(V_{1} + OS + PP) - (1 - ic)(V_{2} + RP)}{-(ET + NR) + ic(V_{2} + RP)} \right\}, \quad ic = \{0, 1\}
$$

Minimizing the expression in Eq. (4.5) is equivalent (Appendix A: Equivalency) to maximizing the ratio of its two positive parts as given in Eq. (4.6):

$$
\max \left[ \frac{ET + NR + ic(V_{2} + RP)}{V_{1} + OS + PP - (1 - ic)(V_{2} + RP)} \right], \quad ic = \{0, 1\}
$$

In this book, the expression in Eq. (4.6) that needs to be maximized is called the Sefficiency (SE) equation as presented in Eq. (4.7):

$$
SE = \left[ \frac{ET + NR + ic(V_{2} + RP)}{V_{1} + OS + PP - (1 - ic)(V_{2} + RP)} \right], \quad ic = \{0, 1\}
$$

Using the terminology of Table 2.2, Eq. (4.7) can be written in a more condensed form given in Eq. (4.8):

$$
SE = \left[ \frac{C + ic \ast R}{I - (1 - ic) \ast R} \right] = \frac{UC + ic \ast UR}{UI - (1 - ic) \ast UR}, \quad ic = \{0, 1\}
$$

Sefficiency definitions according to the two perspectives and in relation to the last two equations are:

- $iSE = \text{Inflow Sefficiency } (ic = 1)$: the ratio of useful Outflow to useful Inflow
- $cSE = \text{Consumptive Sefficiency } (ic = 0)$: the ratio of useful Consumption to Total Unrecoverable Flow (TUF$_S$)

Generally, SE is multiplied by 100 to give a percentage, making it a positive number that has to be less than 100, meaning that the denominators must be greater than the corresponding numerators (if not, data may be inaccurate or unrealistic). It should be noted that Sefficiency rarely, if ever, is 100%, because it is very costly, even impossible, to have a WUS without undesirables (see Sect. 2.5).

There is the possibility of calculating Sefficiency without any quality consideration, because it is informative to see the difference between the Sefficiency (SE) of a WUS and its beneficial Sefficiency (SE$_b$), i.e., one without water quality ($W_{qX} = 1$). Although, we suggest that SE and not SE$_b$ be the main indicators for water management, Eq. (4.9) gives SE$_b$ by using Eq. (4.7):
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\[ SE_b = \left[ \frac{ET + NR + ic(V2 + RP)}{V1 + OS + PP - (1 - ic)(V2 + RP)} \right]_b, \quad ic = \{0, 1\} \] (4.9)

\[ SE_b = \left[ \frac{C + ic \times R}{I - (1 - ic) \times R} \right]_b = \frac{BC + ic \times BR}{BI - (1 - ic) \times BR}, \quad ic = \{0, 1\} \] (4.10)

A caution needs to be exercised as explained in Sect. 2.2 in applying weights to the sum or difference of the flows. For example, if \( ic = 0 \), the inside of the square brackets of Eq. (4.8) and Eq. (4.10) becomes \( C/(I-R) \). However, Eq. 2.2 shows that \( I-R = C \), hence making the inside of the brackets always equal to \( C/C = 1 \) and \( SE = [1]_s = 100\% \). Of course, this is not correct because, as was explained in the said subsection, first we have to apply the weights to each element inside the brackets and then make the arithmetic operations.

4.2 Levels of Management

Multilevel water management (FIW5) is central in understanding the various impacts and trade-offs of a WUS. Section 2.2 presented three levels for a WUS, viz.: Macro, Meso and Micro, which are defined according to the flows considered. Sefficiency is applied to these three levels and are called 3ME (= Macro-, Meso-, Micro-efficiencies) with their schematics shown in Fig. 4.1.

1. Macro Sefficiency (MacroSE)
   a. The main source of water, and consequently the basin is considered.
   b. Condition of the main source of water, e.g., a river, influences Sefficiency.
   c. MacroSE reveals the effect of WUS on the main source of water.
   d. For Eq. (4.7) to Eq. (4.10) \( V1 = VU \) and \( V2 = VD \).

2. Meso Sefficiency (MesoSE)
   a. MesoSE ignores the main source of water.
   b. The prefix meso means “Middle; intermediate” (Oxford Dictionary 2018). Usually, meso comes with micro and macro meaning something between these two.
   c. MesoSE reflects the effect of a WUS on downstream by considering its returns.
   d. For Eq. (4.7) to Eq. (4.10) \( V1 = VA \) and \( V2 = RF \).

3. Micro (MicroSE)
   a. MicroSE does not consider the main source of water nor the returns of the WUS. This means that MicroSE ignores the effects on downstream with \( iMicro = cMicro \).
   b. Micro is about the flows or their proxies (e.g., Euros) of direct interest to the stakeholder (e.g., farmer, factory owner, ecosystem NGO, city planner).
c. It is not based on water balance and as a result prone to errors from the point of view of water management.

d. For Eq. (4.7) to Eq. (4.10) $V_1 = VA$ and $V_2 + RP = 0$.

The dotted rectangle in Fig. 4.1 is for better visualization and indicates a construct showing the flows that are part of the Macro level analysis. Substituting $V_1$ and $V_2$ into Eq. (4.7), we get the following Sefficiency equations:
4.2 Levels of Management

\[
MacroSE = \left[ \frac{ET + NR + ic(VD + RP)}{VU + OS + PP - (1 - ic)(VD + RP)} \right], \quad ic = \{0, 1\}
\]

\[
MesoSE = \left[ \frac{ET + NR + ic(RF + RP)}{VA + OS + PP - (1 - ic)(RF + RP)} \right]
\]

\[
MicroSE = \left[ \frac{ET + NR}{VA + OS + PP} \right]
\]

Equation (4.11) gives the following five Sefficiency definitions:

- \(iMacroSE\) = Inflow MacroSE \(S (ic = 1)\): the ratio of useful Macro-Outflow to useful Macro-Inflow
- \(cMacroSE\) = Consumptive MacroSE \(S (ic = 0)\): the ratio of useful Consumption to Macro-TUFs
- \(iMesoSE\) = Inflow MesoSE \(S (ic = 1)\): the ratio of useful Meso-Outflow to useful Meso-Inflow
- \(cMesoSE\) = Consumptive MesoSE \(S (ic = 0)\): the ratio of useful Consumption to Meso-TUFs
- \(iMicroSE = cMicroSE\) = MicroSE: the ratio of useful Consumption to useful Micro-Inflow

Examples for the above terminologies:

- Macro-Outflow = \(ET + NR + VD + RP\)
- Meso-TUF = \(VA + OS + PP - (RF + RP)\)
- Micro-Inflow = Meso-Inflow = \(VA + OS + PP\)

Based on Eq. (4.9), the following beneficial 3ME equations can be written:

\[
MacroSE_b = \left[ \frac{ET + NR + ic(VD + RP)}{VU + OS + PP - (1 - ic)(VD + RP)} \right], \quad ic = \{0, 1\}
\]

\[
MesoSE_b = \left[ \frac{ET + NR + ic(RF + RP)}{VA + OS + PP - (1 - ic)(RF + RP)} \right]
\]

\[
MicroSE_b = \left[ \frac{ET + NR}{VA + OS + PP} \right]
\]

Equation (4.12) gives the following five bSefficiency definitions:

- \(iMacroSE_b (ic = 1)\): the ratio of beneficial Macro-Outflow to beneficial Macro-Inflow
- \(cMacroSE_b (ic = 0)\): the ratio of beneficial Consumption to Macro-TUFb
- \(iMesoSE_b (ic = 1)\): the ratio of beneficial Meso-Outflow to beneficial Meso-Inflow
- \(cMesoSE_b (ic = 0)\): the ratio of beneficial Consumption to Meso-TUFb
- \(MicroSE_b\): the ratio of beneficial Consumption to beneficial Micro-Inflow

Equation (4.11) and Eq. (4.12) give eight important indicators, namely, \(iMacroSE, cMacroSE, iMesoSE, cMesoSE, iMacroSE_b, cMacroSE_b, iMesoSE_b, cMesoSE_b\).
They have 56 distinct combinations, but only 12 of them in three impact categories are important and will be covered in the following Sect. 4.4.2 (Three Impacts in Differentials of Sefficiency). The two Micro efficiencies are flawed as mentioned above in this subsection, with MicroSEb being analogous to the flawed Classical Efficiency explained in the Sect. 4.5 below.

Real cases are generally one to many and consequently have many WPIs. Here, two templates are available: (a) a free MS-Excel tool at Haie (Sefficiency (Sustainable efficiency) of Water-Energy-Food Entangled Systems 2016) as a supplementary document that has the equations and a simple format to simulate various cases side by side, (b) Appendix B: Sefficiency Template is the compact form used for this book. Although these are one to one templates (i.e., WPT → WPI), they can be edited to accommodate one to many scenarios.

Finally, in many applications, initially, the water managers can use Eq. (4.8) and Eq. (4.10). This reduces the needed water quantities to two, most of the time I and C, and utilizing the water balance equation, i.e., Equation 2.2, R can be found. These three water quantities need six weights for their quality and beneficial attributes to be able to calculate Sefficiency.

### 4.3 Weights

Most of the fields of science, if not all, employ weights explicitly and implicitly. They may be difficult or controversial to set but as the Nobel Laureate Amartya Sen (Inequality Reexamined 1992) affirms “weighting cannot really be, in any sense, an embarrassment” and “We cannot criticize the commodity-centred evaluation on the ground that different commodities are weighted differently.” Prices are weights and we readily accept that different commodities have different prices in the same location, and the same commodity has different prices in various locations.

In this book, there are two weights for each WPI ($W_{bX}$ and $W_{qX}$), which are set according to the objectives of the WUS under analysis. They are explained in the next two subsections, along with a subsection on Usefulness Criterion.

#### 4.3.1 Quality Attribute

“Most economic systems refer to pollution as an “externality;” a cost or benefit unaccounted for in the economic system. Pollution is a negative externality. Anyone taking rudimentary economics should know this. Solutions that have been working in the U.S. and many other places in the world involve government regulation of polluters. Take these externalized costs and integrate them into the system so that humans and aspects of nature that are suffering from their negative impacts without receiving the benefits are protected” (Fitch 2012).
To do this, Sefficiency uses quality weight for each WPI (\(W_{qX}\)) in order to explicitly quantify pollution influence on the performance of a WUS. Sometimes it is easy to set those weights:

- Quality weight for treated water supplied to population is one (\(W_{qI} = 1\)).
- Quality weights of evapotranspiration (\(W_{qET}\)) and some of non-reusable (\(W_{qNR}\)), such as evaporation and bottled water are one.

However, in most situations, quality weight of a WPI is less than one and should be calculated using estimates and measurements having in mind that a water quality index (or quality weight) “is a weighted average of selected ambient concentrations of pollutants usually linked to water quality classes” (OECD 2001). What follows is a small list that can guide in setting quality weights:

- The Water Framework Directive (European Parliament & Council 2000) introduced surface water status and groundwater status, which are general expressions of the status of a body of surface water or groundwater, respectively. Both include chemical status and classify waters into clearly defined categories with associated colours.
- Canadian water quality guidelines for the protection of aquatic life employs Water Quality Index (CCME 2017), which has a calculator and a user’s manual.
- The main global water quality index for domestic purposes is the Global Drinking Water Quality Index of the Global Environmental Monitoring System (GEMS) Water Programme, the United Nations Environment Program (UNEP 2007), and is based on the Canadian Water Quality Index.
- Chinese Environmental Quality Standards with five classes are “formulated for implementing the Environmental Protection Law and Law of Water Pollution Prevention and Control of People’s Republic of China, and to control water pollution and to protect water resources” (MEEC 1997; MEEC 2018).
- To calculate water footprint, Hoekstra et al. (The water footprint assessment manual: Setting the global standard 2011) introduced grey water footprint as “an indicator of freshwater pollution” in order to achieve a water quality objective/standard. In this context, grey water footprint may be employed to set \(W_{qX}\) under some conditions.
- Food and Agriculture Organisation of the United Nations proposes the use of leaching fraction (Ayers and Westcot 1994) that is widely employed in irrigation management to avoid salt accumulation and can be used for setting quality weight (\(W_{qX} = 1 - LFX\), LF being leaching fraction).

### 4.3.2 Beneficial Attribute

The beneficial weight (\(W_{bX}\)) is set by focussing on the nature and objectives of the WUS under consideration without considering its quality (\(W_{qX} = 1\)). This is the usual way that the planning and management of the systems are carried out today, i.e., water quality of a system is dealt with separately according to its inflow
needs and the downstream requirements. This weight should consider all the benefits that water brings to societies and natures: “Valuing water means recognizing and considering all the benefits provided by water that encompass economic, social and ecological dimensions. It takes many forms appropriate to local circumstances and cultures. Safeguarding the poor, the vulnerable and the environment is required in all instances” (UN-HLPW 2017). Hence, water benefits (interchangeable with water values according to this citation and others) are fundamentally linked to the objectives of a WUS, and include those that may not be quantifiable.

FIW4 is about the benefits, which stresses that multi-objective planning and management should be the norm. Total benefits and costs vary due to various local or national goals and even under different water allocation schemes. There are many methods available to come up with those totals (Loucks and Van Beek 2005) and then the weights. Presentation of these methods are beyond the scope of this book, but they are routinely utilized in evaluating economic and social benefits of projects. However, in many cases a competent estimate of the magnitude of the weight is sufficient, which may be valuable as the first step in a learning process. At present, the following is common practice in applications all over the world:

- Public water supply to people has a $W_{bl}$ of one, meaning that all the water that enters into the water supply system (Inflow to a WUS) has the maximum benefit.
- For irrigation systems, the so-called effective precipitation (Brouwer and Heibloem 1986) can be used to set the beneficial weight of precipitation ($W_{bPP}$). This is doubly important for rainfed agriculture.
- The non-beneficial ET is routinely estimated or calculated at least for irrigation systems.
- Evaporation from lakes and reservoirs are calculated with a small fraction considered as beneficial.

Finally, gathering accurate data for the management of water systems is very hard due to many factors, such as, bias (different from prejudice) and noise (chance variability of judgments), shown in Fig. 4.2 (Kahneman et al. 2016). Noise is one of the reasons that a learning process is needed because sometimes what a stakeholder presents under one situation may be different from what he expresses under another (consciously or not). Furthermore, decision makers and politicians act with much noise for advancing their interests, which make the stakeholders even noisier. However, action (Sect. 3.2) truly reveals the real intentions and true mindsets (Sect. 3.2) of all involved in water management (or life in general). Due to such inherent conditions and the idea of bounded rationality (Sect. 4.2), it is suggested that equal weights (or its special case, unit weights) can sometimes be justifiable for complex systems such as, the NASDAQ-100 Equal Weighted Index Shares (NASDAQ-100). This may be used for the beneficial weights ($W_{bX}$) at least in situations that reliable data is not available, an initial estimate is needed in the learning process, or under urgent situations. Although the problem of noise is explained here for $W_{bX}$, but it is applicable for all types of data, including quality and quantity, and should be persistently dealt with in all data handling.
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Fig. 4.2 Noise and bias in data accuracy (Kahneman et al. 2016)

4.3.3 Usefulness Criterion

The quality and beneficial weights vary between 0 and 1 as discussed earlier, and their multiplication defines Usefulness Criterion (Sect. 2.2), which is an equation in the form of \( z = x \times y \). Figure 4.3 gives the contour lines of the domain of \( W_{sx} \) generated by MatLab (MathWorks 2018). This figure shows the non-linear behaviour of \( W_{sx} \) and that its values are mostly low. In fact the average of all the points that formed the figure is just 0.25.

Figure 4.4 shows the histogram and cumulative curve of \( W_{sx} \) using the data produced for Fig. 4.3. The former presents the percentages of \( W_{sx} \) values in each bin or class (e.g. 33.5% in class 0 to 0.10), and the latter shows the percentages that are
Fig. 4.3 Contour lines of the Usefulness Criterion

![Contour lines of the Usefulness Criterion](image)

Fig. 4.4 Histogram and cumulative curve of the Usefulness Criterion

![Histogram and cumulative curve of the Usefulness Criterion](image)

less than or equal to a particular value (e.g. 66.1% for 0.3). It is interesting to note that 84.5% of \( W_{sX} \) values are less than or equal to 0.5, 90.5% to 0.6, and 97.7% to 0.8, which means achieving high usefulness is difficult.

There is yet another important behaviour of the Usefulness Criterion by following the Benford’s Law (Weisstein 2018; Berger and Hill 2015). It gives a fixed probability distribution of the leading nine significant digits, i.e., one to nine, of many types of collections of numbers, such as, river areas and population. The Benford’s Law (or the Newcomb–Benford law) has a logarithmic distribution as given by Eq. (4.13).

\[
P(g) = \log_{10} \left( 1 + \frac{1}{g} \right), \quad for \ all \ g = 1, 2, 3, \ldots, 9
\]  
(4.13)
4.3 Weights

\[ P(g) \] is the probability of \( g \), which is the leading significant digit (non-zero). Figure 4.5 shows the two curves: histogram of the Usefulness Criterion and Benford’s Law. Their differences are negligible, which go from 0.03 to -0.03 with a zero average.

These patterns seem significant particularly parsing the quality and beneficial weights in relation to Sefficiency and in the context of Benford’s Law. For example, the streamflow data so important to the water balance and hence the theory presented in this book should conform to the Benford’s Law and nonconformity could indicate specific issues with the data (Nigrini and Miller 2007). In other words, if the Usefulness Criterion in a locality diverges from the Benford’s law, it should raise a flag as to its accuracy, meaning that the beneficial and quality weights should be re-examined. However, the methodology to actually finding those divergences among many beneficial and quality weights is not clear. Nevertheless and beyond what was mentioned earlier in Sect. 2.2, these findings are indicative that the Useful Criterion defined in this book is sound and valid.

4.4 Trade-Offs

Trade-offs between the three Pillars of water management are inevitable particularly under water scarcity and are highly complex to quantify. Sefficiency as a centrepiece of the theory advanced in this book is about that complexity, meaning achieving a better trade-off and consequently reducing the undesirables. However, water resources development of an area has limits, i.e., the trade-offs of the three Pillars of water management have a reasonable upper bound (Sect. 1.2) in the context of the performance of systems. This feature can be used to reject the development plans, such as a new industrial plant, park or irrigated farm that reduce the performance of the system.
4.4.1 Jevons Paradox

Some water experts in presenting trade-offs refer to the Jevons Paradox (a type of rebound effect), which states that “if there is an increase in efficiency in the use of a resource its price can reduce, leading to an increase in consumption” (Maxwell et al. 2011). However, such an economic analysis does not apply to Sefficiency in light of the following reasons:

- Jevons Paradox is about those resources that have one state after usage and not two like water (FIW2a). Coal energy (the focus of Jevons Paradox of 1865) presents possible paradoxical trade-offs between supply side efficiency, demand (one state) and price. However, in water management, we have iSefficiency, water demand (two states), and price that reveal more complexity than energy efficiency, some of which are made clearer in the following points.
- Various local and global drivers are increasing water scarcity meaning that effective supply is decreasing, which does not allow the price of water to decrease (actually the prices are increasing almost everywhere). These are not the underlying assumptions for Jevons Paradox.
- Jevons Paradox does not consider pollution but Sefficiency does.
- The solutions according to Sefficiency do not necessarily increase water demand or reduce its price because of the complex trade-offs of the three Pillars.
- The use of technology in production processes of energy was another focus of Jevons Paradox. However, technology in Sefficiency is for data gathering in a learning process in order to better estimate the three Pillars, and make water balance (FIW1) more robust. In general, this increases the cost of water supply (not decreasing according to Jevons Paradox) but eventually makes planning and management of this vital resource more sustainable.
- In the absence of proper policies, it is possible that production technologies, e.g., in irrigation, cause water consumption to increase. However, this does not mean that Sefficiency increases because of the trade-offs of the three pillars. In other words, it is not water consumption alone but rather the performance of the WUS within a specific situation that is the deciding factor. This is again different from the logical setting of Jevons Paradox.

4.4.2 Three Impacts in Differentials

The eight important Sefficiency indicators (Sect. 1.2) give twelve significant combinations that show trade-offs between those indicators. These are divided into three impact categories as follows:

- I/O impacts are due to the differences between inflow and consumptive Sefficiencies at the same Level and Pollution. This is done via the following four comparisons:
• iMacroSE and cMacroSE
• iMesoSE and cMesoSE
• iMacroSE\textsubscript{b} and cMacroSE\textsubscript{b}
• iMesoSE\textsubscript{b} and cMesoSE\textsubscript{b}

• Level impacts are due to the differences between Macro and Meso Sefficiencies at the same I/O and Pollution. This is done via the following four comparisons:
  • iMacroSE and iMesoSE
  • iMacroSE\textsubscript{b} and iMesoSE\textsubscript{b}
  • cMacroSE and cMesoSE
  • cMacroSE\textsubscript{b} and cMesoSE\textsubscript{b}

• Pollution impacts are due to the differences between full and beneficial Sefficiencies at the same I/O and Level. This is done via the following four comparisons:
  • iMacroSE and iMacroSE\textsubscript{b}
  • iMesoSE and iMesoSE\textsubscript{b}
  • cMacroSE and cMacroSE\textsubscript{b}
  • cMesoSE and cMesoSE\textsubscript{b}

Under a specific application, we should start with the worst impact difference and analyse it in more detail in conjunction with the trade-off patterns given in the next subsection. In general, these repeating reflections with stakeholders can progress to unconventional scenarios that sometimes can disrupt the usual functioning of a WUS. In other words, having water as the main priority, not the traditional ones, such as, economy, food, land, health or ecosystem, can lead us to innovative scenarios for the sustainable development of a region.

4.4.3 Patterns

Equation (4.7) has more than 13 variables, which are WPIs and their weights. Changing one variable gives a different value for SE in a mostly non-linear fashion. Frequently, if one variable changes, others also vary making the combined effect of all the changes on SE more difficult to assess, meaning that trade-offs are much more complex. In general, the notion of trade-off in this subsection is to understand the behaviour and the structure of the domain (or space) of a policy or in this situation Eq. (4.7). Please see the end of Sect. 2.1 for the clarification of the notion of domain behaviour of an equation.

However, Eq. (4.7) is very complex because of its high dimensions, so let us see the behaviour of Eq. (4.8), which has six variables (I, C, R and their Usefulness Criteria). To start and remembering Eq. 2.2, we define the expressions given in Eq. (4.14).
\[ C_1 = \frac{C}{I}, \quad R_1 = \frac{R}{I}, \quad C_1 + R_1 = 1 \]
\[ WC_1 = \frac{W_dC}{W_dI}, \quad WR_1 = \frac{W_dR}{W_dI}, \quad d = b, q, s \] (4.14)

\( C_1 \) is Consumption fraction, \( R_1 \) is Return fraction, \( WC_1 \) is desirable Consumption fraction, and \( WR_1 \) is desirable Return fraction. For example, if \( d = b \), \( WC_1 \) is beneficial Consumption fraction. Applying Eq. (4.14) to Eq. (4.8), we get Eq. (4.15).

\[ SE = \frac{WC_1 \times C_1 + ic \times WR_1 \times R_1}{1 - (1 - ic) \times WR_1 \times R_1}, \quad ic = \{0, 1\} \] (4.15)

Equation (4.15) and \( C_1 + R_1 = 1 \) form a 4D problem: \( C_1 \) or \( R_1 \), \( WC_1 \), \( WR_1 \) and \( SE \) (for \( d = b \), we should use the symbol \( SE_b \)). This is still difficult to visualize, but keeping one of the variables constant, contour lines of \( iSE \) and \( cSE \) can be shown as in Figs. 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16 and 4.17 (MatLab (MathWorks 2018) was used, with special thanks to Rui M.S. Pereira). These figures give trade-offs and patterns between the variables.

Fig. 4.6 Contour lines of \( WR_1-WC_1-iSE \) trade-offs and patterns along four \( C_1 \) values
Note: each figure shows four graphs in the x-y-z format with the following characteristics:

- Horizontal axis shows C1, R1 or WR1
- Vertical axis shows WC1 or WR1
- Within these axes, contour lines of IN Sefficiency (iSE) or OUT Sefficiency (cSE) are drawn
- Each figure shows various graphs along C1, R1, WC1 or WR1. We give four out of 20 graphs, which seems to be sufficient to portray the patterns and the trade-offs.

For example, Fig. 4.6 gives WR1-WC1-iSE graphs with WR1 and WC1 axes showing iSE contour lines for four fixed values of C1.

It should be mentioned that not all the combinations of the three variables (C1 or R1, WC1, WR1) occur in practice, meaning that there are infeasible combinations within each figure. However, the patterns and trade-offs given by the figures are valid for the feasible combinations, and consequently, in the following discussions, we will not be concerned about the feasibility of an example or case (i.e., one specific

![Fig. 4.7 Contour lines of WR1-WC1-iSE trade-offs and patterns along four R1 values](image-url)
combination of the three variables), but rather how to detect patterns and trade-offs. Furthermore, the figures show the domain (space or hyperspace) of Eq. (4.15), meaning that whatever is mentioned below can be proven by this equation having in mind that $C_1 + R_1 = 1$. In this context, let us see a non-exhaustive list of the patterns and trade-offs inherent in the figures, which can help water managers discussing their own conclusions for their cases.

- Because $C_1 + R_1 = 1$, specifying $C_1$ or $R_1$ will automatically fix the other, which produces equal graphs. For example, the graph for $C_1 = 0.3$ in Fig. 4.6 is the same as the one for $R_1 = 0.7$ of Fig. 4.7.
- For Figs. 4.6, 4.7, 4.8 and 4.9, the contour lines are linear and for any graph the $S_{efficiency}$ increases as $WR_1$ and/or $WC_1$ increases.
- $S_E$ sometimes shows high variation or gradient. For example, in Fig. 4.9c, as $cSE$ increases, the contours get closer to each other.
- Various figures mirror each other. For example, Figs. 4.11 and 4.13 are mirrors of Figs. 4.10 and 4.12, respectively, giving equal $S_E$ for the complimentary $C_1$ and $R_1$ graphs. For example, $iSE = 64\%$, for $C_1 = 0.8$, $WR_1 = 0.4$ in Fig. 4.10c, and

![Fig. 4.8 Contour lines of WR1-WC1-cSE trade-offs and patterns along four C1 values](image-url)
R1 = 0.2 (= 1-C1), WR1 = 0.4 in Fig. 4.11c. For cSE = 60% and WR1 = 0.5, C1 = 0.75 in Fig. 4.12c, and R1 = 0.25 in Fig. 4.13c.

- iSE decreases toward its minimum (zero) if WC1 and WR1 decrease toward zero (on the limit, iSE = WC1 = WR1 = 0). WC1 = 0 means totally useless Consumption or C1 = 0. WR1 = 0 means totally polluted Return or R1 = 0.
- iSE goes toward WC1 if C1 goes toward one, or WC1 and WR1 get closer to each other (on the limit, iSE = WC1 = WR1).
  - If in a real case WC1 is always greater than WR1, which seems to be a valid condition in most of the situations if not all, then the maximum that iSE can achieve is WC1.
  - If WC1 < WR1, then iSE > WC1; If WC1 > WR1, then iSE > WR1.

- iSE goes toward WR1 if R1 goes toward one.
- iSE goes toward C1 if WC1 goes toward one and WR1 goes toward zero.
- cSE decreases toward its minimum (zero) as WC1 and/or C1 goes toward zero.
- cSE increases toward its maximum (WC1) as WR1 and/or C1 goes toward one.

Fig. 4.9 Contour lines of WR1-WC1-cSE trade-offs and patterns along four R1 values
• cSE and iSE go toward each other, if WR1 or R1 goes toward zero. In general, iSE and cSE go toward each other as they get closer to WC1 * C1, which at the limit, we have iSE = cSE = WC1 * C1.

4.5 Alternatives

There are alternative indicators that are also about computing efficiency, productivity, etc. One significant form is to specify the ratio of output to input. Output gives the things that we value, which goes along our objectives, and input is a sort of total. Here, we briefly discuss four alternatives, namely, Classical Efficiency (CE), Water Productivity (WaP), Effective Efficiency (EE), and also Resiliency (RE).

![Fig. 4.10 Contour lines of C1-WR1-iSE trade-offs and patterns along four WC1 values](image-url)
4.5 Alternatives

4.5.1 Classical Efficiency

All sectors, including urban and agriculture, have been employing Classical Efficiency (CE) for decades with Eq. (4.16) giving its generic form.

\[ CE = \frac{\text{Beneficial water}}{\text{Total water}} \]  

(4.16)

This is to say that CE is the ratio of beneficial water to total water (applied). Examples of the word ‘water’ in Eq. (4.16) are as follows:

- Numerator (beneficial water): beneficial water use, consumption or required
- Denominator (total water): total water applied, abstracted, allocated or required

With such a definition, CE is a flawed indicator, having in mind the following issues:

- Incompleteness of water flows, particularly the lack of the inclusion of returns in the equation, which also makes it inadequate for any multi-objective WUS.

![Fig. 4.11](image)

Fig. 4.11 Contour lines of R1-WR1-iSE trade-offs and patterns along four WC1 values
CE does not obey water balance, one of the most important laws in studying and designing water systems.

Partial consideration of Usefulness Criterion, i.e., lack of a comprehensive concern for applying water quality and benefits. For example, the numerator considers the beneficial part, but this distinction is not extended to the denominator. Furthermore, CE is a quantity indicator, with little or no consideration for water quality.

Many experts state that increasing CE by decreasing the total water (denominator) saves water for downstream. However, in most cases such a water saving is actually negligible and close to zero. Please see a common example about this myth in Chap. 6. For now, let us focus on the application of CE in agriculture and urban areas.

In irrigated agriculture, CE is mostly defined as \( CE = \frac{E_{Tb}}{VA} \) (Seckler et al. 2003), meaning the ratio of beneficial ET to water applied. Various other names are given to CE, such as, irrigation efficiency and water use efficiency. As just mentioned CE is flawed and many authors, including Willardson, et al. (1994) and Haie and Keller (2012) have discussed its problems. Additionally, various authors have defined CE with some variations but all are flawed. For example, efficiency is shown as \( \frac{1}{CE} \).

![Contour lines of C1-WR1-cSE trade-offs and patterns along four WC1 values](image-url)
and given a different name, or leaching fraction is applied to VA (see Sect. 1.3), or PP_b (also called effective precipitation) is subtracted from ETb, or change in storage is subtracted from VA (in practice never used, e.g., Burt et al. (1997)), etc. In reality, CE is a fraction, which conveys very little information (Willardson et al. 1994) and not a scientific and logical performance indicator. However, CE is, to some extent, legitimate from the perspective of the crop but not water, meaning that for agronomists, CE may advance some information but for water managers, it is not suitable at all. These two perspectives create confusion in the mind of many experts, making it another example of why this book insists on the centrality of water in managing it.

In urban areas, the concept of CE, i.e., Eq. (4.16), is also widespread and equally flawed due to the three issues mentioned above. Let us see three examples by focusing on concepts (index 1 = before intervention, and index 2 = after intervention for CE improvement):

![Contour lines of R1-WR1-cSE trade-offs and patterns along four WC1 values](image-url)

**Fig. 4.13** Contour lines of R1-WR1-cSE trade-offs and patterns along four WC1 values
First, the California Department of Water Resources (CDWR) defines urban water use efficiency as “Methods or technologies resulting in the same beneficial residential, commercial, industrial, and institutional uses with less water or increased beneficial uses from existing water quantities” (CDWR 2019). Carefully reading this definition, we reach the conclusion that it is about an expression with its numerator being beneficial water use \(X_b\), and its denominator, total water quantity applied \((VA)\), which represents Eq. (4.16). To understand this affirmation, let us enumerate the possibilities that the definition sets forth to improve efficiency:

A. \(X_{b1} = X_{b2}\) with \(VA_2 < VA_1\) (this is the 1st part of the CDWR definition of urban efficiency)

B. \(X_{b1} < X_{b2}\) with \(VA_2 = VA_1\) (this is the 2nd part of the definition, which is after “or”)

C. A third possibility is not presented in the above CDWR definition of urban efficiency with \(X_{b1} \neq X_{b2}\) and \(VA_2 \neq VA_1\). Under these conditions, CE improves if \(X_{b1} \cdot VA_2 < X_{b2} \cdot VA_1\).

Fig. 4.14 Contour lines of C1-WC1-iSE trade-offs and patterns along four WR1 values
Second, the European Union has defined a number of building blocks for water efficiency activities (European Commission Water 2019) which highlights the following two points, among others:

- “A study from 2007 on the water saving potential in Europe, estimates that water efficiency could be improved by nearly 40%.” This study (Dworak 2007) was funded by the European Commission, Directorate-General Environment and produced a report that goes into many sectors and services. Its overall outlook defines water saving potential stating that it “can be achieved by improving the efficiency of various uses of water without decreasing services or by cutting back the use of a resource, even if that means cutting back the goods and services produced by using that resource.” This definition gives two possibilities, which Eq. (4.16) should be used for their understanding: (i) $CE_2 > CE_1$ and $X_{b2} \geq X_{b1}$, (ii) after “or”, $VA_2 < VA_1$ and $X_{2b} \leq X_{b1}$ with an implicit assumption that $CE_2 \geq CE_1$.

- “The study identifies the need for an EU approach that could contribute to water efficiency across Europe, regardless of the variation in climate, population or land use practices in Member States.” This study on water efficiency standards

![Fig. 4.15 Contour lines of R1-WC1-iSE trade-offs and patterns along four WR1 values](image_url)
(Benito 2009) was funded by the European Commission, Directorate-General Environment and produced a report that focusses on urban (buildings and industries) and agriculture. This report defines water efficiency as “the relationship between the amount of water required for a particular purpose and the amount of water used or delivered”, which is a CE type concept.

Third, the Portuguese Water Use Efficiency Plan - PNUEA (National Laboratory of Civil Engineering 2001) is used in many activities related to water, such as, River Basin Management Plans (Portuguese Environment Agency 2019b), and Strategic Environmental Assessment of the Roadmap for Carbon Neutrality 2050 (Portuguese Environment Agency 2019a). PNUEA is defined for various types of water users, such as, urban, agriculture and industry. In its indicator section, it defines water use efficiency as the ratio of “useful consumption” to “effective demand”, and sets water loss (%) equal to (100 – efficiency). This CE type equation does not explain the meaning of the words useful, consumption and effective. In practice, PNUEA uses Eq. (4.16) and defines various efficiency and investment targets that have been adopted by the decision-makers.

Fig. 4.16 Contour lines of C1-WC1-cSE trade-offs and patterns along four WR1 values
Finally, there are those who only use water quantity to calculate the performance of a system in the form of (water quantity/ total water quantity), which obviously is wrong. Section 6.2 gives an example with more explanation.

### 4.5.2 Water Productivity

WaP is defined as in Eq. (4.17) (Haie N., Sefficiency (Sustainable efficiency) of Water-Energy-Food Entangled Systems 2016):

\[
WaP = \frac{production}{water \text{ quantity}}
\]  

(4.17)

WaP does not give a percentage because production is different from water quantity, which mostly shows itself in the unit of the numerator being different from the denominator, e.g. €/mm. Some authors designate WaP as ‘water use efficiency’, and

![Contour lines of R1-WC1-cSE trade-offs and patterns along four WR1 values](image)

**Fig. 4.17** Contour lines of R1-WC1-cSE trade-offs and patterns along four WR1 values
consequently much care should be exercised not to confuse its concept with efficiency indicators (in %) used in this book. Equation (4.17) applied to one specific WUS has the following examples:

- ‘production’ can be yield (kg), mass of production (kg), monetary value (€), amount of product—different from water (m³), etc.
- ‘water quantity’ can be water applied (VA in m³), evapotranspiration (ET in mm), etc.

WaP as a ratio of output to input is similar to CE and equally a flawed indicator for water management due to the issues given for CE, and various other reasons given by some experts and organisations (Wichelns 2014; FAO & WWC 2015). There are also variations to Eq. (4.17), such as 1/WaP and all are flawed. For example, Coca Cola Company uses it under the name Water Efficiency meaning amount of water used (litre) per amount of product made (litre) (Coca-Cola Company 2018). In general, production depends on many inputs including water in a nonlinear fashion, and as an input becomes scarcer, production becomes more dependent on that scarce input. Under what combination of inputs, the productivity of the system (i.e., all input considered) is good-enough? The answer to this question erroneously narrows down to one (not many) input depending on the expert. For example, under the same conditions for an irrigated agriculture, the answer of the water experts is proper amount of water; the answer of the soil experts is better soil; the answer of the pest experts is better pest control; the answer of the economic experts is about market or land ownership, etc. Anyhow, Eq. (4.17) may prove to be valuable for agronomists and particular industries but not for water managers who should aim for a comprehensive and good-enough performance of a WUS.

### 4.5.3 Effective Efficiency

EE is defined as in Eq. (4.18) (Keller and Keller 1995):

$$ EE = \frac{(ET - PP)_b}{(W_{qV1} \ast V1 - W_{qV2} \ast V2)} $$

(4.18)

EE is more complete than CE and meaningfully advanced the concept of water efficiency. However, it was not developed in a systemic and comprehensive manner and consequently is an incomplete formulation and gives inaccurate results. Subtracting PP (inflow) from ET (outflow) is not correct from the water perspective (and cannot be applied to rain fed agriculture). There is no accounting for RP, which can be of great importance, e.g., for groundwater. In addition, it does not include NR (a significant flow in some applications) because EE is for irrigated lands only. On the other hand, it does not comprehensively consider the Usefulness Criterion, i.e., water quality and benefits. For example, the beneficial part of ET is in EE, but this distinction is not extended to V1 and V2; and for quality, it only considers salt, i.e., \( W_{qX} = 1 - LF_X \)
Finally, although its name consists of the word “effective” but it was not defined, and as such, along the paper, it gets diverse meanings as applied to different things, such as effective inflow, effective precipitation, and effective efficiency.

### 4.5.4 Resiliency

RE is defined as in Eq. (4.19) (Loucks and Van Beek 2005; Hashimoto et al. 1982):

$$RE = \frac{\text{number of times a satisfactory value follows an unsatisfactory value}}{\text{number of times an unsatisfactory value occurred}}$$

(4.19)

Having in mind the definition of ‘satisfactory’ given in Sect. 2.4, Loucks and Van Beek (Water Resources Systems Planning and Management: An Introduction to Methods, Models and Applications 2005) define resilience as given in Eq. (4.19) stating that “Resilience can be expressed as the probability that if a system is in an unsatisfactory state, the next state will be satisfactory. It is the probability of having a satisfactory value in time period \(t+1\), given an unsatisfactory value in any time period \(t\).” Hence, resilience is an indicator of the response of the system, i.e., the speed of the recovery from an unsatisfactory condition (CDWR 2019). For example, a young person is more resilient than an old one, because she can recover faster from a sick (unsatisfactory) condition, such as a flu or Covid-19. In evaluating and improving resiliency, a system, such as a water network, has many resilience metrics that can be used depending on the scenario of interest. For an example in water networks, please refer to the WNTR software of U.S. Environmental Protection Agency (Klise 2017).

It is common knowledge that sustainable (water) systems must respond to social, economic and environmental dimensions of change. However, in many studies on WUS resiliency, the authors deal with one or two of the dimensions of sustainability or if all the three are used, they are done apart from each other, even though at the end they are, somehow, put together. In other words, there is a difference between a comprehensive integration of the three dimensions of sustainability (what we have in this book) and studying the three dimensions and then trying to integrate the results, usually partially. This is why the sustainable systems developed according to the theory presented in this book are also resilient, having in mind the following points:

- No system is absolutely sustainable or resilient, meaning that there are degrees to sustainability and resiliency. For example, a resilient system may respond well to a 50-year flood, but fails to recover under more severe ones.
- Any sustainable system must be resilient to foreseeable disruptions. Again, this is not absolute and it is possible to imagine sustainable systems that fail to a particular level of a specific disaster. No system can be highly resilient to all types of disruptions with all levels of intensity and extent.
• The relativity of these concepts does not mean that all systems are adequate. On the contrary, a sustainable and resilient system should be continually enhanced through learning (FIW5b; Sect. 3.2) in the context of improving Sefficiency in Sequity.

References

Ayers R, Westcot D (1994) Water quality for agriculture (FAO Irrigation and Drainage Paper 29), UN FAO (Food and Agriculture Organization), Rome, Italy
Benito P et al (2009) Study on water efficiency standards (final report). Bio Intelligence Service and Cranefield University, Paris
Berger A, Hill TP (2015) An introduction to Benford’s law, 1st edn. Princeton University Press, sl
Brouwer C, Heibloem M (1986) Irrigation water management: irrigation water needs. UN FAO, Rome, Italy
CCME (2017) Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index. [Online]. Available at: https://www.ccme.ca/files/Resources/water/water_quality/WQI%20Manual%20EN.pdf. Accessed 17 June 2019
CDWR (2019) Glossary—California Department of Water Resources (CDWR). [Online]. Available at: https://water.ca.gov/Water-Basics/Glossary. Accessed 23 Dec 2019
Coca-Cola Company (2018) Improving our water efficiency. [Online]. Available at: https://www.coca-colacompany.com/stories/setting-a-new-goal-for-water-efficiency. Accessed 9 July 2019
Coelli T, Rao D, O’Donnell C, Battese G (2005) An introduction to efficiency and productivity analysis, 2nd edn. Springer, Berlin
Dworak T et al (2007) EU water saving potential (Part 1 - Final Report). Ecologic Institute for International and European Environmental, Berlin
EEA (2015) EEA indicators. European Environment Agency, Copenhagen, Denmark
European Commission Water (2019) Building blocks: water efficiency activities (Last updated: 08-Jul-2019). [Online]. Available at: https://ec.europa.eu/environment/water/quantity/water_efficiency.htm. Accessed 28 Dec 2019
European Commission (2019) Environment. [Online] Available at: http://ec.europa.eu/environment/resource_efficiency/index_en.htm. Accessed 31 May 2019
European Parliament & Council (2000) Water Framework Directive, Official Journal L 327, European Union. [Online]. Available at: http://ec.europa.eu/environment/water/water-framework/index_en.html. Accessed 20 Mar 2018
FAO & WWC (2015) Towards a water and food secure future: critical perspectives for policy-makers. UN-FAO, Rome, Italy
Fitch E (2012) King midas: the seven deadly sins and externalities. Water Resour IMPACT 14(1):19
Haie N, Keller A (2012) Macro, meso, and micro-efficiencies in water resources management: a new framework using water balance. J Am Water Resour Assoc (JAWRA) 48(2):235–243
Haie N (2013) Sefficiency (sustainable efficiency): a systemic framework for advancing water security. Wuhan University, Wuhan and Yichang, Hubei
Haie N (2016) Sefficiency (sustainable efficiency) of water-energy-food entangled systems. Int J Water Resour Dev 32(5):721–737
Hashimoto T, Stedinger J, Louccks D (1982) Reliability, resiliency, and vulnerability criteria for water resource system performance evaluation. Water Resour Res 18(1):14–20
Hoekstra A, Chapagain A, Aldaya M, Mekonnen M (2011) The water footprint assessment manual: setting the global standard. Earthscan, London
Kahneman D, Rosenfield A, Gandhi L, Blaser T (2016) Noise: how to overcome the high, hidden cost of inconsistent decision making. Harvard Business Rev, October, pp 36–43
References

Keller A, Keller J (1995) Effective efficiency: a water use efficiency concept for allocating freshwater resources. Winrock International, Arlington, Virginia

Klise KA et al (2017) Water Network Tool for Resilience (WNTR) user manual. U.S. Environmental Protection Agency (EPA/600/R-17/264), Washington, DC

Loucks D, Van Beek E (2005) Water resources systems planning and management: an introduction to methods, models and applications. UNESCO, Paris

Loucks DP (2002) Quantifying system sustainability using multiple risk criteria. s.l., Cambridge University Press

MathWorks (2018) MatLab. [Online]. Available at: MathWorks MatLab https://www.mathworks.com. Accessed 19 Mar 2018

Maxwell D et al (2011) Addressing the Rebound Effect. European Commission DG Environment, s l

MEEC (1997) Environmental quality standards for surface water. [Online]. Available at: http://english.mee.gov.cn/SOE/soechina1997/water/standard.htm. Accessed 17 June 2019

MEEC (2018) 2017 Report on the State of the Environment in China. [Online]. Available at: http://english.mee.gov.cn/Resources/Reports/soe. Accessed 19 June 2019

Merriam-Webster Dictionary (2019) Target. [Online]. Available at: https://www.merriam-webster.com/dictionary/target. Accessed 31 May 2019

NASDAQ-100 n.d. NASDAQ-100 equal weighted index shares (QQQE). [Online] Available at: https://www.nasdaq.com/symbol/qqqe. Accessed 23 June 2019

National Laboratory of Civil Engineering (2001) Programa Nacional para o Uso Eficiente da Água. National Institute of Water (INAG), Lisbon

Nigrini M, Miller S (2007) Benford’s law applied to hydrology data: results and relevance to other geophysical data. Math Geol 39(5):469–490

OECD (2001) Water quality index. [Online]. Available at: http://stats.oecd.org/glossary. Accessed 30 June 2012

Oxford Dictionary (2018) ‘meso-‘. [Online]. Available at: https://en.oxforddictionaries.com/definition/us/meso. Accessed 19 Mar 2018

Portuguese Environment Agency (2019a) River basin management plans—3rd cycle. Portuguese Environment Agency, Lisbon

Portuguese Environment Agency (2019b) Roadmap for carbonic neutrality 2050/strategic environmental assessment. Portuguese Environment Agency, Lisbon

Rawls J (1999) A theory of justice, Revised edn. Harvard University Press, Cambridge

Seckler D, Molden D, Sakthivadivel R (2003) The concept of efficiency in water-resources management and policy. s.l., CABI Publishing and International Water Management Institute

Sen A (1992) Inequality reexamined. Oxford University Press, New York

Stone D (2012) Policy paradox: the art of political decision making, 3rd edn. W. W. Norton & Company Inc., New York

UNEP (2007) Global drinking water quality index development and sensitivity analysis report. GEMS (Global Environment Monitoring System) Water Programme Office, Burlington, Ontario, Canada

UN-HLPW (2017) Bellagio principles on valuing water. United Nations, Sustainable Development Goals (SDG), High Level Panel on Water. [Online]. Available at: https://sustainabledevelopment.un.org/content/documents/15591Bellagio_principles_on_valuing_water_final_version_in_word.pdf. Accessed 29 Sept 2017

Weisstein EW (2018) Benford’s law. MathWorld, A Wolfram Web Resource. [Online]. Available at: http://mathworld.wolfram.com/BenfordsLaw.html. Accessed 24 Mar 2018

Wichelns D (2014) Water productivity: Not a helpful indicator of farm-level optimization. [Online]. Available at: http://www.globalwaterforum.org/2014/11/11/water-productivity-not-a-helpful-indicator-of-farm-level-optimization. Accessed 2 July 2019

Willardson LS, Allen R, Frederiksen H (1994) Elimination of irrigation efficiencies. USCID, Denver, Colorado