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The paracommons of competition for resource savings: Irrigation water conservation redistributes water between irrigation, nature, and society

Bruce A Lankford [a,*], Christopher A Scott [b]

[a] School of Global Development, University of East Anglia, Norwich, NR4 7TJ, UK
[b] Department of Ecosystem Science and Management, Pennsylvania State University, University Park, PA 16802, USA

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ABSTRACT

Based on understandings of a natural resource commons, we examine the competition for redistributed irrigation water following water conservation. A ‘paracommons’ is characterised by an interconnected hydrology whereby changes to a proprietor’s water management alters its distribution into different fractions/dispositions thereby adjusting water allocations to the four paracommoners; including the proprietor conserving water, an immediate neighbour, society and nature. The topic is important given the volumes potentially involved in irrigation savings; for example, a 15% reduction in the annual water depletion of an irrigation area of 30,000 hectares can notionally meet the domestic demands of one million people at 150 l/day/pp. However, this illustration, seeming to indicate that water conservation results in sizeable predictable outcomes, hides how water savings are captured by, or flow to, a paracommoner within the interlinked system. Using data from Mendoza, Argentina, we employ a model to examine 12 scenarios of conservation-driven water reallocation among paracommoners, and conclude with generalizable lessons.

1. Introduction

1.1. Reallocating water out of irrigation

Globally, catchments face rising water insecurities brought by more frequent and intense meteorological anomalies (Gosling and Arnell, 2016; Konapala et al., 2020), growing societal water demand from sectors such as cities and agriculture (Garrick et al., 2019; Greve et al., 2018), and freshwater ecosystems (Stewart et al., 2020). Water insecurities – and the significance of possible solutions – are amplified when catchments host significant areas of irrigated agriculture causing the majority of water to be withdrawn and depleted in this sector, a trend heightened by accusations that it is an inefficient or wasteful user of water (FAO, 2017). Conserving/saving water (these synonymous terms are defined below) and raising irrigation efficiency are purported to make water available for reallocation (Richter et al., 2017; van der Kooij et al., 2017) illustrated by reference to efficiency in the Sustainable Development Goal 6 (UN, 2017); “By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity”.

However, despite its appeal, putting irrigation efficiency at the centre of reallocation presents catchment authorities and stakeholders with hard-to-answer questions such as; (1) how does water reallocation out of irrigation affect food production (Elliott et al., 2014; Haddeland et al., 2014; Pérez-Blanco et al., 2020), and rural livelihoods and landscapes from what has been termed ‘buy and dry’? (Wiener, 2006); (2) can water reallocation be met from within irrigation via water conservation and improvements to irrigation efficiency? (Jägermeyr et al., 2015; Scott et al., 2014; Siderius et al., 2022); and (3) who materially gains from hydrological changes wrought by water conservation? (Lankford, 2013; Owens et al., 2022). Mindful of the emerging consensus that, paradoxically but perhaps unsurprisingly, it is irrigators who primarily benefit from efficiency gains (Grafton et al., 2018), this paper deals with the last two questions.

While there are several ways to address these two questions, we argue that the competition for the water notionally freed up by water conservation in irrigation can be usefully framed as a ‘commons’ type problem (Lankford, 2013; Owens et al., 2022). Illustrating this, the volumes of water thought to exist in ‘losses, wastes and wastages’ in irrigation represent a sizeable resource – as seen in the simple calculation in the abstract (revisited below), and in the more detailed

* Corresponding author.
E-mail address: b.lankford@uea.ac.uk (B.A. Lankford).

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calculations in the paracommons model to follow. Second, rivals lay claim to this realised water as exemplified by Norris' (Norris, 2011; p 1) commentary on a water dispute that revolved around these efficiency gains, and to whom these gains should accrue: "… the United States Supreme Court's 2011 decision in Montana versus Wyoming brings to the forefront one of the most complicated and contested facets of irrigation efficiency: who owns the rights to the conserved water?" Here, Norris is asking about access and ownership over property – a kind of commons – that has become or is becoming apparent but has not yet been claimed.

1.2. Objectives of this paper

Given the above debate and questions, this paper has four main objectives; (a) to introduce the concept of the paracommons drawing on prior work (Lankford, 2013); (b) to develop a new and original paracommons accounting framework and Excel model (Section 2); (c) to demonstrate the uncertain nature of the paracommons outcomes by applying this model to a hypothetical reading of a case study in Argentina (Section 3); and (d) to discuss the implications of the paracommons for both the case study and other situations elsewhere in the world. Within these objectives, the authors reiterate that the paper's approach and model act as quantitative dialogue tools to better understand the complicated consequences of water conservation for different actors within a catchment (van Oel et al., 2019).

1.3. Volumes and significance of water savings potentially realised

The tracking, accounting, distribution and ownership of freed-up, once-inefficiently-used resources will be of paramount importance in water scarce environments dominated by irrigation (Lankford et al., 2020; Lankford, 2023). Although our paracommons computations below are more complex, the question 'are the volumes of water in irrigation savings significant?' can be notionally demonstrated. In catchments with large areas of irrigation (tens of thousands to millions of hectares), the volumes of water potentially realised from water conservation are, on paper, very considerable, which provides one explanation for irrigation improvement programmes promoting precision irrigation (Mazzucato et al., 2023) aiming to reduce consumption and leverage water for other users and uses in the catchment (Flörke et al., 2018; Palazzo et al., 2019). For example, a catchment hosting 30,000 ha of irrigation cutting its annual depletion of 1200 mm of water by 15%, notionally 'frees up' 54 cubic hectometres (hm^3) per annum, equivalent to providing one million people with an approximate water supply of 150 litres per day, a typical usage in many countries.

Although this calculation defines realised water via a reduction in total (aggregate) depletion in irrigation across the whole basin - called real or wet water savings (Seckler, 1996) - it fails to accommodate the interconnections, risks and consequences that this paper and associated literatures (Grafton et al., 2018) critically discuss. It is these interconnections that cause changes in water withdrawals and depletion to cascade through linked paracommons systems, thereby creating final outcomes that differ from initial and hoped-for expectations.

1.4. The significance of scale in water conservation

The correct treatment of scale in water conservation is central to determining whether a reduction in the water withdrawn into an irrigation system, or water applied to a field, is equivalent to a reduction in water depletion expressed at the irrigated basin scale . This is important because allocations out of irrigation can only come from reductions in depletion of basin-accounted water from a combined interlinked irrigated system (Uhlenbrook et al., 2022; Lankford, 2023) rather than reductions in withdrawals, applications, or depletion expressed at the field or farm scale. Put simply, because withdrawals and field applications include in them losses of water that are recovered to the catchment (Perry, 2011), they are not mathematically equivalent to depletion of water from the basin. Distinguishing between consumptive and non-consumptive losses is captured by the two expressions of irrigation efficiency; classical and effective (Seckler, 1996). Therefore one 'classical' argument is that 'conserving water reduces water use and creates water savings' (Christian-Smith et al., 2011). Here, the classical irrigation efficiency (CIE, Table 1) of a single irrigation system says that when losses are reduced, less water is needed in the irrigation system so withdrawals are reduced which frees up spare water to be redistributed elsewhere. However, this argument excludes a full accommodation and calculation of the non-consumptive return flows in irrigation. Taking into account the reuse of recoverable losses from surface irrigation, an alternative argument is that more efficient irrigation paradoxically leads to either little change in, or greater, water depletion (Allen et al., 2005; Grafton et al., 2018; Matthews et al., 2022; Ward, 2022). Related, a higher classical irrigation efficiency can also mathematically describe greater water depletion (Ward and Pulido-Velázquez, 2008) when 'all losses' in the denominator (which includes recovered losses) switch to crop evapotranspiration (beneficial consumption) in the numerator as long as withdrawals are not simultaneously cut (Lankford, 2023). These interpretations identify water depletion rather than withdrawals as the defining metric of whether or not savings have occurred (Uhlenbrook et al., 2022). It is widely believed they are supported by empirical evidence of increased water depletion after projects to conserve water have been implemented (Pérez-Blanco et al., 2020).

If, on the other hand, irrigation efficiency is reduced to only the relationship between consumption and return flows which are then reused (missing out non-recovered flows and non-beneficial consumption – see page 9 of Perry et al. (2023)) we run the risk of over-simplifying arguments associated with managing irrigation

Table 1
Abbreviations in the paracommons.

ABS	Available basin supply	NbNRF	Neighbour NRF
ADC	Aggregate depletion change	NWW	Non-withdrawn water
ADI	Aggregate depletion impact	PWAM	Paracommons water accounting model
AEIE	Aggregate EIE	Pe	Effective rainfall
ADL	All depleted losses	Pr	Proprietor
AgHR	Agro-hydrology ratios	PrBC	Proprietor BC
ALF	All loss fractions	PrCIE	Proprietor CIE
AWD	Aggregate water depletion	PrEIE	Proprietor EIE
BC	Beneficial consumption	PrEA	Proprietor expansion area
BWW	Baseline water withdrawal	PrFA	Proprietor final area
CWW	Corrected water withdrawal	PrNBC	Proprietor non-beneficial consumption
CIE	Classical irrigation efficiency	PrNRF	Proprietor non-recovered fraction/flow
CPA	Core priority allocation	PrSA	Proprietor starting area
EIE	Effective irrigation efficiency	RF	Recovered fraction
ETo	Reference crop evapotranspiration	RRF	Reused recovered flow/ fraction
ETc act	Actual crop evapotranspiration	RUW	Residual unused water
ETM	ET modification	RUWC	Residual unused water change
FWI	Final withdrawal impact	RWO	Realisable water overplus
FWW	Final water withdrawal	RWW	Required water withdrawal
GIR	Gross irrigation requirement	SNR	Society-to-nature ratio
Ha	Hectares	Soc	Society
Hm^3	Cubic hectometres (1 million cubic metres)	URF	Unused recovered flow/ fraction
IWO	Irrigation withdrawal overplus	T1	Time 1, baseline.
Nat	Nature	T2	Time 2, scenarios #
NBC	Non-beneficial consumption	TFIA	Total final irrigated area
NIR	Net irrigation requirement	TIBC	Total irrigation BC
NRF	Non-recovered fraction	TBS	Total basin supply
NbFA	Neighbour final area		
NbBC	Neighbour BC		
NbCIE	Neighbour CIE		
NbNBC	Neighbour non-beneficial consumption		

efficiency, withdrawals, field applications, and depletion at different scales. Furthermore, both these narratives and their treatment of scale do not accurately predict other outcomes contingent upon a paracommons model which explores the pathways and fates of water flowing through a primary, first-use system to other interconnected systems and actors. Accordingly, we now expand on these understandings to provide a fuller treatment of scale-based paracommons interlinkages.

1.5. Introducing the paracommons

The competition over freed-up resources undergoing conservation is termed a 'paracommons' (Lankford, 2013). It is so named because spare irrigation water sits within, or is adjunct to, a commons of 'first-use' water for irrigation, domestic use, energy, industry and nature including instream, downstream and adjacent ecosystems. However, this spare water only becomes available following attempts at water conservation – and usually in unforeseen ways. The prefix 'para' means something near, against, resembling, alongside or in parallel (OED, 2023). Para draws attention to the fact that irrigation losses are not always visible as seen in drainage return flows; they also exist as evaporation that can be forestalled in the future, but in the present is non-beneficial (from open water bodies) or beneficial (to riparian habitat). Para thus reflects that these freed-up resources exist in the future when a water conservation policy prefigures the size of the resource to be realised (Christian-Smith et al., 2011).

Yet because these resources can be difficult to realise, para signals the transient, sometimes hidden, difficult-to-exploit and often unverifiable character of the volumes involved (Lankford, 2018), and the contentious and invariably insufficient policies for how this water may be governed, 'freed up' and redistributed especially to nature as ecological flows (Batchelor et al., 2014). In essence, the paracommons probes the justice and equity of water distribution on the back of efficiency improvements (Owens et al., 2022) asking "who gains from efficiency gains?" (Lankford, 2013). One answer is the proprietor, a term we use for owner of first-use irrigation where the water savings are being made, and who may be considerably advantaged to capture those savings through extra irrigated area, longer periods of irrigation, or changes to more water-intensive crops (Grafton et al., 2018; Lankford et al., 2020).

Prior to our paracommons treatment of water conservation in irrigation, we first introduce a simple non-water representation of a paracommons. The interconnected fates of an apple core sitting within a whole apple in a supermarket depends on the changing consumption and waste-decisions taken by a householder who has purchased this apple (Fig. 1). In pathway A, the apple core is discarded as waste by the householder but is eaten by someone scavenging the nearby city refuse dump (seen conceptually as the 'neighbour' – someone immediately connected to the household). In pathway B, the householder now decides to consumes their own apple core waste, perhaps as a result of being more cost or waste conscious. In pathway C, the apple core 'returns to nature' being composted in the garden, perhaps its seeds producing apple saplings. In pathway D, representing 'society', the apple core is collected from the house but is not sent to the city dump. Instead it is industrially processed as cellulose or for biomass energy (Gautam et al., 2022).

The fate of the apple core moving through each pathway deprives the other actors or players (which we term paracommoners) from the benefits of the apple core. So while multiple scavengers and pickers in the city dump compete over the apple core as a commons of refuse (Danese, 2021), all four parties compete over the apple core as a paracommons of changing waste pathways. Furthermore, it is the hungry scavenger in the city dump who is most aware of the apple core sitting inside of the apple in the supermarket (the dotted line in A). What is important to reiterate, however, is that the pathway the apple core waste takes, resulting in its final disposition, depends on actions taken by the proprietor, the householder in this case. As seen below, the same proprietor dependency arises within irrigation. Except with irrigation there are three waste or loss fractions not one.

1.6. A water commons and paracommons contrasted

To further explain an irrigated river basin paracommons, it can be usefully contrasted with a water commons. Expanding on the introduction above, the 'commons' in a river basin or aquifer (Fig. 2), is the freshwater claimed and subtracted by rival first-use commoners and users (Müller et al., 2017; Ostrom et al., 1999). Water withdrawn by irrigated agriculture is one such claim. Other commoners are found across and within households, cities, industry, the environment, energy production, provinces and countries. Fig. 2 shows that water commons are scalar; commoners exist at the catchment scale but also sit within irrigation systems as irrigators sharing irrigation flows and as 'drainage users' sitting immediately downstream of irrigation systems. A water

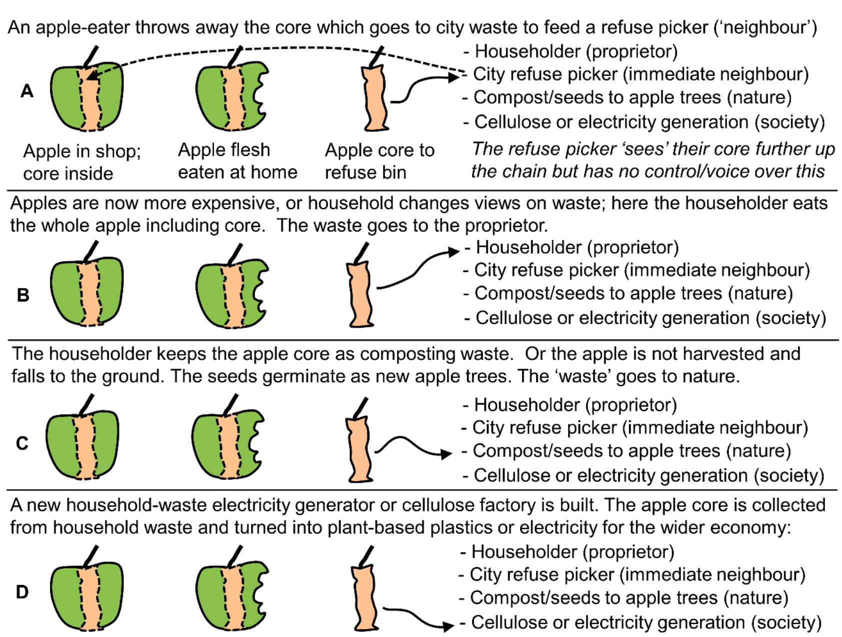


Fig. 1. A simple paracommons of apple core waste.

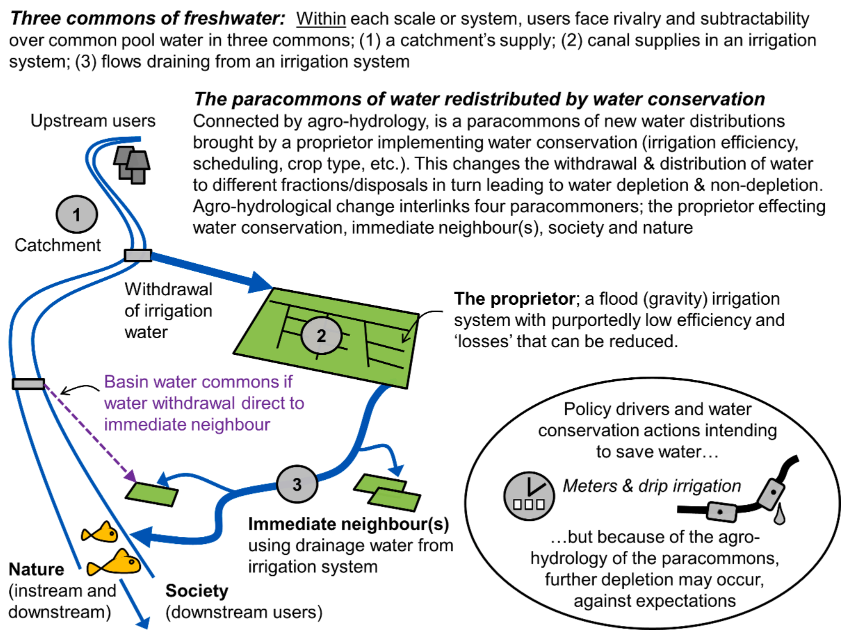


Fig. 2. The commons and paracommons in an irrigated river basin.

commons and their commoners stimulate debate questioning the institutions, power relations and scale effects that shape water governance, equitable water sharing, water property rights and water custodianship (Dietz et al., 2003; Kuswardono et al., 2021; Miller et al., 2020).

An irrigated basin paracommons (Fig. 2) is concerned with the water resource 'freed up' when realised by shifts in irrigation efficiency and related changes to water infrastructure and management (Lankford, 2013). The claims for and competition over this freed-up water defines four interconnected types of paracommoners; the proprietor making the savings, their immediate neighbours, society, and nature. This paracommons is also scalar; it can exist across the basin in which irrigation sits, or arise within different parts of the basin or parts of irrigation systems.

Thus the paracommons incorporates but goes beyond the rivalrous commons of 'wastes' discharging as drainage beneath irrigation systems shown by number (3) in Fig. 2 or when urban effluents are used by wastewater irrigators (Scott and Raschid-Sally, 2012; Singh and Narain, 2019). The latter two are commons of already produced, exteriorised (made-visible) reusable flows situated within one scale beneath (in gravity-flow terms) an irrigation or urban system creating drainage. In addition, the paracommons shows that caution should be applied when too much weight or significance is given to the question of who gets the return flows (the recovered fraction) from irrigation (Owens et al., 2022). Focussing on rivalry over return flows is just one part of the paracommons. As shown below, other decisions and fractions (dispositions) aside from return flows, are implicated in the areal growth of the proprietor system and consequences for the remaining paracommoners. Thus, although less obvious, the paracommons becomes apparent when savings are made in the upstream proprietor system because then return flows to downstream users start to change. Other connections occur if the proprietor's greater or smaller withdrawal or depletion of water impinge on nature and society. Lastly, recovered flows to the basin are not losses that are neutral or discountable (Allen et al., 2005; Keller and Keller, 1995); they interconnect paracommoners and bring costs such as relocated water, poorer inter-irrigator equity, reduced water quality and slower timing of flows (Lankford et al., 2020; Lankford, 2023).

1.7. Building a paracommons approach on water accounting

While the Introduction (Section 1) starts with conventional terms such as savings and losses, these insufficiently explain the science of water conservation and its consequences for a paracommons system. For example, the above water calculation, although based on a net depletion change to derive real savings, misses how all irrigation losses, not just visible recoverable return flows, connect water paracommoners; connections that change when withdrawals and depletion change. In this regard, we find that water accounting (WA) (Perry, 2011; Willardson et al., 1994) whilst providing a basis on which to build a paracommons model (Appendices A and B, supplementary materials), omits factors and calculations that interconnect the different users and variables of the paracommons. For example, the withdrawals of water into the proprietor system are apportioned into five fractions/dispositions by splitting the recoverable fraction (RF) into two fractions. The five fractions are the beneficial consumption (BC), non-beneficial consumption (NBC), non-recovered fraction (or flows), reused recovered flows (RRF) and unused recovered flows (URF). Furthermore, the non-withdrawal of water (NWW) and core priority allocation (CPA) are two specified flows because they physically interconnect the upstream proprietor and neighbour to downstream paracommoners.

Our paracommons model also draws from recent work that builds on WA to present a comprehensive computation of water conservation (Lankford, 2023). However, that work, which uses a much larger model, did not focus on the paracommons distribution of water, and for example, did not include a ratio that apportions water between society and nature.

2. Methods and case study

2.1. Introduction to the paracommons framework

Guided by Fig. 3, we present a paracommons framework with five stages as a precursor to building a computational model of the paracommons. These five stages make up the following sub-sections: agro-hydrological change over time; drivers to conserve water; actions

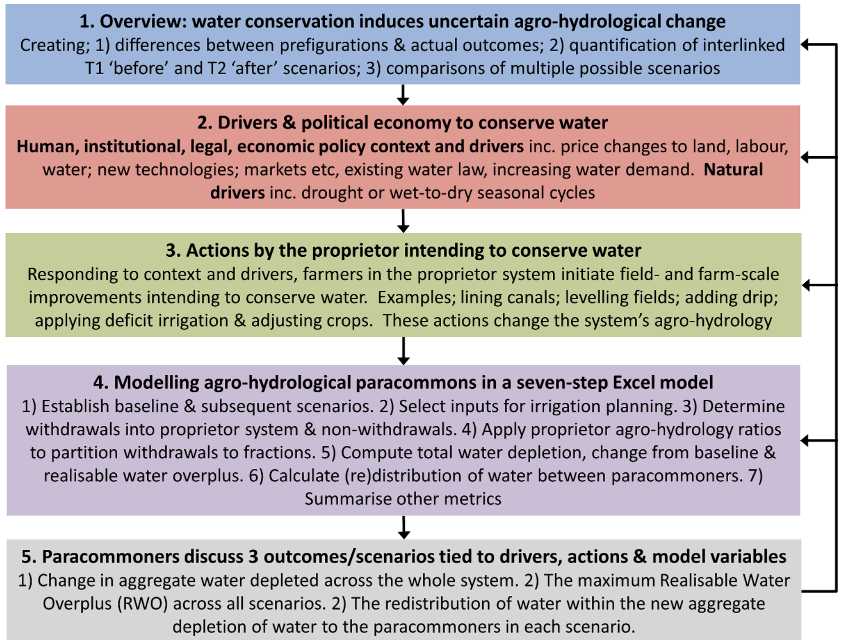


Fig. 3. The paracommons framework.

intending to save water; modelling agro-hydrological changes to pathways; and delivering and discussing three key outcomes across the selected scenarios. At this point we introduce the abbreviations employed in the paracommons analysis and model (Table 1).

2.2. *Paracommons framework in five stages*

2.2.1. *Overview: agro-hydrological change over time*

Implementing water conservation brings uncertain agro-hydrological change over time. It is this change over time that is at the heart of the paracommons in three key ways. First, there is the need to address an overly optimistic prefiguration of future gains; that water conservation will free up large volumes of water savings that can be purposively redirected. Thus, the paracommons reminds us that these expectations can be paradoxically confounded and that outcomes, both the quantities and final locations of savings, are likely going to differ from expectations. An appreciation of these uncertainties is why multiple scenarios of change are generated.

Second, to determine potential savings, and their likely or desirable redistribution, the paracommons is built mathematically on a comparison of change. The model compares the agro-hydrology in a present (T1 or baseline) scenario before water conservation has been implemented against future (T2) scenarios post water conservation. These comparisons can be seen below in Tables 2 and 3, and Figs. 4 and 5.

Third, also shown in the results and illustrations below, the paracommons model intentionally generates many T2 scenarios (and other baseline scenarios if necessary) for comparison. These multiple results have a purpose. They aid discussions amongst paracommoners, policymakers, managers and analysts on possible futures, and attendant risks of unexpected outcomes. Accordingly, they remind catchment actors that freed up savings should not be estimated by judging the size of the irrigation loss fractions in a single timeframe or by comparing only two or three scenarios. Furthermore, multiple scenarios encourage iterative dialogue about preferred outcomes regarding who gains - or loses - the most from water conservation.

2.2.2. *Drivers to conserve water*

Water conservation is driven by overlapping and changing stimuli, not only the application of an external policy designed to 'save and allocate' water. For example, farmers respond to physical or perceived water scarcity in the form of drought (Rey et al., 2017) or rising demands both in and around their irrigation systems (Lankford et al., 2020). Water shortages also might be accompanied by other costs, incentives and scarcities found in land, water, energy, land and labour (Rupérez-Moreno et al., 2017; van der Kooij et al., 2017). Other drivers may include historical irrigation licences for less efficient 'canal/surface' irrigation that allow often-significant savings to be made and retained on-farm after switching to more precise irrigation (Lankford et al., 2023).

2.2.3. *Actions intending to save water*

Responding to drivers, farmers apply water management actions, intending to save water, resulting in new T2 outcomes. Actions usually operate at the farm and field-scale, and are infrastructural (such as switching canal-irrigation to precision drip irrigation) or practice-based, for example, applying deficit irrigation (Geerts and Raes, 2009), shifting planting dates to periods of lower water demand, and using mulching and shade cloth (Gil et al., 2018).

With reference to water accounting fractions/dispositions (see Table 1 and Appendix A), these actions can; raise IE by reducing all three irrigation loss fractions (e.g. fixing leaking infrastructure); aim to reduce the beneficial consumption of water (by applying deficit irrigation); aim to reduce non-beneficial evaporation (mulches); simultaneously cut loss fractions and net beneficial consumption (i.e. reducing the area irrigated); and assist with water control and conservation (e.g. via field mapping, monitoring flows and building farm dams). These actions invariably operate together; for example, a farmer reducing canal leakage or over-irrigation beneath the rootzone will be able to schedule deficit irrigation more accurately. The phrase 'intending to save water' signals that drivers and actions might not produce anticipated outcomes due to incomplete modelling of the hydrology of an irrigated system.

2.2.4. *Modelling agro-hydrology in seven steps*

Actions intending to save water affect the agro-hydrology of flows in and around irrigated systems (Allen et al., 2005). Agro-hydrology describes how variables (such as area and irrigation need) and coefficients (e.g. irrigation efficiency) divide the basin supply into withdrawals to, and fractions/dispositions within, the proprietor. Within-proprietor fractions simultaneously distribute water to paracommoners and determine total water depletion. Therefore, understanding water

Table 2
Scenarios 1 to 12 in the paracommons; input variables.

Scenario	Abbrev.	Units	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Headline			Baseline	Reallocat	Reallocat	Reallocat	Low RF	Low RF	IEP I	IEP II	Offset	High RF	Drought I	Drought II
Proprt'r benef consmp	PrBC		Baseline	Cut	Cut	No chng	Gain	Gam	Gain	Gain	Same	No chng	Cut	No chng
Neighb'r benef consuip	NbBC		Baseline	Cut	Cut	Cut	Cut	Cut	Cut	Cut	Same	No chng	Cut	Cut
Society water	Soc		Baseline	Gain	Gain	Gain	Gain	Gain	Cut	Cut	Gain	Gain	Cut	Gain
Nature water	Nat		Baseline	Gain	Gain	Gain	Gain	Gain	Cut	Cut	Gain	Gain	Cut	Gain
Prop. starting area	PSA	Ha	66,000	53,576	66.000	66,000	75,000	75.000	66.000	66,000	85,725	66,000	66.000	44,289
Proprietor CIE	PrCIE	%	40%	40%	40%	75%	75%	75%	75%	75%	75%	62%	40%	75%
FWW RULE	RWW/BWW		BWW	RWW	RWW	RWW	RWW	RWW	BWW	BWW	RWW	RWW	RWW	RWW
Other change			Baseline					Low RF				Hi RF	Lo Pe/TBS	Lo Pe/TBS
ETo	ETo	mm	960	960	960	960	960	960	960	960	960	960	960	960
ET modification	ETMod		1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Effective rainfall	Pe	mm	450	450	450	450	450	450	450	450	450	450	200	200
Net irrig req (calc)	NIR	mm	510	510	414	510	510	510	510	510	510	510	760	760
Gross irrig req (calc)	GIR	mm	1275	1275	1035	680	680	680	680	680	680	825	1900	1013
Total basin supply	TBS	Hm^3	884	884	884	884	884	884	SS4	884	884	884	650	650
Core priority alloc.	CPA	Hm^3	20	20	20	20	20	20	20	88	20	20	20	20
Prop non-benef cons	PrNBC	%	30%	30%	30%	30%	30%	80%	30%	30%	30%	5%	30%	30%
Prop non recvd fract	PrNRF	%	20%	20%	20%	20%	20%	10%	20%	20%	20%	5%	20%	20%
Reused recvd tract	RRF	%	35%	35%	35%	35%	35%	5%	35%	35%	35%	85%	35%	35%
Unused recvd fract	URF	%	15%	15%	15%	15%	15%	5%	15%	15%	15%	5%	15%	15%
Neighb'r CIE	NbCIE	%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
Neighb'r NBC	NbNBC	%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Neighb'r NRF	NbNRF	%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Soc/Nat ratio	SNR	%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%

Note: Abbreviations are given in Table 1.

conservation requires a system model that reflects this withdrawal/non-withdrawal, distribution of dispositions, and aggregate depletion of water.

Our paracommons model (Supplementary materials, Appendices A and B) has seven interlinked steps. Step 1 establishes multiple scenarios to illustrate technical and policy narratives, and to aid discussions. Step 2 selects input variables that fall under 'irrigation needs planning', and conducts initial relevant calculations. Step 3 collates and computes the basin supply, core priority allocation, irrigation withdrawals and non-withdrawals. During step 3, a key decision is taken regarding whether the T1 baseline withdrawal of water (BWW) carries over to become the T2 withdrawal, or if the new T2 withdrawal is altered in line with new T2 irrigation planning calculations. Step 4 applies irrigation efficiency hydrology ratios to divide withdrawn water to each fraction. This step also computes the volumes from the efficiency ratios. Step 5 computes total water depletion, its change from the baseline, and the identification of a realisable water overplus. Step 6 calculates the distribution and redistribution of water between paracommoners. Step 7 summarises other key indicators. In each of steps 3 to 7, 'before and after' (T1 and T2) scenarios are compared. The calculations in steps 5 and 6 are discussed in more detail in the next sub-section.

2.2.5. *Iteratively discussing three key outcomes*

The fifth stage of the paracommons approach (Fig 3) sees catchment stakeholders weigh all the scenarios together and examine further adjustments to selected variables. This broad iterative approach has four aims. First, it draws attention to three key outcomes of the model (see below). Second, it reminds stakeholders including scientists and irrigation engineers that saving and re-directing water is far from straightforward. Third, it ensures the model is not normative, meaning it does not instruct stakeholders that a given scenario is the right or only way forward. Fourth, it expands and strengthens participatory and democratic buy-in to decisions and actions.

The division of water into the proprietor's dispositions determines aggregate water depletion across the whole system and the allocation of water to paracommoners. In our formulation, these two results allow the calculation of three key outcomes, defined as follows:

1 The change in aggregate water depleted across the whole system is given by the Aggregate Depletion Change (ADC). ADC compares the aggregate water depletion (AWD) in the T2 scenario against the AWD in T1. A negative ADC indicates a cut in depletion. A positive ADC represents an increase in depletion.
2 Deriving the maximum Realisable Water Overplus (RWO). If water depletion is reduced in the future, ADC records a negative result which can be thought of realised irrigation water savings subject to paracommons redistribution. The RWO is equal to the maximum depletion reduction selected from all T2 scenarios. Cautions apply: (1) too few scenarios from which an RWO is identified undermines discussion of possible futures, attendant risks and costs; (2) the term 'overplus' rather than 'losses, waste or surplus' seeks to be neutral and not invite socio-political judgements of surplus, inefficient or lax water use by 'wasteful irrigators' (Boelens and Vos, 2012; Van Halsema and Vincent, 2012); (3) the ADC and RWO emerge when all fractions of depleted water are accounted for (BC, RRF, NBC, NRF); and (4) RWO is not easy to physically measure or derive in the real world (van der Kooij et al., 2017).
3 The redistribution of water within the new aggregate depletion of water examines the losses and gains of water for each paracommoner. The losses or gains by nature and society are particularly salient, as they receive the residual unused water (RUW) which is the sum of the core priority allocation, the unused recovered fraction (URF) and the non-withdrawn water (NWW) of the basin water supply. The society-to-nature ratio (SNR) divides this combined society-nature water volume according to intended policy or observations and measurements. In our model below, in keeping with

Table. 3
Scenarios 1 to 12 in the paracommons; results.

Scenario		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Avail. basin supply (ABS)	Hm^3	864	864	864	864	864	864	864	796	864	864	630	630
Final water withdr (FWW)	Hm^3	842	683	683	449	510	510	842	796	583	544	630	449
Non withd water (NWW)	Hm^3	23	181	181	415	354	354	23	0	281	320	0	181
Final withdr impact (FWI)	%	97%	79%	79%	52%	59%	59%	97%	100%	67%	63%	100%	71%
Proprietor starting area (PSA)	Ha	66,000	53,576	66,000	66,000	75,000	75,000	66,000	66,000	85,725	66,000	66,000	44,289
Proprietor final area (PFA)	Ha	66,000	53,576	66,000	66,000	75,000	75,000	123,750	117,000	85,725	66,000	33,158	44,289
Neighbour final area (NbFA)	Ha	34,650	28,128	34,650	7700	8750	1250	14,438	13,650	10,001	34,650	17,408	5,167
Total final irrigated area (TFIA)	Ha	100,650	81,704	100,650	73,700	83,750	76,250	138,188	130,650	95,727	100,650	50,566	49,457
Distribution of water between dispositions and paracommoners													
Proprietor BC (PrBC)	Hm^3	337	273	273	337	383	383	631	597	437	337	252	337
Neighbour BC (NbBC)	Hm^3	141	115	115	31	36	5.1	59	56	41	141	106	31
Total irrig BC (TIBC)	Hm^3	478	388	388	368	418	388	690	652	478	478	358	368
Society (Soc)	Hm^3	106	236	236	407	354	342	67	106	291	315	69	196
Nature (Nat)	Hm^3	11.8	26.2	26.2	45.2	39.3	38.0	7.4	11.8	32.3	35.0	7.7	21.8
All depleted losses (ADL)	Hm^3	288	234	234	64	73	116	120	113	83	56	215	64
Reused recov fract (RRF)	Hm^3	177	143	143	39	45	6.4	74	70	51	177	132	39
Unused recov fract (URF)	Hm^3	76	61	61	17	19	6.4	32	30	22	10	57	17
Residual unused water (RUW)	Hm^3	118	262	262	452	393	380	74	118	323	350	77	218
Agg. water depl (AWD)	Hm^3	766	622	622	432	491	504	810	766	561	534	573	432
Agg. depl impact (ADI)	Hm^3	89%	72%	72%	50%	57%	58%	94%	96%	65%	62%	91%	69%
Volume change from baseline			RWO (not in drought)		−334	Hm^3							
Final withdr water (FWW)	Hm^3	–	−158	−158	−393	−332	−332	0	−46	−259	−297	−212	−393
Proprietor water	Hm^3	–	−63	−63	0	+46	+46	+295	+260	+101	0	−85	0
Neighbour water	Hm^3	–	−27	−27	−110	−106	−136	−82	−86	−101	0	−36	−110
Society water	Hm^3	–	+130	+130	+300	+247	+236	−40	0	+184	+208	−37	+90
Nature water	Hm^3	–	+14	+14	+33	+27	+26	−4	0	+20	+23	−4	+10
Depleted losses	Hm^3	–	−54	−54	−224	−215	−172	−168	−174	−205	−232	−72	−224
Residual unused water chge RUWC	Hm^3	–	+144	+144	+334	+275	+262	−44	0	+205	+232	−42	+100
Agg depl. change	Hm^3	–	−144	−144	−334	−275	−262	+44	0	−205	−232	−192	−334
Percentage change from baseline													
Proprietor water		–	−19%	−19%	0%	14%	14%	88%	77%	30%	0%	−25%	0%
Neighbour water		–	−19%	−19%	−78%	−75%	−96%	−58%	−61%	−71%	0%	−25%	−78%
Society water		–	122%	122%	282%	232%	222%	−37%	0%	173%	196%	−35%	84%
Nature water		–	122%	122%	282%	232%	222%	−37%	0%	173%	196%	−35%	84%

Note: Abbreviations are given in Table 1.

observations in the region, we have 90% of this volume going to society and 10% to nature.

2.3. *Mendoza case study and interpretation*

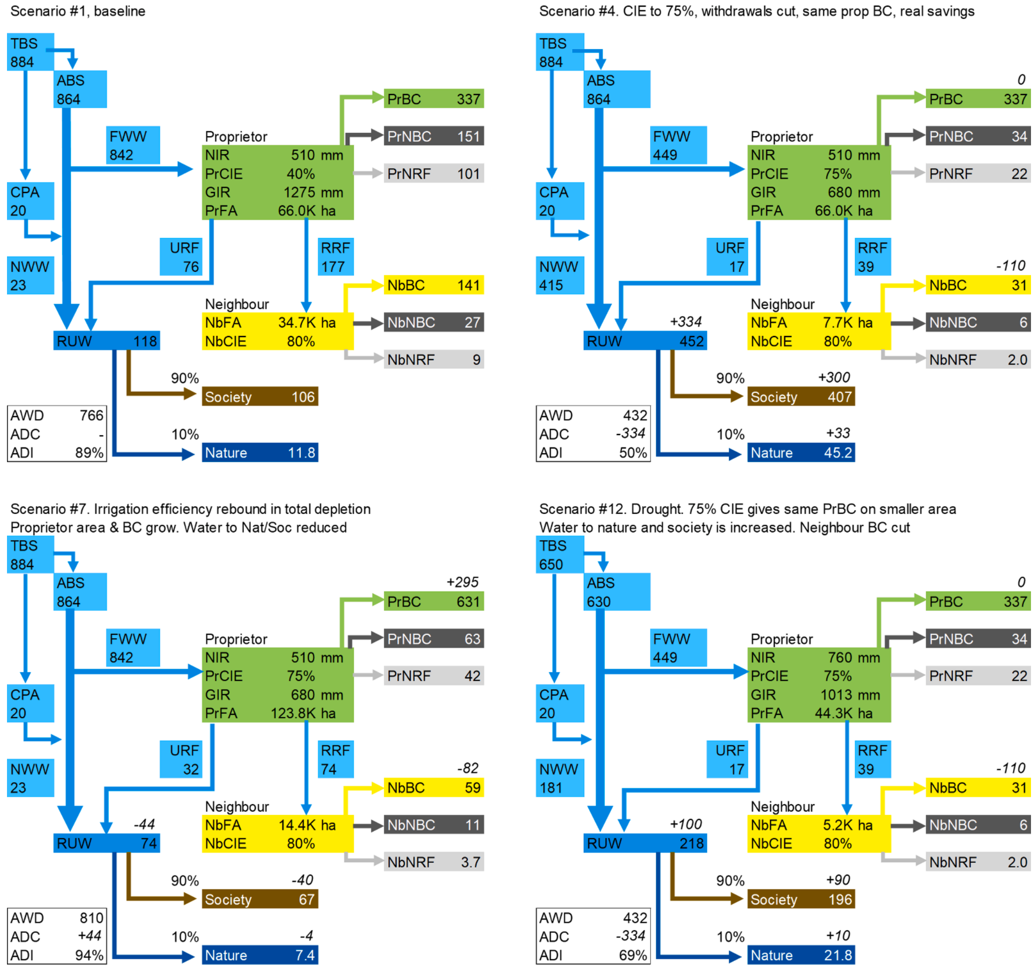
To showcase an irrigated paracommons, we interpret case material and data taken from Mendoza Province, Argentina. The data were collected by one of the co-authors through collaborative field research in the case study location over a decade based on monitoring data collected by the provincial irrigation department. This hypothetical approach pragmatically strikes a balance between a totally abstract model not informed by any real-world problems, and a time-consuming study based on more detailed data. Our purpose therefore is to show that with some relatively elementary agro-hydrological data and estimates (e.g. area, rainfall, ET), a credible paracommons model of irrigation can be constructed.

Mendoza provides a paracommons study of the competition for water savings in irrigation. Here, aridity, well-drained soils and abundant sunshine underpins the significant role of irrigation in agriculture and the drive for water abstraction from both surface and subsurface sources (Hurlbert and Mussetta, 2016; Salomón-Sirolesi and Farinós-Dasí, 2019). Together with climate impacts, these processes have prompted depletion of local water bodies, salinity impairment, the near-total desiccation of the Ramsar-designated Lagunas de Guanacache wetlands, and an inter-provincial water dispute between Mendoza and downstream La Pampa Province on the Atuel River (Castex et al., 2015; Rojas et al., 2020).

Furthermore, an all-too-frequently cited reason for these costs and externalities is inefficient irrigation. Perhaps predictably, the solutions proposed are raising irrigation efficiency through canal lining, land levelling, and the slow, expensive shift to drip irrigation (Chambouleyron et al., 1993; DGI, 2012). It is these solutions together with unacknowledged implications and outcomes that provide us with an irrigation paracommons characterized by a higher-value shift of water abstraction and depletion, a latent energy crisis resulting from rapidly increasing pumping and pressurization of irrigation, and crucially, the inability or unwillingness of authorities to redistribute conserved water away from irrigation to nature and society.

Within the Tunuyán River catchment, we identify the following paracommoners. The proprietor is the Upper Tunuyán Irrigation District. The immediate neighbours are irrigators found in the Lower Tunuyán Irrigation District using return flows from the Upper Irrigation District. Society is represented by (a) water needs for the towns of Rivadavia and San Martín in the peri-urban area adjoining Mendoza city; and (b) downstream needs in the provinces of San Luis and, ultimately, La Pampa, though the current dispute is over the Atuel River in the south of the province, with its own similar challenges. Nature is represented by wetlands downstream of the Campo Las Toscas Tunuyán.

We draw upon irrigation metrics taken from these systems to build a paracommons model. For the purpose of our paper, and given the relatively small Excel model employed to demonstrate the paracommons, these metrics are appropriately indicative of the case study and its future possible scenarios (see next section). As such we are not presenting current and future forecasts of trends in land and water management in the Tunuyán catchment. Instead, we show the value addition of assessing plausible agro-hydrological changes and their impacts on Tunuyán paracommoners.



Numbers without units are hm^3. See Table 1 for abbreviations. Numbers in italics represent changes in water volumes against baseline

Fig. 4. Paracommons water redistribution in scenarios 1, 4, 7 and 12.

3. Results: the paracommons re-distribution of water

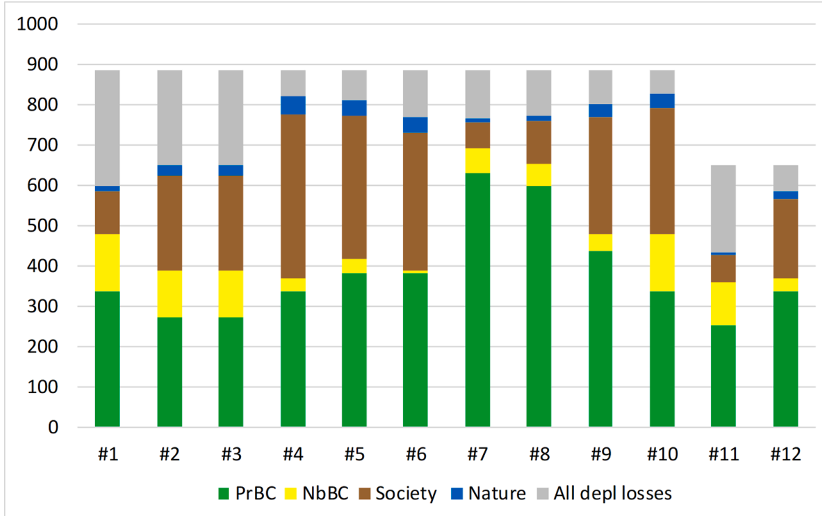
3.1. Introduction to the 12 scenarios

We have drawn up 12 scenarios to reveal the changing water allocations to paracommoners driven by water conservation, depletion and re-distribution. Table 2 presents an overview of the 12 scenarios and their key input variables. Table 3 presents the key results of the changes in irrigated area for the proprietor and neighbour, and both the water provisions and changes in water provision for all four paracommoners. Fig. 4 presents a stylised paracommons hydrology of four of the selected scenarios. Fig. 5 graphs the water provisions for each scenario taken from Table 3, noting that water for the proprietor and neighbour is indicated by their crop beneficial consumption, and water for nature and society combined is that which is not depleted by irrigation.

The 12 scenarios were selected in order to; (a) provide distinct stories of agro-hydrological change showing how paracommoners win and lose; (b) demonstrate differences between scenarios that, with relatively minor changes to selected input variables, can either lead to more or less water consumed by irrigation and therefore changes in water supplies to nature and society; and (c) reveal that changes to different input variables may surprisingly result in similar patterns of water re-distribution. Given the number of variables in the model, including the ability to change the baseline variables, many more scenarios than 12 are possible. Recall also that a key objective of our approach is to get stakeholders to compare and discuss many possible outcomes that can occur when conserving water. Thus a total of 12 is a judicious choice for showcasing an instructive variety of scenarios while containing them in one-page tables and graphs.

Unless stated across all 12 scenarios, similar agro-hydrological variables apply which allows for easier comparison of the effects of changes to key variables (such as the irrigation efficiency (CIE) in the proprietor). Except for drought cases 11 and 12, the total basin supply (TBS) is 884 hm^3. Except for scenario 8, a core priority allocation (CPA) of 20 hm^3 is provided to society and nature. The non-beneficial consumption in the proprietor (PrNBC) is 30% of all loss fractions (ALF). The proprietor non recovered fraction (PrNRF) is 20% of ALF. The reused recovered fraction (RRF) is 35% of ALF; and the unused recovered fraction (URF) is 15% of ALF%. (The exceptions to these ratios are found in scenarios 6 and 10). The CIE of the neighbour's irrigation (NbCIE) is high at 80% reflecting higher scarcity of water in this reuse zone. Thereafter NbNBC is 15% and NbNRR is 5%.

We start with a description of the T1 baseline scenario against which the other 11 T2 cases are compared. Using data from the Mendoza provincial water authority (Departamento General de Irrigación, DGI), Scenario 1 sets an area of 66,000 ha, a CIE of 40% and a gross depth of 1275 mm withdrawn over the season. The latter comes from the basin's available supply (ABS) of 864 hm^3, of which 842 hm^3 is withdrawn into the proprietor. The reused recovered fraction (RRF) supports a neighbour's irrigated area of 34,650 ha. Aggregate depletion from irrigation from both proprietor and neighbour is 766 hm^3 resulting in a residual unused water supply to nature and society of 118 hm^3. This RUW is the



Scenario	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
PrBC	337	273	273	337	383	383	631	597	437	337	252	337
NbBC	141	115	115	31	36	5	59	56	41	141	106	31
Society	106	236	236	407	354	342	67	106	291	315	69	196
Nature	12	26	26	45	39	38	7	12	32	35	8	22
All depl losses	288	234	234	64	73	116	120	113	83	56	215	64

Note: All numbers are cubic hectometres

Fig. 5. Paracommoner water redistribution for 12 scenarios.

sum of the core priority allocation (CPA) of 20 hm^3, the non-withdrawn volume (NWW) of 23 hm^3 and the unused recovered fraction (URF) of 76 hm^3 flowing out of the proprietor system.

Thereafter, new T2 adjustments to the input variables are made, drawing on future and possible goals from DGI. Tested in 11 remaining scenarios, these produce changes in aggregate water depletion, and reveal which paracommoners gain and lose from efforts to conserve water. Scenarios 2–6, 9, 10 and 12 witness the gain going primarily to nature/society. Scenarios 7 and 8 observe an increase in water depletion by the proprietor and/or neighbour. Scenario 9 produces an equal offset switch between water gained by the proprietor but lost to the neighbour. Scenarios 11 and 12 explore distributions during a drought. The following sub-sections lead with a paracommons or water conservation story using one or more scenarios to illustrate them. Scenarios do not probe whether controlling soil salinisation is dependent on over-irrigation represented by the Baseline's low CIE.

3.2. Water to society/nature without changing irrigation efficiency

Scenarios 2 and 3 generate two stories. Changes to different input variables can produce identical water distribution outcomes, and more water (+114 hm^3) can be redirected to nature and society without raising the proprietor's IE. Scenario 2 reduces the command area to 53,576 ha (considered a drastic reduction that would generate local opposition). Scenario 3 reduces the net irrigation requirement down to 414 mm and the gross withdrawal depth down to 1035 mm (considered feasible with better field-level water application and application of deficit irrigation). These choices for both scenarios cut irrigation withdrawals by 158 hm^3 and contribute to the 114 hm^3 gain to nature and society via a reduction in depletion from the proprietor and neighbour. Scenario 11 (discussed below) also reveals that during a drought no change in the irrigation efficiency results in new water distributions. Note, Scenario 3′s reduction of the net depth applied by nearly 100 mm might reduce or eliminate the leaching fraction required to manage soil salinity, bringing future salinization risks.

3.3. Water to society/nature by raising irrigation efficiency

Scenarios 4 to 6 demonstrate the benefits of a higher irrigation efficiency of 75% in allocating more water to nature and society provided required water withdrawals (RWW) are reduced in line with a lower gross irrigation requirement (GIR). The three scenarios are compared together as well as with the baseline scenario. In all three scenarios, the benefits of a higher IE accrue to nature and society rather than the neighbour. Scenario 4 keeps the proprietor starting area at 66,000 ha, while 5 and 6 both raise this area to 75,000 ha. Scenarios 5 and 6 differ only by the low recovered fraction applied to 6, revealing how the role of return flows in the latter diminishes, discussed below.

Scenario 4 raises its IE to 75% which reduces the GIR to 680 mm. This allows a smaller final withdrawal of water into the proprietor which boosts the non-withdrawn water (NWW) of water passing to nature and society. By keeping the proprietor area at 66,000 ha, the beneficial consumption of water in the proprietor remains the same as the baseline at 337 hm^3. However the lower return flows, as a result of the higher IE, cut the neighbour's irrigated area and BC by 27,000 ha and 110 hm^3 respectively.

3.4. Agro-hydrological significance of non-withdrawals of water

By comparing Scenarios 5 and 6, we argue that the non-withdrawal of water (which by-passes the proprietor and neighbour) is an important feature of the changing agro-hydrology of a paracommons system. Recall, both scenarios uplift IE to 75% and, by switching to a lower required withdrawal for these more-efficient systems, allow the non-withdrawal of water to grow from the baseline's 23 hm^3 to 354 hm^3 in both scenarios. Thereafter, the proprietor's dispositions in 5 include a high proportion of return flows (RF = 50%), but in 6 are mainly via non-beneficial consumption (NBC), where RF = 10%.[1] This means 6 delivers

[1] Our argument is that drip irrigation in Scenario 6 delivers higher IE and almost no seepage and drainage losses; thus 'waste' is via the non-beneficial evaporation of moisture from between drip lines and emitters.

smaller return flows (RRF and URF are 6.4 hm^3 each). However, because NWW dominates the provisioning of water downstream, the final paracommoner water distributions between 5 and 6 are not that different; society and nature together receive 275 hm^3 and 262 hm^3 respectively. Concluding, both scenarios reveal the significance of NWW against a mistaken over-emphasis given to the role of return flows (see a fuller critique of the role of return flows in Lankford (2023)).

3.5. The irrigation efficiency paradox demonstrated

Scenarios 7 and 8 both portray the irrigation efficiency paradox (Grafton et al., 2018; Wheeler et al., 2020) that raising IE can result in an increase in beneficial consumption by the proprietor. By raising IE to 75%, and keeping the final withdrawal as the baseline, Scenarios 7 and 8 see beneficial consumption by the proprietor increase by +295 hm^3 and +260 hm^3 respectively. In Scenario 7, the neighbour, nature and society see cuts in their water supply by -82 hm^3, -39.8 hm^3 and -4.4 hm^3 respectively. As a result of the continuation of the baseline withdrawal (which exceeds the gross irrigation requirements of the higher efficiency system) the total command area under irrigation increases from the baseline's 66,000 ha to 138,188 ha in #7.

3.6. Total irrigation area grows without impacting society and nature

Continuing the previous sub-section's observations about area growth, Scenario 8′s story is that the total area under can be grown to 130,650 ha via water conservation without cutting the water flowing downstream to nature and society. However the proprietor gains 51,000 ha while the neighbour loses 21,000 ha. These areal outcomes are also reflected in the beneficial consumption volumes; total BC goes up, but via the proprietor rather than the neighbour. Scenario 8′s distribution of water uses Excel Goal Seek to set the change in water for society to zero, contingent upon the core priority allocation to 88 hm^3. In other words Scenario 8 reduces the amount of water withdrawn into and flowing through the proprietor system, which including its higher IE, results in much lower depleted losses.

3.7. Trade-offs and equity between the proprietor and neighbour

Many scenarios (e.g. 5–8) reveal the neighbour disproportionally consumes less BC water when the proprietor gains BC water. For example, the proprietor's BC in 7 gains 294.5 hm^3 whilst the neighbour's BC shrinks by -82.5 hm^3. Scenarios 9 and 10 manage this unequal trade-off. Scenario 9 sees a gain of 100.6 hm^3 accrue to the proprietor versus a cut of 100.6 hm^3 falling on the neighbour. Scenario 10 sees no cuts fall on the proprietor and neighbour despite an approximate gain of 230 hm^3 flowing to nature and society combined. Scenario 10 achieves this by selecting irrigation losses that occur primarily via recovered flows to the neighbour (RRF = 85%) with lower dispositions in NBC, NRF and RRF (set at 5% each). Once these conditions are controlled, Excel Goal Seek is employed to set the proprietor's CIE at 62% to achieve this outcome. Although irrigation systems in the real world cannot be manipulated this easily, Scenario 10 represents a talking point about how neighbouring systems are sustained by high recovery of return flows.

3.8. Distributing water in a drought is difficult

Scenarios 11 and 12 explore the difficulty of keeping all paracommoners supplied during a drought when the basin supply (TBS) is reduced from 884 to 650 hm^3 and effective rainfall is cut from 450 to 200 mm. In Scenario 11, this scarcity is shared between all paracommoners with significant water cuts falling on all parties. Note however, these drought harms partly exist because no uplift in IE has been applied; CIE remains at 45% and thus within the two irrigation areas, all depleted losses (NBC and NRF) amount to 215 hm^3.

One response to this is seen in water-short Scenario 12. It supports nature and society instead of the proprietor and neighbour. It uses a higher proprietor IE of 75% and, using Excel Goal Seek, cuts the proprietor command area at 44,289 ha to ensure that; (a) beneficial consumption by the proprietor remains the same; and (b) water flowing to nature and society goes up by 100 hm^3 compared to the baseline. However the neighbour sees a BC volume cut of -110 hm^3. This means the total irrigated BC (TIBC) is down by -110 hm^3.

Although space limits the number of drought scenarios to two, it would be possible to explore more permutations to give stakeholders further choice recognising that managing water distributions during drought is both difficult and likely sees one or more parties taking a cut in supply.

3.9. Largest realisable water overplus (RWO)

Of the scenarios delivering water gains to nature and society, number 4 produces the largest RWO of 334 hm^3 delivered downstream. In other words, this is the scenario that achieves the greatest cut in aggregate depletion of water in irrigation. This is achieved by applying a higher efficiency (75%, feasible with the shift to drip irrigation over some of the command area), keeping the same command area as the baseline and reducing the withdrawal volume to match the new lower NIR and GIR. This boosts the non-withdrawal (by-passing proprietor system) up to 415 hm^3 (up from the baseline's 23 hm^3) which is the main contributor to downstream needs.

4. Discussion

4.1. Applying the paracommons approach and model

The 'para' part of the paracommons indicates potential volumes of water freed up and the fates of their distribution are far from intuitable, measurable, or easy to control. This allows parties to purposively or unwittingly promote their water consumption plans without fully appreciating how these will affect other parties. It also means that while policy-makers might prefigure a saved resource can be allocated to a given party (e.g. to cities or nature) (Flörke et al., 2018), outcomes will commonly go against expectations, particularly when available conserved volumes are spatially remote from paracommons redistribution sites, e.g. water releases from the proprietor in the river channel for nature downstream can be clandestinely or otherwise appropriated by the downstream neighbour, or other users and sectors.

The quantitative outputs from the model, in our view, aim to support discussions about the changing orbits of the paracommoners dependent upon changes to input variables. The model reveals to stakeholders the many, subtle and difficult-to-manage agro-hydrological interconnections that link paracommoners. These in turn show that the model and its key indicators are guides to dialogue about the political economy of water governance. For example, although the metric 'maximum realisable water overplus' can be discussed as a possible freed up saving, it is not easily or technically selectable for the water governance reasons discussed in Section 4.2. We now examine these wider constraints on water redistribution, arguing that the proprietor system is asymmetrically advantaged to consume more water via hidden, incremental and overlapping physical and institutional factors.

4.2. The proprietor and neighbour are advantaged to consume water

4.2.1. Hydrological sequencing and context

The sequence of withdrawal, division into dispostions and depletion takes place in the proprietor, followed by water consumed by the neighbour. Flows to nature and society are therefore residuals of decisions taken in the proprietor and neighbour systems. While these zones of depletion might be easy to identify, differences between upper and lower catchments, not only spanning large distances but also falling across agro-ecological zones of varying humidity, make it difficult to ascribe a reduction in downstream river flows solely to upstream actions (Lankford et al., 2004). Across these differences, hydrological dynamics (seen in variable rainfall, droughts and floods) add to the attribution problem, making before-and-after trackable comparisons tricky.

4.2.2. Concrete, hidden, overlapping and incremental water actions

The management of water abstraction, division, field application, infield control and drainage – all enabled by infrastructural endowments and design – occurs within the proprietor irrigation system. The main intake (headworks) of the irrigation system is often physically designed for higher withdrawal flow rates than are needed because irrigation design procedures are tied to historical generous water licences, full command area irrigation and artificially low irrigation efficiencies (Lankford, 2004). If not physically re-sized, or retrofitted to be automated, this intake gate must be manually adjusted to match lower water needs which – to the advantage of the proprietor – can easily be incorrectly carried out. Water withdrawals can also occur unobtrusively in and by the proprietor – examples include small stream abstraction, on-farm ponds and boreholes sunk without licences or external monitoring (Knüppe, 2011; Lankford et al., 2023). Related, the agro-hydrological division of withdrawals to different fractions also arises via incremental actions intending to save water. Some actions may be practically invisible to the outside world such as repairing a leak or applying deficit irrigation. Other more visible actions, such as adopting drip irrigation or land levelling for surface irrigation, nonetheless can be incremental, being phased in over a number of years.

Non-actions (not introducing improvements) may also hinder transparency; in Fig. 2, the dotted purple arrow signals that the direct distribution of water to the neighbour is, in the experience of the authors, not commonly implemented. If this direct link were to happen, the neighbour would not have to depend on return flows that were coupled to depleted losses in the proprietor. Thus, reinforcing previous points, water to the neighbour and to nature/society are 'residuals' of difficult-to-trace changes made by the proprietor. Nevertheless, there are some management and policy solutions to these problems, namely, monitoring by the water authority (which does occur in Mendoza) and by other water users (indeed the name for water user associations in Mendoza is "inspecciones de cauce," or channel inspections, indicates this is part of their formal function).

4.2.3. Institutions and the logistics of institutions

The proprietor's water allocation may be extraordinarily advantaged by water rights and often by water law, which prioritises first-use water and seldom fully recognizes 'saved' or redistributed water (MacDonnell, 2012; Norris, 2011). In other words, institutions that control the paracommons distribution of water arise via the proprietor's established water rights sitting within a legal framework (Huffaker and Whittlesey, 2000). Also, as hinted above, long-standing rules of irrigation design (Lankford, 2004) determine a hidden advantage in allocating water to irrigation (Hooper and Lankford, 2018). Connected to rules and institutions, are scale discontinuities that prevent paracommoners from easily meeting to decide the fate of freed-up overpluses. The proprietor and immediate neighbour sit locally connected in contrast to flows going to nature and society.

4.3. Applications to irrigated systems elsewhere in the world

While the principles of the paracommons model are generic, specific analyses must be adapted to address the context of each case. Irrigation system features that are often present but not considered in the Mendoza case are; extensive reliance on groundwater; more significant inter-annual variability in rainfall and therefore of irrigation demand; downstream or indeed upstream diversions that are dominated by urban water use (which is often the societal water demand that has the greatest influence on paracommons water redistribution); the precise manner in which a neighbour connects materially, legally and geographically to the agro-hydrology of its bigger upstream partner[2]; and greater use of inter-annual large-scale water storage or local informal sources such as farm ponds (Lankford, 2023). Nevertheless, the essential features and agro-hydrological processes captured in the Mendoza case are routinely found in irrigation systems worldwide. Future versions of the model could accommodate these and other factors - the latter including analyses of other outcomes from changes to irrigation efficiency such as water quality, salinity and timing of scheduling.

5. Conclusions

How might a paracommons framing of depletion and related water reallocation bring more harmonious and just water outcomes (Owens et al., 2022)? To address this question, we suggest:

- Taking a long-term, multi-factor, cross-scale approach attentive of multiple scenarios containing hidden and indirect actions/non-actions and consequences. Although the paracommons model is relatively simple, it can act as a guide supporting broad understandings regarding desirable, just and fair outcomes.
- Examining irrigation licences for how they reinforce or adjust the proprietor's advantages. Reforms could start with the acknowledgement that withdrawals and overpluses of water decline over time as catchment water scarcity drives water conservation. Licences should not be fixed in time. Instead, licences could be supply-dictated, taking into account variable hydrology and rising catchment needs, resulting in risk-based or proportional water rights (Gómez-Limón et al., 2021; He et al., 2012). Or licences could be demand-dictated, taking into account a moving average of the last five years of water use, correcting for rainfall. Licences could also be cut or retired (Tsvetanov and Earnhart, 2020; Wiener, 2006) as a means of controlling withdrawals and area irrigated.
- Monitoring agro-hydrology to manage aggregate depletion. One or two streamflow monitoring points, recording withdrawal flows at headworks and assessing the command area under irrigation (observable from satellite imagery) comprise a few datapoints that would optimally inform a paracommons model and decision-making on future water reallocations.
- Encouraging the development of paracommoner dialogue where resource gains from conservation (in relative and absolute volumetric terms), and their pathways can be discussed. We might argue this is the role of a river basin office or other water authority tasked with water allocation. However, the latter's remit is on the commons distribution of water between sectors rather than on the changing orbits of water depletion/non-depletion driven by worthy intentions to conserve water.
- Welcoming multiple perspectives on water conservation. We should accept the lay vernacular language that accompanies water savings, and that farmers are managing real flows – not the individual depletive fractions within them. On the other hand, these must be cross-checked by precise terminology and measurement and modelling of agro-hydrological inputs and outcomes across different scales, especially of aggregate depletion.
- Recognising the wider political economy and externalities of irrigation that contain and redirect overpluses (Grafton et al., 2018). Drivers can operate in both directions, bringing down or boosting withdrawals. An example of the latter occurs when electricity to pump water is provided free of cost or is heavily subsidized (Scott,

[2] For example, there will be situations that are hybrid over space (the neighbour gets its water from both return flows and direct abstraction) and hybrid over time (the neighbour with few water rights in the past establishing their legitimate claims to return flow usage, to ensure this water use is deemed legal).

2013), or when drip irrigation is enabled by the provision of low-cost energy.

Credit author statement

BAL devised the concept of the paracommons, wrote the first draft, built the spreadsheet and composed some of the narratives. CAS provided key data and information about the case study, and contributed to second and third draft writing as well as edits to the model.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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