Decommissioning, discontinuation and abandonment of dams: is there a case for a national strategy?

C. S. MCCULLOCH, University of Oxford

SYNOPSIS. Dam removal has excited much interest in the United States in the last decade. Many small dams have been removed and a start on removing two large dams in Oregon is scheduled for autumn 2008. Valuable lessons relevant to England and Wales are drawn from the burgeoning scientific literature. Multi-disciplinary inspections are needed to assess dams for decommissioning and discontinuance based on aesthetic, ecological and recreational values as well as safety and utilitarian economic considerations. A case is made for a national strategy.

INTRODUCTION

Visions of the longevity of dams and reservoirs differ profoundly. To those impressed by those forces of nature which balance discharge, slope, sediment and channel shape, "Dams are unnatural, short-term features in the landscape" (Evans et al., 2000); "Dams have a finite life span, so dam age can be an important factor affecting removal decisions" (Poff and Hart, 2002). To proud engineers, "an artificial reservoir generally becomes a practically permanent part of the landscape" (Bonazzi, 1989), or "a well-designed and well-maintained dam can be operated indefinitely" (Back, 1989). Both views hold some truth. Some dams have not been well-designed or carefully constructed and some are not well-maintained. Reservoirs may become filled with sediment, concrete may disintegrate, moving parts may seize with rust, spillways may not route floods safely. The question is whether dam maintenance is a life sentence for society or can dams be removed and nature restored once costs outweigh benefits?

Physical changes are inevitable, needing attention and restoration. In addition, all dams are situated in a changing cultural context of values, economic, social and ecological. Economic rationale for a dam changes with time. Major water consumers, such as heavy manufacturing, may relocate overseas; small hydroelectric dams, water mills and canals may become replaced by more efficient power supplies and transport. Aspiration to higher standards of potability may condemn reservoirs with organic or industrial pollution. Conversely, new techniques may make use of brackish water more economical than transfer from distant sources. Economy of

Ensuring reservoir safety into the future. Thomas Telford, London, 2008

scale in water purification may make piping of water from fewer plants less costly than more local supply from small waterworks.

Social values also change appreciation of reservoirs. Post Second World War social idealism resulted in pressure on reservoir owners to open access to reservoirs. A new active group of stakeholders in reservoirs was created with interests in sailing, watersports and fishing. Expansion of population and of the extent of urban areas made many reservoirs local places where a form of 'nature' could be enjoyed. Even the most artificial reservoirs became appreciated for their contrast with noisy, crowded and dangerous urban streets congested with traffic. Some urban councils have purchased reservoirs no longer used for water supply for notional sums for recreation value. In other cases, the risk posed by dams situated upstream of vulnerable settlements coupled with costs of statutory maintenance and may tip decision-makers towards removal rather than change of use.

Ecological awareness and concern for the survival of other species, some of utility to humans, others of intrinsic value, has changed attitudes towards dams. Removal of dams for ecological reasons is advocated in the United States, particularly where damage to migrating fish caused by dam building has been obvious in living memory (Poff et al., 1997, Bednarek, 2001, Hart et al., 2002). In the Western states, salmon, shad and steelhead fish populations are declining so rapidly that 27 species, such as the coho salmon, have become endangered. Some salmon are even transported around dams by barge but such costly mitigation measures may not be sustainable. Whilst fewer than 500 small dams have been removed so far in the US, two high dams(33m and 64m with a joint capacity of $60Mm^3$) on the Elwha River in Oregon will be dismantled for ecological reasons, starting in autumn 2008 at a cost to the Federal government of $184 million, including $75m to provide water-treatment, flood protection and sanitation for settlements downstream (Tweit, 2006, Stokstad, 2006a). Other high dams, including four on the Snake River and the O'Shaughnessy Dam in Yosemite, are being reviewed for possible removal (Gray et al., 2006, Null and Lund, 2006, Gregory et al., 2002, Stokstad, 2006b). Methods of cost/benefit analysis to support such decisions are being refined (Whitelaw and Macmullan, 2002).

This paper will sample the burgeoning literature in the USA on dam redundancy and removal to identify transferable policies and science. Illustrative cases of recent dam breaching demonstrate the need for a strategic rather than an ad hoc approach to the decommissioning and discontinuance of dams in England and Wales.

DAM REMOVAL IN THE USA

The speed of transition of dams from benefits to liabilities pending decommissioning will vary from place to place. American dam redundancy has progressed more rapidly than in England and Wales and ambition for dam removal has grown. Every major US geoscientific and ecological society has held workshops on dam decommissioning/removal and two national panels (Aspen Institute and Heinz Centre) have produced reports (Pohl, 2002, Grant, 2001). Consequently, this presents an opportunity for UK dam stakeholders to learn from the large and growing literature describing US experience.

In dam removal and attempts to restore rivers to their natural state, the US has taken the lead, partly because of the political power of active NGOs, such as American Rivers (http://www.americanrivers.org) and Trout Unlimited (http://www.tu.org) which have demonstrated significant ecosystem damage caused by dams, and partly because of fears of loss of life and property caused by recent dam and levee failures. Pohl (2002) analysed 417 cases and concluded that environmental issues were the main cause of removal, followed by safety, then economic issues.

The hope to restore suitable conditions for migratory fish follows concern about drastic declines of salmon and trout. Canneries have closed and the loss has been devastating for native Indian tribes, such as the Oregon Elwha Klallam tribe, whose culture and nutrition depended on the salmon.

In addition to ecological concerns, the Federal Emergency Management Agency (FEMA) found that about 9200 dams in the U.S. are classed as high hazard because of inadequate spillway design, lack of emergency spillways, inadequate dam maintenance, and/or lack of active sediment management (FEMA, 2002). Accelerated soil erosion has filled many small reservoirs with sediment, reducing capacity and limiting attenuation of severe floods.
Removal can be the cheapest option for a failing dam, "the cost of repairing a small dam can be as much as three times greater than the cost of removing it" (Born et al., 1998).

Ecological and geomorphological investigations of the effects of dam removal are in their infancy. Some introduced fish species may decline and native fish recuperate after removal. Sediments accumulated in the reservoir become mobilised and transported downstream changing channels, with consequences for fishing, spawning and flooding behaviour. More measurements of reservoirs, river channels and their biota are needed before and after dam removal to improve scientific understanding. "When understanding of environmental systems is lacking, scientific consensus, and thus policy, will often be years to decades away."(Doyle et al., 2002)

"Monitoring the site after the dam is removed is essential" and "ideally post removal monitoring should be included in the dam-removal budget (Baish et al., 2002). The aim is to develop dam removal as a science.

Dam removal may not always lead to ecological benefits particularly when contaminated sediments are mobilised. When transported from the disused dam site downstream, these may cause ecological damage. Shuman (1995) reports severe environmental damage caused by removal of the Fort Edward dam from the Upper Hudson:

> *'PCB contaminated sediment has settled over a 300 km length of the river, and commercial fishing of striped bass and other species has been banned due to the risk of bioaccumulation (EPA, 2002)'*

Others are concerned about the amount of carbon and nitrogen released as the sediments are mobilised (Riggsbee et al., 2007, Pacca, 2007).

Several papers make recommendations about good practice (e.g.(Bushaw-Newton et al., 2002, Bednarek, 2001, Babbit, 2002, American Rivers et al., 1999). Before dam removal, the history of the reservoir should be investigated to identify sources of pollution, past or current. The sediment should also be examined before any redistribution downstream is allowed. Precautions include careful control of the speed and timing of drawdown, also capping or dredging of polluted sediment. The dam removal should be considered on a catchment scale to anticipate effects on other parts of the system and to ensure that subsequent actions do not negate the beneficial environmental effects of restoring habitat connectivity.

The planning process for removal should be expected to be time-consuming because of the interests of many stakeholders. The decision to remove the Elwha dams was preceded by three decades of debate and only the decision of the Federal government to purchase the derelict dam and fund its removal resolved the issues.

RELEVANCE TO ENGLAND AND WALES

There are many emerging reasons why the whole life of dams, design, building, maintenance and removal, should be considered seriously in England and Wales. Most of current dams are old, (the average age of dams in the Building Research Establishment Register is 110 years) and reviews are needed of the relationship between the benefits of each dam and the cost of its safe maintenance. Embankment dams in small upland catchments risk damage with flashy flood responses to severe rain storms. Some dams have been poorly-designed with inadequate spillways, for example the Brushes Clough reservoir near Oldham where the existing spillway capacity was calculated to be able to pass only 40% of the PMF (Gardiner et al., 1996). 70% of categorised dams (A, B and C) pose a downstream risk (Hope,

2006) and liabilities have increased with housing expansion and growth in value of property. There is regulatory pressure from the Environment Agency to maintain dam safety despite the high costs involved. Economic change has meant that many dams no longer serve the purpose for which they were constructed. Privatisation of water supply into regional-scale companies has led to some rationalisation of reservoirs and many reservoir owners are faced with rising costs of maintenance without compensating income.

In contrast to American ambitions to restore rivers, pressure to breach dams in England and Wales has been driven by a pragmatic desire to diminish the capacity of the reservoir to below the Reservoirs Act 1975 limit of 25,000m^3 of water held above ground level. Economic drivers govern the choice between repair and rehabilitation on the one hand or breaching of the dam on the other. This difference is reflected in the vocabulary: in England and Wales, 'discontinuance' is used to indicate that the amount of water in the rump reservoir is less than 25,000 m^3 without implying restoration of ecological connectivity of the long profile of the river. The dam itself is usually only partially removed to effect the lowering of reservoir level. 'Decommissioning' is an ambiguous term used to indicate a significant change in the human use when a dam is taken out of the operation for which it was first designed but is sometimes used as if synonymous with removal. A third way, abandonment, postpones decision-making on the future of the dam but since the Water Act 2003, the Environment Agency, in taking responsibility for enforcement of regulations in England and Wales has identified owners of almost all reservoirs under the Act (Hope, 2006) and some will now be faced with decisions between costly repair or discontinuance.

<u>Reservoir inspection as a trigger for change</u> Inspection of dams under the Reservoirs Act 1975 provides an opportunity for review of both the safety and functionality of the dam and consideration of its future with the dam owner. Currently, the emphasis is on dam safety with the inspection being conducted by a sole Panel Engineer at least once every ten years. Ideally, where there is doubt about continuation of the reservoir, the inspection should be an opportunity also for consideration of ecological, recreational, aesthetic and other planning issues. In Wisconsin, interdisciplinary inspections and reviews are now possible and provide the basis for more considered evaluation of future options (Orr et al., 2004).

<u>Opportunities for research</u>

The zeal of the US scientific community reflects an appreciation that dam removal can be a positive environmental improvement and that each case presents valuable research opportunities (Hart et al., 2002, Pizzuto, 2002).

ENSURING RESERVOIR SAFETY

In the England and Wales, more co-ordination is needed between practising engineers and researchers to realise the value of discontinuation of dams as field experiments. Some recent examples illustrate potential for research:

Ecology. Even though ecological river restoration is not usually a stated aim of discontinuance in England and Wales, valuable research could be carried out on colonisation of the newly-exposed banks and on the changes in the biota left in the remnant pond after the lowering of the reservoir. Monitoring of the changes represents a wonderful educational opportunity for greater understanding of ecological principles and might suggest ways in which natural processes might be speeded up to restore landscapes more quickly.

At Boltby, a remnant pond still remains inaccessible to fish from the downstream river. A small fish ladder has been fashioned to link the much reduced pond to a feeder stream in the hope that the fish introduced by the local Fishing Club before the dam was breached might be tempted to migrate upstream to spawn. Research is needed on the long-term sustainability of the fish population confined to the smaller waterbody and on the functionality of the fish ladder.

Dam engineering. Breaching a dam could allow investigation into ageing processes as a cross-section of the dam is revealed. Recording the state of the clay core and other observations would be of use in predictions of behaviour of other old embankment dams.

Industrial archaeology and environmental history. Dams are historical features of the landscape, often part of our rich industrial archaeology, and with long lasting effects on fluvial behaviour. Before removal, records including maps, photographs and diagrams, of all the knowledge of the construction and usage of the dam should be deposited in local archives and in specialist libraries. Exposed on the bed may be traces of early settlements which were not fully recorded before the reservoir was filled[1] as well as artifacts thrown into the reservoir or accidentally lost. Consultation with local industrial archaeologists and historians should guide how many features of the breached dam and its structures should be preserved and advice sought on archiving of records. An example of good practice was co-operation of Northumbrian Water with Tees Archaeology and the Cleveland Industrial Archaeology Society in the removing of the Westworth dam built in 1874-75, near Guisborough. Interesting remnants of the structures were preserved and historical records published (Dixon, 1988, Johnson, 2008).

[1] During a low drawdown at Cow Green in Teesdale a Bronze Age Village was excavated.

Sediments. Sediment accumulation in reservoirs is not as problematic in Britain as in most of the US (White et al., 1997), even though rates of accelerated soil erosion in some places have been increasing with changing farming practices. Quality of sediments may be a problem, particularly in the Pennines and the Welsh uplands, where old lead mining may have released pollutants which accumulate in the reservoir sediments (Shotbolt et al., 2006) or where industrial waste waters have fed in to the reservoir. American experience suggests that before discontinuance, sampling of the sediment should be carried out to determine whether or not it should be removed physically before exposure to erosion and transport. Apart from such safety precautions, examination of the newly-accessible sediments in the reservoir allows calculation of rates of accretion and relationships between historical land use changes, soil erosion, pollution transport, algal growth, bacteriology and chemistry of sediments and reservoir water.

Legacy

Public access to reservoirs in England and Wales is the norm. Even those reservoirs supposedly closed to the public may be attractive to trespassers and perhaps even more prone to vandalism and illicit activity (Gardiner et al., 1996). American experience with tragic accidents at sites of former reservoirs left in dangerous states, gives rise to the advice that “Plans for dam removal should account for use of the site by a variety of people long after the dam has been removed” (Baish et al., 2002).

Discontinuance, like dam construction, needs aesthetic consideration to leave a landscape which will improve with time. Nature will soften disturbance caused by engineering work involved in dam breaching but care is needed over the appearance of the remnants left in situ for future generations. Whilst restoration to the pre-dam, natural state may be an unrealistic ambition, leaving a near-permanent blot on the landscape should not be an option, particularly when the site lies in an area of natural beauty.

This issue may be illustrated by the breaching of the Boltby dam and remedial work on the reservoir site completed in 2007 (Walker, 2008). Visitors to the notched Boltby dam in the North York Moors National Park will be faced with a disappointing vision. There is a striking contrast between the carefully-shaped masonry of local stone laid with appealing precision in the preserved remnants of the former dam and recent contributions of jumbled rough blocks captured in gabion wire netting, which is unlikely to last centuries. Boulders of Carboniferous limestone have been intruded rather than use of blocks of local calcareous grit and sandstone. The much lowered reservoir is now surrounded by oozes and mud which makes access to the shores of the pond hazardous and no standing for fishers has been provided. Fishing has not as yet resumed even though some of the fish introduced by the Fishing Club have survived in the remnant pond. The former Fishing Clubhouse fashioned from a hut built for the original 19th Century workmen stands abandoned.

Source: Author.
Figure 1: New overflow channel breaching the dam at Boltby Reservoir, September 2007, showing the contrast between new gabions on the left and old masonry on the right. The steep channel prevents migratory fish from entering the remnant reservoir. The stream has not been restored nor has the landscape been allowed to revert to nature.

<u>Case for a national strategy</u>
Dam removal is not a simple private matter for an individual dam owner because hydrological and ecological interdependencies involve many other stakeholders, both within the river catchment and nationally. The choice of which dam to remove may involve regional study to understand its relationship with other reservoirs and water sources in the region and on downstream flooding. Removal of a reservoir may throw added stress on other water sources whether nearby reservoirs, groundwater or places for recreation. The full ecological benefit of dam removal will be gained only if subsequent responses do not produce negative environmental effects, such as building a new reservoir or flood defence structures elsewhere. Hopes for the removal of dams from particularly pleasing landscapes may require a

regional strategy so that an order of priority can be established. For example, the case for removal of the Hetch Hetchy dam from the stunning Yosemite landscape in California depends on the continuance of other dams in the region to provide alternative water supply. Ad hoc dam removal without wider consideration is unlikely to produce optimal results.

Small-scale, private interests have little incentive to fund removal and landscape restoration to a high standard. Many dams do not generate sufficient income to fund repairs (Hinks and Williams, 2004). Even though the cost of dam breaching maybe much less than cost of dam remediation, unless there is a serious safety incident some dam owners postpone decision-making on the future of their dams and they are abandoned, left as potential hazards littering the landscape. Financial assistance to encourage removal would be a useful lever both to raise standards and to encourage action. In the US, those states with a policy for removing dams, backed by grants, manage to remove the most. Support is justified because some objectives of dam removal such as restoring connectivity in the river, improving habitats, preserving industrial archaeology and improving recreational facilities are for the public good rather than private gain.

A national strategy would be based on long-term considerations and synergy with other national strategies. Climate change forecasts in England and Wales for more extreme weather events with wetter winters and drier summers may support building more reservoirs to even out water supply, if aquifer recharge is not sufficient. Another implication is that existing reservoirs are likely to be increasingly stressed and several will become liabilities. Spillways may become unable to cope with increased storm rainfalls and prolonged droughts may weaken embankment dams. Moves from use of fossil fuels will forfeit an era of cheap energy. As the water supply industry is a major consumer of energy for pumping water, this change will affect decisions about reservoir location, favouring reservoirs which can supply water by gravity. Ageing structures will need to be reassessed and some will be scheduled for removal when the cost of alteration to meet the new conditions exceeds anticipated benefits; others may become more worthy of restoration.

In the US, many early hydroelectric dams have been made redundant following the establishment of regional grids fuelled by cheap power. At the local level, continuation of such HEP supplies could not be justified but at the national level, attempts to meet carbon reduction targets might have justified continuation of such dams. Subsidised refurbishment might be in the national interest, if carbon reduction were given priority.

A national strategy could give due weight to non-economic factors especially merit goods, such as recreation and nature conservation, and priorities could be established after consultation with many stakeholders.

National support and technical advice would have benefits of data sharing. Cost-benefit analyses could be improved to take into account long-term, regional and even international strategies. Research programmes and standardised monitoring could be promoted to maximise scientific understanding of the fluvial and ecological responses to dam removal.

CONCLUSION

Dams are long-lasting even though they may have a limited economic life. Even when dams are removed, they leave lasting impressions on the landscape. American aspirations to remove dams and restore rivers to pre-dam nature with healthy populations of migratory wild fish have yet to inspire many followers overseas. In England and Wales, our romance with many bountiful rivers largely ended with the Industrial Revolution and permissive pollution of estuaries. Rather than enjoying rivers, cities turned their backs with disdain. In recent decades, better water treatment and pollution prevention is bringing back life to many rivers in their lower courses and ambitions for discontinuing dams and restoring connectivity for migratory fish may grow, as in the USA. Many lessons can be learnt from the American experiences in restoring habitats to hand on landscapes fit for future generations.

REFERENCES

Babbit, B. (2002) What goes up, may come down. Learning from our experiences with dam construction in the past can guide and improve dam removal in the future, *BioScience,* Vol.52**,** No.8**,** pp**.** 656-659.

Back, P. (1989) Reassessment of safety of existing dams In *World Bank Seminar on dam safety and environment*.

Baish, S. K., David, S. D. and Graf, W. L. (2002) The complex decisionmaking process for removing dams, *Environment,* Vol 44**,** No.4, pp**.**20-31.

Bednarek, A. (2001) Undamming rivers: a review of the ecological impacts of dam removal, *Environmental Management,* Vol.27**,** No.6**,** pp.803-814.

Bonazzi, D. (1989) Experience of the World Bank in implementation of dam safety. In *World Bank seminar on dam safety and environment*.

Born, S. M., Genskow, K. D., Filbert, T. L., Hernandez-Mora, N., Keefer, M. L. and White, K. A. (1998) Socioeconomic and institutional dimensions of dam removals: the Wisconsin experience., *Environmental Management,* Vol.22**,** No.3, pp.359-370.

Bushaw-Newton, K. L., Hart, D. D., Pizzuto, J. E., Thomson, J. R., Egan, J., Ashley, J. T., Johnson, T. E., Horwitz, R. J., Keeley, M., Lawrence, J., Charles, D., Gatenby, C., Kreeger, D. A., Nightengale, T., Thomas, R. L. and Velinsky, D. J. (2002)An integrative approach towards understanding ecological responses to dam removal: the Manatawny Creek study, *Journal of the American Water Resources Association,* Vol.38**,** No.6, pp.1581-1599.

Dixon, G. (1988) Guisborough's water supply: a century of development, *The Cleveland Industrial Archaeologist,* Vol.19**,** pp**.**1-14.

Doyle, M. W., Stanley, E. H. and Harbor, J. M. (2002)Geomorphic analogies for assessing probable channel response to dam removal, *Journal of the American Water Resources Association.,* Vol.38, No.6

EPA (2002) Responsiveness summary of Hudson River PCBs site record of decision. U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, Washington.

Evans, J. E., Mackey, S. D., Gottgens, J. F. and Gill, W. M. (2000)Lessons from a dam failure, *Ohio Journal of Science,* Vol.100**,** pp.121-131.

FEMA (2002) Federal Emergency Management Agency National Dam Safety Inspection Program.

Gardiner, K., Sellars, P. and Baker, R. (1996) The discontinuance of Brushes Clough reservoir, *Dams and Reservoirs*.Vol.6, No.3, pp.23-28.

Grant, G. (2001) Dam removal: Panacea or Pandora for rivers?, *Hydrological Processes,* Vol.15**,** pp.1531-1532.

Gray, B., Hastings, U. C., Behar, D., Dempsey, H., Good, R. and McDevitt, R. (2006)Hetch Hetchy: To drain or not to drain, *Hastings Law Journal,* Vol. 57**,** pp.1261-1279.

Gregory, S., Li, H. and Li, J. (2002) The conceptual basis for ecological responses to dam removal, *BioScience,* Vol.52, No.8, pp.713-723

Hart, D. D., Johnson, T. E., Bushaw-Newton, K. L., Horwitz, R., Bednarek, A. T., Charles, D. F., Kreeger, D. A. and Velinsky, D. J. (2002)Dam removal: Challenges and opportunities for ecological research and river restoration, *BioScience,* Vol.52, No.8, pp.669-683.

Hinks, J. L. and Williams, P. (2004) Some problems at small dams in the United Kingdom. In *Long-term benefits and performance of dams* (Ed, Hewlett, H.) Thomas Telford, London pp.629-636.

Hope, I. (2006) Working together for the safety of our reservoirs, *Dams and Reservoirs,* Vol.16**,** pp.15-18.

Johnson, P. G. (2008) Archaeological Recording: Westworth Reservoir, North Yorkshire.Tees Archaeology and Northumbrian Water Ltd, Hartlepool, 21 pages

Null, S. E. and Lund, J. R. (2006) Reassembling Hetch Hetchy: Water supply without O'Shaughnessy Dam, *Journal of the American Water Resources Association,* Vol.42**,** No.2**,** pp.395-408.

Orr, C. H., Roth, B., Forshay K.J., Gonzales, J., Papenfus, M. and Wassell, R. (2004) Examination of physical and regulatory variables leading to small dam removal in Wisconsin, *Environmental Management*.

Pacca, S. (2007) Impacts from decommissioning of hydroelectric dams: a life cycle perspective., *Climatic Change,* Vol.84**,** pp.281-294.

Pizzuto, J. E. (2002) Effects of dam removal on river form and process, *BioScience,* Vol.52**,** No.8, pp.683-691.

Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., Sparks, R. E. and Stromberg, J. C. (1997) The natural flow regime, *BioScience,* Vol.47**,** pp.769-784.

Poff, N. L. and Hart, D. D. (2002) How dams vary and why it matters for the emerging science of dam removal, *BioScience,* Vol.52**,** No.8, pp.659-668.

Pohl, M. M. (2002) Bringing down our dams: trends in American dam removal rationales, *Journal of the American Water Resources Association,* Vol.38**,** No.6, pp.1511.

Riggsbee, J., Julian, J., Doyle, M. and Wetzel, R. (2007) Suspended sediment, dissolved organic carbon, and dissolved nitrogen export during the dam removal process, *Water Resources Research. American Geophysical Union, Washington, USA,* Vol.43, No.9, pp. 9414.

Shotbolt, L., Hutchinson, S. M. and Thomas, A. D. (2006) Sediment stratigraphy and heavy metal fluxes to reservoirs in the southern Pennine uplands, UK, *Journal of Paleolimnology,* Vol.35**,** No.2**,** pp.305-322.

Shuman, J. R. (1995) Environmental considerations for assessing dam removal alternatives for river restoration, *Regulated Rivers: Research and Management,* Vol.11**,** pp.249-261.

Stokstad, E. (2006a) Big dams ready for teardown *Science*, Vol. 314, No.5799 pp. 584.

Stokstad, E. (2006b) Environmental restoration: restoring Yosemite's twin, *Science,* Vol.314**,** No.5799, pp.582-584.

Tweit, S. (2006) Tearing down the Elwha River Dam, *Popular Mechanics*.

Walker, J. (2008) The discontinuance of Boltby Reservoir, *Dams and Reservoirs*. Forthcoming.

White, P., Butcher, D. P. and Labadz, J. C. (1997)Reservoir sedimentation and catchment sediment yield in the Strines catchment, U.K., *Physics and Chemistry of The Earth,* Vol.22**,** No. 3/4, pp.321-328.

Whitelaw, E. and Macmullan, E. (2002) A framework for estimating the costs and benefits of dam removal, *BioScience,* Vol.52, No.8, pp.724-730.