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WATER: THE WORLD'S MOST VALUABLE NATURAL ASSET

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Introduction

The natural-capital concept attempts to integrate economic thinking with ecological principles by considering nature's natural assets, the stocks of materials and energy, as capital. In economics, interest or rents, flow from financial or built capital. And so by analogy in nature, ecosystem services, which benefit mankind, flow from the natural-capital stocks that form our ecological infrastructures of our soils, lakes and rivers, groundwaters, and vegetation systems. These ecological infrastructures underpin the world's wealth. Of our natural capital stocks, water is the world's most valuable natural asset. Water is the *sine qua non* of life.

And there is only as much water in the world today as there was at the beginning of time. But there is a constant churn as water moves across the earth's landscapes in its three phases: ice, liquid and vapour. The hydrologic cycle connects the earth's lands with the world's water resources of its lakes, rivers, groundwaters and the ocean (Figure 1, left).

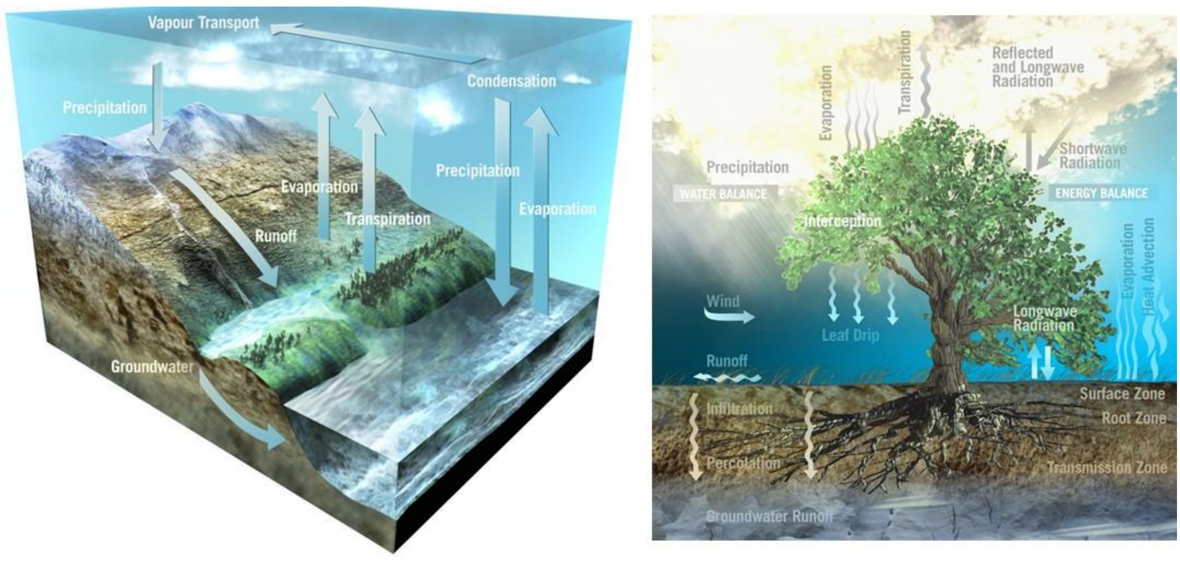

Figure 1. *Left. The hydrological cycle of water flows in its three phases connects the land, with rivers, lakes, groundwater, and the ocean. Right. A critical nexus in the hydrological cycle is the critical zone of the earth's vegetation and top few metres of the soil. (© European Space Agency)*

The critical zone of the superficial few metres of the earth's surface, the vegetation-soil system, is critical in the hydrological cycle (Figure 1, right). The fluxes of energy and mass through this critical zone are massive. These flows, in balance, determine the availability of water for the vital and valuable ecosystem services delivered by the natural assets of our soil-vegetation systems.

In 2013, the New Zealand Institute of Economic Research (NZIER) published a working paper for public discussion on "Valuing Natural Assets: Essential for Decision Making". They begin their paper by noting that "…*New Zealand producers and consumers get much value from natural assets. Much of this value is intangible. This is a fundamental reason to make special effort to measure the value of natural assets, to make sure we make the right decisions about their use and conservation*."

The NZIER lamented that "…*there is currently a gap in the knowledge about the full contribution of natural assets to New Zealand's economic well-being. This creates a risk that natural assets will be undervalued. Ecosystems and the valuable services they provide may be lost or damaged*."

The NZIER consider that their "…*proposed approach could improve understanding of the value of natural assets—giving them more consistent weight in decisions, and improving the way we manage them.*"

The report concludes with six recommendations. Two of which are to:

3. show, in a robust and comparable way, how much economic activity depends on natural assets and to

4. show how sensitive this economic activity is to changes in the natural assets it depends on.

I would have added a seventh to:

7. show how investment into the natural capital assets of our water resources can both increase the value of economic activity, and enhance the quality of the environment.

Rather than just rely on the water that nature supplies us, with its variable pattern spatially and temporally, we need to invest in ecological infrastructures to enhance the availability of this natural asset, whilst ensuring that we minimise wastage and ensure that we continue to receive the ecosystem services from the receiving water bodies after we have used it.

Will there be enough water in the future? Climate change will alter the spatial and temporal changes in water availability?

Water Quantity

Will there be sufficient natural capital stocks of water assets to provide the valuable ecosystem services that the world will require into the future? In 2007 the Intergovernmental Panel on Climate Change (IPCC) released its fourth assessment report on the causes and impacts of climate change. The latest IPCC report, the 5th, was released more recently in 2012/13. But that fourth assessment (AR4) contained an analysis that points to a reduction in the natural capital stocks of water in the world's major food-producing regions according to various climate-change scenarios. Scenario A1B of AR4 is a moderate scenario in terms of the global rise in temperature. In Figure 2 is shown the projections by the IPCC (2007) for the change in annual water runoff, which is a metric of the availability of water stocks, in terms of percentages for 2090-2099, relative to 1980-1999. The predicted diminutions in the natural capital stocks of available water are large in the food-producing areas of the western US, Mexico, Chile, Argentina, South Africa, Australia, and especially the so-called MENA countries of the Middle East and North Africa. This loss of water availability will provide many challenges.

In contrast, the emerging economies of the BRIC countries of Brazil, Russia, India and China might be blessed with largely unchanging, or enhanced stocks of water availability to sustain soil productivity. Although for those countries, this is likely to be a mixed blessing, and the increased water availability is likely to be in the form of extreme events with the attendant risks of flooding. This increase in water availability will provide many challenges.

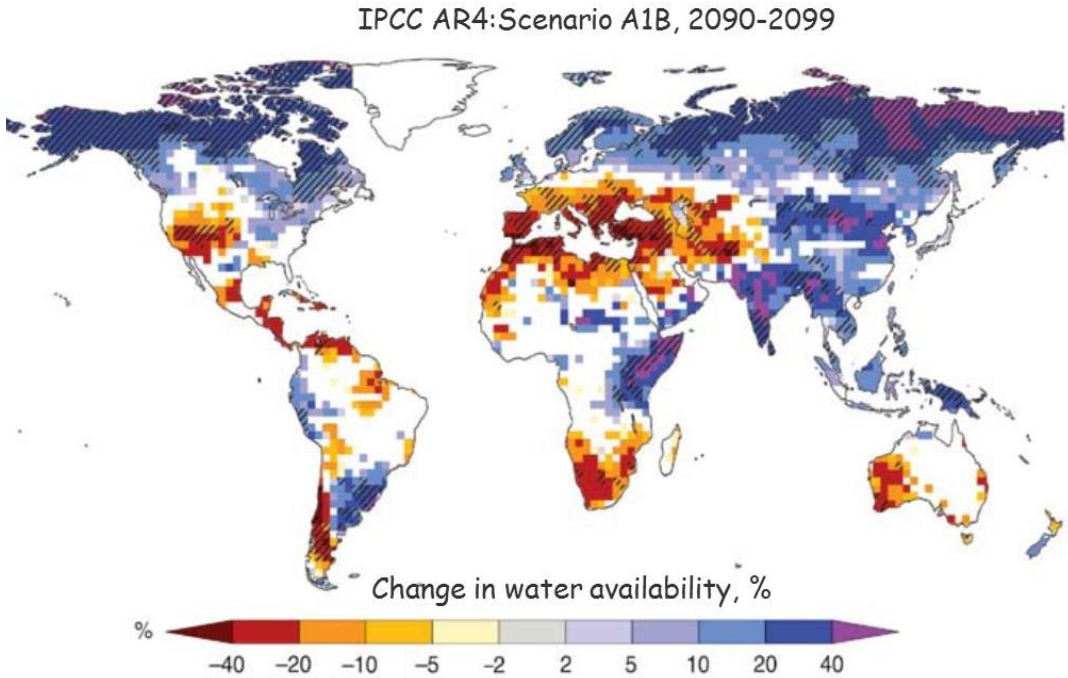

Figure 2. *The projection by the Intergovernmental Panel on Climate Change using 12 models for the relative change, from the present, in the availability of stocks of water at the end of the 21st century under scenario A1B. The cross-hatching indicates where 90% of the models agree on the sign change.* ***(****reproduced with permission from Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Figure 3.5 IPCC, Geneva, Switzerland)*

Irrigated agriculture is a good thing. As from just 17% of the world's land area, we obtain 40% of our food and fibre. But is that irrigation sustainable in terms of the sources of water used to irrigate crops?

Wada *et al.* (2012) have published a global assessment of the non-sustainability of groundwater usage in agriculture. They first noted that globally the use of groundwater for irrigation has risen from 1,217 km^3 per year in 1960, to 2,510 km^3 y^{-1}. Next they carried out an assessment of how much of this water was being drawn from 'fossil' water, or non-renewable sources. Water used for irrigation can be considered to come from different 'coloured' sources. The water used by irrigated crops comes from either; rainwater stored in the soil and taken up by the crop's roots (green water); water drawn sustainably from renewable resources on rivers, lakes and groundwater (blue water); water abstracted unsustainably from aquifers that is not replenished (dark blue water); as well as non-local water that is either obtained from outside of the catchment by diversion, or created by desalination (white water).

By assessing groundwater usage, and modelling of the local hydrological cycle, Wada *et al*. (2012) were able to apportion the usage of groundwater to these various water-colour classes (Figure 3). It can be seen that the dark-blue unsustainable fraction can be significant in many parts of the world.

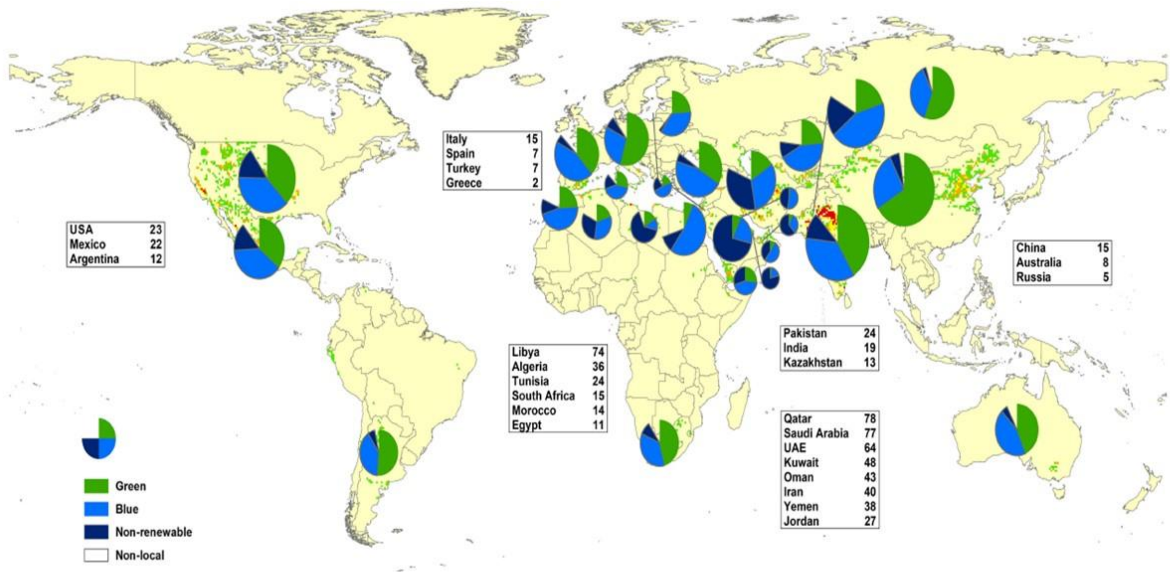

Figure 3. *Three sources of irrigation water: rain for root water uptake (green water), water from rivers, lakes & renewable groundwater (blue water) & non-sustainable groundwater (dark blue water). The numbers in the boxes are the % usage of groundwater that is unsustainable.*

The world's leading user of water for agriculture, India, uses 600 $km^3\ y^{-1}$ of water for irrigation, and 11% of this comes from non-renewable resources. China is the second user in the world at 403 $km^3\ y^{-1}$, and just 5% is unsustainable. Globally, some 9% of the water used for irrigated agriculture is unsustainable. There are challenges ahead.

In the United Arab Emirates (UAE), some 64% of the water used to irrigate farms and forests is unsustainable. The symptoms of this unsustainable usage on groundwater quantity and quality are becoming all too evident. The quantity of groundwater is declining, whilst its salinity is increasing.

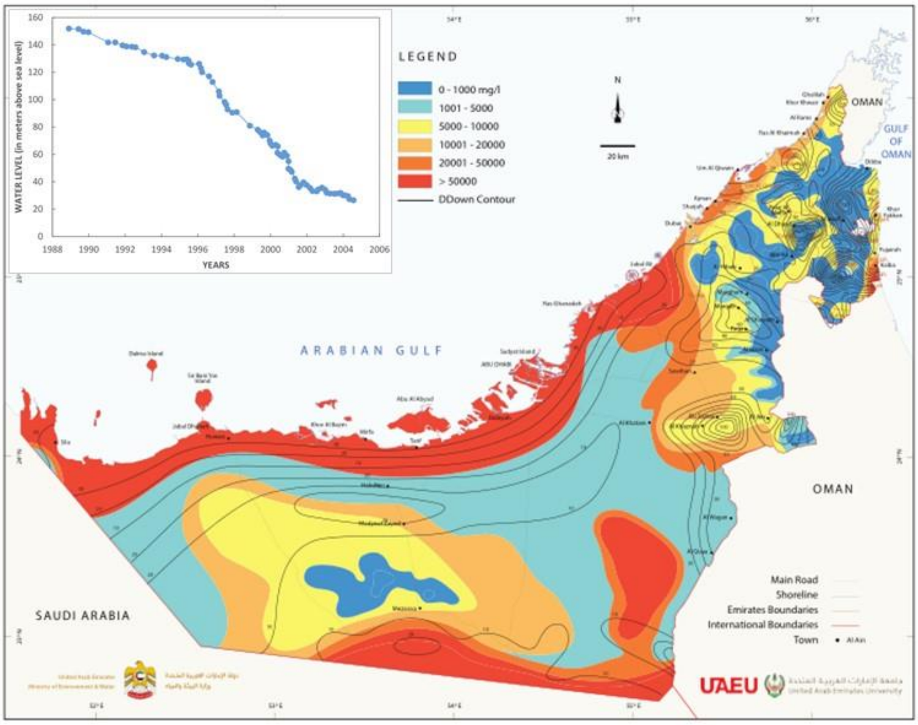

Figure 4. *Salinity increases in the surficial/Quaternary aquifer in the United Arab Emirates between 1962 and 2012, with the contours showing the decline in the water table. The inset upper left shows the decline in water levels in the Al Ain area over the period 1989-2005 (MOEW, 2014)*

The Ministry of Energy and Water (MOEW) in the UAE has recently published a HydroAtlas of the water resources in the Emirates (MOEW, 2014). In Figure 4 is reproduced a map of the change in groundwater salinity between 1962 and 2012. Even in the regions with the 'sweetest' groundwater, the central-west and north-east, the salinity has increased by between 0 and 1000 mg/L. In the coastal 'sabkha' regions, and in the south, groundwater salinity has increased by over 50,000 mg/L. Seawater is 35,000 mg/L! Not only is groundwater quality declining as a result of over-extraction, the depth to groundwater is increasing as the quantity of groundwater is declining.

In the inset in Figure 4 is shown the drop, between 1988 and 2005, in the depth to groundwater in the Al Ain region, in the east of the UAE. The water table has declined by 150 m over the 17 years.

Something needs to be done to stall this decline in groundwater quantity and quality, not only in the UAE, but also around the world.

Two papers in this proceedings highlight the attempts being made in the Emirates to reduce groundwater extraction, so as to improve the state of the subterranean water resource. Al Muaini *et al*. (2016) present results that show that it is possible to minimize the amount of saline groundwater that is required to irrigate date palms. This can be optimized according to date-palm cultivar and the salinity of the groundwater. Al Yamani *at al*. (2016) show how treated sewage effluent (TSE) can be used to replace groundwater. Furthermore, they show that even with groundwater usage, it is possible to reduce irrigation amounts below that currently being used.

The challenge will be to use less water to produce more food and fibre from our agricultural lands.

So, how are we doing in terms of meetings the food needs of our growing population? McLaughlin and Kinzelbach (2015) have provided a recent assessment of food security and sustainable resource management. Their key graph is reproduced here as Figure 5. At first glance, it seems that the world is doing well at meeting this challenge. McLaughlin and Kinzelbach (2015) normalized several metrics of food security and resource management to their values in 1960.

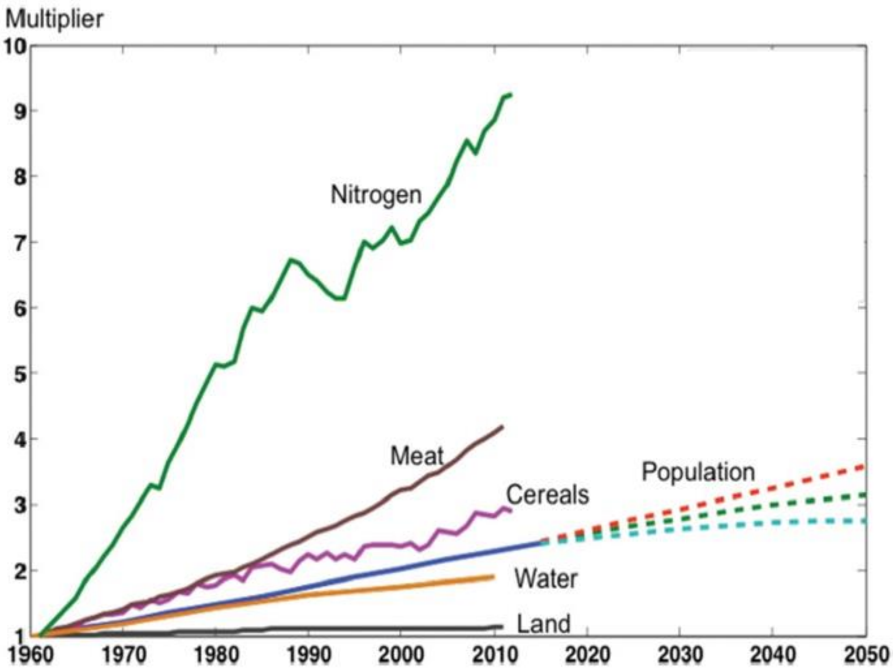

Figure 5. *Trends in global population, crop land, irrigation water diversions, cereal and meat production and nitrogen fertiliser consumed (from McLaughlin & Kinzelbach, 2015)*

It can be seen meat and cereal production have increased at a rate greater than that of population growth over the last 50 years. Furthermore this increased production is coming from the use of less water, and from virtually the same area of land. It seems we are doing exceptionally well.

But there is a catch. This increased production, from less water on the same area of land, has been achieved through a massive increase in the use of nitrogen. This nitrogen is not natural capital, it is built capital from the air using the Haber-Bosch process. The Haber-Bosch process for creating nitrogen fertiliser consumes 1% of the globe's energy use, and the fertiliser feeds one third of the world's people.

This good news is tempered by the impact that our fertiliser use is having on the quality of our natural asset stocks of water in our rivers, lakes and groundwaters. Leaching and run-off of nutrients is leading to eutrophication of our water bodies, which reduces the value of the ecosystem services we receive from them.

Water Quality

Since 1888, the National Geographic Magazine has been inspiring people to care about the planet. Its current global circulation is about 7 million, and it enters the living rooms of the influential middle classes. In May 2013 it ran an article on "*Our Fertilized World"* showing some dramatic photographs of degraded water resources. The strapline for the article was that "… i*f we don't watch out, agriculture could destroy our planet"*. They added that they knew "… *how to grow all the food we need with fewer chemicals*". That poses a global challenge to us all.

In response to public pressure here in New Zealand, the government has gazetted a National Policy Statement for Freshwater Management (NPS-FW) (Ministry for the Environment, 2014). This NPS-FW contains a National Objectives Framework (NOF) with numerical bottom-lines for nitrogen and phosphorus to ensure the ecosystem health in our rivers and lakes. Regional Councils are required to ensure that the waters under their jurisdiction meet these national bottom lines. So Regional Councils will be required to develop rules to ensure these limits are met - by no later than 31 December 2025.

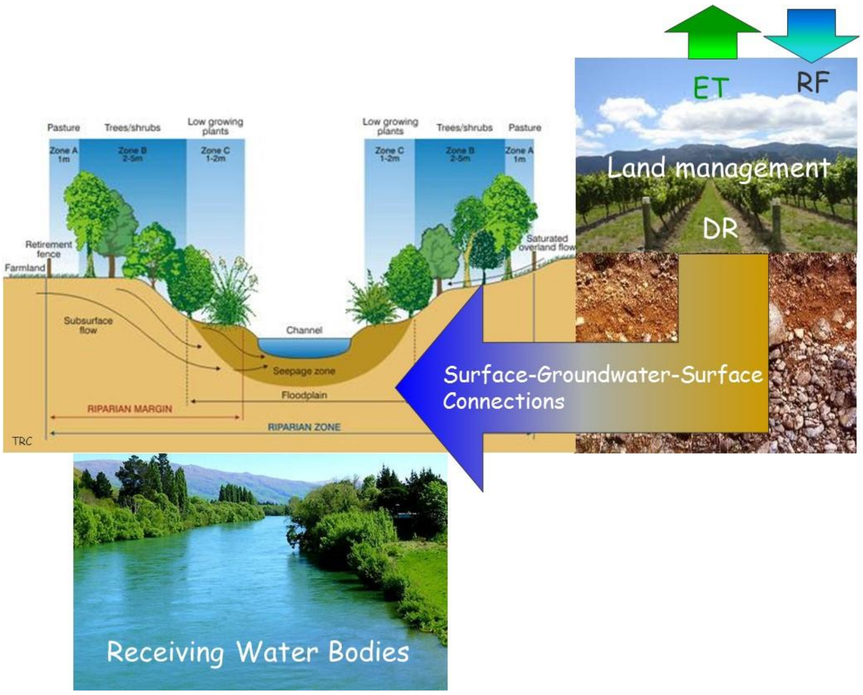

Figure 6. *The link between land management practices and receiving water quality is via the vadose zone and the groundwater systems. Lags and attenuation processes in these connections are a poorly understood part of the hydrological cycle.*

This means that regulations will be required for nutrient discharge limits from farms. The missing link is the understanding of the lags and attenuations in the geohydrological link for nutrients between the various farmlands in a catchment, and the catchment's rivers and lakes (Figure 6). This knowledge gap will need to be overcome if the NOF is ever to be implemented.

It is heartening to see, elsewhere in this proceedings, that emerging work being carried out to geo-hydrologic processes in the transfer pathways between paddocks and farms, and the receiving water bodies.

As already seen in the Horizons One Plan, and Plan Change 6 in the Hawke's Bay, it will be inevitable that some form of nutrient discharge limit will be an integral part of the social licence to operate that will be granted to farmers through the Resource Management Act (1991).

Another metric might be on the efficiency of nutrient use, or the efficiency of water use. For it seems that often when we talk about 'sustainability', we use the word 'efficiency' almost as a synonym. We talk about the goal of 'efficient' irrigation, 'efficient' nutrient use, 'efficient' emissions of greenhouse gases, and 'efficient' energy use. Efficiency is not, however, a synonym for sustainability.

Efficiency: A Poor Metric of Sustainability

Efficiency is generally a dimensionless ratio of outputs over inputs (Figure 7, left). The environment 'feels' impacts that have dimensions. Receiving environments 'sense' litres of water, kilograms of fertiliser, tonnes of $CO_{2\text{-e}}$, and joules of energy (Figure 7, right). Impacts are decoupled from the dimensionless ratio of outputs over inputs.

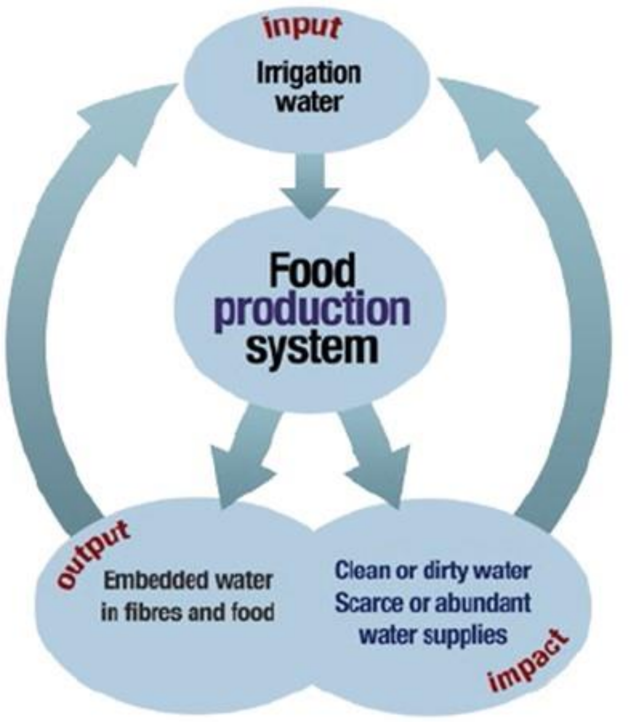

Figure 7. *The link between efficiency is on the left, being the ratio of Output to Input. This is unrelated to the impact of the food production system, which is on the right (from Garnett et al., 2016).*

Some efficiency metrics do indeed have dimensions, such as kilograms of production per unit of input, say litres of water, or kilograms of fertiliser. However, in these cases, the environment still does not 'sense' the numerator of what goes out the farm gate, or enters into the farmer's bank account. It only 'feels' the impact of the denominator values of water use, fertiliser application, greenhouse gas emissions, or energy used. Those bottom-line factors are what we need to consider in seeking sustainable outcomes.

Recently Garnett *et al.* (2016) published a report "*Lean, green, mean, obscene …? What is efficiency? And is it sustainable*?" They conclude that rather than consider 'efficiency' we should "*…start thinking instead about effectiveness – about what an effective food system might look like.*"

In relation to irrigation metrics, Perry (2007) published a review on "Efficient Irrigation; Inefficient Communication; Flawed Recommendations". He noted that in general parlance, efficiency concepts have in common that:

- high efficiency reflects low losses
- losses are a non-recoverable waste of resources
- reductions in 'losses' will mean that more of the input is available for alternative uses
- and, by implication high efficiency is 'good'.

These general concepts do not, however, apply to irrigation, which is governed by the hydrological cycle (Figure 1). Perry (2007) notes that as a result of the work by Willardson, Allen ,and others in the 1990s, there was a move away from the value-laden term 'efficiency'. They suggested that the following components of the hydrological cycles should be considered when discussing water diverted to irrigation schemes:

- The *consumed* fraction (primarily evapotranspiration), which comprises
  - *beneficial* consumption by the crop
  - *non-beneficial* consumption by weeds and soil-water evaporation.

- The *non-consumed* fraction
  - *recoverable* flows such as water to drains returned to the river system, or drained to freshwater aquifers and available for pumping
  - *non-recoverable* flows to saline groundwater, or passage to the ocean.

This mass-balance approach to the diverted water would indicate how effective the use of the diverted water could be. Furthermore, a mass-balance approach to the hydrological system of the water source would indicate how sustainable the diversions for irrigation would be.

As shown in Figure 3 many of the diversions of water for irrigation from groundwater are not sustainable. As noted earlier, globally some 9% of groundwater extractions for irrigation are from non-renewable sources. This problem also applies to diversions from surface waters, and the 'poster-child' of the unsustainable diversion of surface waters has been the destruction of the Aral Sea, which is a closed-basin lake lying between Kazakhstan and Uzbekistan. A failure to consider the hydrologic balance of this endorheic lake has resulted in the destruction of both natural and built capital (Figure 9). This ecological and sociological tragedy highlights the danger of not only living off the 'interest', or ecosystem services provided by water, but also by contemporaneously consuming the ecological capital of the natural asset stocks of water.

So whereas the destruction of our groundwater resources through over-draft seems 'out-of-sight' and 'out-of-mind', the loss of quantity and quality in our surface water resources is garnering more attention. But our surface and groundwaters are connected by the hydrologic cycle (Figures 1 and 6). Hopefully, through the ecological economic efforts being carried out by the NZIER, and others, we will gain a better understanding of the value of our natural capital stocks, and in particular, the value of our water assets. As the NZIER (2013) noted, these valuations are essential for decision making.

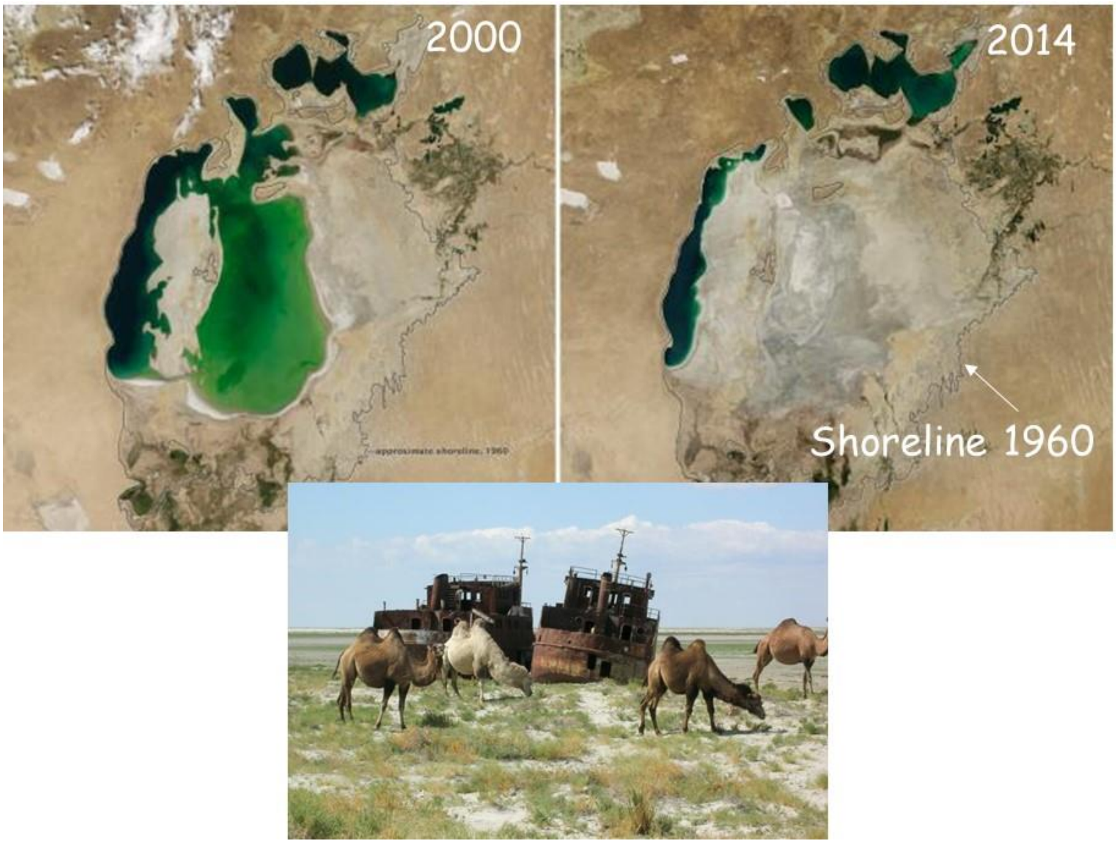

Figure 9. *The loss of the Aral Sea between 1960 and 2014, due to irrigation withdrawals destined for crops in Uzbekistan, Kazakhstan and Turkmenistan. This loss highlights the destruction of both built and natural capital.*

Conclusions

Our future depends on our ability to sustain the quantity and quality of the stocks of our most valuable natural asset – water. These stocks of water are the surface waters of our lakes and rivers, as well as our groundwaters. In sustainably managing the surface and groundwater stocks we need to acknowledge that they are intimately connected through the hydrological cycle. We have the knowledge and understanding to enable sustainable management practices. We need to ensure that we have the political will and social licence to realise this.

References

Al Muaini, A., S. Green, R. Pangilinan, S. Dixon, A. Dakheel and B. Clothier, 2016. Sustainable Irriigation of Date Palms using Saline Groundwater. In: *Integrated nutrient and water management for sustainable farming*. (Eds L.D. Currie and R.Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 4 pages

Al Yamani, W., S. Green, R. Pangilinan, S. Dixon and B. Clothier, 2016. Sustainable Irrigation of Arid Forests in Abu Dhabi using Groundwater and Treated Sewage Effuent. In: *Integrated nutrient and water management for sustainable farming*. (Eds L.D. Currie and R.Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 12 pages.

Garnett, T., E. Roos and D. Little. 2016 Lean, green, mean, obscene? What is efficiency? And is it sustainable? Food Climate Research Network. (www.fcrn.org.uk)

Intergovernmental Panel on Climate Change (IPCC), 2007. Synthesis Report. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm (valid 29 February, 2016)

McLaughlin, D. and W. Kinzelbach 2015 Food security and sustainable resource management. *Water Resources Research 51: 4966-4985*

Ministry for the Environment 2014. National Policy Statement for Freshwater Management. Wellington

MOEW, 2014 Hydroatlas of United Arab Emirates – Ministry of Environment and Water, Dubai, UAE.

National Geographic Magazine, May 2013. Our Fertilized World.

NZIER, 2013. Valuing natural assets: Essential for decision making. NZIER Working Paper 2013-03, May 2013, p51.

Perry, C. 2007 Efficient irrigation; Inefficient communication; Flawed recommendations. *Irrig. And Drain.* 56:367-378.

Wada, Y., L.P.H. van Beek, and M.F.S. Bierkens. (2012). Nonsustainable groundwater sustaining irrigation: A global assessment. *Water Resources Research*, 1-18.