A STATISTICAL ANALYTICAL METHOD TO ASSESS THE POTENTIAL FOR WORKED WATER SHARING BETWEEN MINES

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ABSTRACT

Water allocation regulation and policies are based on assessment of fresh water transfers. Similarly, methods to value water include only consideration of fresh water. However, in regions where there is significant industrial activity, such as mining, it is possible that transfer of water between mines could occur. There is currently little government or company policy support for such transfers. Indeed, without government support *via* incentives it is likely that mines would favour fresh water use because it is inexpensive and creates few risks for production thereby limiting its availability for other uses. The opportunity provided by water savings could be viewed as a source of money to provide incentive for transfer of mine site water (worked water) between mines. In this paper, a method is presented to compute the amount of water potentially available for transfer between mines based on a site water balance assessment using historical climate data. This approach takes into account climate variability, and a mine site water systems model. An analogue of a water trading system is used to determine the potential for exchange of excess water from wetter to dryer sites. It is demonstrated that 340ML could be transferred per year with an unmet need for worked water of 11100 ML per year. The value of the water that could be transferred, if applied to coal mining would be significant. Irrigation may also be attractive if available infrastructure can be used to trade the saved fresh water in existing markets. This indicates that worked water could have significant value if regulated but this requires infrastructure to support transfers of both the worked water and the freshwater saved.

1. INTRODUCTION

In most regions around the world, governments have put in place mechanisms for allocation of water between various possible uses. At one end of the spectrum governments allocate water directly on the basis of a clear societal need or a convincing proposal from a potential user. At the other end of the spectrum water market mechanisms allow potential users to determine allocation of water based on willingness and capacity to pay, i**.**e**.**, water price. In between these two extremes are various charging and cost recovery policies and mechanisms.

A number of mechanisms have been proposed to estimate the value of water. The simplest approach, which is often employed, is to divide the gross margin of a use for water by the volume of water required to deliver the margin; this is generally expressed in terms of $ per unit volume. We will refer to this metric as the “productivity ratio”. Some experts claim that value should include all the water that passes through a production process. For example, a piece of woollen clothing is represented by the total water flux including feeding the sheep, generating power for all aspects of sheep husbandry, transport of all intermediate products etc, i.e., all such embodiments on all the components of a jacket, for example. The sum of all these water fluxes, the so-called embodied water, is related to the value-added at each stage to provide an overall valuation of the water used in production. In some cases estimating this value of water provides an estimate of the shadow price to ascertain a reasonable bid in a water market. In other cases, it is used as a way to indicate that water has value beyond the unit market price, for example, in understanding implications of international trade in virtual or embodied water (Yang *et al*., 2006). In still other cases it is an effort to understand the risks that a business might face when choosing one water supply or security option over another (Moran *et al.*, 2008) or to comprehend how water relates to goals of sustainability (Moran, 2006). These different mechanisms are useful for considering the efficiency of water allocation.

The scaling of individual estimates of value (or return) from an enterprise or type of use to a region seems to be rare. This is possibly because if markets are employed it is assumed that the trading of water will result in maximum water productivity in the region. After all, that is the rationale for markets. In other cases where government allocation is done directly, perhaps there is less interest in the overall efficiency of the allocation regionally. Nevertheless, the question remains: “what constitutes an efficient distribution/allocation of water in any given region?” The simplest way to make this estimate is to take the sum of the gross margins and water volumes and produce a regional water productivity ratio.

All water allocation policies focus on fresh water, either under regulated or “natural” flow conditions. Therefore, regardless of the valuation driver or mechanism of estimation, water value is only considered in terms of fresh water. The implication is that efficiencies across any hydrological domain associated with reallocation or sharing of non-fresh water (herein termed worked water) are not sought. This is unfortunate because the result is that worked water is not valued and therefore does not appear to be an attractive commodity for trade. No policy exists to encourage the exchange of worked water.

Without incentive to trade, it is often cheaper to evaporate worked water and to import fresh water than to attempt to transport worked water between potential users. Such an incentive could be developed by considering the minimum value of worked water to be equal to the value from the equivalent volume of fresh water for an alternative use less the cost of transport. This would increase the "total water productivity" in a hydrological domain because every unit of worked water that is reused generates income as does the fresh water that has now been redirected to a higher value-generating use. In regions where there is substantial mining the differences in relative wetness and dryness of mines compared to their operational water needs create an opportunity for worked water exchange. However, with no incentives available, if fresh water remains less expensive the opportunity to increase total system water productivity is lost.

In this paper we present a method to assess the potential for worked water sharing across a group of mines operating in a single geographical domain. The potential for worked water sharing is computed based on defining an acceptable level of risk to each operation of not being too wet or too dry, in a statistical sense. This permits estimation of the potential for value creation from the fresh water that could be otherwise used. The final result is a calculation of difference in total water productivity with and without worked water exchanges and an estimate of the size of subsidy that would be needed to make this viable.

2. METHOD

Sixteen coal mines from the demonstration region are included in this analysis. To maintain confidentiality of individual site-level data, the location of the region is not disclosed and actual costs have been altered. This does not affect the illustration of the concept. A water balance was developed for each mine that describes the fluxes between various mining and commodity-concentrating tasks, the size of site water stores and the site inputs (e.g., pipeline, rainfall interception and run-off) and site outputs (e.g., discharge). The system model employed for this, *WaterMiner*, has been previously described (Cote et al., 2006). The historical precipitation and evaporation data for the region was then used as model input to drive a simulation of the water balance over a period of years (generally 50 years of historical data were used). This produced a time series of volumes of worked water held on site. A worked water storage exceedence function was then derived from the time series of volumes of worked water in stores (Cote et al., 2006). This function describes the frequency of worked water store at a given % capacity. Figure 1 illustrates exceedence curves of various types. A site that is most often too dry has as high risk of losing production due to insufficient water. Conversely, a site that is most often too wet risks penalties from discharge. Another pathological case is a site where the storage capacity is not matched to the local climate variability (e.g. too little storage capacity) and rapidly switches from too dry to too wet (or vice versa). A desirable system is one that is infrequently too wet (i.e., is >90% full infrequently) and also not too dry (i.e., is not <25% full not too frequently).

Three indices were derived from the exceedence curves:

1. *wetness* index, which is the percentage of time that the site has worked water stores >90% full;
2. *dryness* index, which is the percentage of time that the site has worked water stores <25% full; and
3. *urgency* index, which is the rate of storage change between 25% and 90% full, i.e, |wetness index-dryness index|.

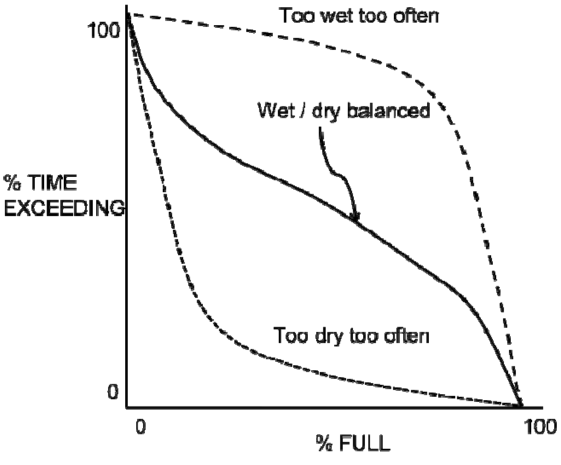

Figure 1. Worked water theoretical exceedence curve examples.

Opportunities exist for worked water to be transferred between sites that are too dry and sites that are too wet in the same region. For each site in the test region, the *need to sell* (dispose of water) and *need to buy* (acquire water) are represented as:

need to sell = *wet index* x *urgency*

need to buy = *dry index* x *urgency*

A matrix is drawn up which maps the propensity for trade between each pair of mines, *i*, *j*, i.e.,:

$\textit{Propensity to Trade}_{i,j} = \textit{Need to Sell}_i * \textit{Need to Buy}_j / \textit{Normalised Distance}_{i,j}$

The *normalized distance* is the geographic distance between mines *i* and *j* divided by the maximum distance between mines in the region. The distance weighting is used as a "cost" to represent the increased difficulty in transferring water over longer distances. The matrix represents the trade potential between all pairs of mines. Before calculating a trade, it is necessary to express % capacity as a volume of water because the *Propensity to Trade* only indicates that a good match for trade exists but does not indicate how much is available to “sell” or how much a site might need to “buy”. The water volume to trade is calculated by first converting the %full axis to volume by multiplying by the site water storage capacity. It is assumed (somewhat arbitrarily) that a reasonable target for wet sites to move towards is the median site worked water storage volume, i.e., the volume of worked water that the site would be expected to have 50% of the time. The water available to sell is the difference in median volume and volume at 90% full.

To compute “trades” the *Propensity* matrix is passed through iteratively from greatest to least *Propensity* until there is no more water available to trade.

Once all trades are completed, i.e., the matrix is fully “relaxed”, the volume of traded water is computed (from the sum of trades) and any unmet requirement or untraded water is recorded.

3. RESULTS & DISCUSSION

The propensity to trade matrix for the 16 demonstration mines is shown in Table 1. From the table it can be seen that a number of mines have little propensity to buy or sell.

Table 1. Propensity to trade matrix for demonstration region of 16 mines. The “Sell” cells are shown in grey.

	SELL																
	Mines	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
BUY	**2**	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3	0.1	0.0	0.1	4.1	0.0	5.2	0.0	0.0	3.4	0.0	0.0	0.2	1.9	1.9	0.0	2.0
	4	0.0	0.0	0.0	0.1	0.0	0.4	0.0	0.0	0.3	0.0	0.0	0.0	0.2	0.2	0.0	0.2
	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	6	0.0	0.0	0.1	0.9	0.0	2.9	0.0	0.0	2.0	0.0	0.0	0.2	1.5	1.5	0.0	1.6
	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8	0.0	0.0	0.0	0.2	0.0	1.3	0.0	0.0	1.0	0.0	0.0	0.2	2.2	2.4	0.0	2.0
	9	0.0	0.0	0.1	1.0	0.0	13.3	0.0	0.0	13.2	0.0	0.0	0.6	4.8	4.4	0.0	5.2
	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	11	0.0	0.0	0.0	0.4	0.0	2.4	0.0	0.0	1.4	0.0	0.0	0.5	5.6	6.2	0.0	5.2
	12	0.0	0.0	0.0	0.2	0.0	1.3	0.0	0.0	0.9	0.0	0.0	0.2	1.9	1.9	0.0	1.8
	13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	16	0.0	0.0	0.1	0.6	0.0	5.5	0.0	0.0	2.5	0.0	0.0	1.4	8.9	7.3	0.0	11.7
	17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Following trading according to Table 1 and taking into account water volumes available/needed, a total of ~324 ML were “sold” with 11100 ML of unmet need. On average, the region did not have sufficient excess water to meet needs across mines. Given this situation, there would appear to be some rationale for sites to increase water storage capacity to hold more water when it is available from infrequent but significant rainfall events. This would allow exchange of water with sites without sufficient capacity. However, even the modest exchange of 324 ML provides opportunity for considerable value (monetary and otherwise Evans *et al.*, 2006) to be generated in this region.

A consultancy study previously estimated coal gross margin to be AUS$18.6k per ML (ACIL Tasman, 2007), indicating a potential gross margin of $6m p.a. It is also worth considering this in terms of revenue because the ACIL report is not based on water use figures for this region and likely includes water reuse, which inflates the average water productivity ratio figures. It is important to consider this water balance term because this water is extracted directly from regulated locations in the water resources management system that could equally well provide off-take for irrigation with little or no marginal cost to irrigators both upstream and downstream of mine off-takes. Moran *et al.*, (2006) provide accurate figures for the imported fresh water component of use for mines in the region. In terms of *revenue* (not profit as no costs are included) for coking coal, with an average fresh water requirement of 210 ML/Mt (Moran *et al.*, 2006), the 324ML transferred could be used to mine an additional 1.5Mt coal. With a selling price of $120 per tonne, the water “traded” in this example could be used to generate ~$AUS180m of revenue per annum.

Given that coal generates the greatest return per unit of water used there would appear to be little sense in trading water outside the coal sector. However, the availability of infrastructure to transfer water to irrigation sites may make a lower return trade to irrigation an option. Also, it is possible to increase irrigation area at marginal costs only if land is available, whereas expansion of coal tends to be via expansion or new projects, which have a fixed additional water requirement without the flexibility of irrigation. Gross margins (not revenue) for a range of irrigation products are shown in Table 2 along with the gross margin from the additional 324ML of fresh water that could be made available. Whilst not as profitable as coal, there is still considerable scope for additional value to be generated by exchanging worked water between mines. In this region, temporary water trades can range from $AUS30-300 per ML, with more trades at the lower end. Based on this, it is unlikely that potential revenue from trading water from coal mine allocation to irrigation would make the transfer of worked water between mines attractive. However, it is possible to consider a government intervention that would make the transfers sufficiently attractive for mining companies to consider worked water rather than fresh water use. For example, a one-off government infrastructure grant could be used to link the mines with the greatest potential for worked water exchange. Precedents for such infrastructure grants to save fresh water in other contexts already exist. However, this proposal requires some lateral thinking and may falter because of the unconventional nature of the proposal compared to traditional water efficiency in irrigation measures, for example.

Table 2. Gross margins from a range of irrigation products in Australia (adapted from Moran, 2008)

Commodity	**mean gross margin ($AUS'000/ per ML)**	**Margin ($AUS ‘000) from 324 ML**
Pasture(Livestock)	0.075	24.3
Rice	0.125	40.5
Dairy	0.32	103.68
Cereal	0.135	43.74
Annual Row Crops	0.225	72.9
Vegetables	1100	356400
Vine & Tree Fruit	450	145800
Viticulture	1300	421200

This analysis has ignored many factors that would be required to create an active and viable worked water trading regime in a coal mining region. In some cases water transfer infrastructure may already exist close to mines that may wish to trade. If there are regulatory, e.g., land access for pipelines, or other, e.g., energy for pumping, constraints this may be a factor in preferring a different trade to one that may appear more preferable according to the algorithm used here. Such additional factors could be added to the matrix relaxation without too much difficulty. However, it should be recognized that these “sub-optimal” trades will likely reduce the overall trade potential that could occur without restriction. An additional consideration is water quality. It may be necessary for a receiving mine to treat water and this cost would need to be subtracted from the new regional total water productivity. Alternatively, consideration of dilution potential on a receiving site could be added as a factor in the propensity matrix and thereby potentially change the order of preference of trades without resulting in a total water productivity compromise.

4. CONCLUSION

Water regulation systems and water value methods generally only take into account fresh water. A method has been demonstrated by which the potential for water trading between a group of mines (or other water users) within a given region can be assessed. The method is based upon the water balance of each site and a consideration of the risk outlook for each site (here it was assumed that each site had the same risk outlook). For the demonstration region, in which 16 coal mines were considered, there was an unmet potential trade for 11100 ML of water and 340 ML could be traded/exchanged. This 324 ML could add significant revenue/margin to the regional water productivity providing an indication of the value of the worked water. In other regions, it is plausible that there is not unmet need in mining and so the fresh water released would be used in irrigation activities. It is concluded that further analysis is warranted in a range of regions to develop a more meaningful overall water productivity approach. This would represent a more complete sustainable development view of the value of water in all regions and could be led by the mining industry as a demonstration of superior water stewardship capacity.

5. ACKNOWLEDGEMENTS

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