GEO-ENGINEERING DAMS FOR BOTH GLOBAL COOLING AND WATER CONSERVATION

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Abstract

Implementing a reflective cover on the surface of a dam to reduce evaporation provides two benefits; not only the useable water gained but a significant global cooling effect; the latter effect arising from "geo-engineering" the dam. To quantify both benefits, this paper derives simple expressions for the global temperature cooling effect, $dT = -30A/Ae$ C and for the additional water yield, $Y = A\varepsilon R$ m^3/yr. Here A is the area of dam covered, Ae is the Earth's surface area, ε is the evaporation mitigation efficiency and R is the evaporation rate in m/yr. To illustrate the benefits for irrigation supply the paper estimates the yield from a cover on the Hume dam and the income from water conserved. For the case of urban water supply it is shown that a cover on the SEQ dams could supply the projected increase in SEQ water yield to 2040 and that, with conservative estimates of cover cost, the increased yield could be provided at a cost significantly lower than the cost of other water supply options. The global cooling effect of the reflective cover can be equated to the cooling effect obtained by geo-sequestration of CO_2. It is shown that the equivalent geo-sequestration is given by $dC = 0.146A$ tonnes CO_2. In the, currently hypothetical, situation where global cooling by geo-engineering receives the same Carbon Credit as global cooling by CO_2 sequestration the implementation of a reflective dam cover would receive a large one-off Credit. The expressions derived are used to estimate this income. The potential ecological effect of evaporation covers on dams is briefly discussed.

Introduction

Geo-engineering involves increasing the solar reflectance of an area so that more solar energy is reflected back to space and a global cooling effect is obtained (Lenton and Vaughan, 2009). A simple example of geo-engineering is painting a black roof white, (Akbari *et al*, 2009). Fresh water absorbs 90% of incident solar energy and the reflectance or albedo of fresh water is very low, < 0.1. As a result a dam surface appears black when viewed from high altitude and is the ideal starting surface to geo-engineer into a reflective surface. If a white cover (albedo ~ 0.6), is installed over a large water surface a large global cooling effect is obtained due to less solar heat being absorbed by the Earth. This does not imply a significant change in temperature of the reservoir water as less absorption of solar heat is compensated by less cooling by water evaporation. The global cooling can be equated to the global cooling that could be obtained by removing CO_2 from the atmosphere, for example by reforestation of farmland. As a result, geo-engineering projects could attract similar Carbon Credits to reforestation projects and could generate a positive economic return. Suspending a cover above a water surface reduces wind speed across the surface and evaporation is reduced by up to 90% (Craig I. *et al*,. 2005). As the rate of evaporation from Australian dams varies from 1 to 3 m/yr (Bureau of Meteorology) depending on latitude, reducing evaporation provides a large increase in water yield. This paper outlines the potential to obtain increased water supply and global cooling and assesses the cost relative to other water supply options.

Potential for offsetting carbon credits against capital cost.

Fig 1A. Modular EMCs comprise a floating framework covered with a reflective fabric. Figure 1B. An image of part of Wivenhoe dam with white rectangles superimposed to represent the appearance of twenty reflective pods, each pod (0.5 km x 0.5 km) comprising 800 EMCs. The twenty pods shown would yield about 10 GL/yr by reducing evaporation.

Evaporation Mitigation Covers (EMC) and Potential Water Savings

The purpose of an EMC is to provide a cover above the water surface to reduce air movement over the surface and to reduce absorption of solar energy. Currently available commercial EMCs are designed for implementation on rural water stores typically a few hectares in size. Of the various types of EMC available (Craig *et al*, 2005) this paper is concerned with the modular type EMC where a reflective fabric or shade cloth is suspended above the water surface on a floating frame. An example of a small (4m x 4m) floating module is shown in Figure 1A. The modular type of EMC illustrated has an efficiency, ε, of about 0.9 (Craig *et al* 2005) i.e. the evaporation loss is reduced by 90%. For application on dams with areas of the order 100 km^2 this type of technology would need to be scaled up by a factor of about 10 (~ 40 m x 40 m) to cover areas of about 1600 m^2 and the form optimised to reduce wind loading on the module and to utilise fabric economically.

Figure 1B shows an image of part of the storage area of Wivenhoe dam. The white rectangles superimposed on the image represent the appearance of pods of EMC modules floating on the dam; each individual pod (0.5 km x 0.5 km) comprising several hundred individual EMC modules. Cost estimates for the modular type of EMC illustrated in Figure 1A were in the range $10/m^2 - $20/m^2 in 2005, (Craig *et al*, 2005). However, these estimates were for applications in farm size water storages. It is likely that cost of EMC for application on 100 km^2 storage could be reduced by technical development and the scale of project. The increased annual yield of water is given by $Y = A\varepsilon R$ m^3/yr where A is the covered surface area of the dam, ε is the evaporation mitigation efficiency and R is the evaporation rate in m/yr for the locality.

Agricultural and urban supply: the Hume Dam

The Hume Dam, currently at 17% capacity and holding 523 GL, when full holds 3038 GL with a water surface area of 202 km^2. A cover over all the Hume Dam (A= 202 km^2, ε = 0.9 and R = 1m/yr) would give an increase in yield of Y = 182 GL/yr. The current price of Victorian Goulburn high reliability water is $2,300/ML (MDBC, 2009) so this additional water would be worth $420M/yr. In addition, should geo-engineering projects of this type be included in any future emission trading scheme (ETS), the project could attract a credit for CO_2 offset worth $600M as indicated below. These figures suggest the commercial benefit of EMC on farm size rural dams could be extended to river basin size dams such as the Hume.

Urban water supply: the South East Queensland (SEQ) situation.

Due to the large predicted increase in Australian population in the next 30 years urban water authorities are examining future water supply options, for example the draft SEQ Water Strategy (2009). Although evaporation mitigation is not currently a significant option within the various Australian water strategies it is useful to examine this option in view of the potential to combine water saving with global cooling which is also of future concern.

SEQ residential water is supplied mainly from the Somerset, Wivenhoe and North Pine dams. The current system yield, 440 GL/yr, exceeds the current residential consumption of 340 GL/yr. However, the residential consumption is expected to increase to 760 GL/yr by 2040 (SEQWS, 2009). To provide that consumption the yield must increase from 440 GL/yr to 760 GL/yr, an increase of 320 GL/yr over 30 years. The draft SEQ water strategy (Queensland Water Commission, 2009) to provide this increase in yield includes the construction of desalination facilities at Marcoola (73 Gl/yr), Lytton (73 GL/yr) and Tugun (36 GL/yr) during the next 30 years to provide an additional yield of 182 GL/yr by 2040 at a cost of about $2B. The strategy envisages the remaining required yield (140 GL/yr) to be provided by construction of the Wyaralong dam and raising the Hinze, Borumba and Wivenhoe dams, a further $1B. The Somerset, Wivenhoe and North Pine dams are located in shallow catchments and have a large surface area to storage ratio. The combined surface area of the existing dams when full is A = 170 km^2. The evaporation rate, R, in SEQ is approximately 2 m per year (BOM). Thus evaporation loss from the three dams is about 340 GL/yr. This equals the current residential consumption, 340 GL/yr, so the dams are losing, by evaporation, as much water as is being consumed by residents. Also, the amount currently lost by evaporation, 340 GL/yr, exceeds the projected increase in residential consumption over the next 30 years, 320 GL/yr. Evidently, most of the projected increase in consumption to 2040 could be supplied by implementing EMC on the dams.

Global Cooling Effect of Evaporation Mitigation Covers

Due to the arid nature of the Australian continent evaporation loss and mitigation has been studied for a long time and there has been significant development of EMC primarily directed to farm sized reservoirs (Craig *et al*, 2005). The possibility of combining the economic benefit of increased water supply with the environmental benefit of global cooling suggests consideration of EMCs on larger reservoirs.

An estimate of the amount of global cooling provided by an EMC can be found from basic climate science. The average temperature, T, of the Earth's surface in a basic two layer greenhouse model (I. G. Model) depends only on the incident solar radiation, S_0, and the average albedo, α, of the Earth's surface according to $T^4 = S_0(1 - \alpha)/2\sigma$ Here T is in degrees Kelvin, S_0 is the solar constant (1368 W/m^2), α is the average albedo of the Earth, (α= 0.3) and σ is Boltzmann's constant (5.67×10^{-8} W/m^{2}K^4). This equation gives T = 303 K which is 5% higher than the actual T, (288 K), indicative of the simple model used. However, the model is sufficient for the present purpose. Differentiating the equation above to find how T changes when α changes by a small amount $d\alpha$ we obtain $dT = -(T/4(1 - \alpha))d\alpha = -108d\alpha$. When a small area, A m^2, of the Earth's surface changes from albedo, αw, to albedo, αp, the average albedo of the Earth changes by $d\alpha = 0.56(A/Ae)(\alpha p - \alpha w)$ where the Earth's surface area Ae = 5.1×10^{14} m^2. The factor 0.56 accounts for the fact that only 56% of the solar radiation passes through the atmosphere and the clouds to reach the Earths surface. Thus the global cooling obtained is $dT = -108d\alpha = -60(A/Ae)(\alpha p - \alpha w)$. The albedo of the surface of a freshwater reservoir is close to 0.1 and the albedo of a weathered white plastic surface is close to 0.6 thus the change in albedo, ($\alpha p - \alpha w$), can be taken as 0.5 and the expression simplified to:

$$dT = -30A/Ae \text{ K.} \qquad (1)$$

For example if a white EMC was implemented on the Hume dam, (filled area A = 202 km^2), the global cooling obtained would be $dT = -11.8\times10^{-6}$ K. This appears to be a small global coolin g. However, it can be shown to be equivalent to the cooling obtained by a large CO_2 sequestration project.

Carbon Credit from Equivalent Carbon Dioxide Sequestration

Any global cooling obtained by geo-engineering can be equated to an equivalent global cooling obtained by removing CO_2 from the atmosphere (CO_2 sequestration). As governments are establishing a price or Carbon Credit for global cooling achieved by CO_2 sequestration the same price can, in principle or by government fiat, be applied to other methods of global cooling.

The current mass of CO_2 in the atmosphere is $C = 3\times10^{12}$ tonnes. If this is changed by an amount dC the resulting change in global average temperature is given by $dT = k.dC/C$ where k is a constant central to climate change science. When there is no positive feedback associated with the change in surface temperature it is generally accepted (BOM) that a doubling of CO2 (dC = C) leads to a temperature increase of 1.2 K. Thus, with no positive feedback, the equation can be written dT = 1.2dC/C. With positive or negative feedback the constant k is respectively greater or less than 1.2. The current IPCC view (BOM) is that positive feedback is dominant and that k is about 4 times larger than 1.2 i.e. k = 4.8. However, for our purposes it is necessary to take the no feedback case in order to compare with the model for albedo change used above as this model does not include feedback. Equating the temperature change due to CO_2 sequestration (dT = 1.2dC/C) to the temperature change due to implementing an EMC of area, A, (dT = -30A/Ae) and rearranging we obtain dC = -25(A/Ae)C. Substituting Ae = 5.1×10^{14} m^2 and C = 3×10^{12} tonnes the expression simplifies to:

$$dC = -0.146A \text{ tonnes } CO_2 \qquad (2)$$

Akbari *et al* (2009), using a much less direct method, found dC = -0.128A tonnes when black roofs are painted white so the expression (2) can be regarded as a conservative estimate of CO_2 sequestration equivalent.

Carbon credit for geo-engineering the Hume dam

As an example, the implementation of an EMC on the Hume dam (A = 202×10^6 m^2) provides global cooling equivalent to the sequestration of dC = 0.146xA = 29.6 M tonnes of CO_2. The projected price of Carbon Credit in the Australian emission trading scheme (ETS) is A$40 per tonne after 2011 (CO_2 Australia Ltd). Thus the cooling obtained on implementing an EMC on Hume dam could be worth A$1200M.

Carbon credit for geo-engineering the SEQ dams

With an combined area of A = 170×10^6 m^2 the equivalent CO_2 offset dC = - 0.146A = 24.8 M tonnes. At the projected $40/tonne Credit under the proposed ETS this geo-engineering project would be worth $1 B.

Could Carbon Credit and increased water income offset EMC investment cost?

The Carbon Credit estimates above raise the interesting question of whether the continuing income from increased water supply and the one-off Carbon Credit income could offset the investment cost of an EMC. In the case of the SEQ dams the combined dam area is A = 170×10^6 m^2 so the potential increase in yield is Y = AεR = 306 GL/yr. This is close to the projected increase in consumption to 2040. Under the draft SEQ Water Strategy most of the increased yield would be supplied by desalination at an operational cost of $1.08/kL. Desalinated water requires no further treatment. However, any increase in water from the dams requires the conventional treatment costing about $0.20/kL. Thus the effective value of water saved from evaporation is $0.88/kL. The additional 306 GL/yr at $0.88/kL is therefore worth $270 M/yr based on offsetting the cost of desalinated water. The potential total area for implementation of EMC is 170×10^6 m^2. Assuming a price range of $10/$m^2$ - $20/$m^2$, as currently available for farm dam covers the potential EMC cost is in the range $1.7 B - $3.4B. With this range of EMC cost and the possible CO_2 credit, ($1B), the net implementation cost could be between $1.7 – $1 = $0.7B and $3.4 – $1 = $2.4B. Both figures are lower than the projected implementation cost (~ $3B) of the draft SEQ water strategy.

Some examples of reservoir covers

North Parkes, NSW, 2008: Nylex and Rio Tinto joined forces to produce a product that achieved 95% reduction in evaporation losses.

Preparing to spread plastic balls: Ivanhoe Reservoir, Los Angeles, 200 ML, 2007. The water needed to be shaded because sunlight with the bromide and chlorine formed the carcinogen bromate. No reduction in evaporation was targetted.

Ecological effects of EMC

The ecosystems in Australian reservoirs are complex and are affected, mainly, by water temperature, salinity, dissolved oxygen, nutrient concentration, blue-green algae, reservoir water level and inter-relations between these, (Walker, 1985). Therefore an assessment of the effect of covering or partly covering a reservoir with an EMC is complex. A recent CSIRO study reported on the ecological benefits of shade covers for potable water storages (Finn and Barnes, 2007). Some general observations can be made. A suspended, reflective cover that reduces evaporation and maintains water volume in a reservoir will reduce salinity, nutrient concentration, blue-green algae and water level change, the reduction of which would normally improve the ecology of a reservoir. The temperature of water in a reservoir is largely determined by the energy balance between solar absorption and evaporation. A reflective cover reduces the solar energy input and reduces the energy output via evaporation. Thus, depending on the balance, it is expected that a reflective cover would have only a small positive or negative effect on water temperature. This is in contrast to transparent, monolayer type covers that do not decrease solar energy input and can substantially increase water temperature (McJannet *et al*). Growth of blue-green algae is promoted by the combination of warm water, light penetration and high nutrient levels. This combination is less likely to occur in reservoirs with a reflective cover. Reduction of blue-green algae should reduce episodes of severe oxygen level depletion that occur following blooms of algae. Water evaporation rate and oxygenation rate depend on the concentration gradients at the water/air interface. The gradients and rates increase with wind flow over the water surface. Thus a system that reduces water evaporation by reducing wind flow will also reduce the oxygen transfer from air to water. As an adequate level of dissolved oxygen (~10mg/L) is critical for a healthy aquatic ecosystem EMC should not be deployed on the entire surface of a dam. In particular the littoral zone around the dam perimeter where aquatic plants grow and photosynthesize oxygen should remain uncovered as in Figure 1B. Further work is necessary to establish whether the effect of reflective covers on the ecosystems of reservoirs is positive or negative.

Conclusion

This paper introduced the concept of implementing a reflective cover on dams to obtain a global cooling benefit and an increased water yield benefit. Expressions were derived to quantify both benefits. An economic value of the increased yield was estimated from current water costs. The global cooling resulting from the reflective cover could be related via a CO_2 offset price to a return on investment in the cover. For dams such as the Hume that supplies water to irrigators in the Murray River Basin the high ongoing income from the increased water supply as well as the potential one-off income from CO_2 offset suggests that the implementation of EMC on such large river basin dams should be commercially viable. Due to the high evaporation loss in Queensland implementation of an EMC on the SEQ dams could provide nearly all the projected increase in residential water supply to 2040. With a conservative range of EMC cost and the potential Carbon Credit for the global cooling effect the implementation cost of an EMC on the three major SEQ dams could be lower than the implementation cost of desalination plants and new and raised dams. EMCs for farm dams are commercially available but the technology for reducing evaporation on large dams is not well developed. However, the dual benefits of water conservation and global cooling as outlined here suggest further development should be a priority. Consideration should also be given to including geo-engineering projects that reduce global warming directly by reflecting sunlight and indirectly by reducing electrical energy consumption within the types of project eligible for Carbon Credits in the proposed Australian ETS.

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