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Grand theft water and the calculus of compliance
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Grand theft water: the calculus of compliance

Water crises are amongst the biggest challenges facing humanity. Uncertain future supply, and growing demand, may lead to higher incidences of theft particularly by agricultural users who account for approximately 70% of global water use. However, research into water theft is underexplored in all disciplines. This paper provides a new conceptual framework designed to improve understanding of both individual and institutional barriers to water theft. The framework explores how effective detection, prosecution, conviction and penalties could be assessed. Three case studies are used to test the validity of our framework. Our findings suggest that while individuals and companies may be responsible for the act of theft, the phenomenon reflects a systematic failure of arrangements (political, legal, institutional, etc.). Additionally, when regulators fail to understand the value of water, inadequate penalties increase the risk of theft. Consistent with a view modelling approaches may offer adequate methods for analysis and insight, we invite others to test our framework and engage in a wider conversation about water theft.

It is estimated that between 30-50% of global water supply [1] is stolen. Although the legal/illegal nature of water appropriation may not always be clear-cut [2], a better understanding of legal rights to water and the motivations for individuals to circumvent those rights during times of acute scarcity is timely. On-going water shortages occur on all continents, increasingly compounded by climate change. By addressing likely drivers of theft at an individual scale, we may prevent irreversible harm to other water users. Theories about the drivers of theft suggest that people: i) deviate from social norms due to a psychological predisposition toward rule-breaking (psychological theory of compliance) or differences in personal moral development (cognitive theory of compliance) [3]; ii) have their decisions conditioned by interactions with their environment (social learning theory) [4]; iii) have divergent perceptions of the legitimacy and fairness of rules (sociological normative theories) [5], and/or iv) are more likely to be non-compliant when the benefits outweigh the costs (economic instrumental theory) [6]. All of these factors, and their interaction within designed contexts (i.e. legal, political, economic, social and cultural institutions) are important for understanding why individuals and entities may engage in illegal activity. In the case of water specifically, we argue that dynamic change and periodic uncertainty over water supply/demand pressures also influence illegal behavior, where gradual or sudden changes in supply occur (i.e. hydrological, climatological, environmental, landscape or biophysical circumstances).

Changes to water supply (e.g. drought periods) may also alter individual/entity perceptions of norms, legitimacy and fairness, and the relative benefits/costs of decision-making., Scarcity increases the probability of water theft where opportunities for detection are reduced due water's different spatial and temporal scales of use within urban, industrial or agricultural networks, its physical mobility, and its non-excludability. As incentives to steal water increase, so does the challenge for regulators with respect to resourcing, detection, enforcement and appropriate sanctions. For example, in Taiwan upstream farmers often stole water even when they didn't need it, as the spatial distribution of users meant theft went largely undetected [7]. Large numbers of water-users in irrigation-supply systems may also reduce detection probability, and increase theft activity [8]. Similar results are observed for Australian water resources where theft may be compounded by perceptions of general non-compliance among users [9]; although inverse results have been reported in European jurisdictions [10]. By contrast, in a South Indian case [11] theft was more commonly perpetrated by downstream users desperate for supply. Different management systems to control illegal extraction were employed at top and tail areas, with positive results. Theft was also minimized in Andean irrigation systems via shared social objectives, widespread assumption of high compliance rates, and effective monitoring [12]. Further, where groundwater resources can substitute surface water, understanding their shared connectivity may minimize tipping points from changes in use. [13]Cultural values may play a role in changing social norms toward compliance and the deterrence of rule-breaking [14,15] especially where individual accountability is ignored and regulatory controls do not mitigate resource exploitation [16]. Finally, if the probability of successful prosecution is low, and the penalty comparatively small, stronger deterrents may be needed to dissuade users from stealing water to maximize profits [17] and/or lowering total resource sustainability.

However, robust theory capable of encompassing these diverse drivers, together with validation models to inform optimal compliance measures, is missing from the sustainability literature [18]. We propose a conceptual framework, based on the theoretical and dynamic drivers outlined above, and offer it up for testing and validation. The basis of the framework is a compliance cost calculus, where Laffont [19, pg. 529] describes the second instrument for addressing incentives to collude (steal) as "mechanisms which limit rents captured by agents or firms based on profit reducing or cost performance worsening outcomes". Intuitively, non-compliance costs equate to the penalty imposed multiplied by the product of detection, prosecution and conviction probabilities—where higher probabilities equate to lower non-compliance costs for society. Thus, while some studies suggest higher penalties may diminish cooperation [20], we argue that they are needed in water contexts to set critical value perceptions and social norms. The probabilities will be set by theoretical individual and dynamic change drivers of illegal activity. These themselves interact with i) designed contexts via regulatory capture wherein individuals or groups may alter these institutions for personal gain or to reduce opportunities for capture, and ii) natural contexts where shocks may increase incentives to steal, and where better understanding of state of nature outcomes over time may improve our designed context and adaptation responses to change (as indicated by the arrow on the RHS in Figure 1). The process by which this is framework links to the calculus process is detailed in the Methods section.

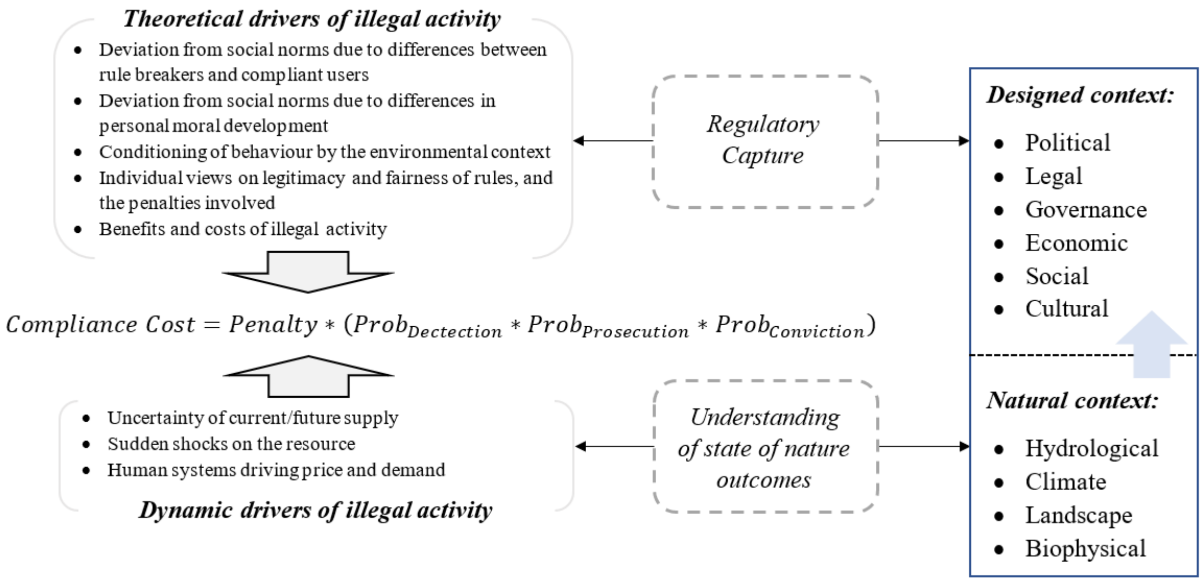

Figure 1: Conceptual framework for calculating compliance costs and institutional investment needs

Ultimately, an improved consideration of these factors may allow us to calculate the value of penalties, including pecuniary/altruist punishments, and investments in detection/prosecution/conviction systems to avoid losses, address dynamic change and lower incidents of theft. Calculating the compliance cost for water resources is critical due to multiple equilibria that can rapidly emerge within supply/demand systems [21]. Sanctions based on normal supply states and mean variance biases (i.e. high probability of occurrence, and thus most experienced by regulators and firms alike) may underestimate the potential profits and/or costs avoided during dry periods (i.e. high probability of inducing water theft outcomes), where the highest public cost/private benefit gains will occur. Disparities may worsen under climate change and reduce the total financial base for effective monitoring or detection. However, little attention is paid to the financial base of regulatory settings, potentially resulting in compliance and monitoring arrangements that are sub-optimal [19]. To the extent that both adequate water delivery infrastructure and monitoring and enforcement of water regulation may also be dependent on user fees, water theft can have a multiple and cascading negative effect [13,14], further undermining enforcement. It is therefore useful to carefully consider the design and implementation of detection and sanction arrangements in water systems within the broader context of individual and institutional incentives to steal. In many contexts' legislation has not been updated to effectively regulate agricultural extraction and ensure sustainable resource use, while inadequate legislative frameworks may provide legal extraction opportunities that impact on other users (e.g. environmental flows). In the interests of informing countries about these issues, we test our framework (see the Methods section at the end of this paper) to identify regulatory options.

Case Study Insights

The cases involve marijuana cropping in California, strawberry cultivation in Spain and cotton growing in Australia, where at the end of each case we have highlighted the relevant examples of theoretical and dynamic theft drivers. Environmental flows and groundwater stocks represent the commonly impacted user in each of the case studies, which in more general terms triangulates well with previous research. The cases also collectively involve individuals that express concerns about the legitimacy of water extraction rules that favour environmental uses over consumptive (e.g. in Australia where some cotton growers did not view the environment as a legitimate user), and examples of authorities questioning the fairness of prosecuting users for theft when those same rules may be ambiguous, and the 'crime' viewed as less serious than other offences (e.g. contrasts between Federal and California laws, and their enforcement, in the US). In some respects, compliance by agricultural users operators is generally viewed as a burden [22], leading to perceived differences between compliant and non-compliant users. These differences may then decrease over time, as users come to view theft as a social norm and morality differences begin to wane (e.g. increasing illegal activity by irrigators in the Doñana, leading to eventual violence against authorities). Efforts to address violent behavior with amnesty arrangements only legitimizes illegal actions in our view, with significant later costs borne by those users with the lowest rights (e.g. environmental or groundwater users). However, the Australian case demonstrates that theft exposure may change social norms toward the better. It also shows that a change in both individual and institutional incentives is possible where the three probabilities/weights associated with detection/prosecution/conviction are increased. This is evidenced by public calls in Australia for improved institutions and personal behavior (e.g. in the Barwon-Darling where civil society organizations sought to enforce the law for environmental users).

Similar observations about the relevance of dynamic drivers of theft, and their potential impact on the compliance calculation, particularly with respect to the setting of penalty levels, are also apparent in the case studies. Consistent with the theory of deterrence and incentive compatibility in mechanism design, if the penalty plus other costs of use approximate the value of water during normal supply conditions, then an effective deterrent against illegal extraction may occur (Figure 2).

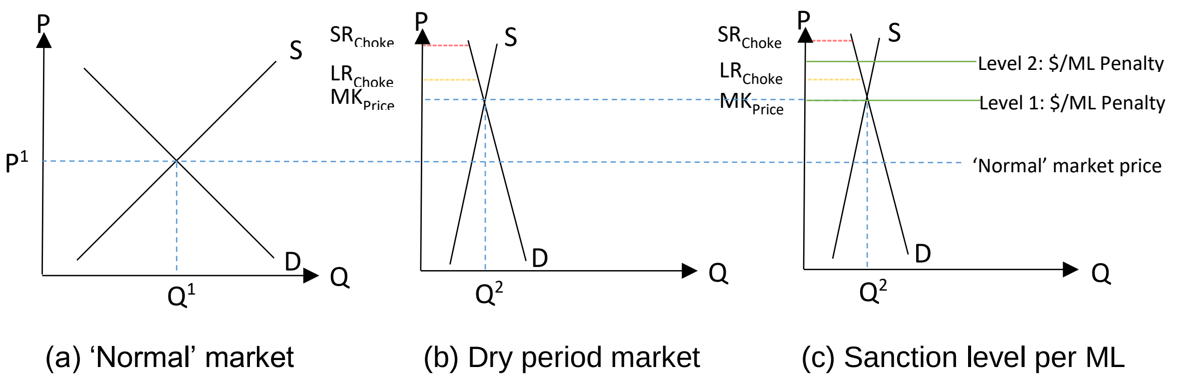

Figure 2: Fixed penalties versus dynamic market pricing of water

However, during water scarcity or limits on extraction substitutes such as groundwater, that same $/ML (megalitre—or one million litres) sanction would leave theft penalties far below the opportunity cost of water; particularly the short-run choke price (SR_{Choke}) that some water users may be willing to pay to secure critical supply. Eventually, users may be forced down to a long-run choke price (LR_{Choke}) due to finance limitations or other constraints—although that will still be above the market price (MK_{Price}). Note that, even at a relatively high $/ML sanction (Level 2 penalty in Figure 2c), the cost/ML would still be lower than the SR_{Choke} price, providing no effective deterrent. In the setting of penalties note also the cumulative effect of low probabilities for detection [23] and enforcement/prosecution of illegal extraction, which some producers will compute, leading to perceptions of ineffective institutions. Building on Becker's [6] work, if we formulate the real cost of a sanction $Prob\delta$ as:

$$Prob\delta = Fine * [Prob^{\text{Detection}} * Prob^{\text{Prosecution}} * Prob^{\text{Conviction}}]$$

where *Fine* is the dollar-value per ML sanction associated with illegal extraction, $Prob^{\text{Detection}}$ is the likelihood of being formally/informally detected while pumping illegally, $Prob^{\text{Prosecution}}$ is the likelihood of the case being enforced or prosecuted, and $Prob^{\text{Conviction}}$ is the likelihood of the producer being convicted, then we can clearly identify a relative weakness in the calculus. For example, the prosecution probability may be relatively high (e.g. 0.70), together with the likelihood of conviction (e.g. 0.60). However, if the likelihood of detection in the first instance is very low (e.g. 0.09 where governance failures mean that the distance between producers and regulators is large and compliance monitoring resources are extremely limited), then the real sanction cost (excluding legal or other transaction costs) could follow the example below (as calculated by the model outlined in the Methods section):

$$\text{Total Penalty} = \text{AU\$3000/ML} * [0.09 * 0.70 * 0.60]$$
$$\text{Total Sanction Cost} = \text{AU\$113.40/ML}$$

In Australia, for example, an AU$113.40/ML real cost is akin to the market price of water during normal supply periods (i.e. non-scarcity). Further, if a producer applies any discount rate ($Prob\delta/(1+r)^t$) to their decision-making—an area of sustainability research deserving more attention [18]—then the real sanction cost over the lifetime of their farm investment may effectively reduce to a zero value and increase the incentive to act illegally. Finally, we must also consider time-lag effects which may impact on decision-making when prosecution could take years to achieve. Under that arrangement, if the opportunity to act illegally continues (especially under ambiguous legislative arrangements), then the perpetrator will continue to profit economically, further diminishing the effect of sanctions [17]. Arguably, water regulators have little capacity to meaningfully affect exogenous conviction probabilities. However, an obvious way to decrease water theft in the example above is to alter the calculus of sanction design by increasing the probability of effective detection ($Prob^{Detection}$) and enforcement/prosecution

(*Prob*$^{\text{Prosecution}}$); both of which are usually needed to maintain cooperative efforts [24]. This could be achieved by real-time telemetric metering of water extraction, and/or more frequent site inspections by authorities. Telemetry is cost-effective in remote and unregulated systems, reducing the need for resource-intensive inspections. New, widely implemented, detection systems may help identify in real time that water theft is occurring. This, coupled with public disclosure of usage data, may increase community confidence in enforcement of, and compliance with, water laws. While the installation and maintenance of meters can be expensive, total social welfare gains from introducing telemetry in high-risk areas would also be high. Another option is to use remote sensing and satellite imagery to monitor (illegal) extraction as discussed in the Australian case. Combined with other forms of evidence (such as seasonal yield, hydrographic and/or metering data), these technologies can assist agencies to meet the criminal burden of proof, which may in turn have a deterrent probability-increasing effect. However, it may not eliminate the challenges of tracing culpability to a perpetrator. For effective satellite enforcement regulators must have: clear regulatory frameworks in support of their efforts; time and expertise to analyse season data and imagery across large areas; capacity to accurately discern the source of water identified and the actual perpetrator; and supporting information from other datasets to avoid false positives/negatives.

Finally, users could be incentivized to monitor and report infringements to authorities under a changed set of cultural attitudes and revised social norms [13], that may need to include altruistic punishments such as a loss of access to supply. Group-enforced penalties may result in smaller resourcing of monitoring and enforcement, and create individual disincentives to steal water, by contrast with more formal arrangements. Water theft is not limited to large areas where detection is challenging. For example, Doñana region detection is feasible through collaborative WWF/river basin authority actions to monitor and report incidents. However, the true cost of theft is lower than the (economic) value of water due to low probabilities of prosecution and conviction. Very few cases are prosecuted and, of those, an even lower number results in a sanction. While 2000 cases of water theft have been reported since 2003 in the Doñana region, data from the district attorney's office indicates a total of 28 guilty verdicts for water theft [25]; a prosecution rate of 2.2% that clearly highlights the importance of effective deterrence. Apparent "solutions" to the problem of water theft, which include legalization of unlawful water appropriations (e.g. Nestlé in California) or attempts to expand supply through infrastructure (e.g. farm water storages) suggest a production-centric institutional approach designed to mitigate impacts on the economy and protect violators. In many instances, this could arise from policy capture by agricultural producers or industry, which is more likely to reduce rather than increase compliance. Whatever the approach, we would argue that regulators must critically assess their sanction design calculus to identify weaknesses, within the context of all individual/entity and institutional incentives, and implement measures to improve detection and/or enforcement probabilities, as exampled in Figure 3. We are keen to see this argument modelled and tested in future studies.

Increase the consequences for theft to promote sustainability

In areas where environmental water is held by governments and released from storages to meet ecological objectives, some downstream users may legally or illegally extract this water. Where such extraction is legal, and will increase productivity in the short to medium term (with on-farm storage allowing for future use), there is little disincentive to refrain from pumping to meet public objectives associated with water uses. This may be particularly true during periods of relative water scarcity when releases of held environmental water may trigger the legal right to pump (e.g. if linked to flow levels recorded at relevant gauges). The case studies all illustrate the relevance of legislative arrangements to clarify the legal status of environmental flows, to simplify water use regulations, and to protect other rights from theft or abuse.

For agricultural producers, theft decisions may simply weigh the value of lost production against the total penalty. High productivity values (e.g. marijuana crops in California) and/or irreversible capital loss (Option d, Figure 4 in Methods section) make water theft the rational option, and may form new social norms. Yet, theft typically results in losses to third-party users such as the prioritization of economic uses at the expense of environmental flows in the Doñana. In developed nation contexts, a high penalty setting with random monitoring schemes may provide appropriate disincentives to engage in undesirable and potentially damaging individualistic behavior, particularly where coupled with programs aimed at altering social norms and attitudes over time.

Framework criteria:	Case Studies: California	Spain	Australia
Theory drivers:			
Social norm deviation due to differences between rule-breakers and compliant users	✓	☑	☑
Social norm deviations due to differences in personal moral development	✓	☑	**X**
Conditioning of behaviour by the environmental context	**X**	✓	**X**
Individual views on legitimacy and fairness of rules and penalties	☑	☑	☑
Benefits and costs of illegal activity	☑	☑	☑
Dynamic drivers:			
Uncertainty over current/future supply	**X**	✓	☑
Sudden shocks on the resource	✓	X	☑
Human systems driving price and demand	☑	☑	☑
Interactions:			
Regulatory capture	✓	☑	☑
Understanding change	**X**	**X**	**X**

Notes: ☑ denotes a strong or clear presence of the framework criteria in the case, ✓ denotes weak presence, and **X** denotes no presence found.

Figure 3: Matrix of conceptual framework outcomes among the three case studies

Ideally, that coupled penalty-setting/norm-changing approach will identify and communicate: i) gross benefits gained from illegal activity, ii) the harm and impact to third-parties from losing water rights, iii) and costs/value gained from effective detection, prosecution and conviction.

For example, the Australian Securities and Investment Commission (ASIC) has proposed that three-times multiple penalties may be sufficient to cover relevant costs of theft. Such a penalty baseline is appropriate for future arrangements where environmental losses will be challenging to calculate, and precautionary approaches make sense. But as plea bargaining may provide cheaper options for farmers considering the calculus of theft, we urge water managers to take the factors outlined in the conceptual framework—including discount rates—into consideration when negotiating. In Australia and Spain civil penalties are legislated and then irregularly reviewed or increased in line with inflation. And courts often discount maximum penalties creating gaps between actual sanctions and community expectations [26]. Or, as seen, authorities step in to pay the penalties for farmers. At present, Australia cannot set civil penalties based on multiples of the benefit gained. However, once again ASIC has suggested that either i) disgorgement of the profits obtained from illegal activity could be applied on top of an existing sanction, and/or ii) a multiple of up to three times the benefit gained should be possible in practice (ibid.).

Additional issues

Consistent with earlier research, the case studies clearly support the importance of well-resourced (financial and human) enforcement and compliance monitoring especially in the remoter parts of delivery systems, to increase the probability of detection and prosecution as a significant driver of theft reduction. If insufficiently resourced, current water charges could be increased to ensure adequate funding, although such moves would likely be unpopular with struggling rural communities and urban areas sensitive to the challenges of farming. An alternative may be to rely on private water users protecting their assets and reporting instances of theft, as raised in these cases where neighbors were red-flagged by one-another. A proviso to this is that individual agents must not be allowed to take enforcement into their hands. Additional governance options may arise under legal reclassifications of rivers as individuals [27] which creates responsible agents to act on a rivers' behalf. However, in cases involving the illegal extraction of environmental water, it is most important to consider the possibility of future collusion to gain upstream and downstream private benefits at the expense of environmental rights—particularly during dry periods and in areas where environmental water is generally viewed as usurping the rights of consumptive users. This could undermine the reliability of self-policing. Thus, in many instances public resourcing may provide a reliable solution to water theft monitoring and compliance, but we would be interested to see how this emerged from other studies or models.

One consequence of increased surface water monitoring and compliance could be an increase in groundwater utilisation as a complimentary supply source [14], where available; although access to groundwater may also diminish incentives to steal [20]. Outside areas that rely wholly on groundwater, if surface water utilization is affected by pumping and/or increased restriction to legal/illegal use groundwater becomes a more valuable product since it may not be, or may not be perceived as, subject to similar restrictions. This would place groundwater resources and any associated rights or markets under stress (if not already), particularly where resourcing associated with bore monitoring and compliance checks were reduced. In the above cases, where we remain uncertain about whether current levels of environmental rights can provide national benefits, we can be certain that any infringement upon those rights via lawful/unlawful extraction will make the systems unsustainable. Once again, this highlights the importance of closing existing legal options to extract environmental flows, and effective compliance monitoring and assessment across the full spectrum of water resources as the first steps to effective deterrents to water theft. Finally, we quickly note the absence in all cases of 'understanding change', which is deeply worrying. This can be addressed, as discussed in the Methods section, via state contingent approaches to setting probability values, and must be more readily incorporated into water management and planning to achieve effective sharing and disincentives for water theft in future.

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Methods

Case study data and analytical approach

An issue with any analysis of water theft will invariably be identifying and sourcing data [28], especially with regard to water theft by the agricultural sector. To address this data deficiency we could turn to stylized figures but this may be easily dismissed by others as unrealistic or groundless in fact. Therefore, we apply case study analysis as a means of capturing and testing the international regulatory context. Case studies are valuable at the stage where candidate theory (as proposed here) are to be tested via history and illustration, leading to interpretation over generalization [29]. This due to the fact that a common issues with the case study methodology can be a lack of general information [30]. To address this, we follow a technique of cross-case analysis which generates more general lessons to increase their applicability. Two analytical techniques including method of agreement to identify common phenomenon in different contexts, and method of difference which identifies the absence of phenomena across contexts keeping most circumstance similar [31] were used to compare the cases to see reasons of variable outcomes from the different cases [32]. We therefore collect and examine three case studies from developed economies: i) northern California where highly valuable legalized marijuana production requires large volumes of water to produce, motivating some growers to steal urban and rural water under a low probability of detection; ii) the Doñana marshlands in southern Spain which is the most important site in Europe for migratory birds protected by international conservation agreements including the World Heritage Convention, and which is under threat due to the illegal expansion of water intensive and highly profitable strawberry production that is being successfully detected but with less successfully prosecutions and convictions; and iii) the Barwon-Darling River system in central Australia that has experienced several alleged, ongoing and proven cases of non-compliance with water laws in recent years (including allegations of water theft by a large-scale agricultural water user, some of which involve environmental water), highlighting the need for greater detection and compliance monitoring. Recently, some of the farmers involved in illegal theft have been successfully convicted and penalised. The full case studies can be accessed in the Supplementary Material. Common findings raise a number of points with respect to reducing water theft in the global context, and highlight a need to build upon the equation provided by Becker [6] via an incorporation of individual and institutional incentives to fully appreciate the relevance of detection and enforcement probability in the calculus of compliance. This can be achieved as follows.

Linking the framework to the calculus of compliance

To link to framework directly to the calculus of compliance equation a model (available as part of the supplementary materials) was developed by the research team. The model involves institutional scores, weightings and probability values used to inform the calculus of compliance equation in the framework.

The value of the model lies in two forms. First, where probabilities are known (see Box 1), the model can be used to capture key institutional or natural driver scores, help identify causality between context, drivers and probabilities (see Figure 1), and clearly point out any implications for management arrangements. Second, where probabilities are not known (and institutional scores cannot be readily obtained), our framework provides the basis for identifying institutional relevance, and the model provides a structure for organising data and sensitivity testing the probabilities/weights delivered via appropriate methods (with suggested approaches provided below). Both model applications can be used to inform water managers on how to address theft problems. The main purpose of the model is to calculate penalty effectiveness in real terms as a signal to water managers regarding the effectiveness of current arrangements.

The Doñana as a model example

From our case study, we know that there were 2000 theft cases from 2003, of which 135 prosecuted (prosecution rate 2.5%) and 50 convicted (conviction rate 37.04%). While these figures may not be 100% accurate they are arguably more reliable estimators than anything produced through expert judgement/QCA/etc. In such an example, using the model to identify probabilities (the second case above) will be redundant. Instead, the challenge is that of understanding the connection between drivers and probabilities so to make theft less appealing. This application of the model is important if we expect that case studies like the Doñana—where water theft can be easily identified—will become the norm in future. In this regards, earth observations and remote sensing will play a critical role. For example, FAO's pilot WaPOR approach informs managers about real time water consumption and biomass production. Provided the water rights are known (e.g. via a census), theft becomes straightforward to detect. This makes it easy to put numbers on the probability of detection, where the model can be used to calculate the causality implications.

As a first step, institutional scores (i.e., values strictly of one) must be derived for the full set of designed context institutional arrangements for successful governance outcomes [24,33] using our framework as a basis. Institutional scores (where not already known) can be identified using appropriate methods such as qualitative comparative analysis (QCA) which bridges qualitative and quantitative data through a capacity to identify cross-case, or within case, study patterns within a 0/1 scoring range [34]. QCA enables assessment of context-specific causality including conditions that might have positive or negative effects depending on the context [35]. Alternative approaches for scoring institutions include multi-criteria decision-making methods (MCDM) [36] which can be used to transform qualitative assessments into unbiased quantitative measures [37], or expert opinion captured e.g. through the Delphi Technique (DT)[38] which allows qualitative expert opinion to be elicited over time toward a common set of quantitative scores or values [39]. Importantly, any quantitative scores/weights will only occur via thorough qualitative analysis following the framework as provided.

Regardless how the scores are assessed, once identified they can be added as values of 1 into the "(A) Institutions" cells of the model. These scores essentially identify how successful an institution is in their role. The second step involves weighting each of the design context institutions with respect to their relevance on detection, prosecution and conviction outcomes in the relevant context. A weighting approach allocates responsibility for certain actions. Again, this may be achieved using the methods stipulated above, as an independent exercise with relevant experts, or by the research team if so qualified. Weightings can be an issue, especially with respect to the complexities associated with water management [40], and must be treated with caution.

In this instance we use an example set of weights to illustrate the real penalty setting challenges. These are shown in the "(B) Weightings" cells of the model. Ultimately, the institution score and weighting values feed into the "(C) Calculus Equation" section of the model. The equation uses both the institution scores and weighting values to generate probability values for each of the relevant design contexts. The final step is to enter a penalty value, based on current laws. Additionally, by altering this value a sensitivity test for various options regulators or water managers may contemplate can occur. The principal focus, however, is on identifying how effective that penalty rate may be in light of the calculated probability values. The following examples (as shown in the model, and Table 1 below) help illustrate the point. A matrix of probability values for each design context category, which can be modified for individual contexts, are listed for each of the detection, prosecution and conviction components of the calculus equation. The probabilities listed in Table 1 relate to a model run scenario we term Total Probability^{I}. A subsequent model run scenario (Total Probability^{II}) is generated by altering one or more of the institution scores; in this case, a shift in the governance arrangements aimed at improving monitoring and detection rates. For three modeled penalty rates (i.e., AU$3000, AU$20000 and AU$50000) the real penalty values are calculated using the respective probability scenarios.

To example a sensitivity test, an institutional shift from strongly absent to weakly present governance arrangements—consistent with other works that explore the value of cooperation or investments in social capital to affect system performance and efficiency [41]—is sufficient to change the probability of detection from 9% to 57%, with a 12% increase in prosecution. There is no change in the conviction probability, as we should expect, given no capacity by water managers to affect conviction processes or probabilities. Note though the relative increase in real penalty values—a roughly 7.5 multiplier effect in real terms—yet in each case still far less than half the prescribed penalty value for an offence. In this example, different model runs can be used to identify the relative importance of combining strongly present legal, water governance and social institutions to bring real penalty values into line with the prescribed rates.

Table 1: Illustrative example of linked framework to calculus

Design Context	**Detection**	**Prosecution**	**Conviction**	**Model 1**	**Model 2**	**Model 3**
Political	0.04	0.04	0.00			
Legal	0.00	0.65	0.50			
Governance	0.00	0.00	0.00			
Economic	0.04	0.00	0.00			
Social	0.01	0.01	0.08			
Cultural	0.00	0.00	0.02			
Prescribed penalty for offence (AU$)				$3,000	$20,000	$50,000
Total Probability I	9%	70%	60%			
Total Probability II	57%	82%	60%			
Real penalty^{I}:				**$113**	**$756**	**$1,890**
Real penalty^{II}:				**$841**	**$5,608**	**$14,022**

It is also possible to deal with contextual complexities via this approach, where different institutional design scores and weightings can be assigned to varied parts of a system (e.g., upstream versus downstream sections, local versus central authority management schemes, formal versus informal arrangements). This enables comparative assessments between those different contextual elements to identify key requirements for change or investment to achieve optimal outcomes, which have been previously assessed using symmetrical [8] and asymmetrical games to determine equilibrium rates of stealing and monitoring. On that front, we believe that our approach could be used in future to optimize institutional conditions or choices to address a range of issues, not just water theft.

If this coupled framework/modelling approach was applied with the help of institutions in a workshop setting, it may help bring to light synergies and gaps within processes (i.e. carefully describe roles) but subsequently lead to a revision of institutional effectiveness. Thus, similar to robust decision-making, our framework does not make decisions for water managers, but guides a decision-making process.

State contingent analysis and understanding change

One of the issues identified in the case study comparisons using the framework was a common absence of water managers to understand change and its consequences for theft. One approach for dealing with that issue, similar to the approaches discussed above, is state contingent analysis (SCA) [42,43]. Assessment frameworks capable of dealing with uncertainty broadly fall into two branches: models where the probabilities of future states are unknown by the decision-maker although possible states are recognized, and models where decision-makers are aware of both the states and their relevant occurrence probabilities can be derived from available data [44]. In the SCA approach, nature (Ω) defines the state space that can be divided into a series of states of nature (s) to define real and mutually-exclusive sets (S) describing uncertainty $(\Omega = \{1, 2, \dots, s, \dots, S\})$. Similar to the design context categories, SCA probability values can be used to frame natural context categories in the framework via probabilities of occurrence (e.g., wet, normal and dry states of nature for water supply outcomes). Importantly the decision-maker has no ability to influence which s occurs; s is determined exogenously. Further, the decision-maker's subjective belief about the frequency $(\boldsymbol{\pi})$ of each s occurring is a probability vector described by $(\boldsymbol{\pi} = \pi_1, \dots, \pi_s)$. Critically for our assessment, this combination of completely describing uncertainty and the contingent outcomes limits the positive/negative impact of uncertainty.

We can express this another way. When parameterising risk and uncertainty any future water supply outcome can only be either greater than, or less than, the chosen parameter, which fits nicely into our requirements to achieve either 'mostly in' or 'mostly out' results in the scoring approach. However, in this case due to the absence of understanding change framework issues, we have not sought to identify probability estimates to represent that concept and its relevance to the calculus of compliance. Future work involving cases where uncertainty is recognised or dominant in the context will form the basis for extensions of the framework into this area by the research team.

Finally, with respect to Figure 2 and in line with SCA, it may be necessary to provide some additional theory to inform the framework application. In the case of agricultural uses/users of water, annual supply characteristics may incentivize theft and complicate the design of effective regulatory mechanisms [21], particularly where low supply conditions continue for several years (Figure 4 below). Incentives to steal water may be present during wet and normal supply conditions, with lower probability. However, in dry conditions a perennial (e.g. almond) producers' choice-set comprises four options which escalate if constrained supply persists, heightening the probability of theft. In an initial dry year, perennial producers may pay well-above market prices (SR_{Choke}) to secure water (Option a). In a second dry year SR_{Choke} investments may be unsustainable and shift to long-run choke (LR_{Choke}) prices to secure water (Option b).

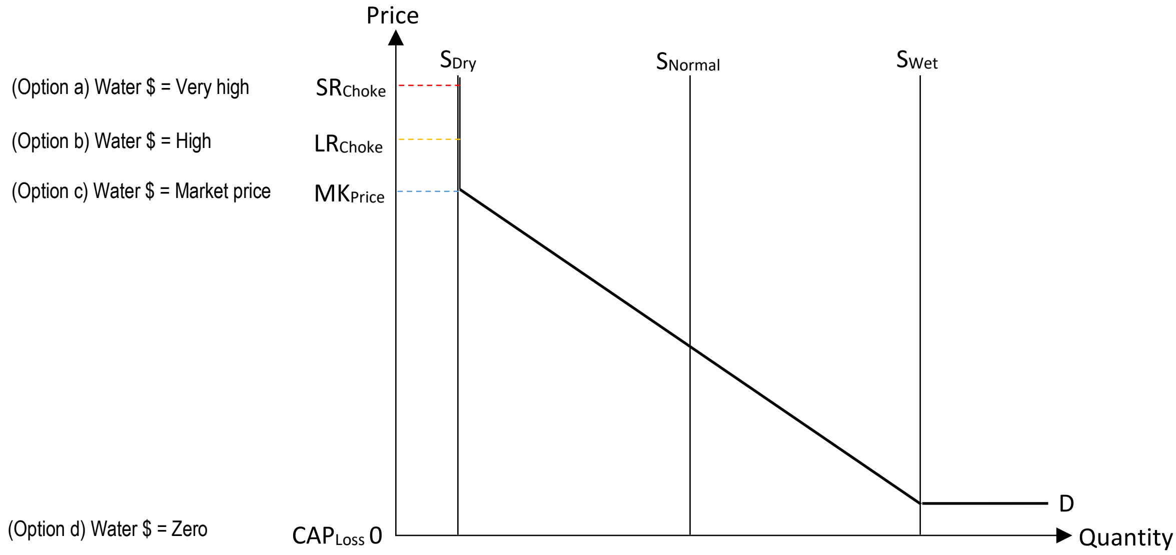

Figure 4: Perennial crop legal/illegal behaviour decision context in response to low water supply [21]

Should dry conditions persist (e.g. >3 years) perennial producers may be forced back to market prices with a focus on securing sufficient water to maintain root stocks (Option c). A corner solution emerges at zero water supply, resulting in rootstock, farm infrastructure, and entrepreneurial capital loss (Option d). This is a worst-case scenario that producers will seek to avoid, and may consider illegal extraction in response—or pre-emptively where on-farm infrastructure permits water storage for use during subsequent periods of scarcity. Similar motivations for water theft may apply equally to annual crop producers facing contract fulfilment and/or high debt pressures in a particular year.