EVALUATING THE EFFECTS OF FIRE AND OTHER CATASTROPHIC EVENTS ON SEDIMENT AND NUTRIENT TRANSFER WITHIN SCA SPECIAL AREAS

Technical Report 4: Research outcomes and implications for the Sydney Catchment Authority

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February 2007

SYDNEY CATCHMENT AUTHORITY - MACQUARIE UNIVERSITY COLLABORATIVE RESEARCH PROJECT
EXECUTIVE SUMMARY

This report is the fourth and final resulting from a 3-year collaborative research project entitled *Evaluating the effects of fire and other catastrophic events on sediment and nutrient transfer within SCA Special Areas*. The project aimed to provide three main deliverables:

1. An understanding of the conditions leading to large scale (extreme) erosion and sedimentation events within SCA special areas with particular emphasis on wildfire;
2. Assessment of the likely impacts of extreme erosion events on water quality and quantity; and,
3. Knowledge of the implications for water management should an event occur within the lifetime of a major water supply reservoir, particularly Lake Burragorang.

As with most projects, these were further refined over time in light of new data and changing priorities within the SCA, but in retrospect the final outcomes still essentially reflect the proposal put forward to the SCA in 2003.

This report provides a summary of the outcomes and implications for the SCA, as well as management recommendations where appropriate. Technical Reports 1 to 3 provide details on methods, results and analysis so for further information the reader is directed to those.
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Cover: Lower Nattai valley with Lake Burragorang in the distance.
1. SUMMARY OF OUTCOMES

From the outset of the project it was recognized that the major outcomes for the SCA would be to assist planning and risk management through (i) an understanding of the scale, mechanisms and triggers of extreme erosion-sedimentation events, (ii) an assessment of the likely return periods of those events and (iii) knowledge of the impacts of those events on water quality and quantity within the Special Areas. That is, this project would provide information upon which the SCA could make management decisions, including development of contingency arrangements should an extreme erosion-sedimentation event(s) occur around the foreshores or within tributary catchments during the lifetime of the water supply reservoirs. It must be advocated that little can be done to prevent or stop extreme natural events from occurring. Rather, it is the response by appropriate managers to such events that is critical to reducing the impacts on water quality and quantity. Hence this project makes a significant contribution to baseline knowledge and understanding of catchment processes which can feed into those response plans and actions. A summary of the main project outcomes with respect to the project aims (listed in the introduction to this volume) is presented below, followed by a hazard-risk assessment. Full details can be found in the previous Technical Reports.

Landforms formed by extreme erosion-sedimentation events (Aim 1)

- Landforms formed by extreme erosion-sedimentation events have been found to occur within SCA Special Areas.
- The areas most affected include the hillslopes extending along the foreshores of Lake Burragorang and major tributaries where the rivers have incised below the resistant Hawkesbury Sandstone and into the weaker interbedded sandstones, shales and claystones of the Triassic Narrabeen Group and fluvio-glacial sediments of the Permian Illawarra Coal Measures and Berry Formation, leading to substantial valley widening.
  - The primary controls are depth of incision relative to the sequence of the Sydney Basin geology.
  - The dominant erosional processes are large scale rotational slumping within the Permian bedrock, landsliding (rock avalanching) through collapse of the valley sides, debris flows within drainage lines on hillslopes and rock falls from cliffs formed within the Hawkesbury sandstone.
  - Large volumes of sediment are stored on the slopes and valley floor or input directly into the river systems and transported downstream.
- Upland swamps on the Woronora Plateau also show evidence of event based erosion via the formation of scour pools in the surface which can become progressively channelised to form continuous gullies dissecting the swamps.
  - The controls on formation of the scour pools are still unknown.
  - Once the scour pools are formed, the dominant erosional processes are knickpoint retreat (through oversteepening in the swamp surface or channel bed) linking the scour pools to form a continuous gully and, undercutting and collapse of the gully sidewalls leading to widening.
  - Sediment generated through gully erosion is deposited on the swamp surface downstream as a sand splay or transported beyond the swamp.

The potential for an extreme event to occur within SCA Special Areas (Aim 2)

- Extreme erosion-sedimentation events could occur within SCA Special Areas under the present conditions.
  - Preliminary radiocarbon dating of charcoal within debris flow deposits along Blue Gum Creek and, within cut and fill channels preserved in upland swamps revealed Holocene ages (i.e. the last 10,000 years).
The dominant processes operating throughout the Holocene are likely to continue to the present under a similar climate and vegetation cover.

Recent erosion events include small rock falls in the lower Nattai valley, landslides along the foreshores of Lake Burragorang (related to underground coal mining) and gully erosion of several swamps on the Woronora Plateau.

- There are also several very large pre-European landslides located around the foreshores of Lake Burragorang including the Tumbledown Landslide in the Nattai catchment. The precise age of the landslides and timing of rotational slumping at the Tumbledown Landslide is unknown.

The triggers of extreme erosion-sedimentation events (Aim 3)

- The triggers of extreme events fall into three categories:
  - Geological: earthquakes (magnitude > 6) and intrinsic thresholds
  - Meteorological: severe wildfires, extreme rainfall and catastrophic floods
  - Human induced: mine subsidence and catchment clearing

- With the exception of intrinsic thresholds, all are caused by external factors. Intrinsic thresholds are determined by the internal forces within a landform and are related to sedimentology, lithology, hydrology and weathering.

- Extreme rainfall includes severe thunderstorms with rainfall intensities of > 100 mm hr⁻¹ and heavy rainfall events caused by east coast cyclones (and occasionally tropical cyclones that move down into the mid-latitudes) which produce widespread catchment rainfall of > 60 mm day⁻¹.

- Catastrophic floods have a discharge which is at least ten times greater than the mean annual flood discharge (Erskine and Saynor, 1996)¹.

- Extreme erosion can result from:
  - A single trigger, which occurs in isolation;
  - Multiple triggers, where more than one trigger could lead to an extreme erosion event; and,
  - The coupling of triggers, where one follows another, or occurs at the same time as another (concurrently), or leads to another.

- Table 1. outlines the relevant geological and meteorological triggers of extreme erosion events on hillslopes and upland swamps. These triggers are often widespread and can affect large areas within the SCA Special Areas.

  - Severe wildfires rarely act as a single trigger of extreme erosion. Instead extreme erosion results when fires are coupled with extreme rainfall (high intensity thunderstorms or continuous heavy rainfall) leading to sediment detachment and transport via runoff.

  - Extreme rainfall is the most common trigger of extreme erosion and can lead to rainsplash erosion, slope wash (sheet erosion, rilling, gullying) and debris flows. Extreme rainfall can also be coupled with fire, floods, and intrinsic thresholds.

  - Catastrophic floods result from heavy rainfall events and can trigger debris flows along tributary drainage lines, as well as rotational slumping in colluvial material or the Permian bedrock situated in the valley floor adjacent to the stream channel (through trimming of the toe).

  - Large magnitude earthquakes can trigger rock falls and rock avalanching especially where slopes are at or close to limits of stability.

Breach of intrinsic thresholds can trigger rock falls. In most other cases, extreme erosion events result from intrinsic thresholds being coupled with an external trigger.

- Human induced triggers are usually localised within SCA Special Areas, and therefore should be considered where appropriate.
  - Extreme rainfall coupled with intrinsic thresholds can trigger gullying within upland swamps, although dewatering through mine subsidence and severe wildfires may increase the sensitivity of swamps to those triggers.
  - Catchment clearing coupled with extreme rainfall can lead to severe rainsplash erosion and slope wash.

Table 1. Geological and meteorological triggers of extreme erosion-sedimentation events within SCA Special Areas

<table>
<thead>
<tr>
<th>TRIGGER</th>
<th>Type of extreme erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Severe wildfire</td>
</tr>
<tr>
<td>Hillslopes</td>
<td>Rainsplash</td>
</tr>
<tr>
<td></td>
<td>Slope wash</td>
</tr>
<tr>
<td></td>
<td>Debris flows</td>
</tr>
<tr>
<td></td>
<td>Rock fall</td>
</tr>
<tr>
<td></td>
<td>Rock avalanche</td>
</tr>
<tr>
<td></td>
<td>Rotational slump</td>
</tr>
<tr>
<td>Upland swamps</td>
<td>Gullying</td>
</tr>
</tbody>
</table>

Recurrence intervals of triggers and extreme events (Aim 4)

- The estimated average recurrence intervals (ARI) of triggers are as follows:
  - Severe widespread wildfire: 33 years (based on the 1968 and 2001-02 wildfires in the Nattai catchment)
  - Extreme rainfall: 1–15 years (based on rainfall records from eight gauges across the Nattai catchment and three gauges on the Woronora Plateau)
  - Catastrophic floods: > 20 years (based on catastrophic floods identified from discharge records in the Nattai River)
  - Large magnitude earthquakes: > 1200 years (Berryman and Stirling, 2003)².

- Where the coupling of external triggers is important, the frequency of extreme events is decreased since the chance of triggers occurring concurrently or in tandem is less than the recurrence interval of each trigger.
- The coupling of triggers however, is likely to increase the magnitude and impact of an extreme event.
- The coupling of intrinsic thresholds with an external trigger(s) may increase the frequency of an extreme event, especially where landforms are at or close to critical limits.
- Recurrence intervals of triggers give only an indication of the chance of an extreme event occurring each year. This does not preclude an event from occurring in any year. The

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likelihood of an extreme event(s) occurring within the next 20–50 years which is relevant to management timeframes is as follows:

- Extremely likely: rainsplash and slope wash resulting from severe wildfires coupled with extreme rainfall (thunderstorms), rock falls from cliffs and gullying through swamps (these have all occurred within the last three years).
- Likely: debris flows under extreme rainfall and flooding, and slope wash and significant post-fire erosion resulting from severe wildfires coupled with heavy rainfall.
- Less likely: rock avalanching and rotational slumping triggered by earthquakes.

Impacts of event-triggered sediment loads on water quality and quantity (Aim 5)

- Rainsplash and slope wash on hillslopes, particularly after fires and extreme rainfall can result in considerable input of organics and fine sediment into the stream network.
  - The organics, mostly charcoal and leaf litter form floating load which can accumulate on the surface of the reservoirs.
  - Fine sediment including clays, silt and fine organic particles are transported as suspended load in the water column, and can have significant impacts on the chemical and physical properties including turbidity, dissolved oxygen and nutrient levels (nitrogen and phosphorus).
- Debris flows can result in considerable input of coarse and fine sediment into the stream network especially if events are widespread within a catchment. This happened in Victoria following wildfires in 2003.
  - The coarse sediment can smother the channel bed and in worst cases form sand slugs which slowly migrate downstream.
  - Debris flows can also impact on water quantity through damming of river flows. This scenario eventuates where a large debris flow from a steeper tributary stream rapidly looses momentum upon the abrupt change in slope at the trunk stream.
  - The finer sediment is often winnowed out under flood conditions, leaving a coarser lag. The sediment lag can take several large flood events to be mobilised (rolled along the bed) or may remain for extended periods forming bed controls within the stream and trapping further sediment.
- The immediate impacts of rock falls are likely to be minor given that few seem to reach the stream network directly. However, the accumulation of rock fall material can produce thick deposits on the lower slopes and valley floor which can result in later slope failures through breach of intrinsic thresholds.
- The impacts of rotational slumping and rock avalanching are likely to vary depending on the size and location of the failure.
  - The most significant effects would result from large-scale slumping and avalanching along the foreshores of Lake Burragorang. These would impact on the reservoir through displacement of water which may possibly trigger a series of waves, as well as provide significant inputs of coarse and fine sediment which would affect water quality (particularly turbidity and suspended solids) and in some instances decrease dam capacity. The impact of a wave(s) through the main reservoir and along the gorge to the Warragamba dam wall is unknown.
  - If a failure occurred along a main tributary such as the Nattai River, flow may become temporarily or permanently dammed with serious implications for reservoir inflows.
- The impacts of gullying through upland swamps are usually localized but significant.
  - The gully removes a small slice of sediment which can be transported through the channel downstream or deposited as a sand splay on the swamp surface.
  - Dewatering of the swamp through lowered base levels results in fundamental changes to swamp hydrology which has flow-on effects on vegetation.
Hazard-risk assessment

The final outcome from the project is a hazard-risk assessment (Table 2), which can be used by the SCA to evaluate and determine acceptable risks to water quality and quantity arising from extreme erosion-sedimentation events that are likely to occur within the Special Areas during the lifetime of the water supply reservoirs (assumed to be in the order of 100 years for this assessment). As advocated earlier, little can be done to prevent natural events from occurring. Instead we envisage planning and actions that relate to minimization or mitigation of effects and/or contingency arrangements for water supply. The assessment is based on the best available knowledge of triggers, recurrence intervals, past events and key geomorphic processes, gained throughout the project. Undoubtedly as further information is obtained over time, estimates will need to be further refined. It is also recognized that one of the major problems with such assessments is that hazards rarely occur at regular or predictable intervals. This is particularly true in the Australian setting where variability is the rule rather than the exception.

Table 2. Hazard-risk assessment for extreme erosion events in SCA Special Areas

<table>
<thead>
<tr>
<th>Hazard (trigger)</th>
<th>Estimated recurrence interval</th>
<th>Risk (No. of events likely within 100 years)</th>
<th>Geographical setting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wildfire:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>30–40 years</td>
<td>2–3</td>
<td>Widespread</td>
</tr>
<tr>
<td>Mild</td>
<td>~10 years</td>
<td>10</td>
<td>Localised (&lt; 100 km²)</td>
</tr>
<tr>
<td><strong>Extreme rainfall:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy rain</td>
<td>1–15 years</td>
<td>10–50</td>
<td>Widespread</td>
</tr>
<tr>
<td>Severe thunderstorms</td>
<td>1–5 years</td>
<td>20–50</td>
<td>Localised depending on storm cell size and direction</td>
</tr>
<tr>
<td><strong>Drought:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extreme</td>
<td>50 years</td>
<td>2</td>
<td>Widespread</td>
</tr>
<tr>
<td>Moderate</td>
<td>2–3 years per decade</td>
<td>8</td>
<td>Widespread</td>
</tr>
<tr>
<td><strong>Catastrophic floods:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quasi-catastrophic</td>
<td>20–100 years</td>
<td>1–20</td>
<td>Localised to widespread</td>
</tr>
<tr>
<td>Catastrophic</td>
<td>100–500 years</td>
<td>&lt; 1</td>
<td>Widespread</td>
</tr>
<tr>
<td>Rare, extreme</td>
<td>&gt; 50 years</td>
<td>&lt; 1</td>
<td>Widespread</td>
</tr>
<tr>
<td><strong>Earthquakes:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M 6</td>
<td>~1200 years</td>
<td>&lt; 1 (0.1)</td>
<td>Widespread</td>
</tr>
<tr>
<td>M 7</td>
<td>~10,000 years</td>
<td>&lt; 1 (0.01)</td>
<td>Widespread</td>
</tr>
<tr>
<td>M 8</td>
<td>~100,000 years</td>
<td>&lt; 1 (0.001)</td>
<td>Widespread</td>
</tr>
<tr>
<td><strong>Breach of intrinsic thresholds:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock fall</td>
<td>Several events per year per km of cliff line</td>
<td>100–200 per km</td>
<td>Localised, restricted to cliff faces or bedrock outcrop on slopes</td>
</tr>
<tr>
<td>Rock avalanche</td>
<td>1 every 2000–250,000 years per km of cliffline</td>
<td>&lt; 1 (&lt; 0.05) per km</td>
<td>Localised, restricted to cliff faces &gt; 150 m height in deeper valleys</td>
</tr>
<tr>
<td>Rotational slump</td>
<td>1 every 2000–250,000 years per km of valley</td>
<td>&lt; 1 (&lt; 0.05) per km</td>
<td>Localised, restricted to where valley incision has breached Permian strata</td>
</tr>
<tr>
<td>Gullying through swamps</td>
<td>1000-5000 years per swamp</td>
<td>&lt; 1 (0.1) per swamp</td>
<td>Localised, confined to upland swamps</td>
</tr>
</tbody>
</table>
2. IMPLICATIONS FOR THE SCA

The outcomes from this project have numerous implications for the SCA particularly those relating to management actions and contingency planning.

2.1. Wildfire

2.1.1. Despite causing significant destruction of vegetation and giving the perception of extreme erosion through transport of charcoal, ash, leaf litter and fine sediment, wildfires alone play a minor role in facilitating extreme erosion events both in the Nattai catchment and in the upland swamps on the Woronora Plateau.

2.1.2. Extreme erosion results from coupling with extreme rainfall. However, the variability in rainfall in eastern Australia means that extreme rainfall events may or may not occur in the vulnerable post-fire period depending on weather patterns which have little relationship to the timing or severity of fires.

2.1.3. Instead a range of post-fire responses should be considered, ranging from no measurable effect (best case scenario) to catastrophic surface erosion and stripping of topsoil (worst case scenario). Hence experienced staff need to be made available both during and after wildfires to conduct regular monitoring and to be able to respond to situations such as the occurrence of an extreme rainfall event in the post-fire period.

2.1.4. Most rainfall events following the 2001-02 wildfires were of low intensity, patchy distribution and/or short duration. These had little effect on runoff and erosion either due to infiltration into the soil profile via bioturbation (ant galleries, tunnels), and/or storage (or absorption) within the topsoil through patchy post-fire soil water repellency.

2.1.5. The window of extreme post-fire erosion is likely to be limited, decreasing with time after fire either through sediment exhaustion, vegetation recovery and/or, sediment storage within litter dams and other topographic features on hillslopes or on valley floors.

2.1.6. An increase in the frequency of fires (wildfires and hazard reduction burns) however, will increase the susceptibility of the landscape to post-fire erosion through increasing the likelihood of the coupling of fire with extreme rainfall events. Hence it is recommended that hazard reduction burning within the Special Areas be reviewed. Despite recent media hype, there is little to be gained from low intensity burning in bushland other than its design to protect property and infrastructure.

2.1.7. Wildfires and extreme rainfall events are likely to become major issues in the future as both are predicted to increase with global warming and climate change.

2.2. Extreme rainfall

2.2.1. Severe east coast cyclones (ECC) are the most significant, frequent and likely cause of extreme rainfall in the Sydney region, followed by tropical cyclones (which are often included in ECC assessments). These cause heavy rainfall across the east coast of Australia over 1–2 days, although rainfall events can last several days or weeks.

2.2.2. The erosion potential from heavy rainfall events is extremely high through generation of overland flow on hillslopes and flooding within streams resulting in significant sediment transport and export from catchments. Actual erosion, however, can be minimized through maintaining a good vegetation cover on hillslopes including riparian buffers.

2.2.3. Less often and less significant is extreme rainfall triggered by severe thunderstorms in the summer months. These can result in severe rainsplash and sheetwash erosion on hillslopes particularly in post-fire periods when the vegetation cover is low. The short-lived nature of thunderstorms (few hours) however, means that the effects of the rain event are brief and sediment export from catchments is limited.

2.2.4. The primary controls on extreme rainfall along the east coast are synoptic scale weather patterns, which show no clear pattern or direct correlation with ENSO, and are instead determined by atmosphere-land surface interactions and global sea surface temperature anomalies.

2.2.5. Global warming and climate change is predicted to have significant impacts on weather patterns including increased numbers of extreme weather events. The implications of
climate change on the frequency and magnitude of extreme weather events should be considered in future catchment management plans.

2.3. Catastrophic floods

2.3.1. Catastrophic floods occur in response to continuous heavy rainfall, often caused by severe ECCs. Catchment conditions such as vegetation cover and soil moisture also play a role in determining runoff rates and the magnitude of flood peaks.

2.3.2. Catastrophic floods play a major role in sediment mobilization, transport and export, often accounting for several decades equivalent of river sediment load in a single event.

2.3.3. The extent of erosion and sediment transport is a function of both sediment supply and discharge. The majority of sediment is derived from reworking of stored alluvial and colluvial material exposed in the stream bed, banks and lower slopes. However, debris flows and other mass movement events on hillslopes can supply significant quantities of sediment especially if they occur during the flood event.

2.3.4. Like extreme rainfall, there are significant implications from global warming, climate change and predictions of increased numbers of extreme weather events. Increased extreme rainfall events will undoubtedly result in an increase in the frequency and magnitude of catastrophic floods.

2.4. Earthquakes

2.4.1. Large magnitude earthquakes are the most likely trigger of large landslides in the Nattai catchment and other valleys incised into the Permian rocks of the Blue Mountains Plateau.

2.4.2. The western Sydney Basin seismic zone, which extends under the Blue Mountains Plateau is the most seismically active in the area due to its location at the intersection of two crustal shear zones formed through plate tectonics.

2.4.3. There is also evidence for (geologically) recent movement along faults within the Lapstone Structural Complex. Movement along the Lapstone Fault, a westward dipping fault which also extends below Lake Burragorang, may be linked to earthquakes recorded in contemporary records.

2.4.4. Small earthquakes of less than magnitude 4 occur frequently in the western Sydney Basin seismic zone but these appear to have had little impact on valley sidewall stability and to the best of our knowledge have not triggered any extreme erosion events.

2.4.5. Rare, large magnitude earthquakes (M 6-8), however, are likely to result in significant ground disturbance including fracturing of rock at the surface, triggering rock falls and landsliding along the steep cliff lines surrounding the Nattai and Wollondilly valleys.

2.4.6. The timing of the next large magnitude earthquake is unknown. The chance of a large magnitude earthquake occurring within the lifetime of the water supply reservoirs is small, but nonetheless ever present.

2.4.7. A seismically triggered landslide could have serious impacts on water quality and quantity if the event occurred around the foreshores of Lake Burragorang.

2.4.8. Further investigations need to be carried out on the existing landslides around the foreshores of Lake Burragorang to determine their age and better define the failure mechanisms and feedbacks.

2.5. Intrinsic thresholds

2.5.1. Intrinsic thresholds are important in facilitating slope failure in the Nattai catchment ranging from individual rock fall to large scale collapse and mass movement such as rock avalanches and other landslides.

2.5.2. The primary controls are internal factors relating to the characteristics of the colluvium, bedrock and weathering, as well as relief and vegetation characteristics.

2.5.3. Intrinsic thresholds vary considerably within the landscape at different spatial and temporal scales. Hence they are the most difficult trigger to measure and predict.
2.5.4. Hillslopes which are most vulnerable are those that are at or close to critical slope angles, are located on softer lithology such as the Permian and Narrabeen Group strata or have groundwater seepage present which enhances weathering.

2.5.5. Intrinsic thresholds can be breached at any time depending on internal factors. i.e. they are not dependent on the frequency and magnitude of an external trigger.

2.5.6. Extreme erosion resulting from exceedance of intrinsic thresholds can be rapid or long-lived via lag effects, and can occur as single or multiple or linked events leading to progressive slope failure.