Calculating the Shadow Price for River Water when there is a Possibility of Ecological Catastrophe: An Application to the River Nura.§‡

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Abstract

Many studies now exist of the Total Economic Value of wetlands. These studies show that they are highly productive ecosystems with many potential uses. However, some of these uses conflict. Reduced flow from the River Nura arising from water being diverted could lead to reduced water inflow into internationally important wetlands and consequent catastrophic damage similar to the Aral Sea. Whilst the economic value of the wetlands is noted in appraisal studies, it has not been included as a component of cost of water.

This paper shows how this could be done, recognising that river flow is highly variable with long periods of successive droughts. This is modelled as a Geometric Brownian Motion stochastic process, and the presence of potential eco-system catastrophe as an absorbing lower barrier at which wetland value goes to zero. Following Dasgupta and Maler, the shadow price is calculated as the marginal effect of water flow on the expected present value of ecosystem services from the wetland, and methods outlined by Dixit enable this to be done for this particular stochastic process.

An estimate of the shadow price for water not getting to the wetlands of 0.50 euro (2000 prices) per m^3 is obtained, and this is shown to be robust to parameter variations. For this value, a World Bank proposal to use the River Nura for water supply purposes would be overturned.

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1 Introduction

The River Nura is the main surface water flow into the terminal lakes of the Tengiz-Kurgaldzhino depression. Its delta, comprising 60 fresh and saline lakes of different salt content, forms wetlands of international significance. It is an essential habitat for many endangered species such as Pink Flamingo, and White Crested Duck. For this wetland, there are now large international expenditures for the conservation of biodiversity through a GEF/UNDP project, and NABU, mainly in order to restore its Ramsar status. Whilst past extraction of water from the Nura had caused increasing salinity and retreat of the wetlands, this had been reversed when the discovery of substantial mercury contamination from past industrial activity upstream from the wetlands at Temirtau led to the prohibition of Nura water use. However, a current proposal to clean up the river basin, and once the mercury contamination has been removed extract and use water from the Nura, retreat could lead to similar impacts from water level reduction and salination, that have been reported in past for Kurgal'dzhino, re-occurring. And consequently lead to similar problems to those that have occurred for the Aral Sea and Lake Balkhash.

Whilst a World Bank study includes consideration of the Kurgal'dzhino wetlands, there are many difficulties and problems in doing this even if there were more knowledge about the ecological behaviour of the area . An important aspect is the extent to which the analysis incorporates uncertainty and variability, especially of sequences of dry years. There is, *in extremis*, a danger if water inflow were to be substantially reduced that certainly the Korgalzhin wetland and possibly also Lake Tengiz could dry up completely. This would lead to the Korgalzhyn lakes becoming saline with a consequent loss of its ecological value. Even if such a catastrophe were avoided, reductions in water inflow will lead to a reduction in the area of the lake with consequent loss of its special habitats. As water inflow is reduced into the lakes, there will be an increasing environmental cost due to two factors. One is the value of area of lost habitat, the other is a cost to being nearer to the potential of a salination catastrophe for the lakes, either in the near or long term.

The Korgalzhin wetlands also have the important characteristic of being shallow lakes. Recent work on shallow lakes, for example in Dasgupta and Maler (2004), point to the problems that will occur if the particular characteristics of these lake systems are neglected in economic models. They provide a model for a shallow lake which is one of hysteresis, where two separate states are possible. One is a high biodiversity state and the other a low one. The system has a possibility to flip from one state to the other. Such a phenomenon has been observed for the situation of dessication and increasing salinity of closed lake systems - the Aral Sea being a well known example. This discussion, reviewed in Ingham et al. (2006) shows how thresholds can arise from the differential equations describing the ecology of a lake system. Such catastrophic effects could arise either from the dynamics of the lake system as discussed earlier, or from irreversible salination due to reduction in water inflow because of diversion of

Nura River water to other uses and/or a succession of dry years. Catastrophe arises from the crossing of a threshold, the location of which we are uncertain about.

Calculating a safe amount of water extraction from the river before damage occurs is complicated by the variability of flow of the river. This variability is in fact required for the ecology of the wetlands. But if a constant amount of water were extracted, based on mean flow, then in some years flows into the Kurgal'dzhino wetland could be sufficiently low as to cause the wetlands to dry up. Unless a strong system of water management is put in place, then given the costs of the various options and the fact that this water is likely to be much cheaper than any of the other options, presumably this level of extraction is what will happen. If the planning methodology treats the wetlands as a residual, then the potential damage to the wetlands should be included in costs. This requires that a social price for river water to be obtained, so that overall costs include an element that recognizes potential catastrophe and loss of value in the wetlands.

This relates to concern about the sustainable use of water, and the conservation of wetlands in such river basins. This is reflected in such international measures as the Water Framework Directive(WFD) of the European Union, which seeks to implement a management approach to river basins based on sustainability, and the Ramsar Convention which seeks protection and conservation for wetlands, particularly with regard to their bird populations. How the WFD translates into the question of the appropriate shadow price is set out by Brouwer(2004). As a result of these concerns, two rather separate exercises have been undertaken. One is to place an economic value on wetlands themselves. The other is to include in the Water Management Strategy some element either though regulation of quantity of water extracted, or through an additional cost element, Using valuation studies for the wetlands, this is translated into a social price that can be added onto operating costs for water that recognizes uncertainties and potential catastrophe.

2 Describing the System: The underlying stochastic model

By looking at the density function for river flow, it is clear that the distribution for the Nura is highly skewed. Evidence from stochastic modelling for other rivers suggests that a log-normal distribution would be a good first approximation to this distribution. The log-normal distribution is used widely as a good representation of various data processes. It is especially useful in modelling various financial series such as stock market prices. As a consequence, it has been very widely studied, and there are many important results that can be used directly. The log-normal is useful in that the 2 parameter version is described entirely by the mean and median. Using the formulae for average (mean) and 50% probability (median), an approximate log-normal distribution is shown in the following diagram for both the Nura, and a river where the mean/median ratio = 1.007, such as the Rhine. This is shown in figure 1.

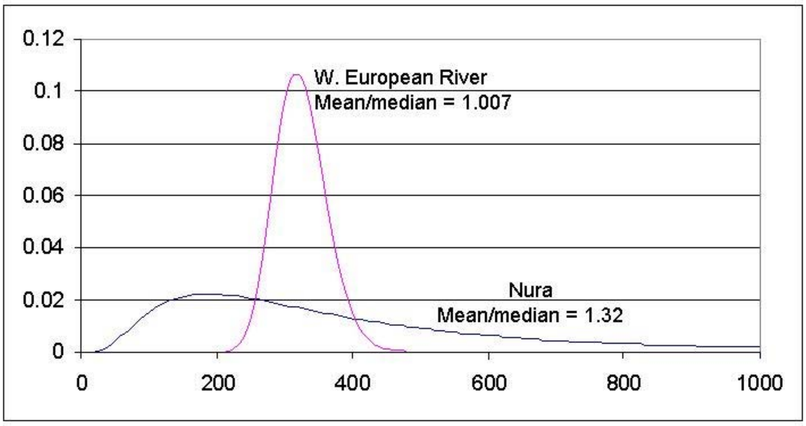


Fig. 1 Probability density for river flow of Rhine and Nura

We take a log-normal stochastic , or Geometric Brownian Motion (GBM), model for water flow into the Korgalzhin wetlands as described in Ingham, Yakovleva, Ilyushchenko (2006) It yields the log-normal distribution for river flows, and also replicates the pattern of serially correlated years of high flows and low flows, which is a feature of the Nura. Whilst this is an approximation, it allows for an analytic treatment of results in order to derive an expression for social value. Such a treatment has the great advantage is that it is quite general and can be translated between countries and river basins when appropriate local conditions are included through the appropriate stochastic equation for water flow, and appropriate equations for social value.

Formally, let X(t) be water flow at time and dz be a standardized Wiener process X(t) is given by Geometric Brownian Motion, so that the distribution function for X is that of the log-normal, see Aitchison and Brown (1957)

$$\frac{dX}{X} = \nu.dt + \sigma.dz$$

A simple logarithmic transformation allows for Geometric to be translated into an equivalent Normal Brownian Motion. Let x = ln(X), then the use of Ito's lemma gives a convenient alternative formulation:

$$dx = (\nu - \frac{1}{2}\sigma^2).dt + \sigma.dw$$

Water flow generates ecological value, and reductions in it on a permanent basis generate ecosystem damage We capture this by a function that gives an instantaneous flow payoff given by a function $f(.)$ which depends on the state of flow. This function includes many components of the river and its ecosystem. It will depend on both the hydrological model for the wetlands and the socioeconomic valuation relation.

Expected Present Value of flow is given by

$$E(V) = E\left\{\int f(X)e^{-\rho t}dX\right\}$$

X will depend on various parameters such as the rate of water withdrawal perhaps expressed as a water management strategy, This expression is the forecast of value that is required for the analysis of shadow price outlined by Arrow et al.(2003) and the discussion there shows that if the quantity variable for which we require a shadow price is y then the price that should be used is $\partial E(V)/\partial y$ This requires that we are able to derive an expression for the integral. For an important class of functions of f, which fits in with how we might model the valuation of wetland and changes in it, we are able to do this. This is where

$$f(X) = X^{\lambda}$$

And for those models for which we can obtain valuation parameters and estimates this allows expected present value and marginal changes in it to be calculated. Value is derived from area of wetland. In the long run area of wetland depends on water flow into the wetland system, so if area of wetland = W, then on average over several years and hydrological cycles $W = \theta X$. Socioeconomic value is derived from wetland area, and there is a shadow price for wetland we calculate to be $\zeta(W)$ so that socioeconomic value in the wetland depends on how much there is. This reflected issues of returns to scale, or relative scarcity. Value is derived from two (at least) communities, one local/regional, the other international. Valuations corresponding to these will be different. In particular we expect that local values will depend on the size of the local population and GDP (or incomes) in the area.

We now consider the potential for irreversible damage, such as has happened with the Aral Sea, and is reported may be happening at Lake Balkhash.This is modelled by there being an absorbing barrier for the stochastic process for X. The nature of an absorbing barrier is discussed in Dixit (1993) and in most references on Stochastic Processes. It is a state that once X(t) attains a specific value, c, say, then the process terminates, with possibly a terminal value/cost of k.

In order to evaluate the social price it is necessary to calculate, and then differentiate expected present value. As an explicit expression is obtained for this it is then possible to see how this social price changes as key parameters of the situation such as the variance of water flow in the river. This enables the comparison of social price of water between river basins based on the hydrological characteristics independently of socio-economic aspects. The expected present value is G(X) where $G(X) = E\left\{\int_0^\infty f(X)e^{-\rho t}dt \mid X_0 = X)\right\}$ and X follows Geometric Brownian

Motion starting at point $X_0 = X$:

$$\frac{dX}{X} = \nu.dt + \sigma.dz$$

Consider now a lower absorbing boundary. This affects the solution to the differential equation by introducing a boundary condition.If this is at a level X = c, then the general solution will be $G(X) = G_0(X) + CX^{-\gamma}$ So

$$C = c^{\gamma}(\frac{K^*}{\rho} - \frac{c^{\lambda}}{\rho - \nu\lambda - \frac{1}{2}\sigma^2\lambda(\lambda - 1)})$$

and all of the parameters in this expression will be known. ν and σ come from the stochastic process of flow in the river, ρ is the discount rate. However, it is not so straightforward to calculate c and K^*, in the absence of detailed analysis of the hydrology and ecology of the wetlands, and of some method of evaluation for them. We now turn to these empirical issues. First, we obtain appropriate discount rates for national, and international, use.

Time plays a pivotal role in the analysis of water extraction options and their costings. Investment costs will occur early in the planning period and benefits will be spread over many years into the future. Pearce et al. (2003) show that the the 'social discount rate' and its relation to parameters of an economy is given by the Ramsey equation:

$$s = \rho + \mu.g$$

where s = social discount rate, ρ = the 'pure' rate of time preference , μ = elasticity of marginal utility of consumption, and g = growth rate. For a western economy such as the UK, Pearce et al. use parameters in the Ramsey equation of : $\rho = 0.05$, $\mu = 1.0$ and $g = 0.02$, so that $s = 0.025$. Clearly for a transition economy, and one with a high growth rate due to oil production, such numbers would be inappropriate. Evans (2005) provides estimated for 20 OECD countries, for both high and low income figures and for a transition economy it is given by s $\mu = 1.58$. This would give an overall value of s for Kazakhstan of s = 0.208, compared to that for the UK of 0.025. This discounts future costs and benefits very rapidly, as costs and benefits after 12 years carry a weighting of only 0.1

However, it may be that such a high theoretically justified discount rate is observed in practice, such as the answer of , where the official representative from Kazakhstan to the question of withdrawal of Nura river flow from Tengiz-Korgaldzhyn lake systems, UNESCO (2002) Consideration of water for Astana and supply to the lakes was considered only within a two or three year horizon, which is consistent with a very high discount rate.

Another factor that should be taken into account is that of uncertainty. In the Ramsey equation outlined above it is taken that the parameter values are constant and known certainty. Even if other values remain constant it will be the case that the growth rate will be stochastic, if only because of uncertainty in the ecological value derived from variability in climate and rainfall. If that there are two sectors to the economy, a produced goods sector with certain and constant growth rate, g, starting from a base level of Y_0 and an ecological sector which is stochastic and is given by a value E_t , then the Total Economic Value of Output is given by $V(t) = Y_0 e^{gt} + E(t)$ which will be a random variable, and it is the growth rate of V(t) which ought to enter into the expression for the discount rate. Gollier (2002). obtains the appropriate certainty equivalent discount rate when the growth in the economy is uncertain and has a mean of E(g) and a variance of var(g). This is given by

$$\delta = \rho + \mu.E(g) - 0.5.\mu^*(1+\mu).var(g)$$

μ^* is the elasticity of marginal utility of income with respect to static risky choices. In this expression, there are two effects acting in different directions. One is a wealth effect, $\mu.E(g)$, which acts to increase discount rates and make future benefits (and costs less important). In effect, if society is going to much richer in the future then the future can look after itself. The second is a prudence effect. If there are substantial risks in the future then we should take more account of it. If risks are large, then discount rates should be low.

This measure of the degree of risk aversion is also quite likely to vary across countries, and is also likely to be difficult to estimate in the absence of detailed country studies.

Suppose that we take the growth rate of GNP to be a certain figure of 10% pa, as before, for indicative purposes. The only uncertainty arises from the stochastic nature of ecological value. The amount of wetland loss is assumed to be linearly related to flow of water in the river Nura, so that the Total Economic Value of output and ecological resource = $V(t) = Y(t) + \nu E(t)$ where the appropriate value of the ecological resource is ν, then assuming that the shares of GNP and the ecological resource in Total Value is non random then $var(g) = w_E.\sigma^2$ where σ is the parameter in the underlying Brownian motion for river flow and hence quantity of wetland. Data for the river Nura suggest that $\sigma^2 = 0.397$, hence :

$$\delta = 0.05 + 1.58 \times 0.1 - 0.5 \times 4 \times (1 + 1.58) \times w_E \times 0.4$$

$$= 0.208 - 1.8 \times w_E \text{ where } w_E = \frac{\nu E}{V}$$

So the discount rate is reduced from the previous figure, dependent on the share of the services derived from the wetlands in Total or Green GNP. If this takes a value of 0.01, then $\delta = 0.19$, if it takes a value of 0.1 then $\delta = 0.0208$. Constanza et al. (1997) estimated that the ratio of ecosystem services to GNP at a world level was in the order of 1.8, so if the wetlands counted as 5% of the ecosystem services of Kazakhstan then $w_E = 0.09$ and so $\delta = 0.046$, which seems a reasonable figure that might have been used without much thought. In this case, the high wealth effect for Kazakhstan arising from the high growth rate of an oil rich economy is entirely offset by the prudence effect that should be included because of a very high level of uncertainty relating to river flow and consequent ecosystem damage.

1 Basic parameters for the Kazakhstan economy suggest that there are reasons why a high discount rate may be used in decision making. This in itself may be a rational calculation.

2 However, consideration of the wetland system and the variability of the ecosystem services it generates should reduce the discount rate substantially from the order of 20% to around 5%.

3 The expression for the discount rate is in fact time dependent, and if the value to be placed on the wetlands by the local community increases over time, as has been obtained by meta-analysis of CVM and other valuations for wetlands, then there will be a declining discount rate into the future. The calculations undertaken here for Kazakhstan suggest that similar high discount rates would be derived if ecosystem services and their potential variability were to be ignored. This would support the positions taken by the relevant parties in the Almaty IUCN meeting reported above and in the discussions concerning the nomination of the proposed Saryarka-Steppes nature reserve for World Heritage Status. The comments of Magin (2005) about the management structures in place would be consistent with a difference in discount rates and implicit time horizons between a national government and an international conservation agency

4 An important conclusion from this is that there will be a difference between the discount rates used, quite rationally, by governmental and other decision making bodies in different countries and at an international level. This will impact on time horizons considered and how conservation agreements are interpreted and implemented.

5 An important issue arising is the question as to what discount rate ought to be used in subsequent analysis. This depends on the question that it is desired should be answered. For the question that we address here of the value of the wetlands and the damage cost arising from water extracted from the Nura, then we use two discount rates depending on whose values are being considered. For international conservation value we use a rate similar to that quoted for the UK, which is based on western parameter values. For locally based values then we take the discount rate as that used by a prudent but local management agency.

As the ecological damage derivivng from Nura water use comes in large part from effects of the terminal wetlands, it is necessary to obtain a valuation for those. Van Beukering and Hirsch (2000) use a “Conservation Supply Price”, derived from a study of Ruitenbeek (1992). The basic idea is that International Agencies such as UNEP, GEF and so on provide funding for conservation projects and this gives an indication of what values they put on the environmental resources whose conservation they fund. In the context of the Nura and the Korgalzhin/Tengiz wetlands we can see a process of choice taking place. In the World Heritage Thematic Study for Central Asia, Magin (2005), the IUCN makes clear issues surrounding substitute provision of similar ecosystem sites. For Korgalzhin/Tengiz, whilst they consider alternative steppe sites, it is by far the largest of these areas,and plays a particularly important role in the global conservation of the steppe ecosystem.

In essence, Ruitenbeek constructs a market for biodiversity from which a price for marginal quantities can be obtained. It comes from information about the payments that are made for conservation to take place.However for the last, or most expensive piece of conservation, it is also the amount that international conservation communities will pay for conservation. It has advantages over other methods for estimating theses values. Firstly it is based on actual payments, and not on what individuals or governments say they might pay Secondly, it measures values directly related to conservation and biodiversity values. It is the cost to the international community of transfers that must be paid in order for conservation to take place. However for the last, or most expensive piece of conservation, it is also the amount that international conservation communities will pay for conservation, in other words what value they place on this, and it is this value that is desired for purposes of cost benefit and the decision to allocate funds and resources to conservation. This price is then an annual per ha. minimum payment for conservation to take place, in the case of this particular study rainforest. This number is then used by van Beukering and Hirsch as a price for wetland biodiversity. The value that Ruitenbeek derives for the supply price, or WtP is 15.76 ecu per ha. per annum in 1989 prices. In terms of 2000 prices, using the same inflation and exchange rates as elsewhere gives a WtP of € 27.55. Using an 8% discount rate, the present value price for the total flow of biodiversity services would be € 344.3 per ha. Using this value directly to the wetlands gives a total capital value of € 89.5 million.

An alternative approach to valuation that we use is based on meta-analysis. This is now a recognised technique for investigating valuation methods and the values that they generate, and enables the transfer of valuations between locations to be undertaken, whilst recognising differences between those locations. For these wetlands, values derived from meta-analysis will be very useful as organizing new Contingent Valuation surveys would be both slow and expensive. Firstly we need a value to be ascribed to international conservation. This will not be obtainable from local considerations. The second is a value for local values such as the local use of the wetland as a recreational area, and given that the local population is increasing both in size and income allows for increases in this value as the local economy grows.

We use two different meta- analyses, firstly that of Brander et al.(2006), and then that of Woodward and Wui (2001), The coefficient on the amount of the area which is designated as a Ramsar site requires some comment as it is both significant at a 10% level and negative indicating that the more of an area has Ramsar designation then the lower valuations will be. This can be explained by the fact that the values that are being measured by survey techniques such as CVM or valuations based on surrogate markets to record local values, whereas Ramsar designation is about international value. There have been found to be conflicts between local and international attitudes and preferences towards protected areas, see Bonaiuto et al. (2002) for example, also If the characteristics of a wetland are more directed at international conservation rather than local use then CVM of local individuals would report lower values than for locations where the use of the wetland is of more local importance, for example for recreation purposes. The negative shift that the Ramsar dummy variable brings about will be important if it is a local value that is being calculated.

Using the coefficients obtained by Brander, and data for the Korgalzhin wetlands and the locality gives an expression for the value of wetland ecosystem services per unit of area s_1 which is given by

$$s_1 = \alpha_1 \left(\frac{GDP}{N} \right)^{1.16} \left(\frac{N}{A} \right)^{0.47} (X)^{-0.11}$$

so that if we assume that GDP and population N grow at constant rates g_1 and g_2 .and if base levels are indexed by the subscript 0, then the value of wetland ecosystem services for the whole wetland at time t will be given by

$$s_1(t)X(t) = \alpha_1 \left(\frac{GDP_0}{N_0} \right)^{1.16} \left(\frac{N_0}{A} \right)^{0.47} (X(t))^{0.89} e^{(1.16g_1 - 0.69g_2)t}$$

The table gives two sets of the constant parameters α. Theses are for when a non marginal change is being considered, such as total loss due to a catastrophe, α_1 and one for when marginal or loss of wetland area which is reversible, α_2

		Hunting included	Hunting excluded
Marginal	$\ln(\alpha_1)$	-6.42	-5.32
Non-marginal	$\ln(\alpha_2)$	-7.37	-6.27

Table 1: Values for α

These equations for marginal and total value allow for consideration as to how values would increase as the wealth of the country and the local area increase over time. That we should allow for such increases in value reflects the well established fact of the Environmental Kuznets Curve, see Stern (2003), Arrow et al. (1996).

Woodward and Wui (2001) consider a somewhat different set of variables. In particular they omit local variables such as population density and GDP, and alternatively include variables related to the “quality” of the studies being considered. Thus, their specifications can be used to obtain an alternative valuation to the wetland, which being independent of local variables, can be taken to be equivalent to a CVM study for international values such as conservation and biodiversity.

The value equation for wetland, similar to Korgalzhin, that we have derived from Woodward and Wui is for a value per ha. given by $s_2 = \alpha_2 X^{-0.17}$. As international value will not depend on regional GDP and population, we do not include any considerations of an Environmental Kuznets Curve in these. For example, much concern and action involved in reinstating the wetland as a Ramsar site and promotion of it as a potential World Heritage site has come from NABU - a German

Conservation Body- and the UNDP. We therefore have two separate aspects to the economic-environmental valuation of the wetlands, one corresponding to local values and the other to global values.

V_2, the international value, is then derived from a value of wetland services. Using the estimates obtained by Woodward and Wui, and specific local data, it is

$$V_2 = \alpha_2 E \left\{ \int_0^\infty (X(t))^{0.83} e^{-\varsigma_2 t} dt \mid X_0 = X) \right\}$$

where ς_2 is the discount rate appropriate to international intertemporal valuations

This displays a slightly greater degree of diminishing returns, than for the Brander et al. calculations. The degree of diminishing returns can be seen as a measure of risk aversion, and the lower the exponent giving returns to scale, then more concave is the value function and consequently the more risk averse is the underlying welfare function. This conforms with the discussion on local and international valuations of environmental resources where greater valuation was placed on these in the international sphere, and so the more risk averse we might expect such valuations to be. And, for the area of the wetland as a whole of 260 thousand ha., this gives an overall value of € 97.2 million euros (2000 prices).

We saw earlier that the value derived from the Supply Price approach was € 89.5 million euros (2000). These values are remarkably close, but both are substantially greater than those calculated from the Brander et al. meta- analysis. One obvious reason for this is that the Brander calculation is based on local variables such as regional GDP and population. So this must be interpreted as being the value that can be ascribed to the local population. This is an important feature when benefits from environmental assets accrue solely to local populations. Where an environmental asset is locally scarce, but not regionally or globally then ascribing value to a wider area than values the asset will lead to serious discrepancy. However the main benefits of the wetlands lie in its provision of biodiversity and habitat for endangered species. This is recognised in its listing as a Ramsar site and in its nomination for World Heritage Status, recognition of which would appear to depend on having appropriate management strategies in place. Valuation depends critically on whether the coefficient for bird watching is included or not. Including this causes a reduction of one sixth in value. Bird watching is an important aspect of the Korgalzhin reserve and there is a developing eco-tourist business in promoting this. It is still in its infancy, but there is considerable potential for development these two valuations with, and without, bird watching potential show how much value there is in its development.

3 Calculating the Shadow Price

The analysis of Dasgupta (2001), Arrow et al. (2003).shows what the shadow price should be if the management of the economy does not follow first best principles. They point out that the concept of 'Sustainability' is particularly important in economies where first best policies are not followed, or where there is some disagreement as to what a first best policy might be. Such optimality requirements on the nature of the overall objective are also required for the usual analysis of 'Sustainability'. Where non-economic issues form a substantial part of the objective then a modified method will be required. However, it is not of a very different form, and in this case may be easier to calculate, as what is suggested is that the shadow price will be the marginal effect of increases in all forms of capital, including natural capital, on actual value of social wealth, and not the marginal effect that arises out of a full optimization problem. However, we consider two constituencies for wealth, one a national constituency as would be usual, the other an international one, which is appropriate for wetlands with Ramsar status. Also, the linear nature of wealth, means that we can consider each constituency in turn and then simply sum the resulting social prices to get an overall price, and we can also consider wealth arising from the wetlands independently of wealth elsewhere in the economy.

If the intertemporal value function is W, which may or may not be derived from some form of optimisation, and that this results from the use of various capital stocks X_i, then the accounting price for the i'th capital stock, or resource, p_i will be given by the derivative $\partial W/X_i$. In general, if the quantity variable for which we require a shadow price is y then the price that should be used is $\partial E(V)/\partial y$, where V is actual rather than optimised value The model we have gives the expected intertemporal value of wetland services, for any given pattern of water flow and withdrawal. This requires that we are able to derive an expression for the integral, for which a derivative can be calculated For an important class of functions of f we are able to do this.

Shadow price is then $\partial V/\partial X$, where

$$V(X) = E\left\{\int_0^\infty f(X)e^{-\rho t}dt \mid X_0 = X)\right\}$$

Following our discussion of valuation, V is taken to have two parts One is due to local values V_1 the other to international values, V_2 and overall value is $V = V_1 + V_2$. Overall shadow price will be $p = \partial V/\partial X = \partial V_1/\partial X + \partial V_2/\partial X$ We are able to treat these as the derivatives of two separate integrals, each for a GBM with an absorbing lower barrier. It will be the same process and barrier for both integrals. There are several ways that the marginal effect for the use of water might be defined, depending on the evolution of the quantity of water withdrawal. Each specification will have a different value or the derivative, and consequently for the shadow price. Possibilities are:

1 The use of an amount of water for a very limited time period. We could ask what is the social value of a litre of water from the Nura today. The amount of water and the time scale are both very small in relation to the totality. This is almost the same as asking about the change in an integral when there is a change made on a set of measure zero, and the answer would, of course, be zero. This neglect of long-term consequences may be what has driven misuse of water in the past.

2. Two on-going scenarios for water withdrawal are considered. In the spirit of Sustainability, one scenario is that of a constant amount of water withdrawal, and in the spirit of the Water Framework Directive, a value for the environmental-economic impact is derived, which will aid in the concept of wise use of water. This constant withdrawal amounts to a reduction in the mean of wetland size, but apart from that there is no change in the stochastic process. It corresponds to a constant downwards shift in quantity of water entering the wetland system, and so in the area of wetland, and given the simple model used, the quantity of wetland ecosystem services. This management of water resources in the Nura River Basin is completely non-reactive to circumstances.

3. An even more drastic non-reactive scheme is to consider not just a constant amount of withdrawal, but one that is changing (presumably increasing) over time. This amounts to a change in the parameter ν in the stochastic process. For a negative value of ν then the amount of water declines at a constant rate of ν

4 A possible reactive scheme is to consider a withdrawal proportional to the difference between current and some base level (a new long run average) flow, so that water is extracted when it is plentiful, but is replenished when it is scarce. This would correspond to a scheme which converts the stochastic process of flow from one that is GBM into one which is a mean reverting or Ornstein-Uhlenbeck process.

We now consider the interesting specifications, 2, 3 and 4, in turn.

4 Social Price of Water with Reduction in Mean Value for Process

This corresponds to specification 2 It is the shadow price that applies when there is a constant level of withdrawal, and a reduction in the mean of wetland size.

C and γ are independent of X , so in this case, they can be regarded as constant and so

$$s(t) = \frac{\partial W}{\partial X} = \frac{\lambda X^{\lambda-1}}{\rho - \nu\lambda - \frac{1}{2}\sigma^2\lambda(\lambda-1)} - \gamma C X^{-(\gamma+1)}$$

$\partial W/\partial X$, the shadow price, falls as X increases, which confirms intuition that wetland will become more valuable the less of it that there is But there is a non-linear relationship reflecting the diminishing returns to value of wetland.

For the base data and parameters used, values for the social price of water, s* and for the amount deducted from expected present value due to the presence of the absorbing lower boundary that represents the possibility of ecological catastrophe for the wetland and lake system.

	€ Per m^3 per year	Cost of Loss of Wetland ($mn.$€ 2000) $= CX^{-\gamma}$
Operating cost only	0.07	
Domestic valuation. (i.e. using Brander et al.)	0.19	44.8
International valuation (i.e. using Woodward and Wui	0.40	603.0
Both valuations	0.59	647.8

Table 2: Different shadow prices for Nura water and Valuations for loss of Wetlands

So if we include these value of the wetlands, including potential catastrophic loss into the cost of water from the Nura then the cost comparison is reversed and by a significant amount. If the cost of the cheapest alternative is € 0.17 per m^3 then water from the Nura is no longer substantially cheaper (€ 0.07), but more expensive if we just use domestic valuation, and substantially more expensive (up to 3.5 times) if we add on an element for the international value that leads the wetlands to have Ramsar status.

5 Management of River basin so that river flow is a mean reverting process

This corresponds to implemention of a strategy that could be thought to be sustainable in that whilst water flow is stochastic, there is an in-built mechanism that reverts water flow to a given mean. One important question that we consider here is whether such a policy is ever feasible. For the mean reverting Ornstein-Uhlenbeck process there is an equilibrium level and an in built mechanism or stabilizer, that brings the random variable back towards its mean. Such a process would be:

$$dx = -\theta(x - \overline{x}).dt + \sigma.dz$$

This process is in fact one of 'Geometric Mean Reversion' where it is the logarithm of the underlying variable that has a tendency to revert to its geometric mean. Such a process could result from or be required of, judicious, or in the terminology of the WFD ‘wise’ management. A first question is what type of management would result in this process if the underlying or natural process is

$$\frac{dX}{X} = \nu.dt + \sigma.dw$$

The resulting water flow z = log(Z) = y + x such that dz is mean reverting is given by then

$$y = (\widetilde{x}(t))^{-\theta} \left(\int a\widetilde{x}(t)^{\theta}.dt + C^{*} \right)$$

where $a = \left(\theta\overline{z} - \nu + \frac{1}{2}\sigma^2\right)$, and $\widetilde{x}(t) = e^{\int x(t)dt}$ $\displaystyle\int a\widetilde{x}(t)^{\theta}dt$ is increasing and unbounded in t. and so, as Y is a proportion ≤ 1, and $y = ln(Y)$, then $-\infty < y \leq 0$,. and so if $a > 0$ then eventually y $>$ 0 for any C*. This implies that Y will be $>$ 1 and so negative quantities are taken out of the river. So to control to obtain a mean reverting process only possible indefinitely if a $<$ 0, or $\theta\overline{z} + \frac{1}{2}\sigma^2 < \nu$, which is not possible if $\nu = 0$ In any case it is possible only if θ, $\overline{z}$, or σ^2 are not large in relation to ν. So if 'Sustainability' is interpreted to mean a strategy that can continue indefinitely, whilst ensuring strictly positive use, then no feasible sustainable strategy exists. One unsurprising result is that increases in σ^2 lead to increases in y. So the more variable is the flow in a river, the smaller has to be the amount of withdrawal if reversion to mean has to be maintained.

Several conclusions follow from this. The World Bank study suggests that water flow into the wetlands will be maintained at a level which will allow them to ecologically function. The water withdrawal rule that permits this may not be a simple or straightforward one. If flow is GBM, and if maintenance corresponds to flow into the wetlands being a mean reversion process then the fraction of natural flow that should go into the wetlands is given by

$$Y = e^{\left(\int_{0}^{t} \left(\frac{\widetilde{x}(s)}{\widetilde{x}(t)} \right)^{\theta} dt \right)^{\left(\overline{z} - \nu + \frac{1}{2}\sigma^2\right)}} \qquad where \quad \widetilde{x}(t) = e^{\int x(s)ds}$$

This is a highly non-linear function of present and past flows as well as the underlying parameters.In any case, it is not clear that a mean reversion process is desirable on an economic or ecological basis. There is no immediate reason as to why this form of process would maximise economic welfare, apart from the fact that it would be a second best rule in that it could ensure that flow into the wetlands is kept away from critically low levels with appropriate probability. One special aspect that would suggest that such a mean reversion rule would be far from optimal or desirable from a social, as opposed to ecological viewpoint, is that the amount of water extracted depends on the fluctuations in current water flow, and not on any fluctuations in demand. There are good reasons as to why these would be inversely correlated, in that periods of drought when natural water flow is at its lowest may be precisely the times when there is high level of demand. Were such a management rule to be adopted, then it is possible to calculate an expected present value for the consequent ecological services generated that could be compared with the present vale for natural flow, or for where there is another management plan in place, such as that for constant withdrawal of water, that was earlier calculated. This would then allow for a comparison of the shadow price for water when the rule follows a plan that generates mean reversion. However such a calculation is not straightforward.

6 Sensitivity Results from the Model

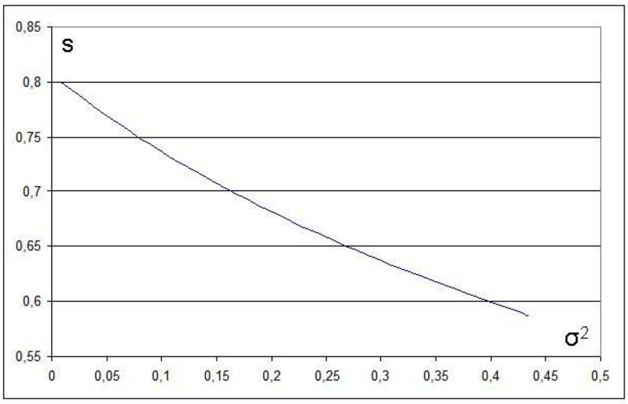
However, we need to ensure that this is not just because of particular parameter values. This is what we now do.

1) Sensitivity of shadow price to parameter values

How s* varies as variance of water flow increases can be calculated from the expression derived earlier that .

$$\frac{\partial s}{\partial \sigma^2} = \frac{\partial}{\partial \sigma^2}\left(\frac{\partial W}{\partial X}\right) = \frac{\frac{1}{2}\lambda(\lambda-1)X^{\lambda}}{(\rho - \nu\lambda - \frac{1}{2}\sigma^2\lambda(\lambda-1))^2} + \frac{\partial}{\partial \sigma^2}\left(CX^{-\gamma}\right)$$

However, it is clearly a complex and non-linear expression It is not clear from the expression whether this would be positive or negative. The diagram below comes from evaluating s* for different values of σ^2.

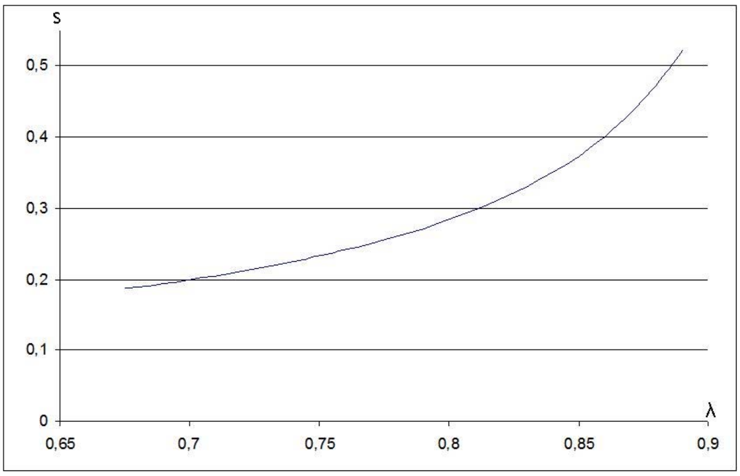


Sensitivity of Social Price to Variance in River Flow

As σ^2 increases the shadow price s* falls. This is perhaps somewhat counter-intuitive. The reason is that as σ^2 increases V decreases as expected but also decreases.

Variations in the exponent of area in equations for valuation

As λ varies, the shadow price for water varies as is shown in the following graph: Loss of wetland means that loss of some more arising from increased variance, which both increase wetland area as well as decrease it according to the log-normal distribution. It is perhaps partially explained by the concavity of the valuation function $V = \alpha X^{\lambda}$. This is plotted below for different values of λ.

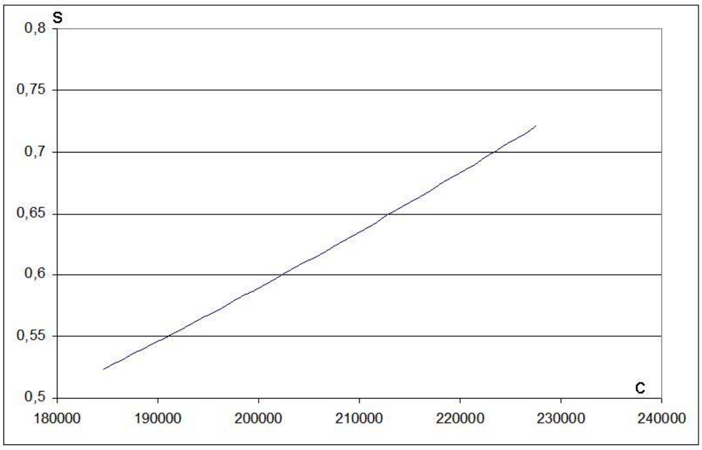


Sensitivity of Social Price to Degree of Diminishing Returns in Wetland Value

These depend on how the valuation expressions of the form $V(X, \lambda) = \alpha X^{\lambda}$ change as X and λ vary. Changing the value of λ will have two effects. It will change the overall value to be attributed to the wetlands, but also change the responsiveness of value to changes in wetland area. The first of these effects will be the same as those changes which operate in a linear scaling fashion, just the same as changing the factors that determine the level of the parameter α, such as whether bird hunting is included or excluded. So here, the focus is on the effect of the non-linear response that comes from changes in curvature of the value function, so in the above diagram both α and λ are varied together so that αX^{λ} is constant when X = 260,000 taken to the be the natural median value for wetland area. So the base value of wetland remains unchanged and the diagram shows the effect of a more non-linear response of value to area. The shadow price of water falls as the extent of diminishing returns increases (or λ falls). The reason for this is that decreasing λ reduces the marginal loss or gain in value for a given loss. Value of wetland is less area responsive and so the value loss from water diversion is not as great as it otherwise might be.

The effect of lowering the catastrophe level

Next, there is consideration of the level at which the absorbing barrier is set. This is a parameter that comes from the ecological analysis, and there is no economic guidance for its value. A value was chosen that seems consistent with previous studies. However, it is clearly going to be important in the level of the shadow price. We consider, therefore drastic increases and decreases, to see if the cost comparison biasing water use away from the Nura comes from fixing the level determining catastrophe at a high level. First is a graph for increasing c towards the initial wetland size.



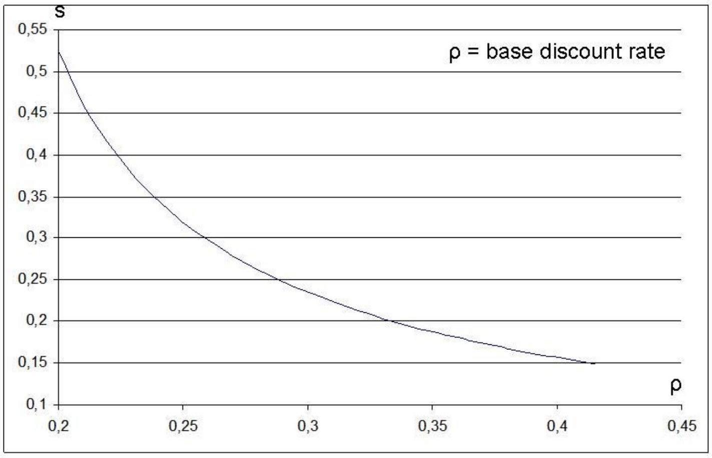
Effect on Social Price of when catastrophic loss of wetland occurs : increases

The shadow prices reacts linearly and approaches a value of 0.75 as c approaches the initial (taken to be mean) value. For reductions in the level of the barrier c from the value of 184550 ha., to 50,000 ha. This is one fifth of the current area. This is a drastic reduction in size, and if catastrophe is a possibility it would seem likely that it would be for reduction of area to an amount above this. For such a permissible reduction in size to 50,000 ha. the shadow price to be attributed to water that does not find its way eventually into the wetlands will be above.18 euros per m^3 (2000 prices) . This remains well above the potential cost savings that would accrue to use of Nura water. There is initially a similar linear response, but eventually the price starts to level out and for a barrier at 50,000 ha. - that is one fifth of initial size- a value of 0.18 is reached.

When international values are fully incorporated, the shadow price remains above € 0.17 even for reduction in wetland area to one fifth of its present before the occurrence of ecological catastrophe.

Changes in the discount rate

Finally, there is consideration of the effect of increasing the base discount rate. This is for a change in rate that applies to both valuation elements, so that for both local and global values the discount rate changes by an increment of 0.05, and for simplicity it is the base discount rate for local values that is used for the horizontal axis.[1] This is from the base levels of 5% for international wetland valuation, and the high value that was calculated for the domestic rate of 20% in equal .005 increments (from 0.05 and 0.2). As would be expected discounting the future more reduces the shadow price and at an exponentially declining rate, but again even so the shadow price remains above 0.15 for even very high discounting.



Effect on Social Price of discount rate

As is expected increasing the discount rate has an exponential effect on the shadow price, although yet again it remains above € 0.15, for even very high discount rates.

2) Suppose that the growth in GDP per head and population is ignored in valuations. In part, this corresponds to ignoring issuers surrounding the Environmental Kuznets Curve for the local population. Results are presented in the table below:

With 'EKC'	0.123
Without 'EKC'	0.024

So including, considerations of the increasing wealth and population levels will have a sixfold effect on the value per acre of wetland conservation. This is not altogether surprising given that it is equivalent to a substantial change in the effective

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[1] The domestic discount calculated in earlier section is used. This is 20.8%, whereas for international valuations a discount rate of 5% is used

discount rate that is being used from one which is very high at 20.8% to one much lower at 2%.

The above are values for the Brander et al. meta regression which uses data from a local/regional level. The comparison with the value from the Woodward and Wui meta regression which does not and so is more of an overall global valuation is :

Brander et al. (local valuation)	0.123
Woodward and Wui (global valuation)	0.401

3) Calculating the price for change in trend of water diversion. This corresponds to specification 3. For $\nu = 0$ then $dW/d\nu$ takes the values € 17.3 / m3 for V_1 and for V_2 € 4.5, giving a total of € 21.8. This value is so high in relation to alternative water sources that no sensitivity analysis need be done.

7 Conclusions

The World Bank(2003) study concluded that the Nura Clean Up Project was justified on a cost-benefit basis because of the large cost savings arising out of Nura water use[2]. We see here that if the costs arising from potential catastrophe are factored in, this no longer holds, and Nura water is more expensive, substantially so if the international value underlying Ramsar status is included. This result is quite robust to changes in parameter values. We used previous work that recognizes water flow is highly variable with long periods of successive droughts. This is modelled as a Geometric Brownian Motion stochastic process, and the presence of potential ecosystem catastrophe as an absorbing lower barrier at which wetland value goes to zero. A social or "shadow" price for water was calculated as the marginal effect of water flow on the expected present value of ecosystem services from the wetland. The following stages were necessary:

1. Calculation of appropriate discount rates that will be used by national agencies and that should be used taking into account international conservation considerations,

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[2] This proposal to clean up Mercury from the river basin, was the subject of a study, undertaken by the World Bank (2003). This study reports that the cost of water in Astana coming from the Nura is \$0.07/km^2 compared to the next cheapest alternative of \$ 0.17/m^3, and that 90% of projected water demand for the new city of Astana could possibly be met from diverting water from the River Nura. This represents a quantity of 90 m. m^3 per annum., or equivalently approximately 2.85 m^3/sec. As it has been estimated that a reduction in flow in the River Nura of 1 m^3/sec. over a year degrades 40 km^2 of wetland, then up to 114 km^2 of wetland and lake area could be lost from this level of extraction. Currently, the area of the Korgalzhin wetlands is 133 km^2 , and that of Lake Tengiz is 654 km^2 We treat the two areas together, and do not make any distinction. Clearly, they are different and will have different dynamics and values, but in the absence of more detailed and usable information it is probably better to consider the two together rather than to focus on one, say Korgalzhin, alone. The basic question we consider here is what happens to the cost comparison of water for Astana, if we include all of the environmental impacts, especially allowing for the potential catastrophic loss of wetland, such as has occurred for the Aral Sea.

and the growing population and income levels of the population local to the wetlands in the new capital city of Astana.

2. Separate Valuations for the wetlands as a whole. Firstly, a valuation which includes local parameters and variables in its drivers, and so can be used to represent a local valuation. Secondly, a valuation which is independent of local considerations and does not include such factors in its drivers and so can be used for international considerations.

3. A specific model for a GBM process which allows for an explicit expression for the Social Price to be obtained as the derivative of a stochastic integral. This gives a value for the Social Price of 0.5 euros (2000 prices) that should be added on to other costs to give a full price that should be used in financial appraisal such as that undertaken by the World Bank for the clean up project for the Nura. One component of this is the use of Nura water by the new capital of Astana. Including this social component of cost makes the use of Nura water uneconomic.

Using a meta-analysis, a wetland that contributes just birdwatching and habitat provision, such as the Korgalzhin reserve, would have an average value of $3,750 per hectare. If this were applied to the current area of Lake Tengiz alone, this would result in a value of € 245,215,000, and if, as calculated, water withdrawal would lead to a loss of an area of 114 km^2, out of an area of the Korgalzhin wetlands of 133 km^2 and of Lake Tengiz of 654 km^2, then a value of €42,700,000 would be lost.

Another way in which the possibility of irreversible damage or catastrophe, which comes about under uncertain conditions for the Nura and its terminal wetlands is that of "option value" (or more correctly quasi-option value). Such values are usually included as components of overall value but very rarely included. In a subsequent paper, a discrete model has been developed that enables this to be done for this case, and a quasi-option value for the wetlands to be calculated depending on how much the social price for the wetlands and water for the Nura is included in financial calculations. One stage in this calculation is to derive the cost minimising choice of water supply option for Astana. This shows that if the social price, that we have derived here, is fully included in the price of Nura water than it is never used, if it is not included it is always used, and where there is only partial recognition of ecological and conservation value, then small changes in parameters will lead to any of the available options being chosen. So that decisions will be very sensitive and a slight change towards full recognition of social value will lead to full conservation. This suggests that obtaining the correct shadow price is a task of much importance.

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