A Review of Ross River Dam Gate Operations to Improve Downstream Flood Immunity

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Abstract

Ross River Dam is located approximately 9 kilometres upstream of the urban area of Townsville. The dam was built for flood mitigation, but also served to provide a reliable and ongoing raw water source for the growing Townsville population. The Ross River catchment downstream of the Ross River accounts for less than 10% of the total catchment area. Between 2004 to 2007 the dam was upgraded with the main embankment raised by approximately 0.8 m and three radial gates were installed on the dam's only spillway.

Initial flood modelling from the 2011 Ross River Flood Study identified that in the 100 Year ARI flood event there were still up to 870 properties potentially impacted by flooding. Review of the Ross River Dam gate operations was quickly identified as a potential measure for reducing the extent of downstream flooding, however, any benefits needed to be assessed against potentially adverse impacts including:

- reduction in water security;
- increase in dam safety risk; and
- increases in upstream flooding.

The review of dam operations showed that by throttling the dam outflows to a higher water level in the dam, a reduction in the downstream flooding can be achieved with minimal adverse impacts. The change in operations meant that up to 90% of properties previously identified as flood impacted, would no longer be impacted by the 100 Year ARI flood.

Study Area

The Ross River catchment is the largest catchment within the Townsville Local Government Area. The Ross River Dam is located at AMTD 26.4 km with an upstream catchment area of approximately 760 km^2. Ross River Dam is upstream of the City of Townsville with the central business district only 19 km north-east of the dam. Land-use in the catchment upstream of the dam is predominantly rural, with controls in the planning scheme to limit intensification within the dam catchment.

Downstream of the Dam, Ross River flows northwards for approximately 10 km before flowing generally northeast for 16 km to Cleveland Bay adjacent to the Port of Townsville. Kelso is the closest suburb of Townsville to the Ross River Dam and is only 1.6 km downstream of the dam spillway. There are three weirs downstream of the dam that create permanent water within the river around the urban area: Black Weir, Gleesons Weir and Aplins Weir. The 10 km of Ross River downstream of Aplins Weir is tidal. There are also four existing bridge crossings of the river downstream of Ross River Dam, plus another bridge under construction at the mouth of Ross River.

The catchment upstream of Ross River Dam is much larger than the contributing catchment downstream of the dam. A further 145 km^2 drains to Ross River below the dam, mainly through the tributaries of Stuart Creek, Gordon Creek, Annandale Drains and University Creek. Typically the response of catchments downstream of the dam is much shorter than the response time of the upstream catchment (Maunsell Australia 2005). Critical durations downstream of the dam can range from 3 to 24 hours, while the critical duration of the catchment upstream of the dam is 72 hours (Sinclair Knight Merz 2005, Townsville City Council 2011). The left bank of the Ross River is perched for most of the reaches downstream of the dam. The older suburbs of Townsville are located on this bank, and local runoff in these suburbs drains away from the Ross River, however overflows from Ross River have the potential to inundate large areas of these suburbs.

Figure 1 illustrates the study area.

Ross River Dam
Ross River Dam was originally constructed in 1974, following a feasibility investigations phase that commenced in 1965. The dam was originally constructed for flood mitigation following the large flood event of March 1946, and given the expansion of the urban area of Townsville following the Second World War. During the March 1946 flood, a peak discharge of 4500 m^3/s was gauged at Gleesons Weir. Ross River dam now also acts as the primary water source for potable water to Townsville.

The structure for Ross River Dam includes the spillway at Ross River and a combination earthfill and rockfill embankment to contain the water. The 8 km long embankment spans from the Mount Stuart range in the east to The Pinnacles range in the west. Ross River Dam was originally constructed in the early 1970's and underwent various upgrades over the next 10 years. From 2005 to 2008, another major upgrade strategy was commenced in order to bring the dam in line with current industry standards and to increase its storage capacity by 10%. The upgrades included lowering of the spillway crest to 34.656 m AHD and installation of spillway gates, upgrades to the spillway stilling basin and major upgrades to the 7.5 km long earthfill embankment. Figure 2 shows the layout of Ross River Dam.

The operation of the radial gates implemented with the upgrade project seeks to initially throttle dam outflows by sequencing all three gates openings with increases in headwater level. Once a headwater level of 41.5 m AHD is reached, the centre gate is fully opened, with the outer gate gates remaining partially opened. Both outer gates are fully opened at a headwater level of 41.75 m AHD. Above 41.75 m AHD, dam outflows are a function of headwater level alone with no control by gate operations. Table 1 shows the gate opening heights as a function of dam headwater level. Figure 3 shows the resulting rating curve for this operating rule.

Table 1 - Ross River Dam Pre-review Gate Opening Sequence

Head Water Level (m AHD)	Gate Opening (m)		
	Left (Gate 1)	Centre (Gate 2)	Right (Gate 3)
38.60	0	0	0
38.65	0	0.25	0
38.75	0.25	0.25	0.25
39.00	0.5	0.5	0.5
39.25	0.75	0.75	0.75
39.50	1.00	1.00	1.00
39.75	1.25	1.25	1.25
40.00	1.50	1.50	1.50
40.25	1.75	1.75	1.75
40.50	2.00	2.00	2.00
40.75	2.25	2.25	2.25
41.00	2.50	2.50	2.50
41.25	3.00	3.00	3.00
41.50	3.50	10.50	3.50
41.70	3.50	10.50	3.50
41.75	10.50	10.50	10.50
48.00	10.50	10.50	10.50

Above 46.0 m AHD, there is a second outflow path from Ross River Dam, through the Toonpan Lagoon area. Outflows through the Toonpan Lagoon flow into Majors Creek then into the Haughton River.

In addition to catchment flows into Ross River Dam, the water storage can be topped up from water pumped from the Burdekin system. When the storage within Ross River reaches 5%, 130 ML/d can be pumped through the Haughton Irrigation Channel to Ross River Dam, with an allowance for 20% losses due to seepage and evaporation during transit.

Draft Ross River Flood Study

The Draft Ross River Flood Study (Townsville City Council 2011) was undertaken as part of Townsville City Council's City Wide Flood Constraints project, informing the preparation of a new planning scheme for Townsville. The study reviewed and built on numerous previous studies (Maunsell McIntyre 2001, Maunsell Australia 2005, Sinclair Knight Merz 2005 and Gutteridge, Haskins and Davey 2005).

Essentially the Draft Ross River Study developed a hydrological model for upstream of the Ross River Dam and hydrological and hydraulic model for downstream of the dam. The upstream hydrological model, was a RORB model modified from the hydrological studies completed with the dam upgrade work between 2002 to 2007. The hydrological analysis incorporated:

- rainfall depths specifically analysed for the catchment based on at-site and regional frequency methods (Sinclair Knight Merz 2003);
- catchment isohyets based on review of local rainfall gauge records and consideration of orographic effects (Sinclair Knight Merz 2003);
- a joint probability assessment to evaluate the correlation between design rainfall event and initial reservoir level (Sinclair Knight Merz 2005);
- recent hydrographic survey of the dam completed in 2007; and
- a spillway rating curve reflecting the operation of all three gates based on the upgrade works.

The upstream catchment RORB hydrological model was calibrated to the following flow events with various spillway configurations:

- December 2010 (3 operational gates);
- January 2009 (3 operational gates);
- February 2007 (lower spillway prior to gate commissioning); and
- January 1998 (previous Ogee Crest spillway).

The hydrological response of the local catchments downstream of the dam was represented using XP-RAFTS. The hydraulics of the downstream floodplain were represented using a MIKE FLOOD model. The hydraulic model uses a 30m grid and incorporates all the weir and bridge structures downstream of the dam. The MIKE FLOOD model was calibrated to the December 2010, January 2009 and February 2007 flow events.

On the basis of the outflows from Ross River Dam and the runoff from downstream local catchments, the impact of flooding in Ross River was assessed with the MIKE FLOOD model. The critical duration flood event was determined to be the 72 hour event based on an assessment of storms between 6 hour and 168 hour duration. Results of the flooding assessment in terms of dam outflows and numbers of impacted properties are provided in Table 2. The results show a significant increase in the number of properties impacted in the 100 Year ARI flood compared to the 50 Year ARI flood. This significant increase in the number of properties is the result of additional overflows from the Ross River because of the large increase in dam outflows between the 50 and 100 Year ARI events. Figure 4 shows the location of the overflows from Ross River for the 100 Year ARI flood.

Table 2 – Draft Ross River Flood Study Results

Design Flood	Ross Dam Spillway Outflows (m^3/s)	Impacted Properties
2 Year ARI	198	0
5 Year ARI	349	0
10 Year ARI	446	0
20 Year ARI	607	27
50 Year ARI	725	85
100 Year ARI	1153	960
200 Year ARI	1552	1475
500 Year ARI	1717	2150
1000 Year ARI	1870	2680
2000 Year ARI	2057	3645
PMF	4135	12890

In terms of gate operation, between the 50 Year ARI and the100 Year ARI, is where the gate operation goes from partially open to fully open. This "ramping up" of dam outflows gives rise to significant increase in outflows between the 50 Year ARI and the 100 Year ARI floods.

Based on these draft results of the Ross River Flood Study (Townsville City Council 2011), it was identified that reviewing the Ross River Dam gate operations provided an opportunity for reducing the flooding impact in the 100 Year ARI flood.

Dam Management Considerations

In order to resolve the downstream flood frequency issue, a number of operational and capital solutions at Ross River Dam were suggested. The available options were grouped into the following categories:

- Modification of gate operations without capital expenditure;
- Modification of gate operations with gate retrofitting;
- Modification of gate operations with embankment raising; and,
- A combination of the above.

Given the magnitude of cost likely for capital expenditure, non-capital options were investigated in line with the following factors:

- Maintaining or enhancing raw water security;
- Consideration of Toonpan overflows;
- An Acceptable Floodway Capacity (AFC%) compliant with the Dam regulator.
- Early releases above FSL;
- The feasibility of early releases below FSL; and,
- Transition to fully open gates;

The scope of the investigation focussed on works at Ross River Dam. Downstream flood mitigation solutions were not investigated at this time as the opportunity provided by the proximity of the dam to Townsville meant that substantially cheaper non-capital solutions were likely to provide the largest benefit.

Raw Water Security

Townsville City Council (TCC) discussions with DERM indicated that raw water security is high on the State Government's priorities, and they were in the process of completing their North Queensland Regional Water Supply Strategy on the basis of Townsville being able to achieve a Level of Service (LOS) where the supply would be depleted at a frequency of less than 1 in 1000 years. This frequency is considered by the State as an appropriate LOS for large communities. The performance of TCC's current water supplies, which includes the Burdekin system allocations, provides a supply security of about 1 in 600 years (for a demand of 60,000 ML/a – 2007/8 demand), and is based on current operation and restriction regimes (Priman, 2012). To achieve a LOS of 1 in 1000 years, TCC needed to undertake a combination of modified restrictions, operations and increased holding of "High Priority" water allocation from the Burdekin system.

Given the above impediment, and that infrastructure bring-forward costs would far outweigh other solutions, any flood mitigation measure that involved altering raw water security was not entertained.

Transition to Fully Open Gates

The transition to fully open gates is critical to downstream flood flows. Prior to fully opening the gates, there is control over the dam outflows. Once the gates are fully open, outflows are governed by the storage attenuation and spillway capacity with no control through operations.

Transitioning to fully open gates does however require consideration of the overtopping freeboard of the gate, and overall risk to the dam through reduce AFC% as well as changes in water levels and associated impacts on the risk of failure mechanisms.

Toonpan Flows

For the 2007 upgrade design, the assumed outflows for Toonpan were based on the natural state of the overflow through the Toonpan Lagoon. There could be scope to increase these flows with channelisation works, thus reducing the calculated peak flow during the design flood (probably maximum precipitation – Design Flood) . This could result in a modest increase on AFC%, and could partially or completely offset a revised gate operating regime. Any constructed works for the Toonpan overflows were likely to be expensive and also potentially increase the flooding risk within the Haughton River including the township of Giru.

Early Releases

Consideration was given to making higher releases up to the currently accepted "safe" discharge rate of 500 cumecs, or higher if acceptable, but be determined under a risk assessment.

Early releases below FSL were feasible but was considered difficult as consideration had to be given to water security, and the timing of the resultant peak flow with any downstream peaks such as storm surge, high tide, and localised flooding.

Dam Regulator

Given the high costs of capital upgrades, an acceptable reduction in AFC% (and dam risk profile) was a viable option. Combinations for AFC% reduction and improvement in downstream flood protection were calculated and presented to the Dam Regulator.

It was assumed that the Dam Regulator would be reluctant to accept a higher risk profile, however once discussions with the Dam Regulator took place, it was clear that they were open to an outcome that both protected the dam and provided a higher degree of downstream protection. The magnitude of the change needed to be understood by the Dam Regulator in order to determine if the risk was tolerable.

Preferred Gate Operation Option

The following technical issues were considered as part of any potential adjustment to the current gate operating rules:

- Target a desirable Q100 discharge of no more than 900 m^3/s.
- The overall risk profile of the dam should not be adversely affected.
- The spillway gates should not overtop and should maintain current design freeboard provisions.
- Maintain the current gate operational philosophy and design provisions.
- Minimise the extent of changes required to operational systems.

Initially a series of operating options were developed based on the overtopping freeboards. Rating curves for these operating options were developed and applied to the hydrological model of the dam to evaluate design event outflows for each option. The design outflows across a range of frequencies were then applied to the risk model of the dam developed in the 2007 upgrade (Gutteridge Haskins Davies, 2007). Details of the dam risk assessment are provided in the following section.

Four options for gate operation were evaluated to determine the preferred gate operation option. A brief description of each option is provided below:

- Option 1 “Maintain Freeboard” – This option aims to stay within the original design zone that helped maintain the 0.5 m freeboard design provision. It is quite similar to the existing gate rules except that it:
  - provides some minor additional throttling of flows above RL 40.0
  - defers trigger for gates to commencement transition to fully open position to RL 42.25
- Option 2 “Zero Freeboard” – This option aims to fully utilise the current freeboard for additional flood storage. That is, flows are throttled as much as possible, without the gates overtopping (with the exception of wave action). This option represents the maximum amount of throttling, and hence maximum outflow reduction that can occur with the existing gate configuration. This option also defers the trigger for gates to commence transition to fully open position to RL 42.25.
- Option 3 “Extend 2005 Curve” – This option utilises the gate rule used in the Sinclair Knight Merz 2005 report. These rules result in flows that are slightly more throttled than the current EAP. A trigger level of RL 42.25 for commencement of gate transition to 100% open has also been set for this option.
- Option 4 “Extend Current EAP Curve” – This option maintains the current gate rules for levels up to RL 41.00. It then extends those rules up to RL 42.25 at which level the trigger point for transitioning the gates to fully open occurs.

The total outflows from the dam, including both spillway and Toonpan overflows, are provided in Figure 5. Flows for each of the four options above are shown for a range of ARIs and are compared to the outflows previously determined from the Draft Ross River Flood Study, (Townsville City Council, 2011). For clarity of the impacts on dam outflows of more regular floods, Figure 6 shows dam outflows for ARIs between 10 Year ARI and 1000 Year ARI.

The preferred option was "Option 1" and was selected due to the following:

- It achieves TCC's target reduction in Q100 flows whilst not making any significant impact on the dam's overall risk profile
- It remains within the original design range developed for the gates including, in particular, the minimum freeboard targets for the gates.

- It maintains the current operational philosophy and requires only minor amendment of current operational arrangements.

All of the options presented resulted in a significant reduction in peak Q100 discharges from currently 1153 m^3/s. All options resulted in flow less than the 900 m^3/s flow identified from the Draft Ross River Flood Study as being the flow at which significant impacts to the community occur.

Following selection of Option 1 as the preferred option, some refinement of the operation option completed. The gate opening sequence for the preferred option is shown in Table 3.

Table 3 - Ross River Dam Preferred Gate Opening Sequence

Head Water Level (m AHD)	**Gate Opening (m)**		
	Left (Gate 1)	**Centre (Gate 2)**	**Right (Gate 3)**
38.60	0	0	0
38.65	0	0.25	0
38.75	0.25	0.25	0.25
39.00	0.5	0.5	0.5
39.25	0.75	0.75	0.75
39.50	1.00	1.00	1.00
39.75	1.25	1.25	1.25
40.00	1.50	1.50	1.50
40.25	1.50	1.75	1.50
40.50	1.75	1.75	1.75
40.75	2.00	2.00	2.00
41.00	2.25	2.25	2.25
41.25	2.50	2.50	2.50
41.50	2.75	2.75	2.75
41.75	2.75	3.00	2.75
42.00	3.00	3.00	3.00
42.25	3.25	3.25	3.25
42.50	3.75	3.75	3.75
42.75	3.75	10.50	3.75
43.00	10.50	10.50	10.50
48.00	10.50	10.50	10.50

The total dam outflows for the preferred Dam gate operation are compared to the current dam operation outflows in Figure 7. Similarly, a comparison in peak water levels within the dam between the preferred dam gate operation and the current dam operation are provided in Figure 8. The impacts of these changes on flooding are reviewed in the following sections.

Dam Safety Risk Assessment

Assessing the change to the overall risk profile was a far more complicated undertaking and beyond the bounds of a preliminary assessment. An initial assessment of the impact on dam safety due to modified gate rules during extreme events indicated that the change in peak water levels was minor (~50 mm maximum at PMF). The review of the overall risk profile utilised the risk profile model developed during the dam upgrade between 2004 and 2007.

The 2004 to 2007 upgrades to Ross Dam were undertaken in accordance with Australian National Committee on Large Dams (ANCOLD) "Guidelines on Risk Assessment" (ANCOLD, 2003). A comprehensive risk model was developed at the time to consider all potential modes of failure including:

- embankment overtopping,
- piping through the embankment,
- piping through the foundation; and
- failure of the spillway structure.

The risk profile of the upgraded dam was compared to ANCOLD guidelines and was shown to be compliant with industry standards (Gutteridge Haskins Davey, 2005). Outputs from the hydrological assessment of the preferred gate operation were provided as input to the risk profile model, to evaluate the risk profile of the proposed gate operation option. Figure 9 shows the risk profile outputs for the proposed gate operation compared to the current gate operations and the ANCOLD tolerable limit (ANCOLD, 2003). The results of the risk profile show that while there is a small increase in risk profile compared to existing gate operations, the risk profile is still under the ANCOLD tolerable limit.

Impact on Downstream Flooding

The proposed change in dam operations has resulted in reductions in dam outflows for smaller events up to the 200 Year ARI, with some increases in dam outflows for events greater than 500 Year ARI. A comparison of the spillway outflows between the initial gate operations and the proposed gate operations is provided in Table 4. The increase in flows is greatest for the 1000 Year ARI and is progressively less for the larger flood events.

Table 4 – Comparison of Spillway Flows from Initial and Proposed Operation Options

Design Flood	**Spillway Outflows**	
	Initial Outflow (m^3/s)	**Proposed Outflow (m^3/s)**
20 Year ARI	607	571
50 Year ARI	725	656
100 Year ARI	1153	745
200 Year ARI	1552	960
500 Year ARI	1717	1777
1000 Year ARI	1870	1985
2000 Year ARI	2057	2146
5000 Year ARI	2326	2373
10000 Year ARI	2531	2565
50000 Year ARI	2937	2967
100000 Year ARI	3120	3140
500000 Year ARI	3561	3626
1000000 Year ARI	3756	3823
PMF	4135	4268

This reduction in dam outflows for the 100 Year ARI has resulted in Ross River flows generally being contained to the river, with no overflows through Hermit Park, Murray or Fairfield Waters that had previously been determined from the Draft Ross River Flood Study results. Figure 10 shows a comparison of the 100 Year ARI flood extents for the initial and proposed Ross River Dam gate operation scenarios. Conversely, the increase in flows for the 1000 Year ARI has resulted in some increase in the extent of inundation between the dam operation scenarios as demonstrated in Figure 11.

Table 5 shows the updated results from the MIKE FLOOD model based on the proposed gate operations. Because of containing overflows from Ross River in the 100 Year ARI flood, there is a reduction of 930 impacted properties. It is considered that this reduction in flood impacted properties at this relatively frequent flood offsets the increase of 530 impacted properties in the 1000 Year ARI.

Table 5 – Proposed Operational Change

Design Flood	Ross Dam Spillway Outflows (m^3/s)	Impacted Properties
2 Year ARI	251	0
5 Year ARI	373	0
10 Year ARI	446	0
20 Year ARI	571	27
50 Year ARI	656	28
100 Year ARI	745	90
200 Year ARI	960	105
500 Year ARI	1777	2260
1000 Year ARI	1985	3210
2000 Year ARI	2146	4280
PMF	4268	13250

Impact on Upstream Flooding

Flooding upstream of the dam is governed by the dam water level. The changes in dam water level for the proposed gate operation are shown in Figure 8. The greatest increase in dam water level is observed for the 200 Year ARI, where the water level is increased from 42.05 m AHD to 42.50m AHD as a result of the proposed gate operation. An assessment of increased extent of inundation for the 200 Year ARI has been undertaken by reviewing contours of the dam. Figure 12 shows the expected change in flood levels resulting for the 200 Year ARI. The change in flood extent does not impact any residential buildings or major infrastructure.

Conclusion

A review of Ross River Dam gate operations, has been shown to achieve a reduction in flooding to Townsville for events up to the 200 Year ARI flood. This reduction has resulted from throttling the dam outflows to a higher water level and has:

- maintained water security of the dam as potable supply;
- had only marginal increases in dam safety risk but is still within the ANCOLD tolerable limit; and
- not significantly increased the risk of flooding to upstream infrastructure.

The largest benefit from the review comes from containing flows downstream of the dam within the banks of the Ross River in the 100 Year ARI and 200 Year ARI, reducing the number of impacted properties by 90% and 93% respectively.

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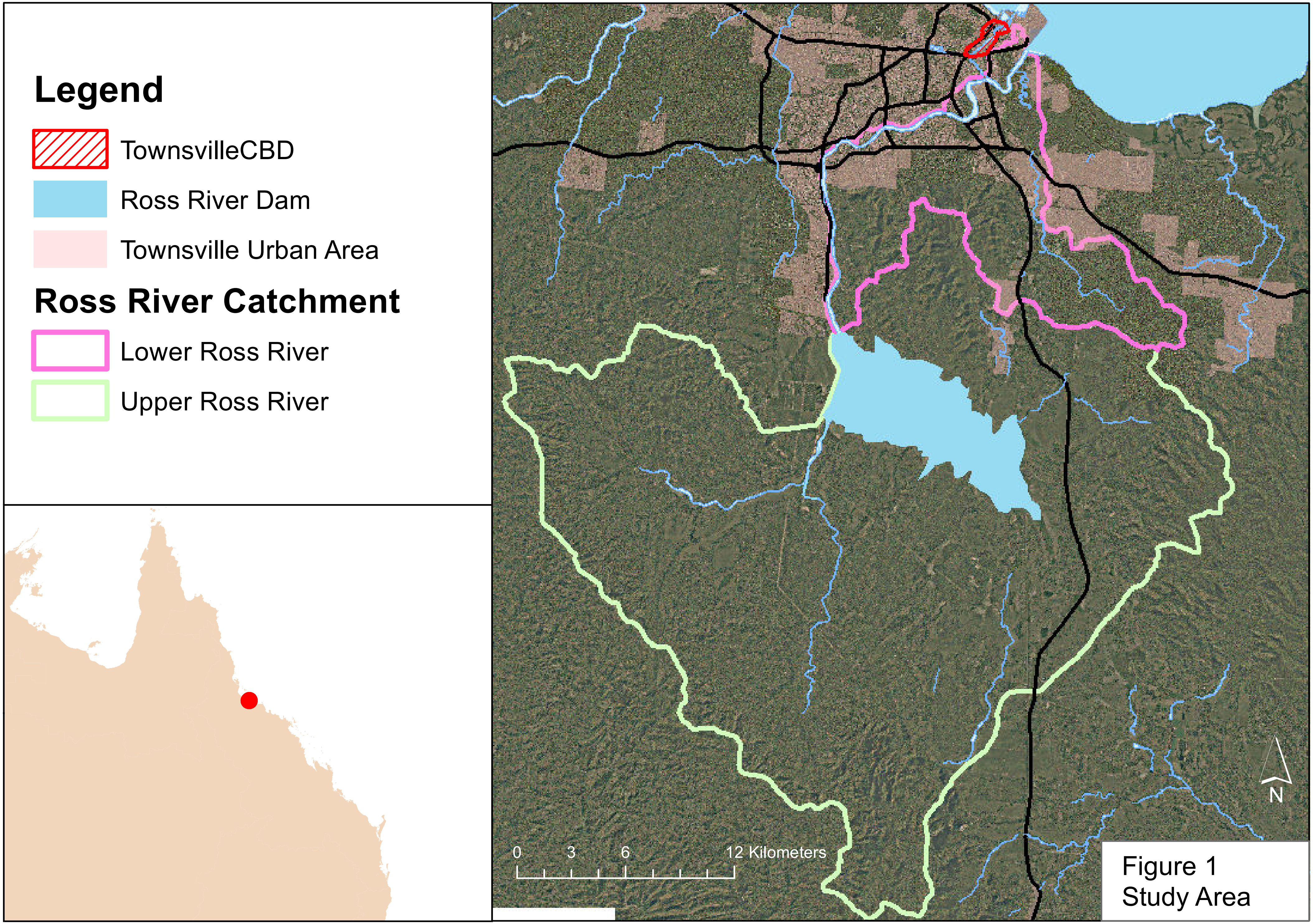
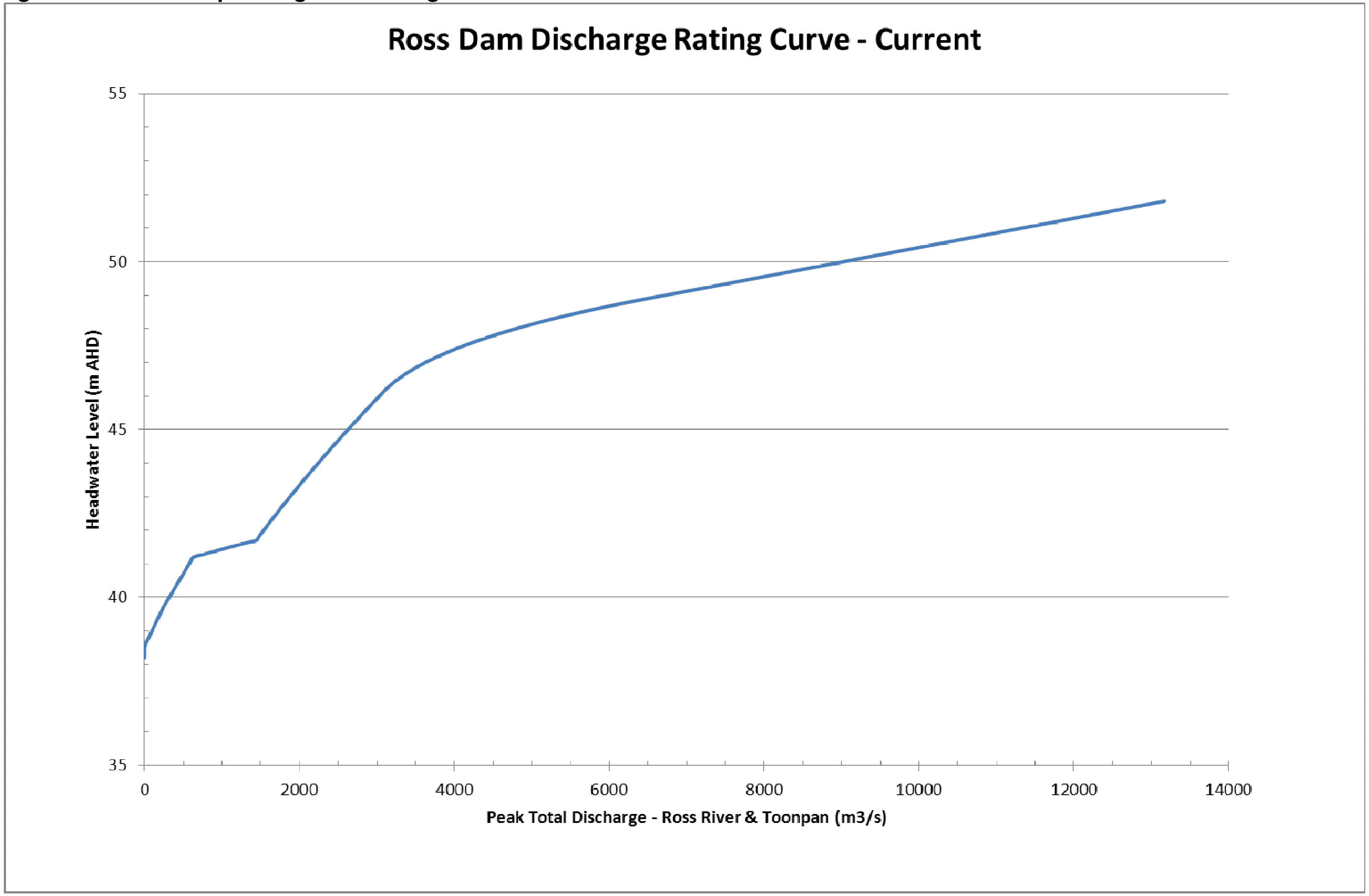


Figure 1
Study Area


Figure 2
Ross River Dam
0 0.75 1.5 3 Kilometers
N
Spillway
Embankment
Toonpan Overflows

Figure 3 – Current Operating Rule Rating Curve



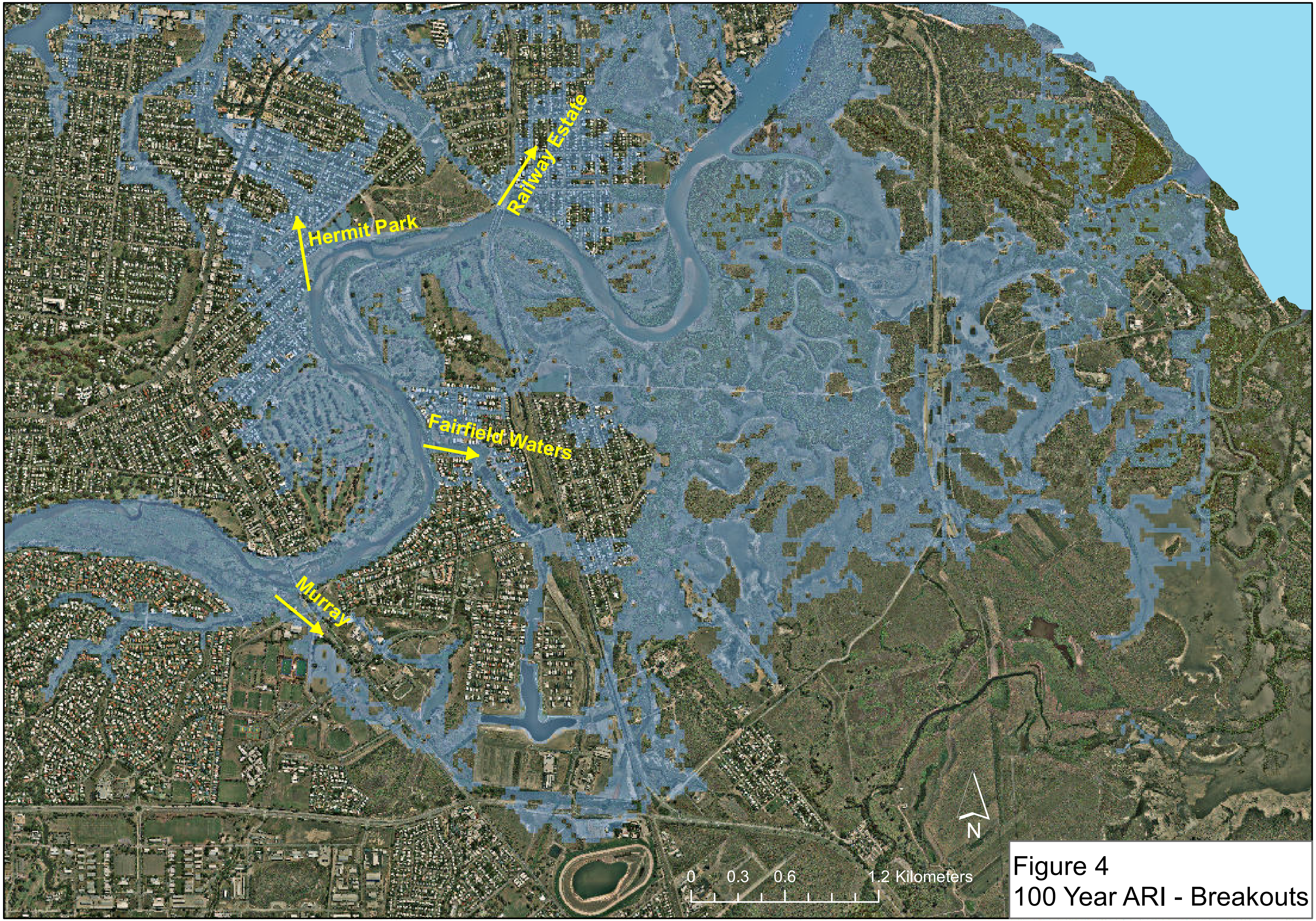


Figure 4
100 Year ARI - Breakouts

Figure 5 - AEP vs Total (Gates + Toonpan) Discharge for Gate Operation Options

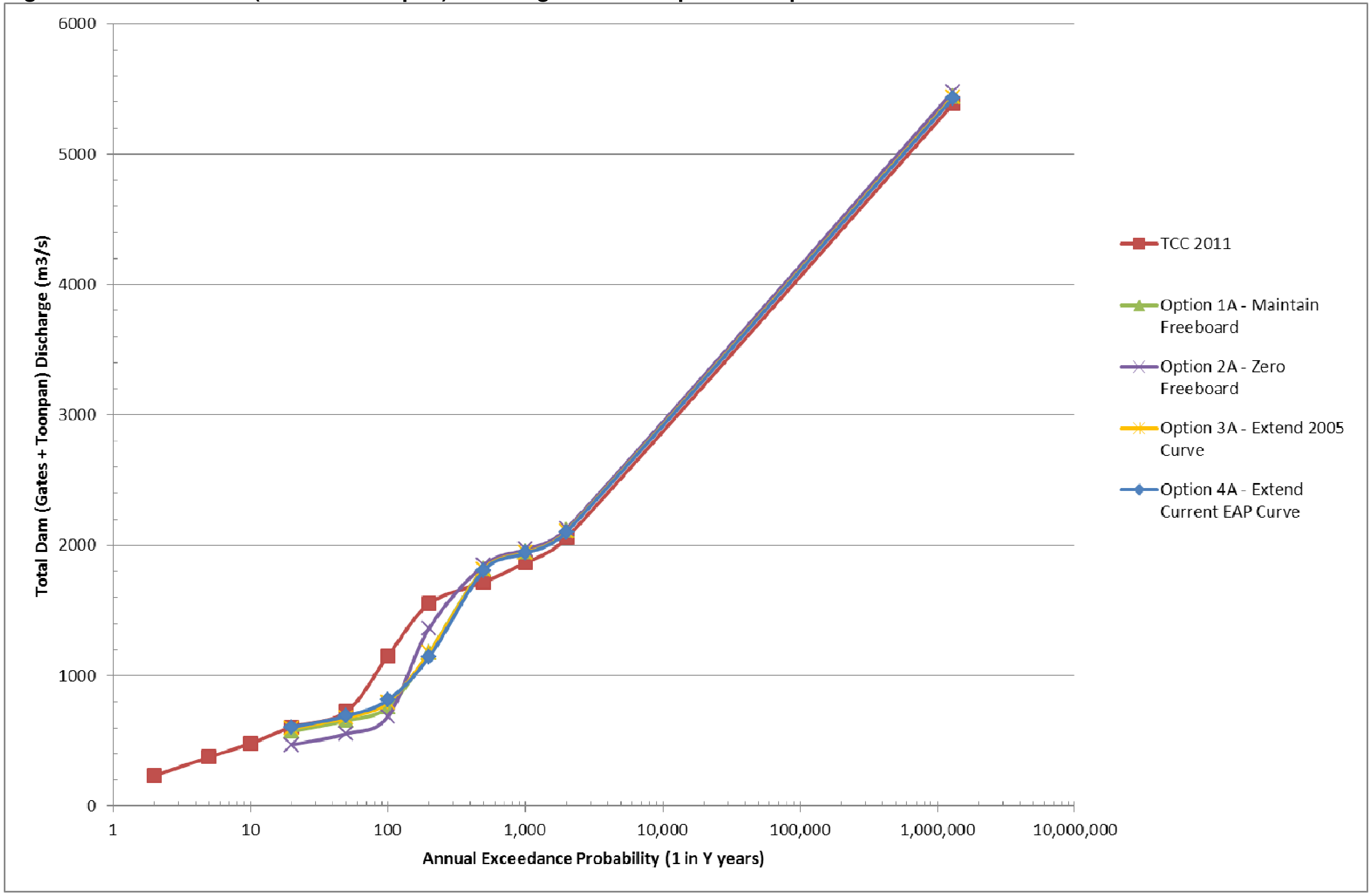


Figure 6 - AEP vs Gate Discharge (AEP 10 to 1,000 Years) for Gate Operation Options

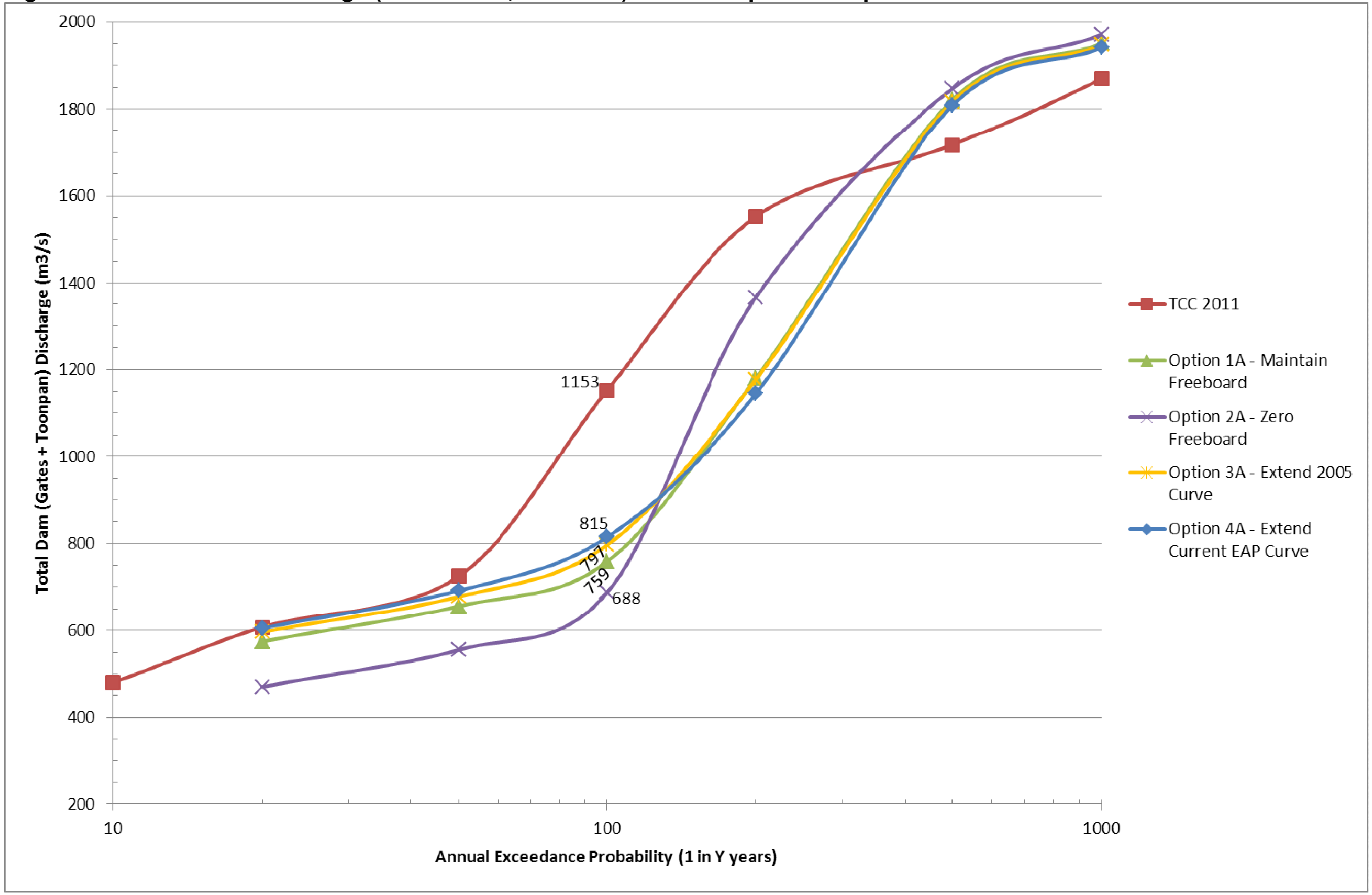


Figure 7 - Peak Flood Discharge Comparison (Total Dam Outflows)

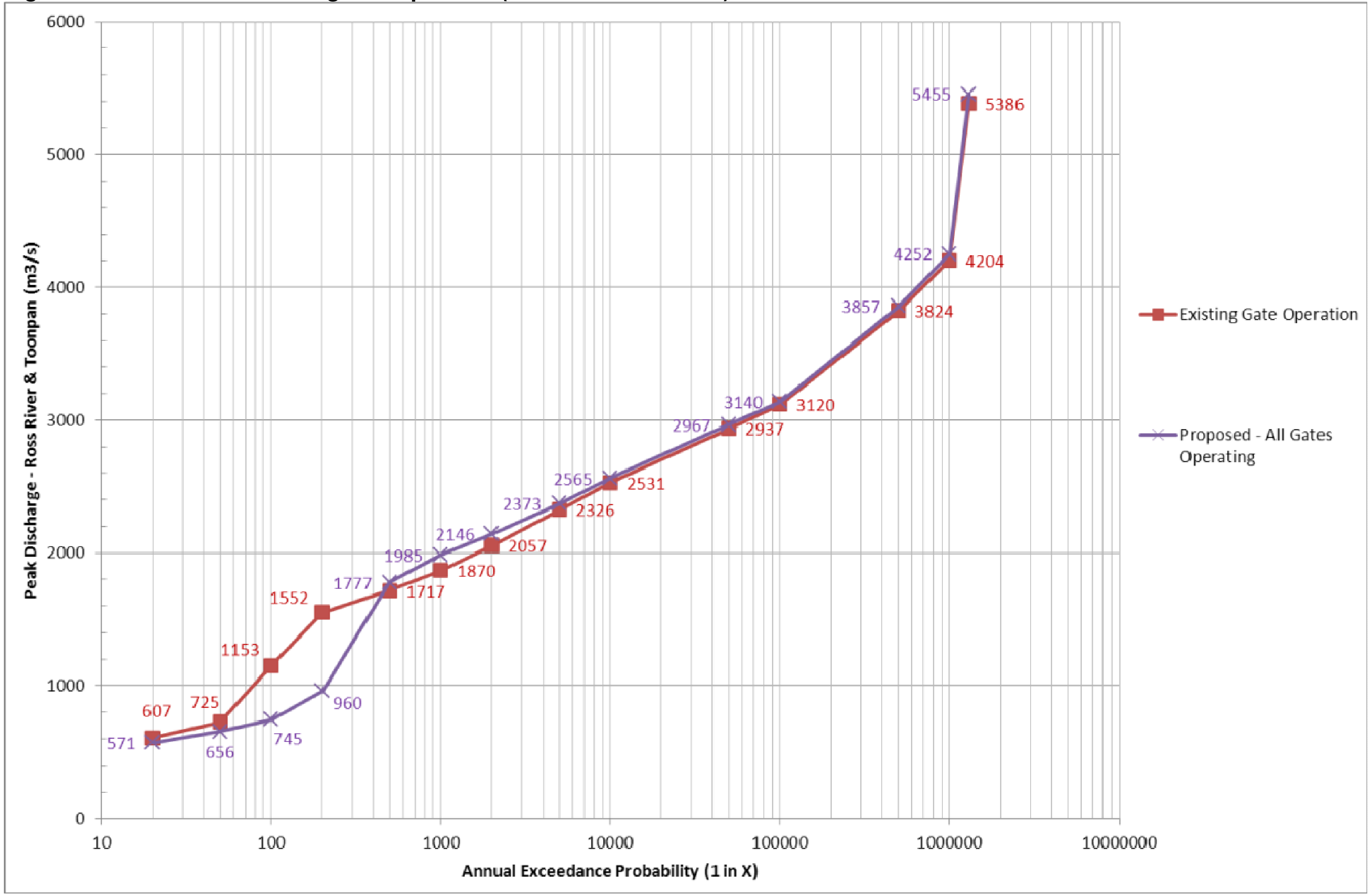


Figure 8 – Peak Dam Water Level Comparison

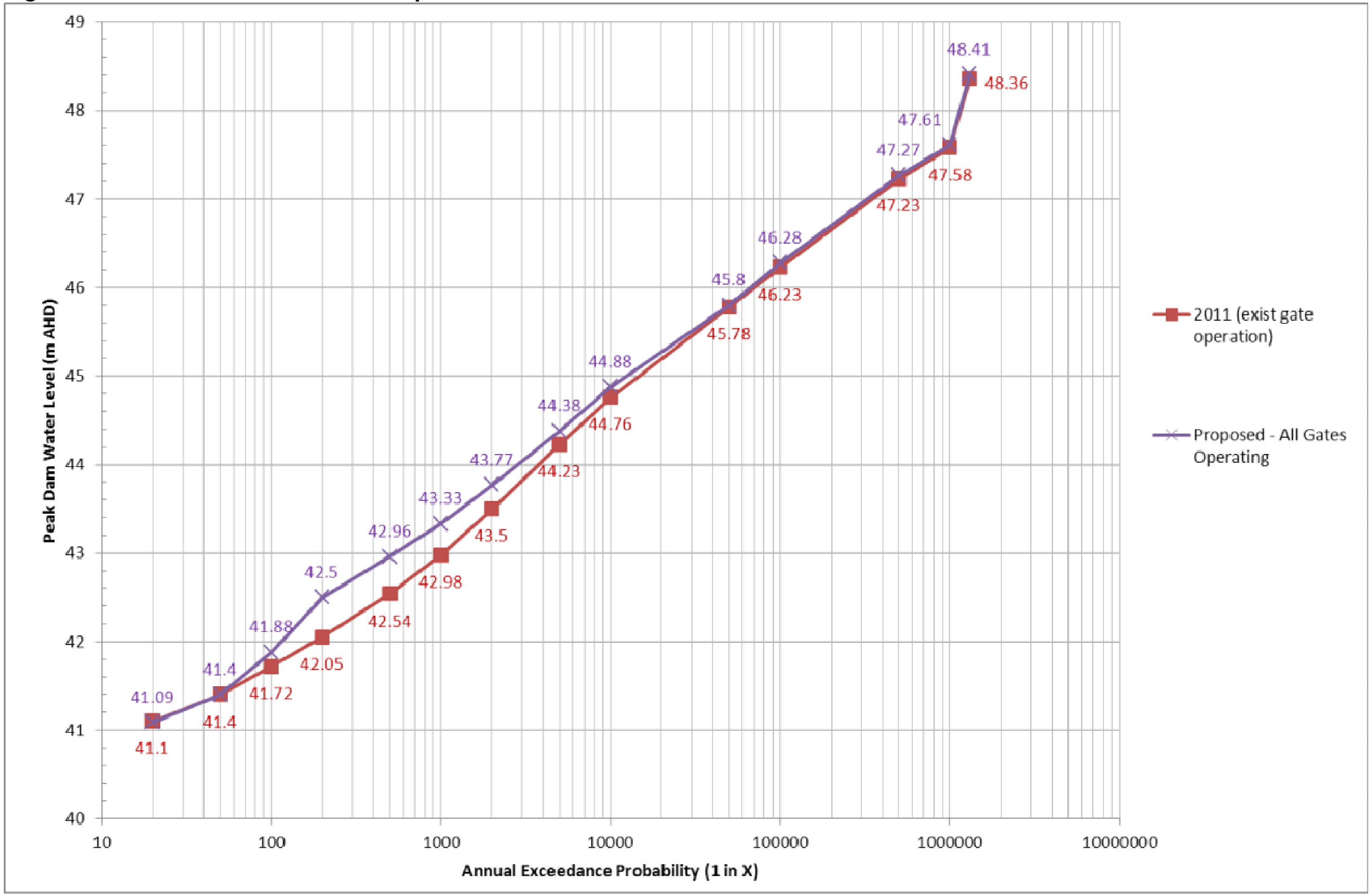
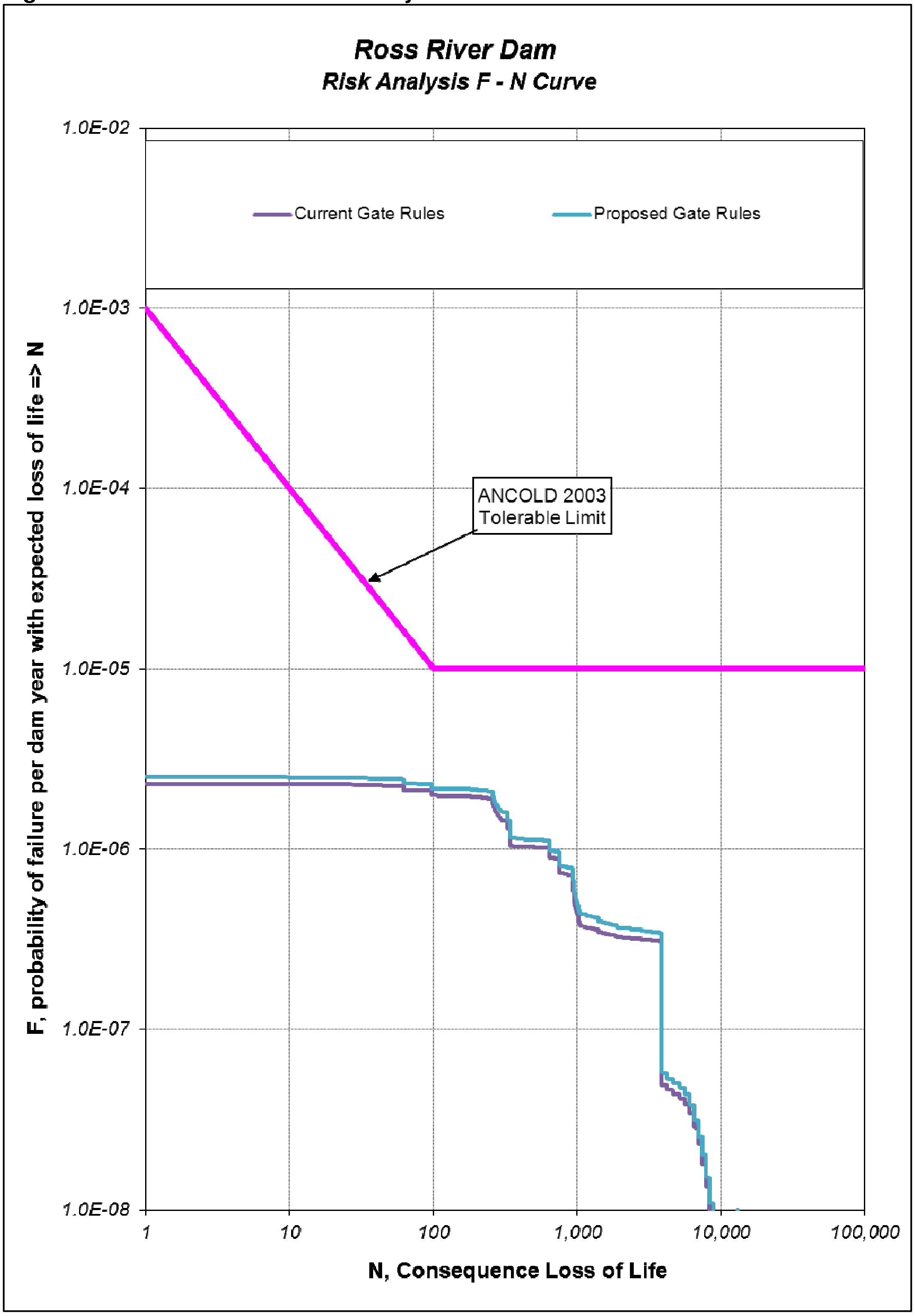


Figure 9 – Ross River Dam Risk Analysis F-N Curve



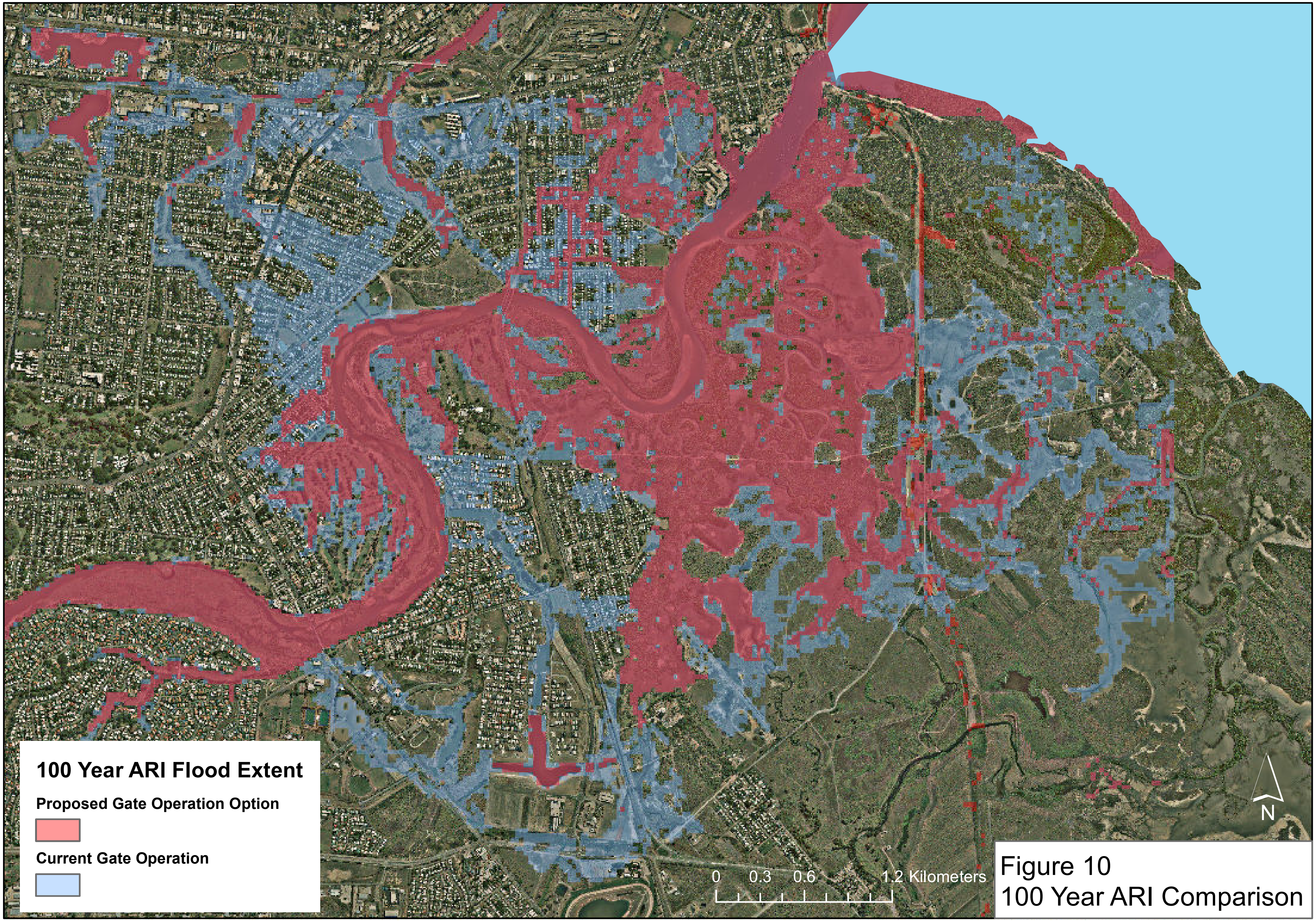


Figure 10
100 Year ARI Comparison

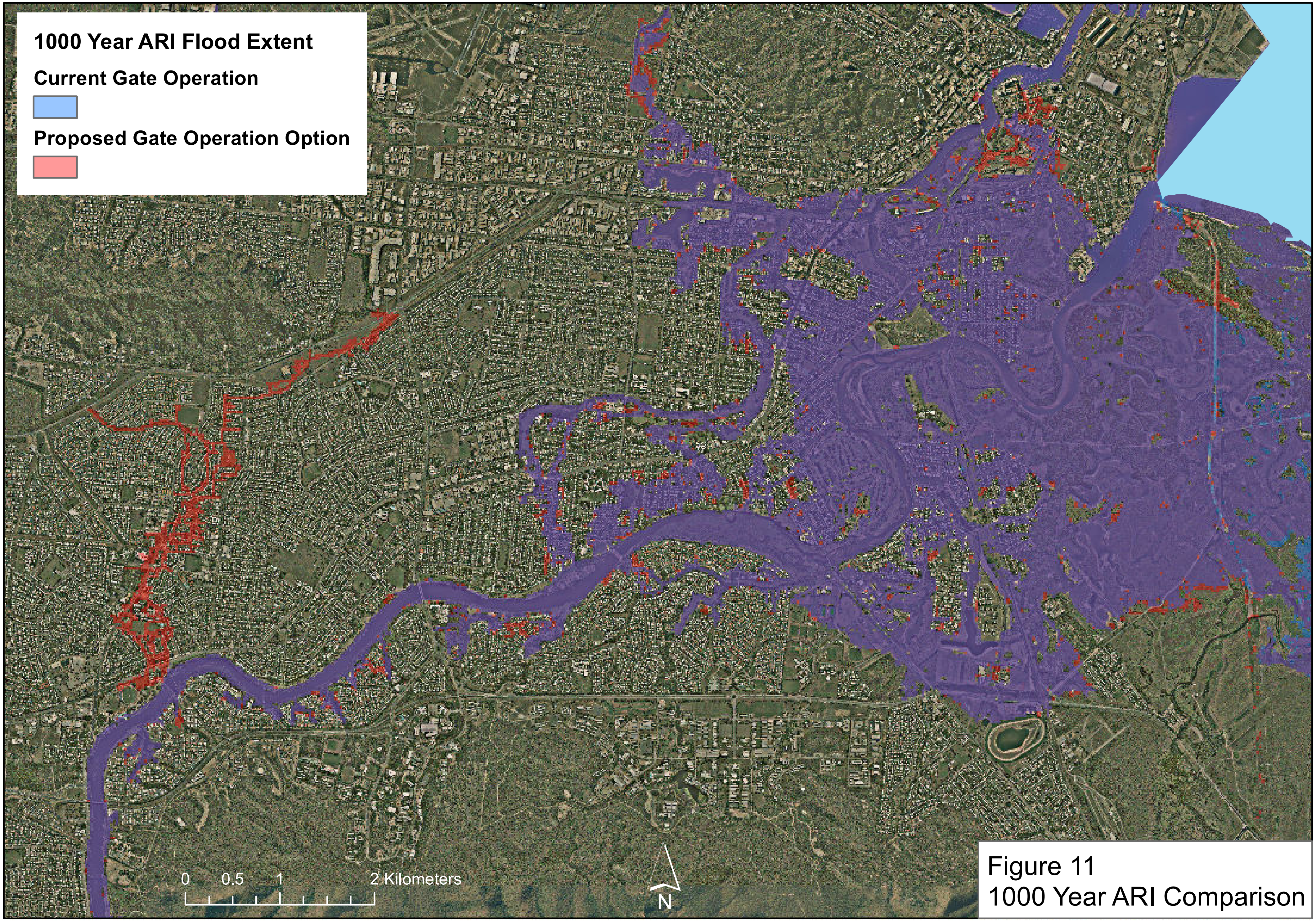


Figure 11
1000 Year ARI Comparison

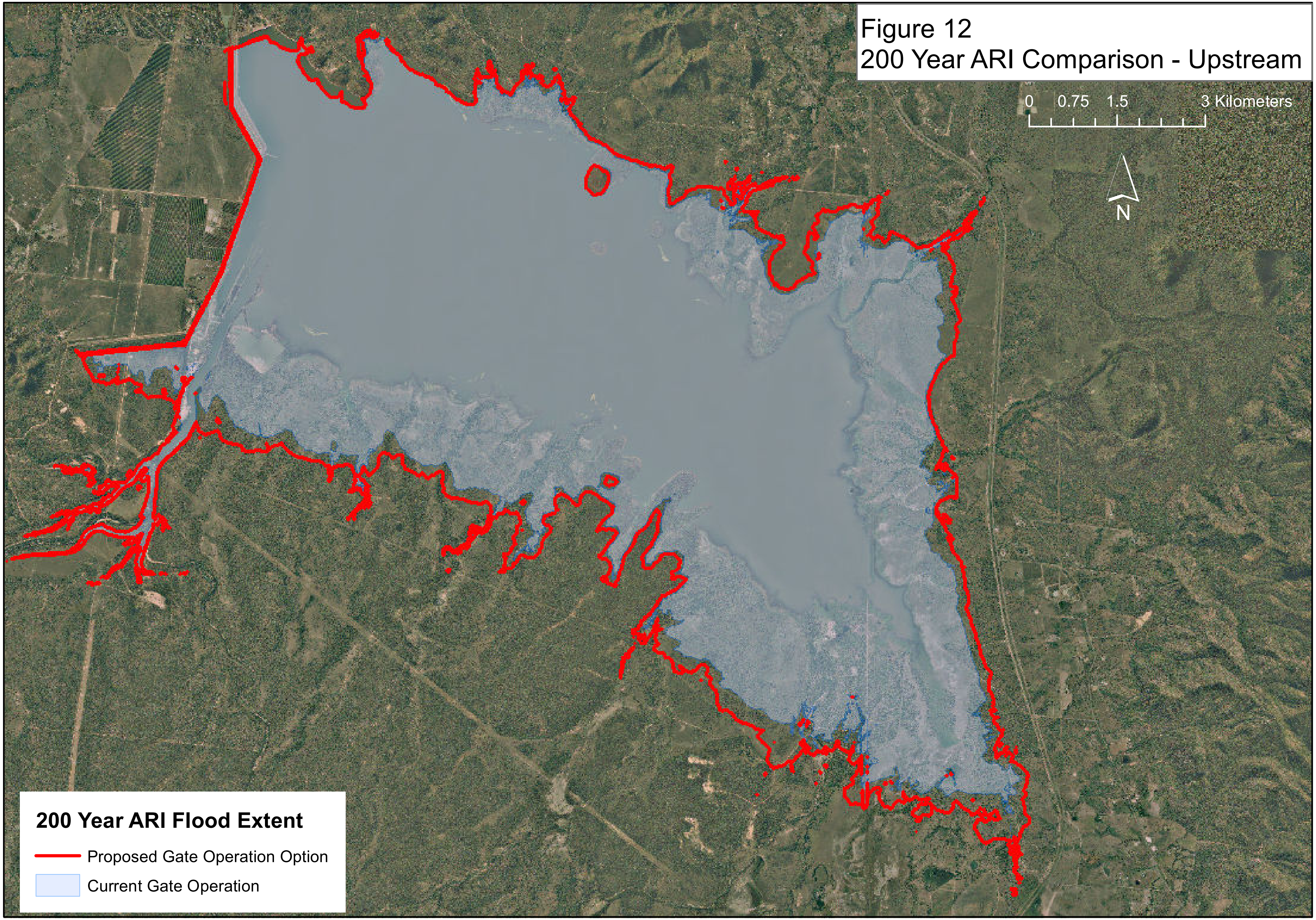


Figure 12
200 Year ARI Comparison - Upstream
0 0.75 1.5 3 Kilometers
N
200 Year ARI Flood Extent
Proposed Gate Operation Option
Current Gate Operation