The role of dams in creating a water secure world

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Halcrow

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1.Introduction

In a recent speech by John Beddington, the British government's chief scientific adviser, he explained the problems that the world is likely to face in 2030. In particular he explained the issues in feeding 9 billion people, providing them with clean water and addressing their energy demands. This paper aims to discuss the contribution of reservoirs in the context of a water-scarce world.

The idea of forming a barrier to store river water is an ancient one. In our 21st-century world, the need for water storage is now greater than ever. The focus here is on water supply for drinking water and crop production: the many additional benefits of reservoir development for hydropower, navigation, flood control and amenity purposes are not covered but should be kept in mind as many reservoirs provide multiple benefits. Just one example of this is the Oyan dam in Nigeria[1] which provides:

- irrigation water
- regulation of river water to improve water supply from the river downstream
- hydropower
- flood control
- fish production in the reservoir
- recreation facilities

There is enough fresh water for everyone on the planet but it is often in the wrong places at the wrong times and in the wrong amounts. It is a fact of nature that the hydrological cycle is neither constant nor predictable, whereas the water demands of a human population can be predicted with relative certainty and is often much less variable over time.

Fundamentally, the purpose of a dam is to create a reservoir – an area in which to temporarily store water and hence to regulate the flow of water that passes downstream of the dam. By allowing a reservoir to fill through the wet season when water availability exceeds demand, we can aim to meet the water demands during the dry season when the demand exceeds the natural supply. Although this simple idea has been fundamental to how we have been able to develop our modern world, there are many challenges to be faced in developing new dam sites if we are to avert a water crisis in the 21st century.

Water scarcity is not restricted to the third world. Many cities in the developed world have had to deal with periods of water shortage without clear and reliable contingency plans. The United States, United Kingdom, Australia, Italy, Spain and South Africa are example countries where shortages have arisen due to:

- unsustainable urban development planning that fails to consider water scarcity
- population growth

[1]Akanmu, J.O. Management of the downstream impacts of dams operation – O-Orbda experience and hydropower dams as case study, ICOLD. Q85 – R.32. 2006

- an increase in per-capita consumption
- limitations on reservoir operation
- environmental requirements for compensation releases from reservoirs
- climate change where rainfall trends are becoming more severe and/or less assured in some regions leading to an imbalance between water availability and demand

By 2025, it is estimated that 1.8 billion people worldwide will live where water is scarce. Water scarcity is finally receiving the attention it deserves: the Royal Academy of Engineering has recently published a report on global water security[2] which highlights the importance and value of managing water variability and providing surface water storage facilities along with a number of other strategies such as water efficiency in agriculture.

[2]Royal Academy of Engineering. 2010. Global Water Security – *an engineering perspective. (Online)*, 2010, Available at: www.raeng.org.uk/gws
[3]Smith, N., 1971. "A history of dams". London: Peter Davies.

2. The historical role of dams in meeting water demand

According to Smith[3], one of earliest known dams is the Sadd el-Kafara dam, located about 20 miles south of Cairo. The dam dates from between 2950 and 2750 BC and is thought to have provided a secure water supply to men and animals engaged in quarrying stone to build monuments for the pharaohs. Egypt then had no use of dams for irrigation as it relied on the Nile floods, but elsewhere in the world many of the earliest dams were associated with irrigation.

It would be easy to assume that water scarcity is only relevant to drought-stricken and/or poor and/or under-developed countries of the world, but this would be a mistake. Even well-developed and water-rich countries have long depended on water storage facilities for their water and food security, and these in turn have been an essential stepping stone to industrial and economic growth.

The United Kingdom is a good example of where dam development in the 18th and 19th centuries provided the water supply required to support large populations in cities and the water to drive the industrial revolution, as well as canal water to transport goods for trade. The economic growth of Britain during the Victorian period was firmly founded on the establishment of a reliable supply of water and water transfer infrastructure.

The Hoover Dam development on the Colorado River in 1936 marked the start of large dam projects which continued unabated through the second half of the 20th century. Such schemes were typically designed to serve multiple purposes, including hydropower which can, in turn, provide the energy to pump water for large distances from the reservoir site to make greater use of the substantial water volumes created by large dams. Large reservoirs were found to make economic sense, providing a relatively large reservoir volume for the investment in dam construction and reservoirs were even developed on very large rivers in China and South America. The recently constructed Three Gorges Dam on the Yangtze River is one of the best-known examples of such a scheme.

For those wishing to read more on the history of dam development, a useful summary by Turpin[4] has recently been published.

[4]Turpin, T. 2008. "*Dam*". Reaktion Books.

3. Responsible dam development

The price for large reservoir developments cannot be measured in monetary terms alone, and it must be acknowledged that they came with a social and environmental cost.

In the past, reservoir schemes have been developed which did not fully evaluate the benefits in a holistic manner and this led to the rise in international 'anti-dam' movements, notably the International Rivers Commission. The depth of feeling is encapsulated in McCully's 1996 book *Silenced Rivers*[5].

The concerns for the manner in which some governments were developing large reservoirs eventually led to the *World Commission on Dams* (WCD), partly funded by Halcrow, which was published in 2000. The report's key recommendations were for dam development to be considered according to the core values of:

- equity
- efficiency
- participatory decision-making
- sustainability
- accountability

And for these values to be underpinned by seven strategic priorities to provide a principled and practical way forward for decision-making:

- gain public acceptance
- comprehensive options assessment
- addressing existing dams
- sustaining rivers and livelihoods
- recognising entitlements and sharing benefits
- ensuring compliance
- sharing rivers for peace, development and security

The WCD report was generally welcomed in so far as it covered all of the main concerns associated with dam development and provided some good practice guidance to developers and engineers.

Since the publication of the WCD report, increasing concerns over climate change, population growth, food security and energy deficits have underlined the importance and need for continued reservoir development in many countries.

The Worldwide Fund (WWF) for Nature pointed out that, five years after the WCD report, many dams continued to be constructed without some or all of the strategic priorities being taken into account. The WWF stated that "the development of new dams in accordance with the seven strategic priorities recommended by the WCD is the best way to ensure that dams really deliver their intended benefits and avoid unacceptable impacts".

The Third World Centre for Water Management, with other international organisations, recently embarked on a project to assess the impacts of several large dams all over the world. This study[6] clearly underlined the value of large dams to meet the water, energy and food needs of an increasing population as well as their potential to bring wider societal benefits if properly planned, designed, constructed and managed.

In the words of Professor Jia Jinsheng (president, ICOLD)[7]: "negative impacts should never be suppressed, overlooked, or underestimated, when promoting future development." He adds: "benefit-sharing should be more inclusive, rather than just relating to a region or state. All stakeholders should be involved. One should remember that all members of society have the right to benefit from a project."

[5]McCully P. 1996. Silenced Rivers – *the ecology and politics of large dams*. Zed Books. 1996
[6]Tortajada, C. et al, 2009. *Assessing impacts of large dams*. Berlin. Springer Verlag.
[7]International Journal on Hydropower and Dams, World Atlas and Industry Guide 2009

4. Addressing water scarcity through reservoir development and improvements

4.1 Groundwater dams

For many people, dam development conjures up thoughts of large dams, but dams come in many forms and every dam is unique.

Most dams aim to capture and store surface water but some are designed to store water in permeable alluvial deposits below the river bed.

In parts of Africa and the Middle East, underground dams or groundwater recharge dams aim to intercept sub-surface flows that pass through permeable river gravels to allow local people to access groundwater by hand pumps. By holding up water that would otherwise be transported away from a demand area, water is given more time to percolate downward through relatively impermeable horizons to the water table. By raising groundwater levels in this manner, water is made easier to access at wells for drinking and irrigation.

4.2 Sediment management

Once created, reservoir storage does not last forever because of the effects of sedimentation. The rate and degree to which a reservoir will lose its useful storage depends on many factors, notably the sediment yield of the incoming water. As many of the best reservoir sites have already been developed it is important to consider means of extending the operational life of the reservoirs that already exist. In the case of new reservoirs, careful consideration of sediment management is particularly important for many parts of the world if the reservoir volume is not to be quickly lost through sedimentation. A number of approaches and techniques can be considered to reduce the impact of sedimentation and the World Bank produced a useful guide to the various strategies in 2003[8].

Much of the storage lost through sedimentation can be regained where economically viable. Many different methods have proven successful, including dredging, reservoir sluicing, reservoir venting and reservoir flushing and the optimum method is highly site-dependent. Under

Figure 1. The Bani Naji Dam in Yemen was recently revitalised as part of a Halcrow contract to refurbish and design dams and improve water reliability where water supply depends greatly on groundwater sources.

[8]Palmieri, A. et al. 2003. *"Reservoir Conservation"*. IBRD.

appropriate conditions, sediment flushing is one of the most attractive methods in redressing the loss of sediment yield to the downstream environment and increasing reservoir yield. Large gates in the base of the dam are opened when the river is fast flowing and the reservoir is drained down, allowing the riverine conditions to erode the deposited sediments and transport them out of the reservoir area. Halcrow has been studying this technique for more than ten years and it is slowly becoming established as a practical and effective, low-cost solution where the reservoir characteristics and environmental conditions are appropriate.

This method is commonly associated with regions where reservoirs are located in narrow valleys subject to monsoon rains, such as the Himalayas. However, experience has found the technique can be applied to many other regions. For example, several reservoirs in Japan have been flushed[9]. The Sefid-Rud reservoir in Iran[10] does not lie in a steep narrow valley but clearly shows the value of the technique if applied intelligently.

4.3 Dam modifications

Increased water demand is a common reason why some existing dams have been modified to increase storage. One technique commonly considered in improving reservoir yield is to heighten the dam. This approach is often one of the simplest and most effective means of increasing storage but the increase in reservoir storage is usually limited to a small fraction of the original storage. It is attractive as a short-term fix to address water shortfall where longer-term provisions require more time to develop or finance. There are three basic approaches commonly used:

1. Increase the height of the dam to increase the gross storage

Halcrow recently carried out a study for the Roseau Dam, St Lucia, which serves much of the island's water supply demands. In this case, sedimentation had reduced reservoir yield and increasing water demand was expected to exceed the capacity of the water supply system. In addition, the island has recently experienced drought. Designs were developed to increase the height of the dam.

2. Lower the lowermost draw-off level to increase the net (usable) storage

Australia has now suffered many years of drought. One of the largest water supply reservoirs in New South Wales is the Warragamba reservoir. Halcrow assisted the Australian authorities in planning a lowering of the draw-off outlets to increase the reservoir yield.

3. Modify the spillway arrangement to safely allow higher retained reservoir levels

Reservoir storage can be improved even without increasing the dam crest elevation. A recent example is the Maccheronis Dam[11] in Sardinia where an extra 3m depth of storage was obtained by substituting a gated spillway for the original overflow spillway. This allowed water to be safely stored at a higher elevation without compromising flood safety. Similarly, Wedbila Dam[12] in Burkina Faso was modified by adding concrete fuse blocks to the free overflow spillway to increase storage capacity by 25 per cent. Under extreme floods, the fuse blocks are washed away and subsequently replaced with retrieved original or replacement blocks.

[9]Sumi, T. Environmental Study on Sediment Flushing in the Kurobe River, ICOLD Q85-R.16. 2006
[10]Morris, G and Fan, J. 1997 *"Reservoir Sedimentation Handbook"*. McGraw-Hill
[11]Lazaro, P. et al, Heightening of the Maccheronis dam in Sardinia (Italy), ICOLD. Q87- R.35. 2006
[12]Nombre A et al, ICOLD Q.90-R.23, 2009.

5. Challenges for the future

As well as altering rainfall patterns, climate change is having a marked effect on glaciated regions. Melting glaciers might provide ample water in the short term but their demise could have significant impacts on the depletion of Asia's large rivers. Water shortages, together with power shortages, are likely to affect food production. In the face of reduced river flows, countries will increasingly consider reservoir development to regulate the ample water available through the monsoon season. China recently announced plans to construct up to 59 reservoirs in Xinjiang province to store melted glacier water.

Where rivers flow across international boundaries, this might lead to conflict. The future peace of India and Pakistan might well be affected by water security as the two countries share the glacier-dependent Indus. China has already dammed the Mekong which has affected Indochina, and it apparently made tentative plans to divert the Brahmaputra which could lead to a dispute with India.

Large reservoirs can, and do, displace people. Worldwide, many tens of millions of people have been displaced by reservoirs and there have been many highly contentious projects. It will be important to balance the demands for new reservoir storage with the recommendations of the WCD to improve decision making.

In the United States, many dams have been removed over the last ten years, mostly driven by environmental concerns for, notably, fish. In California, water supplies to farms have been reduced in order to safeguard native fish species and there have been many associated lawsuits. In a region where water demand greatly outstrips the natural resources, there will inevitably be greater pressure in the future to put people first. Steven Chu of the US Department for Energy recently said that, "California will not be able to produce agricultural products within 25 years," and that he had serious doubts about the viability of Californian cities to meet water demands unless there was significant investment in infrastructure. Recent legislation has been passed here to cut water use in cities by 20 per cent by 2020 and there are proposals for investment in reservoir development as part of a suite of measures including water conservation efforts, wastewater recycling and desalination plants. It should be remembered, however, that irrigated agriculture uses 70 per cent of all the

Figure 2. Halcrow reconnaissance visit to southern Ethiopia to address irrigation demand.

freshwater consumption by humans, so farmers have the potential to make greater water savings. Globally, the use of food-producing lands to produce bio fuels, and international trade agreements, can affect food production and availability.

In the future we can expect to see more reservoir development associated with trans-boundary water transfer schemes. Many such projects have been planned and reservoir development will often be a component of schemes to address water shortages that threaten political, economic and food security. In the same manner that some countries export power to neighbouring countries, we can expect to see an increase in water exports.

In the developing world, aid can be put to good effect to help people help themselves. A recently published article[13] ran a story on the people of Konso in southern Ethiopia who grow their food on hillside terraces. With the help of WaterAid, the local people installed a pump to divert water from the river into a reservoir on the top of a nearby mountain. The reservoir now enables irrigation of their terraces. Halcrow recently worked in this area to identify and evaluate sites for irrigation dams and one site is now at feasibility design stage.

The African regional paper prepared for the 5th Water World Forum in Turkey in 2009 stated that "the biggest challenge in delivering African water resources development is putting in place the appropriate storage infrastructure and an institutional platform that will boost growth to the double-digit rates needed to reduce poverty". Regional initiatives such as the Nile Basin Initiative are important in promoting cross-boundary planning and implementation of water resources schemes. Halcrow is currently active in the Nile basin, developing dams for large-scale irrigation.

[13]*National Geographic*, April 2010.

6. Conclusions

The earliest dams were built to address the problems posed by highly populated areas. The drivers for building dams in pre-history still hold true today. With the world population set to reach 9 billion by 2030, and an increasing trend towards urbanisation, these trends will place great pressure on water resources infrastructure. Reservoirs can bring added benefits in flood control and hydropower, but they come at a cost both in financial and human terms. The role that dams can play in alleviating water stress around the world is clear but reservoir developments must take full account of the impacts in the widest possible sense. Experienced designers can bring added value to reservoir developments by providing the means to maximise long-term storage, new reservoirs or by extending the life of existing reservoirs.

Figure 3: Halcrow is providing technical services on the Bengoh water supply dam in Malaysia, which will improve the resilience of the water supply for Kuching, Sarawak.

Planning, design and management services for infrastructure development worldwide

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