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A case for adaptive management in the Wungong Catchment

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ABSTRACT: Over a century of disturbance in Perth's surface water catchments, primarily from forestry and mining, has left young regrowth forests in a less hydrologically productive and markedly changed environmental state. Jarrah regrowth's tough nature means this situation will not self correct on a timescale helpful for our water supplies and some environmental values. Leaving our regrowth forested catchments untouched is unlikely to be the best option. What has the history of catchment management taught us that can guide future management?

Past forest and catchment management was mostly funded from forestry income. Major reductions in the available annual cut and changes in the forestry industry could mean fewer resources for management of forested catchments. Without intervention, regeneration after logging and mining will continue to change the environment and impact negatively on water quantity.

Historically, climate was something considered constant over many decades, but in the south- west of Western Australia multi-decadal steps in the climate are observed. Also under many future climate scenarios, this century is expected to be hotter and drier than last. If forested catchments are not managed for water quantity as well as other values, the result would be a further reduction in catchment runoff. This will negatively impact both the terrestrial and aquatic environment, and the water generated for the community. Catchment management now needs to consider water quantity as well as water quality.

Learning from history, the Water Corporation, as a beneficiary of improved catchment management, is facilitating a 12-year adaptive catchment management trial in the Wungong Catchment near Perth. The trial will include catchment thinning and the gradual conversion of exotic vegetation back to native species, consultation with peak groups, monitoring, research, auditing and public reporting. This will provide a sustainable water source making best use of existing water infrastructure and helping the ecology.

1 INTRODUCTION

Access to a reliable supply of high quality drinking water is vital for any community. Water is essential for life and impacts directly on most aspects of the human and natural world. Catchments that supply this water integrate changes in human activity and natural processes, such as rainfall. In the south-west of Western Australia (WA) catchments are usually forested, and often modified by forestry, mining and farming. They have also been subject to significant changes in climate. As an important source of water for the community, catchments need to be adaptively managed under the current drying climate for water and environmental values.

Catchments are natural systems with multiple land-uses that impact on water quality and quantity, are managed by multiple organisations often having overlapping areas of responsibility, and are surrounded by a community with a range of changing values. In response to changes in these catchment aspects, catchments and their values have changed in the past and will continue to change into the future.

This paper considers the focus of the past management of Integrated Scheme surface water catchments in the light of a changing climate, and aims to provide a solution for their sustainable management. The Integrated Scheme is a public water supply that services one and a half million people in Perth, Mandurah, Harvey and out to Kalgoorlie. As part of adaptive management, a staged approach is often prudent and hence a research trial of new management is a logical step. The location for a trial should be somewhere that is representative of other areas, well understood, in need of improvement, and ideally close to the public and researchers.

2 CLIMATE

Climates vary and change on many spatial and temporal scales due to natural and human induced causes (Bureau of Meteorology, 2003). In the Mediterranean climate of the south-west of WA there are wet winters and dry summers, with considerable rainfall variation between years. This variability between years is overlaid with longer term changes. The summers have become longer and the winters not as wet since 1975. The change around 1975 resulted in a step decrease in rainfall for the south-west corner of WA and occurred in conjunction with significant changes in global atmospheric circulation (IOCI, 2002). This rainfall change is considered to be primarily due to a combination of natural variability and the enhanced greenhouse effect, with possible secondary effects from changes in solar forcing, land-use and air pollution (IOCI, 2002).

After 1975, rainfall reduced 10–12% across the catchments in the south-west of WA and average annual streamflow to the 4460 km^2 of mainly forested Integrated Scheme catchments reduced by 50% for 1975–1996 compared to the wetter 1911–1975 period. Streamflows in the current period, 1997–2003, have reduced by another 30% compared to the 1975–1996 climate due to a further 8% reduction in rainfall (Figure 1 and 2). In total, streamflows for this current period are only a third of those in the middle of last century. Long term decreases in streamflow will have a negative effect on soil moisture, aquatic and terrestrial ecosystems, and water resources.

Looking forward, the projections from climate models combined with hydrological models used on the Stirling Catchment (east of Harvey), show runoff could reduce by 31% for an 11% reduction in rainfall for a case where evapotranspiration is constant (Berti et al., 2004). These changes are projected from a modelled 1990 climate base to 2050 using a medium economic growth emissions scenario (“A2” scenario with 1.7 times current CO_2, IPCC (2001)).

For both surface water and groundwater sources, the water originally comes from a fraction of rainfall. For the Integrated Scheme surface water sources, this fraction ranges from 2% of rainfall for large dry catchments such as Mundaring Catchment north east of Perth (as an annual average based on 1975–2003 hydrology), to 19% for wetter catchments such as Stirling Catchment. The annual average runoff for Integrated Scheme catchments is 6% of rainfall, with the remainder of the rainfall evaporating and transpiring back into the atmosphere. Evaporation and transpiration are controlled by the climate, land-use and vegetation. The relationship between rainfall and runoff is non-linear due to factors such as interception losses, level of catchment moisture before rainfall, timing of rainfall, regolith properties and vegetation structure and dynamics.

From observed trends of increasing temperature, multi-decadal steps in rainfall, and climate modelling of the impact from the enhanced greenhouse effect (Whetton, 2001) – it is highly probable this century will be hotter and drier than the last for the south-west corner of WA. That said there is always uncertainty about the future climate, especially now it is appreciated that it is non-stationary, and so planning is required for a range of climate scenarios. The climate has changed and will continue to change, so catchment management and the community need to be adaptive.

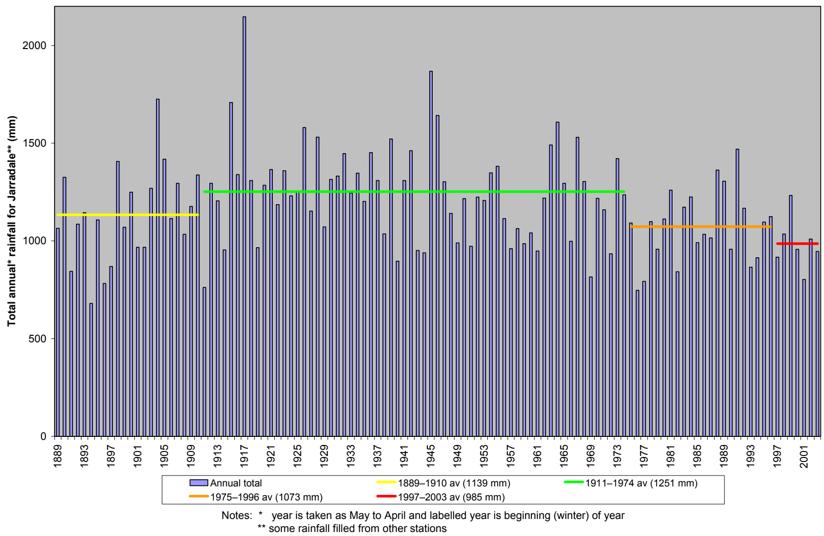

Figure 1. Annual rainfall for Jarrahdale, indicative of Integrated Scheme catchment rainfall (1889–2003)

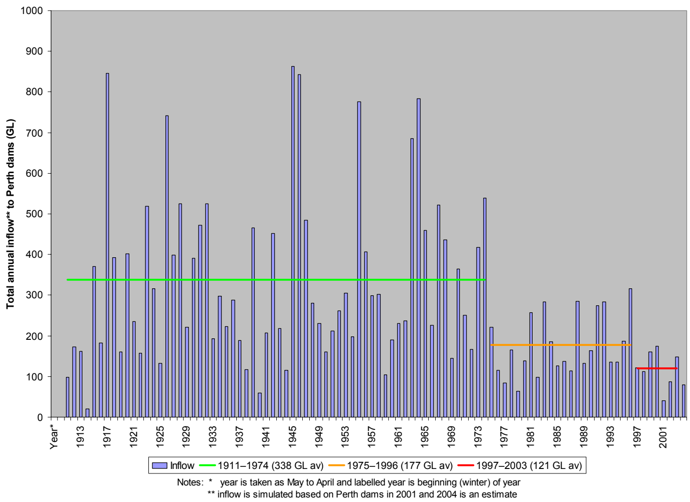

Figure 2. Annual streamflow to Integrated Scheme surface storages showing changes in climate (1911–2004)

3 PAST CATCHMENT MANAGEMENT

The surface water supply system around Perth, that harnesses catchment runoff, is important for the community. Catchment runoff is affected by climate and land-use, both of which are dynamic. Forests have been changed from old growth to regrowth, mining is continuing, and farming has been reduced. Overall, past catchment management has had a water quality focus. With our current drying climate, water quantity needs to be added as a management focus.

3.1 *Water supply*

Like many places in the world, WA uses surface water and groundwater resources for public drinking water supply. The first water for Perth, the capital of WA, came from shallow groundwater and the first artesian well was sunk in 1879. Then followed a surface water focused source development starting with Victoria Dam in 1891. The use of surface water exceeded groundwater in 1925 with the construction of the Wungong pipehead dam (the current large dam replaced the pipehead in 1979) (Hunt, 1980).

Drinking water quality is often put at risk by human interaction with catchments. In 1892, a year after Victoria Dam started supplying Perth, Victoria Dam's catchment was polluted by cattle and residents of the Canning Timber Mills (Hunt, 1980). Due to public outcry, legislation was passed to stop catchment pollution, but it had little effect due mainly to the poor controls on the privately owned water supply company running the dam. In 1896 the dam was bought back by the Government and in 1897 a diversion around the mill was built to stop polluted streamflow entering the storage. Nearby, forestry techniques were used for catchment management, such as the ring barking of trees near Mundaring Weir around 1900 to increase water production, and later in the 1921 Mundaring Working Plan which had water production as the primary objective followed by wood production (Stoneman et al., 1989). These early attempts did not always work for all values.

More successful was the early catchment management undertaken in the Wungong Catchment. The forestry township of Jarrahdale during its earlier years was substantial and required food for workers and their families, as well as the large number of animals used for log-hauling. A number of small farmlets, orchards and market gardens were established, including up to 400 ha within the Wungong Catchment. With the establishment of the Wungong pipehead dam on the Wungong Brook in 1925 there were concerns with sources of potential pollution, and these small blocks were progressively purchased or resumed and then reforested. By the mid 1950s all farming activities within the Wungong Catchment had ceased. In the Mundaring Catchment salinity problems were tackled with farm buying, tree replanting and regeneration of bush. In 1976 clearing controls were established to help reduce the dryland salinity problem, after experiment work in the Wellington Catchment (Loh, 1988; WAWA, 1989). At this point there were few people in the catchments, abundant water and a reliance on surface water over groundwater.

Drinking water quality has improved vastly since the late nineteenth century when there was a typhoid epidemic, which peaked in 1897 when there were 1408 cases and 134 deaths (Hunt, 1980). Although the community now has some aesthetic water quality issues, they assume correctly that the tap water is always safe to drink. This is primarily because of water source protection planning and enforcement that actively discourages practices that have water quality risks within drinking water catchments and groundwater recharge areas. But problems still occur in the Western world when there is complacency, such as Walkerton Ontario in May 2000 and North Battleford Saskatchewan in April 2001. In these cases there were failures in catchment to tap drinking water protection and people became sick (6500 in North Battleford from a 15 000 population) and some died (7 in Walkerton from a 5000 population) (Hrudey and Hrudey, 2002). The "catchment to tap" approach to drinking water management has been adopted within Australia after the Sydney cryptosporidium scare in 1998. This approach manages water quality risk with many points of control (multiple barriers) and acknowledges a single water quality control (e.g. water treatment) is not enough to reduce risk to acceptable levels (NHMRC & ARMCANZ, 1996). There is clear evidence that allowing human contact with reservoirs will significantly decrease water quality (Stewart et al., 2002). Catchment to tap water quality management with multiple barriers is critical and ensures the community has safe drinking water.

In the mid 1970s the proportion of groundwater sources increased as rainfall decreased. Also the unit cost of developing water sources increased as water was taken from greater distances, and there was more environmental and recreation pressure. In 1977–78 there was a 14 month total sprinkler ban due to a drought and pay for use water was introduced. The community responded by reducing per capita water usage and sinking domestic garden bores. Water quantity had become an issue along with water quality. In 1996 the Water Corporation formally reduced the expected water yields to reflect the drier post-1975 climate. Following the derating there was a large program of source development. This program, costing $678 million to date, has doubled water source capacity in a decade recovering the reliability lost through the shift to a drier climate in 1975. With current demand the Integrated Scheme has just over half its water supplied by groundwater and the remainder by surface water. The response to a drying shift in climate was a reduction in demand and development of new sources. In the overall development of the Integrated Scheme there has been a significant investment in infrastructure, with the dams now having an asset value of $700 million – but all currently have low storages.

By 2006, seawater desalination will be added to the mix of sources in response to a further reduction in system capacity due to a decrease in streamflow from 1997, changing levels of service and pressure on groundwater resources. The balance between water supply and customer demand is maintained by managing demand, water trading, reusing wastewater for industry and developing new water sources when required. The approach is to provide security through diversity.

Not all new sources of water involve building new infrastructure. Catchment management that includes catchment thinning is such a water source, and involves removal of selected trees to allow more runoff (this thinning is usually non-commercial). It has been researched at a small catchment scale, included in Perth's Water Future (WAWA, 1995) and is part of the "A State Water Strategy" (WA Government, 2003). Except for ring barking near Mundaring Weir and small experimental research catchments through the 1980s and 1990s on 60–100 ha sub-catchments, there has been no active management of Integrated Scheme catchments specifically to increase runoff.

Management of the majority of land that covers Integrated Scheme catchments is implemented by the Department of Conservation and Land Management (CALM) under policy set by the Conservation Commission of WA. Important parts of land management have included conservation, timber products, mining rehabilitation and fire. All of which can have a large impact on water, in particular water quantity.

3.2 *Forestry*

Data obtained from CALM show that most of the areas that are now harnessed catchment were first logged well before 1920, with few if any controls, as the Forests Department was not established until 1919. CALM records show that large areas within the 12 845 ha Wungong Catchment were further cut-over under tree-marking during 1930–49 (10 600 ha) and 1970–89 (7200 ha). Overall, 9% of this catchment area has been cut over once, 26% twice, 57% three times and 6% four times.

Logging is normally followed by growth in the canopy of the retained stems and by regeneration of the eucalypts and understorey species. The initial effects of logging on increasing water yield are therefore likely to be transient (Stoneman et al., 1989). However, the longer term effects when old-growth stands are replaced by dense regrowth stands are likely to be considerable. Unlike the *Eucalyptus diversicolor* (karri), without intervention the *E. marginata subsp. marginata* (jarrah) and *Corymbia calophylla* (marri) regrowth, that dominates the Integrated Scheme catchments, will remain locked up as dense pole stands for many years. If it survived at all it would probably take 300 years to grow from 20 to 50 cm diameter (Stoneman et al., 1989).

Data from eucalypt forests in New South Wales (Roberts et al., 2000) indicate that reductions in water yield that averaged 30% were recorded for *E. sieberi* regrowth stands aged between 8 and 20 years compared to the previous mature stands. Similar studies in Victoria with 20- to 40-years-old regrowth of *E. regnans* showed a reduction in water yield of between 50% and 60%. Correspondingly, research in WA has shown that thinning of regrowth stands can substantially increase water yield (Stoneman et al., 1989; Bari and Ruprecht, 2003). A mature forest or a thinned regrowth forest allows greater catchment runoff than a regrowth forest without active management.

Thinning of forests has been carried out for many years by foresters to improve crop tree growth. Also potential habitat trees would reach a size suitable for producing habitat hollows much earlier if selected surrounding trees where thinned. While forest management has considered water quality and quantity in the 1920s then again from the 1970s to present (Lee and Abbott, 2004), thinning is not being specially targeted within harnessed catchments.

Forest management planning in the 1980s used a range of variables, such as rainfall and landform, to demarcate zones for priority uses (Forest Department of Western Australia, 1980). In theory this planning approach gave a priority to each area and described compatible and incompatible activities. For example, the higher rainfall zone within harnessed catchments had a water production priority with forestry as being compatible, but regeneration of dense forest or water polluting land-uses as incompatible. In the 1990s forest management moved to multiple use planning with no overt priority. As in the past, the actual priority was timber production as this was the core business of those responsible for implementing the plans. The current Forest Management Plan 2004–2013 (Conservation Commission, 2004) continues the multiple use planning approach, now with an emphasis on conservation. This plan recognises thinning as a catchment management tool to achieve water production outcomes and allows the land manager, CALM, to work with water agencies to develop proposals these agencies may have for catchment management. It also allows for adaptive management trials.

3.3 *Fire*

Traditional owners of the land, the aboriginal people, used and travelled across the catchments before they were dammed. This would have included hunting and a form of fire-stick burning practice (Hallam, 1975; Pearce, 1989).

The Forests Department introduced fire protection measures in State forests, initially practising a policy of fire exclusion, then, when this failed by dividing the forest into 200–400 ha compartments surrounded by firebreaks between 100–200 m wide strips that were burnt frequently (McCaw and Burrows, 1989). A change in policy was introduced in 1954 that involved the introduction of widespread prescribed burning to provide for hazard reduction by removing ground fuels (McCaw and Burrows, 1989). More recently, there has been a reduction in prescribed burning as a result of various factors. Fire management has become increasingly more complex with a changing climate, community concerns over smoke, and management objectives covering biodiversity, fire risk reduction and asset protection.

Positive effect of prescribed fire on increasing water yield is likely to be transient as the canopy and understorey recover – in the order of two years. However, large wild fires can have a dramatic effect on water yield, with major negative impacts on water quality and the ecology. McArthur (1964) notes that there was a 72% increase in the yield from the North Dandalup Catchment in the 1961 winter, following the devastating Dwellingup fire the previous summer that completely burnt the 15 000 ha catchment. By 1962 the flow was recorded as “very nearly normal”.

The impact of wild fires within Canberra’s drinking water catchments in January 2003 was dramatic. There was water quality deterioration from silt and ash that impacted the ecology and water supply, prompting the need to build a water treatment plant. It is clear that water needs to be included in fire management planning to obtain sustainable water quality and quantity outcomes.

3.4 *Mining*

Mining for bauxite commenced in the south-west of WA near Jarrahdale in 1963 and extended into the Wungong Catchment by the late 1960s (Bartle and Slessar, 1989). It then continued within the catchment until 1998, with a total of approximately 2500 ha mined and rehabilitated within the Wungong Catchment and approximately 7000 ha overall within all Integrated Scheme catchments (growing at 500 ha/a). The State was originally responsible for rehabilitation and the initial techniques were very basic. As expected, over a period spanning three decades these procedures improved substantially (Bartle and Slessar, 1989). Later the responsibility for rehabilitation rested with Alcoa, which has been recognised with several State and international environmental awards.

Clearing of forest for mining substantially increases water yield for some years (Schofield et al., 1989). Extensive monitoring of water quality over many years showed no significant increases in salinity and no major events where acceptable levels for turbidity were seriously exceeded. The rehabilitated stands are progressing with little evidence of self thinning (Ward and Koch, 1995) and some are upwards of 25 years of age. These dense stands of regrowth have the potential to reduce water yield significantly, possibly even below the original yield from native regrowth forests. Management practices and thinning may also provide an opportunity to rehabilitate areas that were originally planted to exotics with species that are native to these sites.

4 COMMUNITY EXPECTATIONS

The community benefits from catchments directly and more often indirectly through catchment products. The community also influences catchment management outcomes. Community values and expectations have changed over time. The community now requires greater involvement in decision making and expects more environmentally focused solutions. In particular the community has had concerns with forests, catchment management and biodiversity. "Green politics" is now almost main stream and good environmental policies are essential for political and other organisations. Building on the campaign to stop the damming of the Franklin River in Tasmania in 1983, some politicians were being elected primarily for their strong environmental policies. In WA the Gallop Government was elected in 2001 in part due to its policies on the creation of many additional National Parks and setting a direction of reducing the annual volume of timber cut. Forests and their management evoke strong community views. The forest management policy trend is to reduce the volume of native timber cut annually and to increase the area of land held without active silviculture, mining or water development within reserves.

Recently there has been a specialisation of organisations related to forestry, the environment and water (eg. splitting the Water Authority of Western Australia into the Water and Rivers Commission and Water Corporation in 1996; and splitting CALM into **C**ALM and Forest Products Commission in 2000). This has resulted in a more transparent resolution of issues and included the community in decision making. However, more specialization combined with additional regulation of these industries has reduced the opportunities for creating optimum solutions for multiple values.

Public debate on water supply, sanitation and public input to catchment management, has been ongoing since WA was settled by Europeans (Hunt, 1980). In WA because the community is now comfortable with the quality of drinking water, their focus is on the reliability of the supply. Low rainfall from 1997 across southern Australia, and in particular from 2001–2004 for the south-west of WA, has focused community attention on the need to conserve water and on the impact climate has on our water supply. The community has coped with the current two-day per week sprinkler regime (2001–2004), but this has raised questions in their minds about a drier future climate which are more unsettling than the inconvenience of having to change their water reticulation systems.

Most of the surface water catchments near Perth have been harnessed. Only the Murray River Catchment remains undammed, with no plans for it to be dammed. Also Australia has an aging population with more time for recreation. The combination of wanting more recreation but having less land available, means there is more environmental pressure on areas outside drinking water catchments (ie. downstream of dams and in other areas) and more pressure to allow recreation within drinking water catchment – which would increase the risk of water quality problems.

5 DISCUSSION

Through the history of the Integrated Scheme's surface water catchments there has been limited active management for water, although other historical land management practices not contained specifically to catchments, such as forestry, have had a large impact on water quantity. Where there has been active management it has focused on water quality, such as the criteria for mining rehabilitation. While there will be pressures in the future on water quality, such as from recreation, there are potentially more risks from reduced water quantity. The largest impact on water quantity has been, and will continue to be from a drying climate – compounded by the harnessed catchments being covered by a regrowth forest, that use more water than a mature forest.

Overstocking and less rainfall reduces the access to water for individual trees. There is also an emphasis in the Forest Management Plan on minimising more intensive management. A forest with reduced access to water will become stressed, more susceptible to disease and parasites, and can collapse. The current crown decline of *E. Wandoo* (wandoo) and *E. gomphocephala* (tuart) is testament to environmentally stressed forests. It is not unreasonable to expect the jarrah forest to eventually alter, decline or collapse under a severe drying climate if left in an over dense state.

Past forestry practices have made the largest change in the water balance of catchments with the conversion of the forest structure from old growth to regrowth. Continued silviculture within the northern jarrah forest, such as thinning, can help move the forest towards a more mature forest faster than a reliance on nature alone. However, with the reduction to the forest industry, funding for forest management activities is also reducing. Hence, an alternative funding source is required.

In the orderly development of water sources for WA, catchment thinning should occur on its merits as a low cost long-term water source that can benefit the environment. Given the community sensitivity to forest management and a regulatory emphasis on conservation without active intervention, catchment thinning could take many years to implement. In the interim, more expensive and potentially less environmentally attractive water sources may need to be considered. The observed impact of climate change on the environment and water systems has put catchment thinning back on the discussion table. With a drying climate and reducing streamflows, it is clear the ecosystem will suffer, in particular the stream ecology, unless something is actively done.

Improving the runoff efficiency of existing harnessed catchments is low in cost compared to most other demand and supply management options, and some of the savings would be used to improve catchment management. It is reasonable the beneficiary should prompt change. As a key beneficiary of increased water source reliability, the Water Corporation is facilitating and proposing to fund improved catchment management.

The fact that the catchments are now vegetated by a dense regrowth forest provides an opportunity. The Water Corporation believes that the best state for these forests from an environmental, aesthetic, social and water perspective is for a more open, diverse and mature structure. If the forests within these catchments were currently at this "ideal" state there would now be limited incentive to change them. To some proponents of minimal forest management, a "no action" approach may seem a more desirable alternative within the Integrated System water supply catchments. As attractive as this approach may seem, it may not deliver outcomes that are optimal for biodiversity conservation, water and forest management.

6 RECOMMENDATIONS - WUNGONG CATCHMENT MANAGEMENT PROPOSAL

The recommendation is to improve the efficiency of our existing surface water sources through catchment thinning and prescribed burning as part of catchment management. This includes the removal of selected trees from dense native regrowth and rehabilitated stands and fire protection. As the extra water recovered from the catchment is achieved very efficiently, the costs associated with this proposed forest management can be sustained from the value of the recovered water. Forests and water are part of the same system and need to be managed together.

Research in the past has provided understanding about the streamflow increases from thinning (Bari and Ruprecht, 2003), but there is more uncertainty about environmental impacts. There will always be some uncertainty and a staged approach is prudent. The Wungong Catchment is an ideal trial location given the good understanding about this catchment, the level of dense regrowth and rehabilitation (20% cleared and replanted, and most areas logged three times), the dam supplies customers by gravity with minimal energy requirements, and it is close to Perth.

The Water Corporation's plan is to implement a 12-year research trial to test the hypothesis that the proposed catchment management of the Wungong Catchment is sustainable and has positive environmental, social and water quality and quantity outcomes. The trial would involve on ground activities being managed in an adaptive framework. The proposal contains a package of catchment thinning, staged conversion of exotic species to natives, water and environmental monitoring, integrated multi-disciplinary research, third party auditing, transparent reporting, consultation with peak groups, and projects for additional environmental benefit.

A whole of catchment approach is required in order to preserve the integrity of the trial. Some areas will be untreated (as reserves, fauna habitat zones, experimental controls or areas that already have an appropriate density and structure), and the 7800 ha planned for thinning as a mosaic over 4–6 years (to a basal area of 15–18 m^2/ha, in stages if required) will be within mining rehabilitation (native and exotic vegetation), plantations and dense native regrowth forest. It is anticipated that the trial would provide on average an additional 6 GL annually (GL is a gigalitre or million kilolitres) at a unit cost of $0.23/kL (kL is a kilolitre or a thousand litres) with approximately zero net greenhouse emissions. The annual Wungong streamflow for 1975–1996 has been 20 GL and for 1997–2003 only 14 GL, a major reduction from the 1911–1974 average of 29 GL. Assuming the trial is successful, other high rainfall areas within the Integrated Scheme catchments could be treated at a sub-catchment scale to help move the forest structure towards a mature state. Within 20 to 30 years catchment thinning could annually provide 40 GL of extra streamflow at less than $0.20/kL. For comparison consumers are charged approximately $0.80/kL for water from the Integrated Scheme (including both consumptive and fixed costs) and the 45 GL south-west Yarragadee groundwater source and 45 GL seawater desalination water source are costed at $0.85/kL and $1.11/kL respectively (all costs are in Australian 2004 present value dollars, with values including both capital and operating components).

7 CONCLUSIONS

Good management, good science and good communication are the building blocks of a successful adaptive management trial. To ensure the community and regulators make informed decisions about the trial, they need to be brought along on the journey.

While management of catchments in the south-west of WA is complex and contentious, when the catchments are harnessed there are opportunities for using part of the value of water produced for their management. Catchments integrate natural processes and human activities, similarly their management needs an integrated approach. Because there is no one organisation responsible for all aspects of catchments, the Water Corporation is in a position to facilitate and fund improved catchment management through benefits derived from improve catchment water yields.

Because the Integrated Scheme catchments are vegetated by dense regrowth forest and the climate is drying there is an opportunity to link forest and water management through catchment management. Progressing the Wungong Catchment management trial is the opportunity to determine whether it is sustainable catchment management. The potential benefits are shown in Figure 3. There is always uncertainty with any change to management as there is uncertainty about the future of our climate. Given the drying climate and its impact on the water cycle it would be precautionary to develop knowledge as early as possible with appropriate research about options for the future management of our forested harnessed catchments.

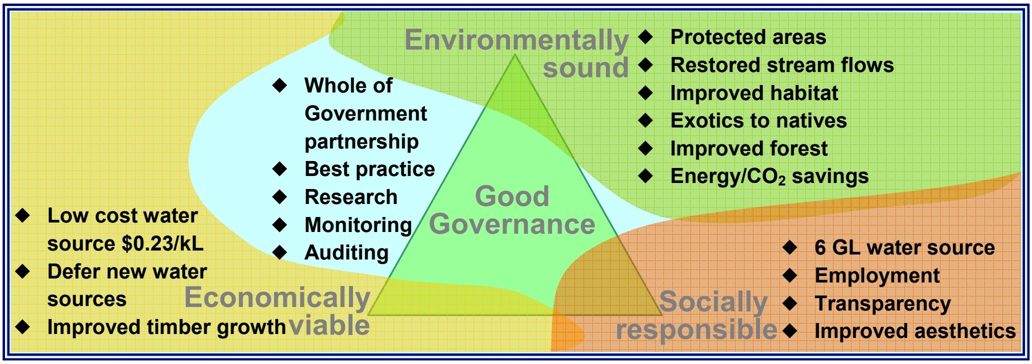

Figure 3. Benefits of Wungong Catchment management research trial

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REFERENCES

Bari, M.A. & Ruprecht, J.K. 2003. *Water Yield Response to Land-use Change in South-West Western Australian*. Salinity and Land-use Impacts Series Report No. 31. Perth: Department of Environment.
Bartle, J. & Slessar, G.C. 1989. Mining and rehabilitation. *The jarrah forest – A complex Mediterranean ecosystem*. Dordrecht: Kluwer Academic Publishers: 357–377.
Berti, M.L., Bari, M.A., Charles, S.P. & Hauck, E.J. 2004. *Climate Change, Catchment Runoff and Risks to Water Supply in the South-West of Western Australia*. Perth: Department of Environment.
Bureau of Meteorology. 2003. *The Greenhouse Effect and Climate Change*. Online at http://www.bom.gov.au/climate/ Melbourne: Bureau of Meteorology.
Conservation Commission. 2004. *Forest Management Plan 2004–2013*. Perth: Conservation Commission
Forest Department of Western Australia. 1980. *Land-use management Plan Northern Jarrah Forest. Management Priority Areas*. Perth: Forest Department.
Hallam, S.J. 1975. Fire and heart. *A study of Aboriginal usage and European usurpation in south-western Australia.* Canberra: Australian institute of Aboriginal Studies.
Hrudey, S.E. & Hrudey, E.J. 2002. Walkerton and North Battleford – Key Lessons for Public Health Professionals. *Canadian Journal of Public Health.* 93(5): 232–233.
Hunt, S-J. 1980. (ed.) Morony, F.B. *Water the abiding challenge*. Perth: Metropolitan Water Board
IOCI (Indian Ocean Climate Initiative). 2002. (ed.) Nicholls, N. *Climate variability and change in south west Western Australia.* Online at http://www.ioci.org.au/ Perth: Department of Environment.
IPCC (Intergovernmental Panel on Climate Change). 2001. (ed.) McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., & White, K.S. *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change.* Cambridge and New York: Cambridge University Press.
Lee, K.M. & Abbott, I. 2004. Precautionary forest management: a case study from Western Australian legislation, policies, management plans, codes of practice and manuals for the period 1919–1999. *Aust. For.* 67 (2): 114–121.
Loh. I.C. 1988. *The History of Catchment and Reservoir Management on Wellington Reservoir Catchment, Western Australia*. Report No. WS 35. Perth: Water Authority of Western Australia.
McArthur, A. 1964. Streamflow characteristics of forested catchments. *Aust. For*. 25 (1): 106–122.
McCaw, W.L. & Burrows, N.D. 1989. Fire management. *The jarrah forest – A complex Mediterranean ecosystem.* Dordrecht: Kluwer Academic Publishers: 317–334.
NHMRC & ARMCANZ. 1996. *Australian Drinking Water Guidelines.* National Health & Medical Research Council and Agriculture & Resource Management Council of Australia and New Zealand.
Pearce, R.H. 1989. Pre-colonial usage of the jarrah forest by indigenous people. *The jarrah forest – A complex Mediterranean ecosystem.* Dordrecht: Kluwer Academic Publishers: 219–228.
Roberts, S., Vertessy, R., Grayson, R., Bren, L., & Cornish, P. 2000. Water Yield in Eucalyptus sieberi Forests. *Institution of Engineers, Australia's 3rd International Hydrology and Water Resources Symposium (Hydro 2000) in Perth 20–23 November 2000*. Canberra: Engineers Australia.
Schofield, J.J., Stoneman, G.L. & Loh, I.C. 1989. Hydrology of the jarrah forest. *The jarrah forest – A complex Mediterranean ecosystem.* Dordrecht: Kluwer Academic Publishers: 179–201.
Stewart, M.H., Yates, M.V., Gerba, C.P., Rose, J.B., de Leon, R. & Wolfe, R.L. 2002. Predicted Public Health Consequences of Body-contact Recreation on a Potable Water Reservoir. *Journal AWWA.* 94 (5):84–97
Stoneman, G.L., Bradshaw, F.J. & Christensen, P. 1989. Silviculture. *The jarrah forest – A complex Mediterranean ecosystem.* Dordrecht: Kluwer Academic Publishers: 335–355.
WA (Western Australian) Government. 2003. A State Water Strategy for Western Australia. Online at http://www.ourwaterfuture.com.au/community/statewaterstrategy.asp Perth: State Government of WA.
Ward, S.C. & Koch J.M. 1995. Early growth of jarrah (Eucalyptus marginata Donn ex Smith) on rehabilitated bauxite mines in south western Australia. *Aust. For.* (58): 65–71.

WAWA (Water Authority of Western Australia). 1989. *Stream Salinity and its Reclamation in South-West Western Australia*. Report No. WS 52. Perth: Water Authority of Western Australia

WAWA (Water Authority of Western Australia). 1995. *Perth's Water Future – a water supply strategy for Perth and Mandurah to 2021*. Perth: Water Authority of Western Australia.

Whetton, P. 2001. *Climate Change projects for Australia.* Online at http://www.dar.csiro.au/publications/projections2001.pdf Aspendale: CSIRO Atmospheric Research.