NSW DEPARTMENT OF PLANNING

Independent Review of Tillegra Dam Hydrology

as described in the Environmental Assessment Report, August 2009, and the Environmental Assessment Submissions Report, March 2010

Artist's impression of the proposed Tillegra Dam on the Williams River.
(Date: Unknown.   Source: Dugong Shire Council website).

Final Report

27 September 2010

Bewsher

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1. INTRODUCTION

1.1 BACKGROUND

Hunter Water Corporation (HWC) is seeking approval to construct a 450GL dam at Tillegra, near Dungog in the Upper Williams River catchment.

The proposed dam would inundate an area of approximately 2,100 hectares at full supply level (FSL). The project is within the Dungog Local Government Area, within the Hunter region of NSW, approximately 70 kilometres north of Newcastle.

The proposal is a project to which Part 3A of the *Environmental Planning and Assessment Act 1979* applies by virtue of an Order made by the Minister for Planning under section 75B of the Act on 13 November 2007. Consequently, the Minister for Planning is the approval authority for the project. On 13 May 2009, the Minister for Planning formed an Opinion under Section 75C of the *Environmental Planning and Assessment Act 1979* that the project is essential for the State for economic and social reasons and therefore declared the project to be a critical infrastructure project.

The Environmental Assessment for the proposal was exhibited from 10 September 2009 until 13 November 2009. Some 2,659 public submissions were received and also a further ten submissions were received from government agencies.

The project was also declared a “controlled action” on 23 January 2009 under the Commonwealth’s *Environment Protection and Biodiversity Conservation Act 1999* (EPBC), for downstream impacts to RAMSAR wetlands, in the Hunter Estuary. The project will be assessed under Part 3A of the *Environmental Planning and Assessment Act 1979* and will also be conducted in accordance with clause 13.2 of the Bilateral Agreement between NSW and the Commonwealth, made under the EPBC Act, relating to environmental impact assessment.

In May 2010, the Department of Planning commissioned Bewsher Consulting Pty Ltd to independently review the hydrology studies used to inform the assessment of the proposed impacts of Tillegra Dam on the Williams River and the inflows into the Hunter Estuary.

This document provides the findings of that review.

1.2 SCOPE OF THIS REVIEW

The science of hydrology concerns itself with many aspects of water in our environment. Whilst there are numerous fields of hydrology, this current review has focussed on consideration of streamflows in the Williams River catchment. A thorough understanding of streamflow characteristics has been a key input to many of the environmental assessments for the proposed Tillegra Dam in the Environmental Assessment Report (EAR) and the Environment Assessment Submissions Report (EASR), including assessments of water quality, geomorphology and aquatic ecology, as well as various wetland and estuarine assessments.

The streamflow hydrology which is the subject of this review comprises that under both existing and future conditions, including the filling period of the dam, and once filled, its normal operation. The hydrologic data which has been used comprises that obtained from existing records of past behaviour as well as computer simulations of future behaviour.

The terms of reference (TOR) for this review are listed in **Section 1.4** below.

1.3 DOCUMENTS PROVIDED FOR REVIEW

The documents provided for review are listed in **Table 1**. Other documents that were provided for reference are also listed in **Table 1**. It is noted that a key document describing HWC's hydrology model was not produced by HWC until after the review had commenced. Consequently this was not available during the preparation of the EAR, the public exhibition or the preparation of the EASR. This document is referred to in this review as the *'SoMo Report'* and is listed as Document 17 in **Table 1**.

1.4 TERMS OF REFERENCE (TOR)

The Department's initial brief in May 2010 requested the reviewer to comment on the following broad issues in relation to the modelling conducted by HWC (the Proponent):

TOR 1. *the validity and appropriateness of the modelling undertaken*;

TOR 2. the validity, accuracy and precision of the data and assumptions on which the modelling has been based;

TOR 3. the validity, accuracy and precision of the interpretations that have been drawn (by the Proponent in their assessment documentation) on the basis of modelling results;

TOR 4. should the modelling be found to be deficient in any way, the reviewer is to provide suggestions of any amendments that would be required to improve the rigour of the modelling, its output or the interpretations drawn from it.

The Department's brief also included the following specific questions:

TOR 5. is the predicted contribution of Williams River flows to the Hunter Estuary accurate and representative (of annual, seasonal, monthly and daily variation and of drought conditions), with and without Tillegra Dam?

TOR 6. is the use of annual average flow statistics (by the Proponent) appropriate for assessing the contribution of Williams River to the Hunter Estuary, pre and post Tillegra and will using these statistics allow the assessment of the worst-case scenario for hydrologic and water quality inputs into the Hunter Estuary?

TOR 7. is the information presented by the Proponent on the likely impacts of Tillegra Dam on flows to the Hunter Estuary accurate and representative (of annual, seasonal, monthly and daily variation and of drought conditions)?

TABLE 1: DOCUMENTS CONSIDERED IN THIS REVIEW

Doc No	Date	Title	Author / Agency	Source
Documents Provided for Review				
1a	2009	Assessment and Management of Impacts on the Williams River. Chapter 10, Volume 1, Environmental Assessment Report accompanying the Project Application for Tillegra Dam. *Note that the Environmental Assessment Report is referred to as the **EAR** in this review.*	Aurecon on behalf of HWC	DoP
1b	2009	Ramsar Wetland Study. Appendix 6, Volume 2, Environmental Assessment Report accompanying the Project Application for Tillegra Dam	Aurecon on behalf of HWC	DoP
1c	2009	Working Paper A – Water Quality and Hydrology; and Working Paper D – Environmental Flows and River Management. Volume 3, Environmental Assessment Report accompanying the Project Application for Tillegra Dam	Aurecon on behalf of HWC	DoP
2	2010	Environmental Assessment Submissions Report. Hydrology issues are discussed in a number of sections in this report with the key sections being Chapter 4 – Issues in the Williams River Catchment Upstream of Seaham Weir, Chapter 5 – Consideration of other Key Issues, Chapter 6 – Assessment of Issues in the Estuary, Chapter 7 – Matters relating to the Commonwealth EPBC Act and Section 8.6. *Note that the Environmental Assessment Submissions Report is referred to as the **EASR** in this review.*	Aurecon on behalf of HWC	DoP
3	18 November 2009	NSW Office of Water – submission on the Environmental Assessment Report	NOW	DoP
13	June 2010	The Impact of the Proposed Tillegra Dam on the Hunter River Estuary, its Ramsar Wetland and Migratory Shore Birds. *Note that this report is referred to as the **UNSW Report** in this review.*	R T Kingsford & C J Hankin, UNSW, Australia Wetlands & Rivers Centre.	DoP
17	12 July 2010	Précis of Tillegra Dam. EAR Hydrological Modelling. *Note that this report is referred to as the **SoMo Report** in this review.*	Brendan Berghout, HWC	HWC
Documents Provided for Reference				
4	7 June 2010	Description of Source Model.doc. Email to DoP	HWC	DoP
5	24 May 2010	HWC water resources model – additional information. Email to Bewsher Consulting containing an email from HWC to Department of Planning dated 12 May 2010	DoP	DoP
6	2003	Hunter Water - Water Resources Model Review, Detailed Report	SKM	DoP
7	2003	Hunter Water - Water Resources Model Review, Summary Report. Final	SKM	DoP
8	12 December 2008	Review of Yield Estimates – Review of Yield Estimates for Hunter Region. Final Report	SKM	DoP
9	12 March 2010	Seaham Weir Outflow Scenario Modelling	HWC	DoP

Doc No	Date	Title	Author / Agency	Source
10	March 2006	Seaham Weir Hydrology Study, with attached email from HWC to the Department of Planning dated 7 June 2010 with subject “Seaham Weir/Hydrology”;	HWC	DoP
11	2006	Reducing the Impact of Weirs on Aquatic Habitat NSW Detailed Weir Review – Report to the NSW Environmental Trust, Hunter/Central Rivers CMA Region” with attached email from HWC to the Department of Planning dated 7 June 2010 with subject: “Emailing: Hunter-Central-Rivers-DWR-report”	NSW Department of Primary Industries and Environmental Trust	DoP
12	7 June 2010	Email to DoP entitled ‘Reports’.	HWC	DoP
14	January 2010	Hunter River Ramsar Modelling (Stages 1 & 2) — Comparative Analysis of Salinity Regime within Hunter River Tidal Pool and Kooragang Wetlands.	BMT WBM Pty. Ltd for HWC	DoP
15	August 2007	Why Tillegra Now?	HWC	DoP
16	December 2008	The $H_2$50 Plan. Securing our Water Future. A Long-Term Strategy to Meet Water Supply Needs for the Lower Hunter.	HWC	DoP
18	2003	Experimental Reintroduction of Woody Debris on the Williams River, NSW: Geomorphic and Ecological Responses. Technical Paper published on line in Wiley InterScience.	A P Brooks, P C Gehrke, J D Jansen & T B Abbe	HWC

TOR 8. *is the water balance for the project, presented in the Environmental Assessment (Figure 10.7), correct, particularly with reference to recorded data from Mill Dam Falls gauging station (No. 210010) located immediately upstream of Seaham Weir Pool?*

In late June 2010 after the review had commenced, a report was published by the University of NSW (UNSW)[1] which raised further issues for which the Department requested consideration, including:

TOR 9. *the appropriateness of the use of average annual statistics given the comments made in the UNSW Report;*

TOR 10. *the dam filling times presented in the EAR, (see Section 3.4 of Working Paper A and Section 5.3 of Working Paper D) including those discussed in the UNSW Report;*

TOR 11. *the water balance and comparison of flows presented in Pages 55 and 56 of the UNSW Report;*

TOR 12. *the contribution of the Williams River inflow to the Hunter estuary considering daily, monthly, annual, seasonal, drought and worst case conditions; and*

TOR 13. *in particular, comment on a worst case scenario (from a hydrologic streamflow perspective) which should be considered in determining potential impacts on the Hunter estuary.*

1.5 ACTIVITIES UNDERTAKEN

In addition to consideration of the documents listed in **Section 1.3**, this review has also involved:

(a) discussions and correspondence with Anna Scott and Neville Osborne of the Department of Planning;

(b) inspection of the Williams River catchment including key items of HWC's water supply infrastructure on 1 July 2010 with Brendan Berghout and Roland Bow of HWC;

(c) discussion at HWC's office on 2 July 2010 with Brendan Berghout, Roland Bow and Bob Broadfoot;

(d) various telephone discussions and email correspondence with Brendan Berghout since commencement of the review in June 2010; and

(e) discussions with staff from the NSW Office of Water (NOW) during July 2010. These included hydrographers based at Maitland and hydrologists based at Newcastle.

[1] Refer Document No. 13 in Table 1.

2. HWC'S SOURCE MODEL

2.1 MODEL OVERVIEW

HWC's Source Model (referred to as '*SoMo'*) is the key hydrologic simulation tool that has been utilised throughout the EAR and the EASR. As well as simulating future conditions in the valley after construction of the dam, the model has also been important in defining the existing hydrologic data sets. This is because the model uses these data sets as input and consequently, as part of the initial establishment of the model, it was necessary to derive procedures to fill gaps in the data sets, and to extend them.

2.1.1 Model History

It is understood that *SoMo* was originally developed in the mid-1980s as a monthly time step model to simulate the principal components of HWC's headworks system and their ability to satisfy bulk water demands.

Like many such models developed by water authorities, *SoMo* was custom built with the unique characteristics and water management planning requirements of HWC's system.

It appears that the model has been revised and expanded on a number of occasions over the last couple of decades. A description of these changes is provided in the *SoMo Report.* The following changes are the most relevant for this review:

(a) inclusion of a daily time step for the simulation of key components of the Williams Valley, including the operation of Chichester, Tillegra and Grahamstown Dams, and Seaham Weir;

(b) improved simulation of the evaporation from, and rainfall onto, the surface of Grahamstown Dam. Given the relatively large surface area and shallow depth of this reservoir, evaporation is significant;

(c) development of daily runoff submodels for the principal subcatchments in the valley. These submodels, when combined with the historical records when available, allow streamflows to be determined for every day of the model simulation period; and

(d) as the model became progressively used to inform studies for the EAR and the EASR, it appears numerous revisions and enhancements were made. These were necessary for example to test various dam operating strategies (e.g. transparent and translucent releases, simulation of 'freshes', etc).

2.1.2 Documentation

As far as the reviewer is aware, *SoMo* has not been previously documented by HWC. This may be because the model was developed in-house and has been continually changing, and possibly because there has never been an internal requirement for such documentation to be produced within HWC.

It appears that both the EAR and the EASR were prepared in the absence of any formal documentation of *SoMo*. Nevertheless, the model has now been documented in the *SoMo*

Report listed in **Table 1**. As far as the reviewer is aware, in addition to the copy provided to the reviewer, a copy has also been forwarded to the Department of Planning. The reviewer is not aware that the report has been circulated to other government agencies nor made available to interested members of the general public.

2.1.3 External Review and Auditing

It is normal practice for important hydrologic simulation models to undergo external review or formal auditing by an independent third party.

Two reviews of *SoMo* were carried out by SKM in 2003 and 2008. Copies of the SKM reports have been listed in **Table 1** and have been provided for review. It is understood that these SKM reviews were necessary components of HWC's application to IPART in support of a price path review. As such the SKM reviews are principally concerned with HWC's bulk water supply system which is simulated at a monthly time step. The SKM reviews found that *SoMo* was an appropriate basis from which to estimate the system yield.

The SKM reviews provide some confidence that *SoMo* is appropriately representing the major components of HWC's bulk water supply system, including those which are located external to the Williams River Valley. Nevertheless the simulation of the proposed Tillegra Dam and its impact on streamflows within the valley on a daily time step (which are some of the principal issues in this review), have not previously been subject to review.

This current review has focussed on model issues relevant to the environmental assessment of the Tillegra Dam project as reported in the EAR and EASR. It has not included a review of the model software nor has it included a format audit of the model.

2.1.4 Williams River Modelling

HWC have divided the Williams River catchment into four subcatchments within their model as shown in **Figure 1**. These are:

(a) Chichester subcatchment;
(b) Tillegra subcatchment;
(c) Glen Martin subcatchment; and
(d) Seaham Weir subcatchment.

Within each subcatchment the principal inflows and outflows have been simulated on a daily basis. These inflow/outflow components comprise:

(a) evaporation from Chichester Dam, the proposed Tillegra Dam and Seaham Weir pool. The source of evaporation rates used is discussed in **Section 2.2.2** below. The surface areas of Chichester and Tillegra Dams have been calculated based on the volume in storage, whilst the Seaham Weir areas were assumed to be constant, noting that the surface area of the weir pool does not fluctuate significantly;

(b) subcatchment inflows have been derived from the available streamflow records, as discussed in **Section 2.2.1** below;

(c) river losses and weir pool losses, including irrigation, have been approximately determined. Monthly losses that are fixed proportions to the average monthly evaporation have been used over the entire simulation period;

(d) Balickera pumping rates have been determined within *SoMo* on a daily basis. Another part of the model separately simulates Grahamstown Dam on a daily time step. The available space in Grahamstown Dam influences the operation of the Balickera pumps;

(e) environmental releases, transfers and spills from Tillegra and Chichester Dams are simulated in accordance with the various rules discussed in the EAR and EASR. These are further documented in the *SoMo Report*; and

(f) Seaham Weir outflows including fishway flows and both controlled and uncontrolled gate flows, as discussed in the *SoMo Report* (and in particular, Appendix B of that report).

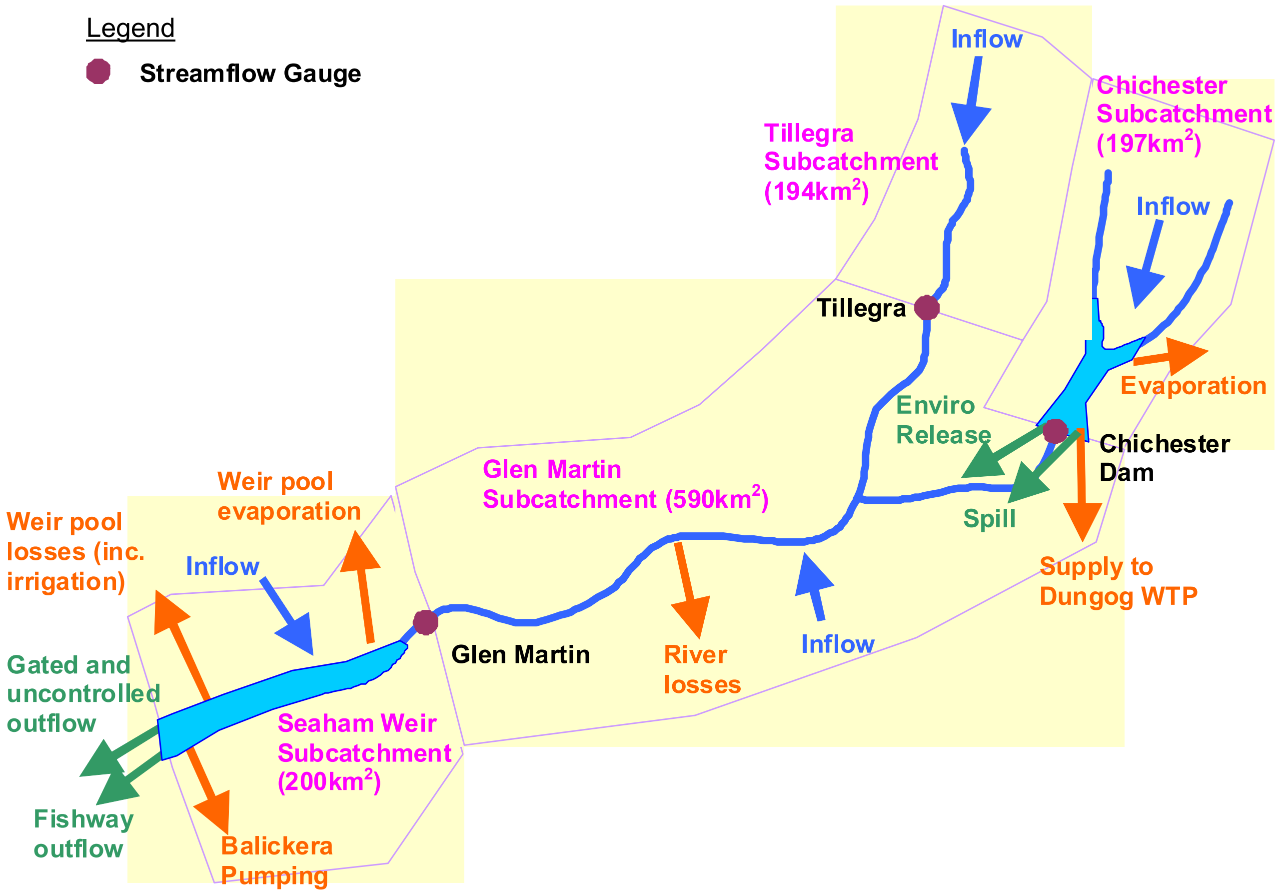

Figure 1: Williams River Model Schematic
(Source: Page 3, *SoMo Report*)

2.1.5 Model Simulation Period

As previously discussed, the principal components of *SoMo* which are of relevance to the EAR and the EASR operate on a daily time step, whilst other components of the model (external to the Williams Valley) including most bulk water demands, are simulated on a monthly basis.

The model simulations are carried out over a 77 year period from January 1931 through to December 2007. There is an inherent assumption in such simulation models that the climate of the past will reproduce itself in the future. Consequently, there are advantages in having the longest simulation period possible as it allows for the response of the system to a range of wet and dry periods to be examined.

It is understood that the principal constraint in utilising a longer simulation period was the establishment of the streamflow gauging station at Tillegra in 1931. There were significant extended droughts in the first two decades of the twentieth century, including the 'Federation drought' from 1902 through 1905. Obviously these droughts are not simulated in *SoMo* and to do so would require generation of streamflow records (based on rainfall) for all catchments within the model (noting that limited Chichester streamflow data is available from 1912).

The usefulness of extending the model simulation period back to the beginning of the twentieth century is strongly dependent on the availability of suitable rainfall records and the accuracy with which daily streamflow records can be synthesized based on these rainfall records. Although these matters have not been investigated further during the review, in the opinion of the reviewer, HWC's decision to commence this simulation in 1931 appears reasonable.

2.1.6 Model Results — Data Sets

Since March 2008, the model has been operated at various times to inform the EAR and the EASR. At the request of the reviewer, HWC have documented the basis of these model runs and listed them in Table 11 of the *SoMo Report*. There are a total of eight different data sets listed there. Further, through the use of Table 12[2] of the *SoMo Report*, it is possible to determine which data set was used to inform the relevant sections of the EAR and EASR.

As there has been a progressive development of the potential operating rules for Tillegra Dam and other structures during the preparation of the EAR and EASR, *SoMo* has been continually revised and updated to reflect these new operating conditions as the documentation of the EAR and EASR has progressed. Consequently, Table 12 of the *SoMo Report* provides useful information in correlating the various model runs with the relevant sections of the EAR and EASR.

The reviewer understands that one of the '21Jan10' data sets comprising:

> "*Post-Tillegra at 120GL/yr, 30%ile transparent release at Tillegra, 2.5GL/yr ECA from Tillegra, 95%ile transparent release at Chichester and 20ML/day fishway at Seaham*",

contains the results of the 'final' Tillegra Dam operating policy which HWC has proposed in the EASR.

Streamflow data series simulated by the model have been provided to the reviewer at some key sites. These include Tillegra Dam inflows, Glen Martin flows, Balickera transfers and Seaham Weir outflows. The simulated storage behaviour of Tillegra Dam from the '21Jan10' data set has also been provided.

[2] Most of the contents of this Table have been reproduced in **Appendix A**.

2.2 DATA SOURCES

2.2.1 Streamflow

The inflows to the four subcatchments shown in **Figure 1** have been derived using the procedures discussed below.

Tillegra Subcatchment

The streamflow records for this catchment have been recorded at the Tillegra stream gauging station (see **Photograph No 1**) since 1931.

Data for the 1.5% of days when records were not available were 'gap-filled' based on a *SimHyd*[3] rainfall runoff model using the rainfall records from Chichester Dam. This is an appropriate procedure.

Photograph No. 1: *View from the Tillegra Bridge (i.e. site of stream gauge) looking downstream towards the gravel bar which forms the hydraulic control for the Tillegra stream gauging station. It is understood that the movement of the bar (e.g. due to erosion or sedimentation during floods) has necessitated over a hundred rating table changes over the period since the station was established in 1931. The stage and streamflow records at this site have been subject to intensive review by NOW's hydrographers over the last decade.*

It is noted however that there is a lack of moderate and high flow gauging records of the Tillegra site. Consequently, HWC carried out a theoretical extension of the streamflow rating using a MIKE-11 model. This extension procedure was documented and has been

[3] *SimHyd* is a well recognised rainfall-runoff model that allows daily streamflows to be synthesized from daily rainfall.

reviewed. Whilst in the opinion of the reviewer it is unusual[4], the rating extension adopted by HWC appears reasonable. The reviewer further notes that these higher flows occur during less than 1% of the time at Tillegra, although nonetheless they contain approximately 25% of the long-term average streamflow volume.

Chichester Subcatchment

Chichester Dam was constructed over ten or twelve years prior to 1930 and consequently was present for the entirety of the 1931-2007 simulation period. Inflows to the dam were not directly measured and therefore were computed from the dam outflows, the change of storage volume recorded, and estimates of water lost by evaporation (or gained by rainfall). HWC has spent considerable time analysing this data and the reviewer is satisfied that the calculated Chichester streamflow time series have been appropriately[5] derived from this data. Where data gaps existed (approximately 2.3% of days), a *SimHyd* rainfall runoff model was used to generate the missing data. The reviewer believes that this has been an appropriate procedure for HWC to use.

Glen Martin Subcatchment

Whilst this subcatchment area is three times that at Tillegra, its annual runoff volume is comparable with that of Tillegra. This is due to its lower rainfall and different catchment characteristics.

The Glen Martin streamflow records are collected at the Mill Dam Falls stream gauging station shown in **Photograph No 2.**

The usual procedure to derive the subcatchment inflow is to calculate the difference in observed streamflows at the streamflow site and any upstream sites. In this case, this residual inflow would represent the difference between the Glen Martin streamflow records and those at Tillegra and Chichester. A significant issue in this review is whether these Glen Martin residuals have been determined appropriately by HWC. (Further comments are provided in **Section 4.3**). The procedure adopted by HWC is discussed below.

It is understood that when HWC derived the Glen Martin residual inflows, they found that the residuals contained many unexplained river flows (including some negative values). Consequently, HWC decided not to directly use the residual flows as input in *SoMo* but rather to fit a *SimHyd* model[6] to the observed data. In deriving these streamflows, HWC confined their assessment to the period of record after 1963 because a significantly improved 'fit' of the *SimHyd* model was obtained over this period. Whilst HWC were uncertain as to the reasons why the period prior to 1963 could not be used, the reviewer's discussions with NOW's hydrographers in Maitland (who are responsible for maintenance of the gauging site) indicate that during this earlier prior, streamflow records were based on manual daily readings, whereas post-1963, both Stevens and Bristol chart recorders[7] were installed and consequently, improved measuring accuracy will be obtained.

[4] For example, the extensive number of cross sections utilised and the modelling effort expended on the upstream river system (which has no influence on the water level behaviour at the gauging station), both appear unnecessary.
[5] Some uncertainty remains however and should further amendments be required to better simulate flows at Glen Martin (refer subsequent discussion) revision to the Chichester outflows may be warranted. Such revisions might address the negative flow values in the calculated Glen Martin residuals (discussed later in this Section).
[6] This *SimHyd* model was based on observed rainfall at Dungog.
[7] Chart recorders allow continuous recording of river stage. Thus variations in streamflow over a day can be taken into consideration when determining the daily streamflow. This is a distinct advantage over manually read gauge data which provide only a single 'snapshot' of the flow at one time in the day. This is likely to be particularly relevant in the Williams River where streamflows may vary considerably over a 24 hour period in response to localised rainfall.

Figures 8 and 9 in the *SoMo Report* present the performance of the *SimHyd* model fitted to the post-1963 data. Whilst this indicates that reasonable correlations[8] are achieved, it is of some concern that the overall mass balance is not preserved. Over the period since 1963, the simulated flows under-estimate the observed flows by about 10%, whilst over the full period since 1931, an average of 14% under-estimation occurs.

***Photograph No 2**: This photograph shows the rock bar which is immediately downstream of the Mill Dam Falls stream gauging station at Glen Martin. The presence of the rock bar has enabled the station rating to remain relatively stable over the period since the station was established (circa 1927). Discussions with NOW's hydrographers have indicated that prior to 1963, stream stage (i.e. water level) was manually measured once a day. Around 1963, chart recorders were installed which enabled the continuous measurement of stream stage. Consequently, these later records provide a much more accurate estimation of daily streamflow than the records for the period prior to 1963. Further the hydrographers also indicated that the Mill Dam Falls records have not undergone revisions and reconstruction to the same extent as been undertaken for the Tillegra gauge. Therefore there is potential for further refinement of the streamflow records at this site.*

It is further understood from the reviewer's discussions with NOW's hydrographers, that the Tillegra streamflow records have been carefully reviewed and revised by NOW in recent years, whereas the same opportunity has not been afforded to the Mill Dam Falls' records. Given the importance of the Mill Dam Falls' records, it is unfortunate that NOW have not been requested to undertake such revisions.

[8] Nevertheless, the correlations presented are for the Glen Martin streamflows, not the residual streamflows (i.e. the streamflows arriving at Glen Martin which do not originate from the subcatchments serviced by a streamflow gauge (i.e. Tillegra and Chichester Dam). The Glen Martin streamflows are strongly influenced by the Tillegra and Chichester flows and therefore mask the influence of the residual catchment flow to some extent. Correlation statistics for the residual inflows in isolation would likely show poorer performance of the *SimHyd* model than that documented in the *SoMo Report*.

Seaham Weir Subcatchment

Seaham Weir, which is shown in **Photograph 3**, has its own subcatchment that is comparable in size to that at Tillegra. The average inflow however has been estimated by HWC to be only about 40% of that at Tillegra.

Photograph No 3: *Seaham Weir provides a barrier across the Lower Williams Estuary and was constructed around 1967-1970. Vertical lift gates allow catchment flows that have collected on the upstream side of the structure to be released in pulses, typically of 1-1.5 hour duration. This maintains the upstream weir levels within the normal operating range. During flood times, the gates are lifted clear of the weir pool level until such time as the weir pool has dropped back to the normal operating range. Although not shown in the photograph, there is also a small fishway constructed through the weir which HWC have estimated passes approximately 5ML/d on average over a normal 28 day tidal cycle. This fishway is proposed to be upgraded to improve fish passage and allow up to 20ML/d to pass the weir. Note that in very dry times, the upstream water level can drop below the downstream level (due evaporation and other losses) and both the existing and proposed fishway flow 'backwards'.*

There are no streamflow records of the outflows from Seaham Weir. In the past, no equipment or procedure has been implemented to continuously record the streamflow contribution of the Williams River to the estuary. This has been a hindrance to developing a proper understanding of the hydrology of this area.

HWC have advised that currently both the upstream and downstream water levels, and the gate openings at the weir are continuously recorded, and it would appear possible now for the instantaneous streamflow to be computed using hydraulic formulae. It is recommended that procedures be put in place to record continuous streamflows[9] at Seaham Weir.

[9] To provide adequate representation of streamflows, the minimum recording interval may need to be half hourly when the gates are shut, and at intervals of no more than 10 minutes when the gates are open. The system also needs to be able to record back flow (i.e. flow upstream) that occurs through the fishway when the upstream weir level drops to low levels.

Because of the absence of streamflow records at Seaham Weir, it was not possible to derive estimates of the runoff from the 200km^2 local catchment between Glen Martin and Seaham Weir. Therefore HWC used the Glen Martin *SimHyd* model to simulate these inflows. This process utilised the smaller subcatchment area of Seaham Weir compared to that of Glen Martin, as well as observed rainfall from Clarencetown (in lieu of the Dungog rainfall used for Glen Martin)[10]. Whilst these adjustments compensate for the effects of rainfall and catchment area on streamflow, the use of the Glen Martin *SimHyd* model inherently assumes other catchment characteristics are similar. Given the differing topography this is unlikely to be the case.

Consequently the derivation of the Seaham Weir local catchment flows is subject to not only any errors in the Glen Martin *SimHyd* model itself, but also the additional uncertainties associated with the assumption of catchment similarity.

2.2.2 Rainfall and Evaporation Data

Rainfall and evaporation records form an important input to *SoMo*. They are used:

(a) to estimate changes in storage volumes resulting from direct rainfall onto, or evaporation from, the surface of storages. These adjustments are made within *SoMo* for the simulation of the storage behaviour of the proposed Tillegra Dam, Chichester Dam, Grahamstown Dam and Seaham Weir[11];

(b) as input to the *SimHyd* models for the Tillegra, Chichester and Glen Martin subcatchments. These models have been used for gap filling of the streamflow records of Tillegra and Chichester. As discussed above, these gaps comprise only 1.5% and 2.3%, respectively, of the daily records. Therefore the gap filling procedure is unlikely to have a significant outcome on the model results. Nevertheless, the *SimHyd* model derived at Glen Martin is utilised extensively[12] in *SoMo* and it is important that the corresponding rainfall records are accurate and representative.

It is unfortunate that the *SoMo Report* does not detail all the available rainfall and evaporation stations nor discuss the potential for use of these stations in the Glen Martin *SimHyd* model (for use in simulating local streamflows at Glen Martin and Seaham Weir).

Further, it is noted that the rainfall and evaporation estimates for Tillegra are based on data recorded at Chichester Dam. The evaporation is factored based on consideration of the evaporation records at Lostock Dam, and the rainfall is also factored after assessing the limited rainfall records at Tillegra between 1960 and 1986. In the opinion of the reviewer, this factoring procedure is reasonable.

Evaporation from Seaham Weir has been based on records from Grahamstown Dam. Again, this approach appears reasonable to the reviewer. Nevertheless, it appears that the impact of rainfall onto the surface of Seaham Weir has not been simulated explicitly and this may be an oversight.

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[10] This use of these *SimHyd* models by HWC results in the average annual runoff generated per km^2 in the Seaham Weir subcatchment being slightly higher than that generated in the Glen Martin subcatchment. Whilst this is possible, given its lower position in the catchment, it is unusual.

[11] As noted later, and in contrast to Tillegra, Chichester and Grahamstown Dams, direct rainfall onto the surface of Seaham Weir is not explicitly simulated.

[12] For generation of daily streamflows of the residual catchments at Glen Martin and Seaham Weir, throughout the 77 year simulation period.

Despite the above deficiencies, the overall use of rainfall and evaporation data by HWC has been satisfactory.

2.2.3 Irrigation Extractions and Other Losses

No attempt has been made to model irrigation extractions. The current irrigation entitlement in the Williams River Valley upstream of Seaham Weir is approximately 8.3GL/year[13] which, whilst small, is not insignificant.

Seepage and transmission losses from the River cannot be directly measured but can be inferred from water balance calculations. HWC have undertaken such calculations and determined rough estimates of these losses during extended dry periods.

Both irrigation extractions and losses have been simulated assuming they are proportional to average monthly evaporation rates. This is a somewhat simplistic approach as losses would be expected to vary with changing river flows and other climatic conditions. The resultant losses and extractions are less than 2% of the mean annual river flows which, to the reviewer, appear to be under-estimated based on other river systems. Whilst the actual losses and extractions in some periods may be significantly different from the assumed values, the impact of any errors in estimating these losses is unlikely to be significant when considering average annual water use in the Williams Valley.

2.3 MODEL VERIFICATION

Models are only approximations of reality. Consequently, when establishing a hydrologic model, it is normal practice to verify its simulation capabilities by comparing the output with observed data wherever possible in order to validate the model.

Ideally, verification of *SoMo*'s ability to reproduce streamflows should occur by comparison with actual flows at the Mill Dam Falls gauging station at Glen Martin, and at the outflow from Seaham Weir. Unfortunately the latter is not possible because streamflow records are not directly available at Seaham Weir, neither have they been derived from the weir pool records. The only location at which the simulated streamflows from the model can be verified is therefore at Glen Martin.

Whilst HWC have examined the correlation between the predicted and recorded streamflows at Glen Martin, they have made no attempt to reproduce the average annual streamflow volumes at Glen Martin and this has been criticised by UNSW and is discussed further in **Section 4.3** below.

Further verification could also be attempted by comparing the observed and predicted Balickera pumping and possibly the Chichester releases.

Consequently in hydrologic modelling terms, *SoMo's* ability to predict streamflows in the Williams River has not been properly verified. This reduces confidence in the model's streamflow predictions.

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[13] Page 7, Working Paper d, EAR. Note that currently this entitlement is unlikely to be fully utilised as it includes 'sleeper' licences. It nevertheless represents the ultimate usage that could occur in the future as a result of trading or expansion of irrigation in the Valley, within the constraints of the current Water Sharing Plan.

Re-calibration of the Glen Martin *SimHyd* model and a more rigorous verification of the *SoMo* output against recorded data could be undertaken. Whilst this would improve model confidence, it is unclear whether such work is essential at this stage of the project. As noted elsewhere, such revisions to the model would likely lead to a general reduction in the impacts of the Dam on the estuary. Flows to the estuary would increase in average annual terms although the likelihood of increases occurring over all flow ranges cannot be confirmed without further investigation.

In addition these model revisions would likely lead to marginally less reliance on the water supply from Tillegra Dam.

3. RESPONSE TO KEY HYDROLOGIC ISSUES

3.1 MASS BALANCE ISSUES

Average annual streamflow volumes at key locations were presented in Figure 10.7 of the EAR[14] using results from *SoMo*. This figure shows the 'pre-Tillegra' and 'post-Tillegra' conditions. A slightly revised version of this figure is presented in **Figure 2,** incorporating amendments made by the reviewer.

In relation to the mass balance information provided on Figure 10.7:

(a) the source of the average annual values provided on Figure 10.7 is not immediately apparent. The 'post-Tillegra' numbers do not correspond exactly to any of the *SoMo* data sets described in the *SoMo Report*. Nevertheless, the differences are minor and would be unlikely to alter any of the conclusions one draws from this figure. It is apparent that the model has been operated and refined on occasions during the preparation of the EAR and the EASR, and as a number of different data sets have been provided to the consultants documenting the EAR and EASR, it may be difficult to identify the true origin of all the information used;

(b) the mass balance in all parts of the system illustrated in Figure 10.7 is not necessarily preserved. Imbalances occur in a few locations and HWC have clarified[15] these in response to questions asked by the reviewer. In particular:

   (i) there is an imbalance at Grahamstown Dam for 'pre-Tillegra' and 'post-Tillegra' conditions. In both cases, this is due to a change in storage in the Dam which was not reported in Figure 10.7. These amendments have now been made in 'red' and are shown on **Figure 2**.

   (ii) a similar mass-balance error occurs with Tillegra Dam on Figure 10.7 and this has also been corrected in 'red' on **Figure 2**;

   (iii) discussions with HWC have indicated that *SoMo* assumes approximately 10% of water specifically released from Tillegra for transfer to Grahamstown Dam is assumed to be inaccessible to the Balickera Pumps due to unforseen operational constraints which may occur. On the advice of HWC, this additional loss stream is assumed to pass through the Seaham Weir pool and into the estuary. Accordingly, modifications to this part of the diagram have also been included in 'red' on **Figure 2**;

   (iv) in addition, spills from Grahamstown Dam find their way into the estuary and have been included in 'red' on **Figure 2**.

(c) note that the modifications made in 'red' on **Figure 2** seek to resolve inconsistencies in Figure 10.7 of the EAR based on the *SoMo* results. Further corrections could be made to these results themselves (e.g. to improve the prediction of local catchment inflows to Glen Martin and Seaham Weir), but these have not been attempted by the reviewer.

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[14] Refer Figure 10.7, Page 10.20, Part D, Volume 1, EAR.
[15] Refer Page 39 of *SoMo Report*.

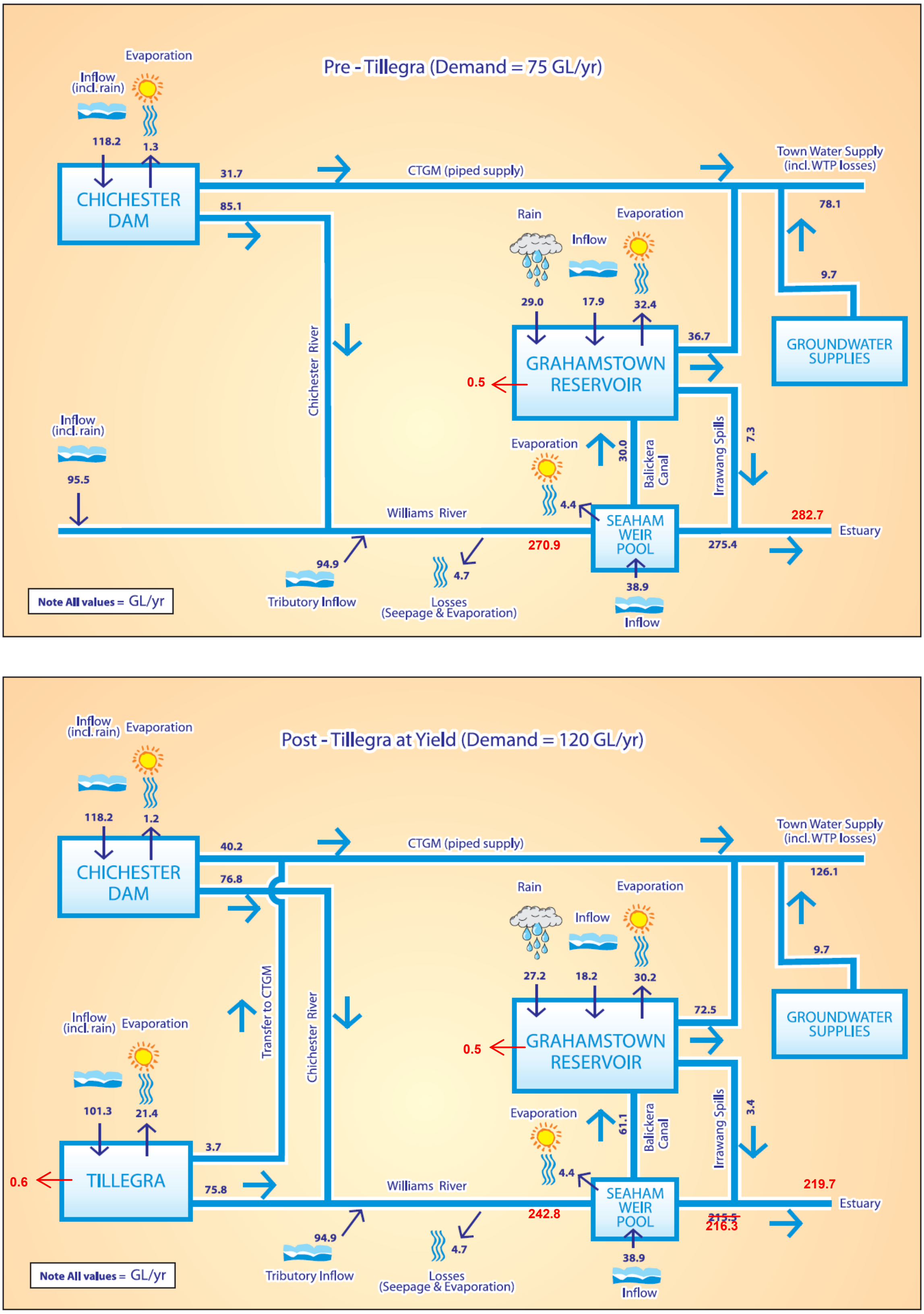

Figure 2: Mass Balance Diagram

(This is a reprint of Figure 10.7 from Volume 1 of the EAR. Additions in 'red' have been made by the reviewer. Note that the local catchment inflows at Glen Martin and Seaham Weir are based on the *SoMo* results and the reviewer has not attempted to rectify the identified deficiencies in the simulation of these inflows. For example, the 270.9GL/yr inflow to Seaham Weir, pre-Tillegra, should probably be around 320Gl/yr).

As shown on **Figure 2**, the construction of Tillegra Dam allows the average annual water demand to increase from 75GL/year to 120GL/year, i.e. an increase of 45GL/year. **Table 2** provides a breakdown of the capacity of the system to supply this increase in demand including the contributions of various system components. This indicates that in order to provide the additional 45GL/year supply:

(a) 21.4GL/year of evaporation occurs from Tillegra Dam and there is a resultant 2.2GL/year reduction in evaporation from Grahamstown Dam. The net change in evaporation from all storages is an increase of 19.1GL/year;

(b) there is a slight increase in runoff into the storages due largely to the construction of Tillegra Dam. *SoMo* assumes that when rainfall lands on the new water surface, additional runoff will result compared with the pre-dam situation when infiltration and evapo-transpiration losses would have occurred. (The reviewer agrees that such an increase in runoff will occur); and

(c) the outflow to the estuary at Seaham Weir is reduced on average by 63GL/year (i.e. 22%) compared with the pre-dam situation. This change includes a reduction in spills from Grahamstown Dam of 3.9GL/year.

Photograph No 4: *Balickera Pumps looking upstream to the pump station outlet. When this photo was taken, six pumps were in operation and the installed pump capacity was around 1350ML/day. (The 2004 licence indicates that the approved capacity was 1400ML/d). Note that recently two additional pumps were installed taking the installed capacity of the pump station to approximately 1800ML/day although actual pumping rates are dependent on levels in Grahamstown Dam and may vary. HWC's hydrologic model, SoMo, which has been utilised in the EAR and the EASR, has assumed a pump capacity of 1650ML/day. This would appear a reasonable assumption and provides for some 'downtime' when pumps may not be fully operational. NOW have advised that HWC's existing licence allows them to extract 1810ML/d and there is provision for them to increase this to 2000ML/d in the future.*

TABLE 2: BREAKDOWN OF SYSTEM SUPPLY[16] (AVERAGE ANNUAL FLOWS)

	Post-Tillegra GL/yr	Pre-Tillegra GL/yr	Change GL/yr	Change (%)
A. CTGM Delivery and WTP Losses	6.1	3.1	+3.0	+97%
B. Rainfall and Inflow into Storages				
Grahamstown Dam	45.4	46.9	-1.5	-3%
Chichester	118.2	118.2	0.0	0%
Tillegra	101.3	95.5	+5.8	+6%
Seaham Weir	38.9	38.9	0.0	0%
Sub Total	**303.8**	**299.5**	**+4.3**	**+1%**
C. Evaporation from Storages				
Grahamstown Dam	30.2	32.4	-2.2	-7%
Chichester	1.2	1.3	-0.1	-8%
Tillegra	21.4	n.a.	+21.4	n.a.
Seaham Weir	4.4	4.4	0.0	0%
Sub Total	**57.2**	**38.1**	**+19.1**	**+50%**
D. Change in Storage				
Grahamstown Dam	0.5	0.5	0.0	0%
Chichester	0.0	0.0	0.0	n.a.
Tillegra	0.6	n.a.	+0.6	n.a.
Seaham Weir	1.1	0.5	+0.6	+120%
Sub Total	**2.2**	**1.0**	**+1.2**	**+120%**
E. Other Tributary Inflow below Dams	94.9	94.9	0.0	0%
F. River Losses	4.7	4.7	0.0	0%
G. Groundwater Supplies	9.7	9.7	0.0	0%
H. Estuary Outflow at Seaham Weir	219.7	282.7	-63.0	-22%
I. Rounding Adjustment	-0.4	0.0	-0.4	n.a.
SYSTEM SUPPLY (-A+B-C-D+E-F+G-H-I)	**120.0**	**75.0**	**+45.0**	**+60%**

n.a. = not applicable

The use of average annual values such as that in **Table 2** are unlikely to reflect median conditions nor the behaviour during significantly dry or wet periods, nor the behaviour over shorter time periods such as daily or monthly.

[16] The term 'supply' has been used in this document rather than 'yield' to prevent confusion with the manner in which 'yield' is used elsewhere by HWC. For HWC, 'yield' is defined as the capacity to meet demand within a specified risk profile.

3.2 GRAHAMSTOWN DAM SPILLS

Although **Figure 2** shows spills from Grahamstown Dam entering the Williams River below Seaham Weir, the reviewer understands that the streamflow data sets that have been provided to BMT-WBM for assessment of any changes to the estuary, have not allowed for spills from this Dam. It is noted that these spills reduce on average from 7.3GL/year to 3.4GL/year following construction of Tillegra Dam. This is a 53% reduction in the spill volume but represents only a 2% change in the Williams River contribution to the estuary.

A brief assessment of the frequency and magnitude of the spills was undertaken by the reviewer using the '12July10' data set provided by HWC. This indicates that prior to construction of Tillegra Dam, Grahamstown would spill on average every 1.4 years and this frequency of spills would reduce to every 3.0 years following construction of the dam.

The frequency and magnitude of the spills is depicted in **Figure 3**.

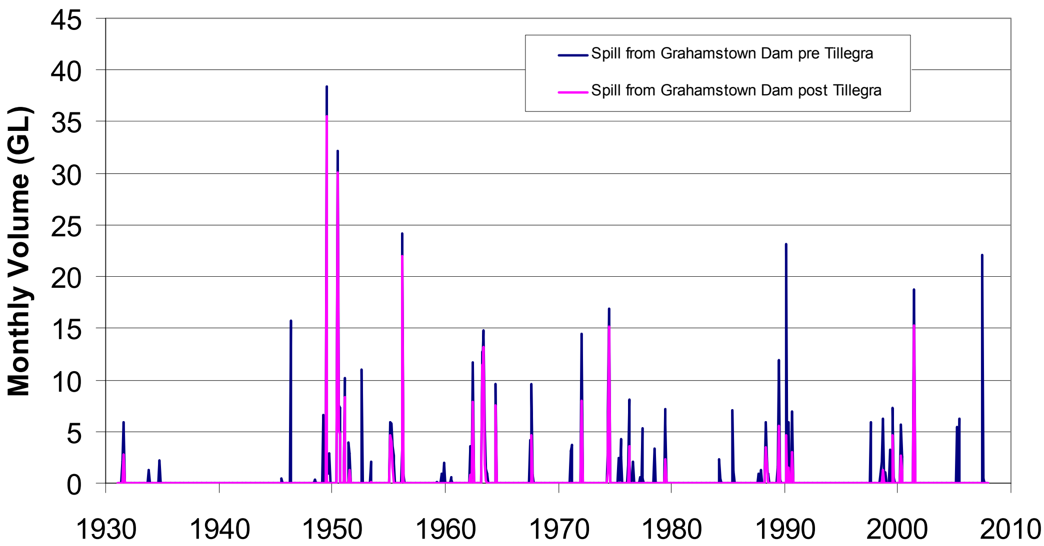

Figure 3: Spills from Grahamstown Dam simulated by *SoMo*

3.3 CATCHMENT BEHAVIOUR 'WITHOUT-DEVELOPMENT'

When considering major water infrastructure projects, it is common practice to provide information concerning the 'natural' conditions[17] in the catchment or the 'without-development' conditions[18]. The reviewer did not find a description of the hydrologic behaviour associated with either of these catchment conditions described in the EAR or the EASR. It is difficult to understand how consideration of changes in the cumulative impacts

[17] 'Natural conditions' are usually taken to mean the catchment conditions existing before European settlement. When compared with current conditions, this involves not only the removal of dams and other man-made water supply infrastructure but also consideration of alterations to the catchment response to rainfall which has resulted from landuse changes within the catchment. These landuse changes are still not well understood and are much more difficult to predict. Consequently, 'without-development' conditions are often simulated in hydrologic models as a substitute.

[18] 'Without-development' conditions assume that catchment runoff responses are those for current land uses within the catchment, but with the influence of all man-made water supply infrastructure and dams, removed.

on a catchment can be assessed without consideration of 'natural' conditions or 'without-development' conditions.

In the limited time available, the reviewer has prepared an estimate of the average annual streamflows under 'without-development' conditions, based on the information shown in **Figure 2**. This assessment is presented in **Figure 4**.

A brief comparison between the average annual flows to the estuary under the three scenarios shown in **Figures 2** and **4** is provided in **Table 3**. As can be seen, under current conditions the average annual flows to the estuary have been reduced by 21%, and with the construction of Tillegra Dam, a further 22% reduction will occur, resulting in a cumulative flow reduction of 43% from 'without-development conditions'.

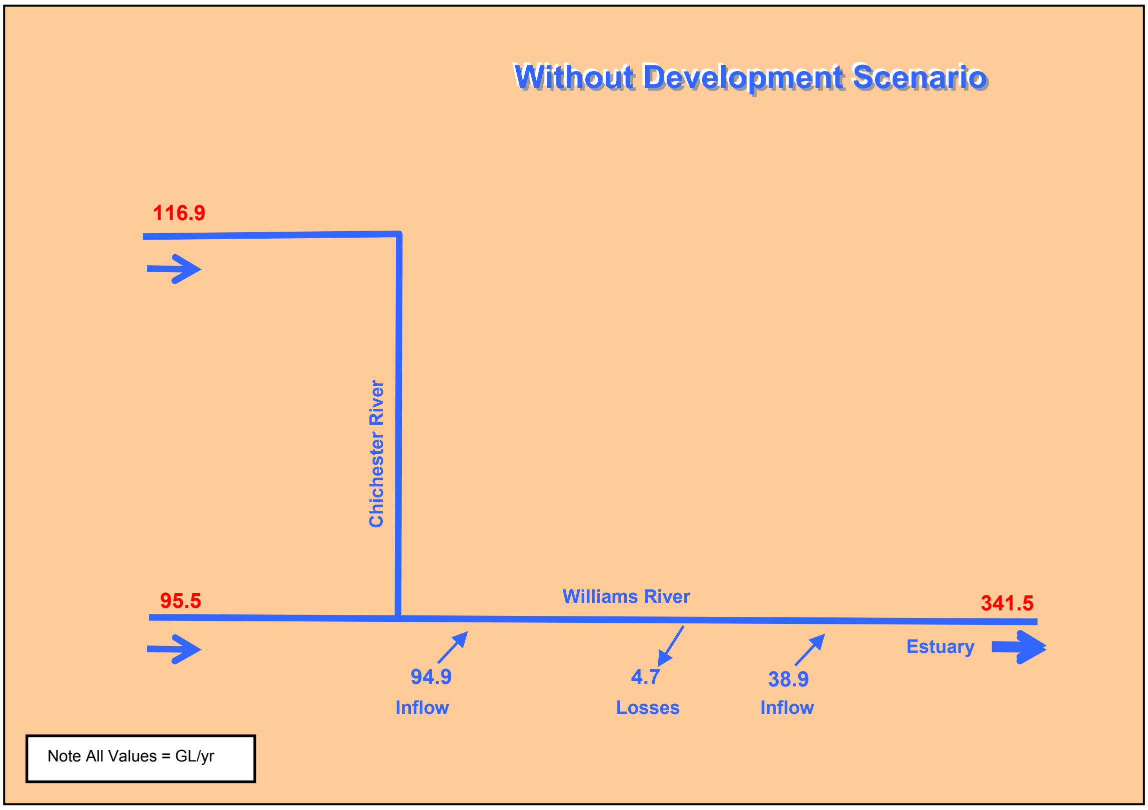

Figure 4: Average Annual Streamflows for 'Without-Development' Catchment Conditions'

Note that the above discussion, which is based only on annual streamflows, ignores the impact of the construction of Seaham Weir on tidal processes. Prior to the construction of Seaham Weir, there was a large portion of the lower Williams Estuary located above the weir and the significant tidal exchange which would have occurred prior to weir construction is no longer possible.

TABLE 3: FLOWS TO ESTUARY UNDER DIFFERENT CATCHMENT CONDITIONS

CATCHMENT CONDITIONS	AVERAGE ANNUAL FLOW	CHANGE[19]
Without-Development	341.5GL/yr	—
Pre-Tillegra	282.7GL/yr	21%
Post Tillegra	219.7GL/yr	43%

3.4 FILLING TIMES

In the documents listed in **Table 1**, the reviewer has identified at least four estimates for the time taken to fill Tillegra Dam:

(a) between 3 years (during wet periods) and 9 years (during drought)[20];

(b) between 2.5 years and 12 years, taking into account evaporation from the dam and no releases[21];

(c) around 6 years, based on the rainfall patterns since 1980[22]; and

(b) 8 years during a wet period and 15 years[23] during a dry period.

In order to better understand the likely filling times of the dam, the reviewer made his own assessment based on the Tillegra inflows provided by HWC as part of the '12July10' data set. The reviewer's assessment was approximate and assumed:

(a) transparent operation of the dam for all flows up to 100ML/d[24];

(b) the dam to commence filling at any time during the 77 year period from 1931;

(c) evaporation and rainfall impacts on the dam storage were estimated assuming two-thirds of the average annual values[25] for these parameters shown on **Figure 2**;

(d) an ECA allowance of 2.5GL/year assumed to apply over each year of the filling period; and

(e) four releases of 232ML each year to simulate the proposed release of 'freshes'.

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[19] To prevent confusion with other relative changes presented elsewhere in this report, the percentage changes in Table 3 have been calculated relative to pre-Tillegra flow conditions.
[20] Text in Section 3.4.2, Working Paper a, Volume 3, EAR. Although not stated in the text, supposedly this estimate ignores evaporation and releases (and therefore is unrealistic).
[21] Figure 3.3 and text in Section 3.4.2, Working Paper a, Volume 3, EAR.
[22] Text in Section 3.4.2, Working Paper a, Volume 3, EAR.
[23] Page 73 of the *UNSW Report*.
[24] Flows up to 100ML/d occur on 70% of days. With the transparent release rules, these flows are all passed downstream. On the other 30% of days when flows exceed 100ML/d, 100ML/d is passed downstream. The total volume of streamflow released in this manner represents about 20% of the volume of the total inflow to Tillegra over the long term.
[25] This is an approximate allowance in the absence of more complete simulation modelling that would progressively predict the change in surface area as the storage fills. Nevertheless it is expected to be a reasonable assumption.

The probability of filling was determined and is plotted in **Figure 5**. This indicates that at worst, the dam could take almost 18 years to fill, which is broadly consistent with the predictions made in the *UNSW Report*. Whilst it could fill in as little as three years, the most likely filling estimate is approximately eight years. Note also that the allowance for releases and evaporation can have some impact on the filling time[26]. This appears to be one reason for the different estimates of filling provided in the EAR.

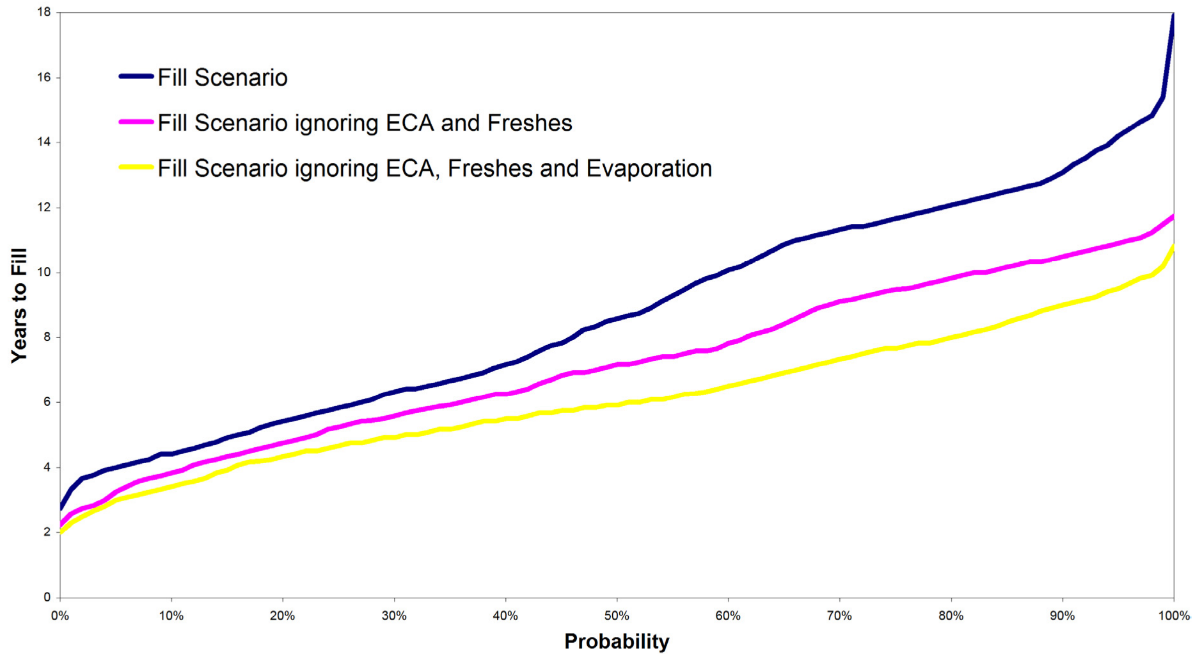

Figure 5: Probability of Dam Filling

Note also that if only the climate from 1980 to 2007 was considered, the filling time would still range from 3 to almost 18 years but the most likely filling time would now be 12 years.

3.5 USE OF HYDROLOGICAL DATA SETS IN EAR AND EASR

A number of different data sets have been generated by *SoMo* and used in the EAR and the EASR.

A brief review of the use of these data sets within different sections of the two reports has been undertaken and is summarised in **Appendix A**.

Based on the data available, this review did not identify any significant anomalies in the manner in which the data sets had been used.

[26] For example, increasing the assumption of the number of freshes from four to six per year would increase the maximum filling time from 17.9 years to 19.1 years.

3.6 FLOOD BEHAVIOUR

A review has been undertaken of the hydrology of the flood modelling for the estuary which is described in Chapter 4 of the Ramsar Wetland Study[27]. The flood modelling undertaken by BMT-WBM utilised an existing TUFLOW model which that firm had developed for the NSW Roads and Traffic Authority (RTA) in connection with an extension to the F3 Freeway at Heatherbrae. It is understood that project established a 100 year average recurrence interval (ARI) design discharge of 3060m^3/s in the Williams River downstream of Seaham Weir. Note, for the purpose of the current review, this design flow has been assumed to be correct and no separate review of the earlier work for the RTA, or any review of the TUFLOW flood model itself, have been undertaken.

Within the Ramsar Wetland Study, BMT-WBM examined the impact of Tillegra Dam on flood peaks by examining flood frequencies derived from the daily flows at Seaham Weir and produced by *SoMo*. This was undertaken for 'pre-Tillegra' and 'post-Tillegra' conditions. This investigation identified that for a range of ARI from 2 years to 200 years, Tillegra Dam reduced the corresponding daily flood peak by approximately 20%. It is noted that the flood peaks determined from the *SoMo* daily flows represent average daily flows and so do not necessarily correspond to the peak of the floods. Consequently, the 100 year flood peak at Seaham Weir based on the *SoMo* data is approximately 1810m^3/s which is a little less than 60% of the flood peak in the RTA's study.

The procedure used by BMT-WBM assumed that the (approximate) 20% attenuation of flood peaks determined from *SoMo* could be applied to the RTA design discharges.

In the opinion of the reviewer, this is an appropriate methodology to adopt although it is noted that the attenuation provided by the Dam, will be strongly dependent on the 'airspace' in the Dam at the onset of floods. This is, in turn, is subject to the operating policies adopted for the Dam. It is not clear from the data provided to the reviewer, the precise nature of the operating procedures that were assumed by BMT-WBM in deriving the attenuation factors, and whether these are now the same dam operating procedures which have been proposed in the EASR.

3.7 SIMULATED TILLEGRA STORAGE LEVELS

In order to understand the likely long-term variation in storage volume within Tillegra Dam (after the initial filling phase), simulated storage volumes were provided by HWC to the reviewer corresponding to the '21Jan10' data set. This is understood to be the final release proposal presented by the Proponent in the EASR and includes the 2.5GL/year ECA release and the 'ultimate' domestic water supply demand of 120GL/yr.

Figures 6 and **7** illustrate the proposed storage behaviour. As can be seen from these figures:

(a) the storage remains more than 90% full for 90% of the time;

(b) the storage remains more than 95% full for 83% of the time; and

[27] Appendix 6 of Volume 2, EAR. Note also that no review of the flood model has been undertaken. Only the impact of Tillegra Dam on the discharges used in that model, have been reviewed.

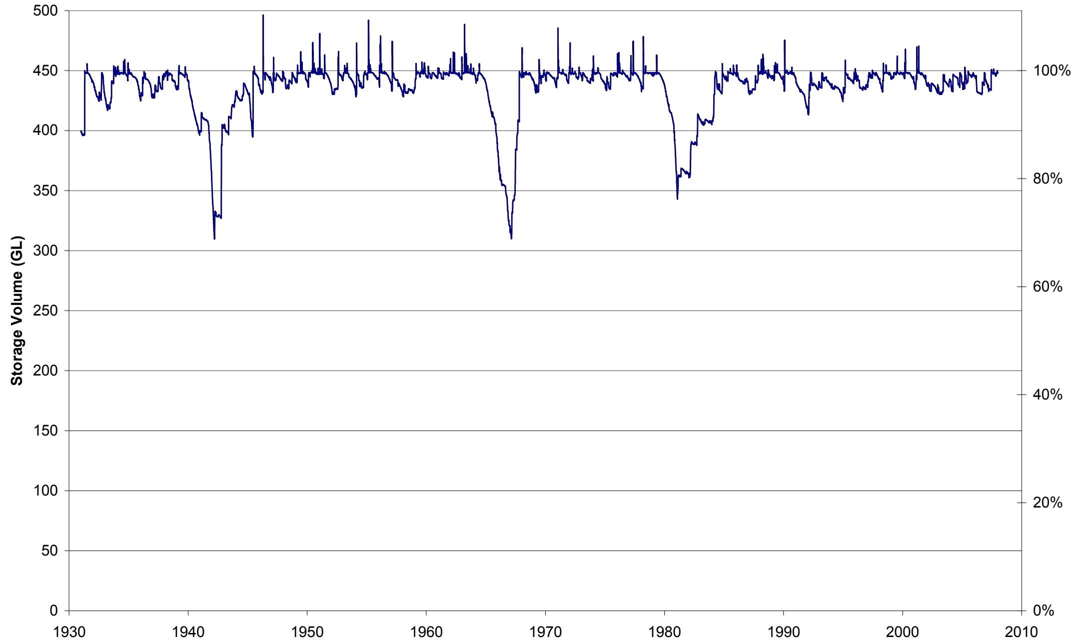

Figure 6: Simulated Tillegra Storage Volumes

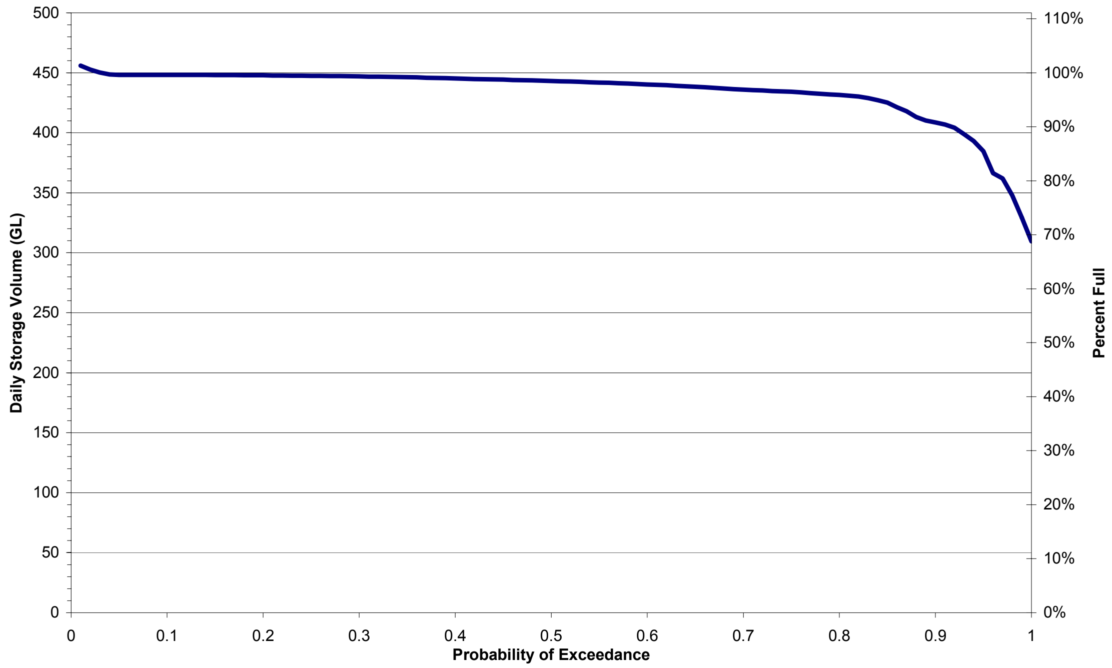

Figure 7: Simulated Tillegra Storage Volumes – Exceedance Probabilities

Note that the simulated storage volumes presented in **Figure 6** and **7** were provided by HWC in their '21Jan10' data set. The adopted release strategy used to derive these storage volumes comprises: "*Post-Tillegra at 120GL/yr, 30%ile transparent release at Tillegra, 2.5GL/yr ECA from Tillegra, 95%ile transparent release at Chichester and 20ML/day fishway at Seaham".*

(c) the minimum storage volume achieved over the 77 year simulation period would occur in March 1942 if the historical climate was to repeat itself in the future. The minimum storage volume achieved was 309GL (i.e. 69% of capacity). The next lowest storage level would occur in January 1967 when the storage would drop to 70% of its capacity.

3.8 CONTRIBUTIONS OF WILLIAMS RIVER TO THE ESTUARY

An important consideration in the environmental assessment of the impacts of Tillegra Dam has been the size of the Williams River flow contribution to the Hunter River estuary relative to other freshwater inflows to the estuary.

The fifth Terms of Reference for this review specifically addresses this issue and requests advice on whether the *"predicted contribution of Williams River flows to the Hunter Estuary is accurate and representative (of annual, seasonal, monthly and daily variation and of drought conditions), with and without Tillegra Dam?".*

In responding to this request, the reviewer notes that whilst data has been simulated with *SoMo* to allow these contributions to be calculated, limited details of these streamflow contributions are presented in the EAR or the EASR, although various references to the annual streamflow contributions are made (see separate discussion on the use of annual data in **Section 4.1**).

3.8.1 Reviewer's Calculations

Consequently the reviewer has carried out his own analyses of these contributions[28] and presented the results in **Figure 8** and in **Appendix B**. The contributions to the estuary from the Williams River and from other sources were determined over the 67½ year period[29] from January 1940 to June 2007 using daily data as follows:

(a) the Williams River contribution was calculated from:
    (i) the flow passed downstream of Seaham Weir; plus
    (ii) any spills from Grahamstown Dam;

(b) the other freshwater inflows to the estuary were determined from:
    (iii) the Hunter River at Greta; plus
    (iv) the Paterson River at Gostwyck; plus
    (v) contributions from the local catchments including Wallis, Throsby and Ironbark Creeks and other contributing areas[30];

(c) contributions on a daily, monthly, annual and seasonal basis were assessed;

(d) data for (i) and (ii) were taken from *SoMo*[31]. Estimates for (v) were provided by HWC. It is understood that the data for (i) and (v) was identical to that used in the TUFLOW-FV analyses in the EASR. As discussed in **Section 3.2**, data (ii), which is a relatively infrequent and minor contribution, was not included in the TUFLOW-FV analyses;

[28] Both volumetric 'contributions' and 'relative contributions' have been calculated. It is important to note that the term 'relative contribution' has a special meaning in this review (see penultimate paragraph of **Section 3.8.1**). The 'relative contribution' is a ratio (units are percentages). Also, the reviewer's calculations relate only to freshwater contributions into the estuary.

[29] This is the longest period for which data was available for each of the five contributions (i)-(v).

[30] Note that inflows/losses from the surface of the estuary due to rainfall and evaporation were not considered in the reviewer's assessment. (The reviewer understands however that an allowance for evaporation and rainfall was made in the TUFLOW-FV analyses).

[31] Consequently, the likely underestimation of the Seaham Weir flows discussed in **Sections 2.2.1** and **2.3,** will be carried through into the reviewer's estimates of the Williams River contributions to the estuary.

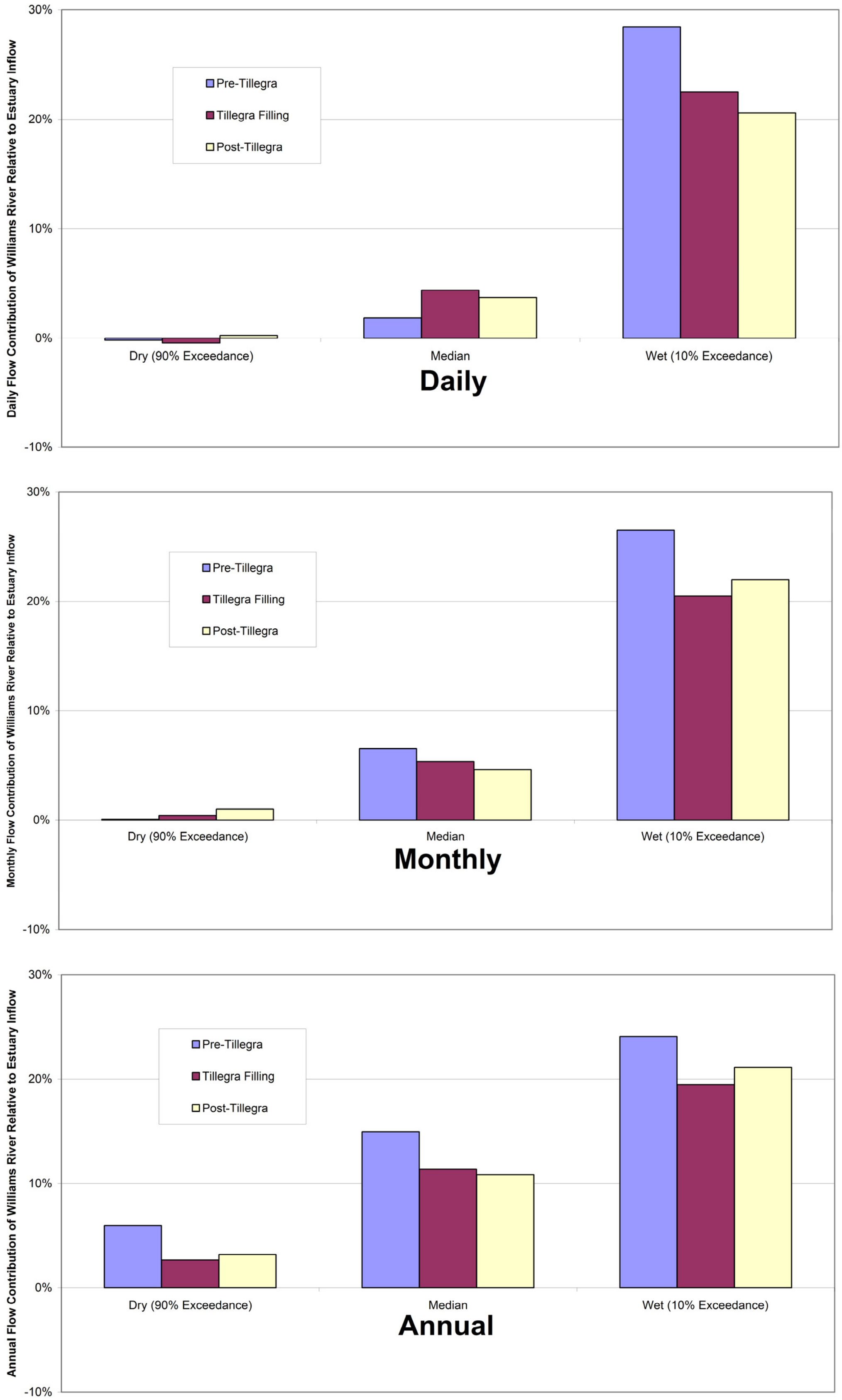

Figure 8: Relative Contributions of Williams River to Estuary (based on daily, monthly and annual assessments)

(e) data for (iii) and (iv) was provided by NOW based on IQQM modelling[32] for current conditions in the Hunter and Paterson Valleys;

(f) all the data sets were daily and from these, contributions on a monthly, annual and seasonal basis were calculated;

(g) in each case contributions under pre-Tillegra, post-Tillegra and a filling scenario were assessed[33].

The relative contribution was determined as the Williams River inflow to the estuary, divided by the total freshwater inflow to the estuary, on each day, month or year, over the 67½ period. These relative contributions are ratios on each day, month or year, as the case may be, and are expressed as percentages. Time series of these relative contributions were analysed statistically and some summary statistics are presented in **Figure 8**. Further details of the frequency of occurrence of these relative contributions are presented in **Appendix B**, including a seasonal analysis.

Note also that because the relative contributions are ratios, the mean of these ratios will be different from the long-term volumetric contribution of the Williams River divided by the total inflow to the estuary.

3.8.2 Reviewer's Assessments

In reviewing this information over the period 1940-2007, the following comments can be made concerning the inflow volumes and the relative contributions:

(a) without Tillegra Dam, the total inflow volume from the Williams River is approximately 16.9% of the total freshwater inflow volume from the estuary. Average annual, monthly and daily relative contributions are 15.5%, 10.2% and 8.0%, respectively[34];

(b) with the construction of Tillegra Dam and under the assumed 120GL/yr domestic water demand, the total inflow volume will reduce to 13.7% (-3.1%), and the average annual, monthly and daily relative contributions will reduce to 11.6% (-3.9%), 8.0% (-2.2%) and 7.2% (-0.8%), respectively. (Note that differences are quoted in brackets);

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[32] The Integrated Quantity Quality Model (IQQM) is the hydrological model used by NOW as the principal simulation tool for long term water resource planning in the Hunter Valley and its tributaries. These IQQM data sets include current flow rules in the Water Sharing Plans. Consequently the amount of water reaching the estuary compared with historic is lower due to increased water use in the Valley particularly by power stations. NOW's IQQM data sets for (iii) and (iv) were compared with those utilised in the TUFLOW-FV analyses and were found to be almost identical.

[33] The *SoMo* results for pre-Tillegra and filling scenarios were taken from the '21 Apr 09' data set and the post-Tillegra scenarios from the '21Jan10' data set. Data for items (iii), (iv) and (v) was assumed constant under each of these scenarios. Data for (ii) had not been provided to the reviewer for the filling scenario and was assumed to be the same as that for post-Tillegra scenarios. A description of the assumptions used in *SoMo* to derive the filling scenario is presented in the footnotes accompanying **Section 4.3**.

[34] Further investigations might be warranted to better understand the reasons for the differences in these percentages, e.g. why is the average daily relative contribution almost one half the average annual value? One explanation may be that the Williams inflows to the estuary are not well correlated with the inflows from other sources. Further it appears that the Williams contributes significantly more in relative terms to the estuary during higher flows than it does during lower flows. Whether this is due to climate and catchment differences or the impacts of existing infrastructure on flows (such as Seaham Weir) requires further consideration (of which very little has been provided in the EAR or the EASR).

(c) the EASR[35] erroneously estimates the Williams River inflow as 3% (on average) of the total freshwater flow in the estuary which is considerably less than the 16.9% inflow contribution referred to in (a);

(d) further the EAR[36] states that the reduction in freshwater flows out of the Williams River due to the Dam is expected to be 10%, which is consistent with the 0.3% reduction in annual inflows to the estuary referred to elsewhere in the EAR[37]. Nevertheless as discussed below, this 10% estimate also appears to be an error;

(e) as well, the EASR[38] quotes the mean of the monthly[39] contributions as 23%. This is somewhat more than the 16.9% computed by the reviewer. This is because the EASR writers have:

- ignored the freshwater contributions to the estuary from other local catchments which were included by the reviewer[40] (and were also used in the TUFLOW-FV modelling) – refer item (v) in **Section 3.8.1**;

- apparently carried out their analyses over the period from 1969-2006 rather than the longer period used by the reviewer; and

- used recorded flows for the Paterson and Hunter River inflows to the estuary rather than the IQQM data which provides a better simulation of current conditions than the historic records. (Note that this IQQM data was also used in the TUFLOW-FV modelling);

(f) the reviewer has calculated that a 22% reduction in Williams River contributions is caused by construction of the Dam. This is consistent with the EASR's (Table 6.2) mean monthly contributions of 23% (pre-Tillegra) reducing to 18% (post-Tillegra), and the reviewer's estimates of 16.9% (pre-Tillegra) reducing to 13.7% (post-Tillegra)[41];

(g) the inflow to Seaham Weir will reduce by 10%[42] although the outflow from Seaham Weir will reduce by 22%[43] as a result of construction of the Dam. This may be the

[35] EASR Section 7.2.2, page 176. This may be derived from the "3 per cent" referred to in the last sentence of Section 8.3.1 of the EAR, Working Paper a. However this latter number appears to refer to both freshwater and saltwater flows and this may be the cause of the error in the EASR. Note also that this erroneous 3% inflow contribution estimate appears only once in the EASR. The value of 23% is used more widely − see (e) in this Section.

[36] EAR Volume 3, Working Paper a, Sections 8.3.1 and 8.4.

[37] EAR Volume 1, page 10.63, Paragraph 5. (This would appear to be a reference to both freshwater and saltwater flows).

[38] EASR Table 6.2, Page 169

[39] The terms used in the EASR in Section 6.2.2 including Figures 6.2 and 6.3, and Table 6.2 are unnecessarily confusing. Terms such as "monthly mean daily discharge" and "mean monthly discharge" appear to be used inter-changeably in the text to refer to nothing more than monthly discharges (expressed in units of ML/d).

[40] The reviewer also allowed for the inflows from Grahamstown Dam spills into the Williams River downstream of Seaham Weir which were not included in the EASR analysis or the TUFLOW-FV modelling. However the influence of these additional flows would be small and would tend to increase the assessed Williams River contribution, not reduce it.

[41] The relative changes in both estimates are as follows. HWC: (23%-18%)÷23%=22%, and reviewer: (16.9%-13.7%)÷16.9%=18%. However this 13.7% relative contribution is the ratio of the Williams River inflow to that of the total estuary inflow under post-Tillegra conditions. If this post-Tillegra Williams contribution had been computed relative to the pre-Tillegra estuary inflows, the result would have been 13.2%. Thus the reviewer's relative change is (16.9%-13.2%)÷16.9%=22%. So HWC's and the reviewer's estimates of the percentage reduction in inflows to the estuary are consistent (although the inflow volumes calculated by HWC and the reviewer are different).

[42] This can be calculated from the Weir inflow figures on **Figure 2**, i.e. (270.9-242.8)÷270.9=10%.

source of the erroneous 10% change in estuary contributions referred to in (d) above; and

(h) the median annual relative contributions of the Williams River to the estuary will reduce from 15.0% to 10.8% (i.e. -4.1%) through construction of the dam. The median monthly relative contributions will reduce from 6.5% to 4.6% (i.e. -1.9%), whilst the medium daily relative contributions will increase from 1.8% to 3.6% (i.e. +1.8%)[44].

Given the importance of the estuary contributions it is unfortunate that a more comprehensive assessment of the Williams River contributions was not provided in the EAR or EASR.

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[43] After also allowing for the Grahamstown Dam spills. Note also that the EASR Section 6.2.3, paragraph 2, page 169 quotes the reduction as 20% which is close to the reviewer's figure of 22%. (The 20% estimate is based on the uncorrected flow numbers shown on **Figure 2**, and has not allowed for Grahamstown Dam spills).

[44] This latter increase is largely the result of increased low flows that will be released from Seaham Weir with the construction of the new fishway.

4. UNIVERSITY OF NSW REPORT

A number of issues relating to hydrology were raised in the *UNSW Report.* These have been reviewed and comments are provided in the following sections.

4.1 RELIANCE ON AVERAGE ANNUAL STREAMFLOW VALUES

4.1.1 Downstream of Seaham Weir

Consideration of the impacts of Tillegra Dam within the estuary below Seaham Weir is a matter for others to determine. The scope of this review focuses only on the streamflow hydrology within the Williams River at Seaham Weir and upstream. Consequently, there are a number of issues raised in the *UNSW Report* which are outside the terms of reference of this review. Nevertheless some comments have been made in relation to the reliance of average annual flow estimates in the EAR and EASR. These are discussed below.

The reviewer agrees with UNSW that there are a number of references in the documents to annual streamflow volumes when evaluating potential impacts of Tillegra Dam on the estuary. Because of variability in the hydrologic cycle, reliance on such annual values will often mask underlying behaviour at shorter timeframes which is not apparent solely from an examination of average annual data. In this regard, the EAR and EASR reporting appears to be somewhat deficient.

As far as the reviewer is aware, all streamflow data sets for Seaham Weir have been derived from *SoMo* and are available at daily intervals over the 77 year simulation period. It is this daily data which has been used for input in the modelling processes using both the ELCOM model and the TUFLOW-FV models[45]. It is unclear to the reviewer whether UNSW were aware of the existence and use of this daily data.

To the extent that UNSW's criticism relates to the reporting of impacts in the estuary based largely on annual average streamflow volumes, the reviewer agrees with UNSW that more comprehensive reporting based on smaller temporal scales (including daily and monthly) is necessary before drawing any conclusions regarding impacts. However it appears that daily data was used in the model assessments, particularly those based on TUFLOW-FV, although the summary reporting in the EAR and EASR does not always reflect this.

4.1.2 Upstream of Seaham Weir

Whilst the focus of the *UNSW Report* has been on downstream wetlands and the estuary, the reviewer notes that within the EAR and the EASR, there is a heavy reliance on a range of statistical measures for reporting streamflows above Seaham Weir, in addition to use of annual averages.

This reporting has generally utilised 'flow-duration' curves with some limited examination of the seasonal variability of streamflows. Generally the reviewer considers this reporting to be acceptable, nevertheless in his opinion, it would benefit[46] from a spells-type analysis on

[45] However whilst the daily data was available for both models, the data was not used directly in the ELCOM model as this model relied on percentile flow estimates derived from the daily data.
[46] A spells analysis could be generated easily from the *SoMo* model results that are already available. Nevertheless the need for such analysis should be based on the environmental requirements of the project.

streamflows. This would allow the impact of the dam and the frequency of duration of streamflow spells (i.e. periods when flows were above or below certain thresholds) to be determined and then used to provide input into the associated environmental assessments.

4.2 MONTHLY VOLUME CHANGES DOWNSTREAM OF SEAHAM WEIR

UNSW provided much analysis concerning the changes in monthly flow volumes passed downstream of Seaham Weir as a result of construction for the Tillegra Dam.

In relation to the changes in flow volumes within the Williams River itself, the reviewer has carried out similar calculations of the changes in monthly flow volume based on the '21Apr09' and '21Jan10' data sets provided by HWC. **Figure 9** shows the change in monthly Seaham Weir flows over the period from 2000-2007 during both a filling scenario[47] for Tillegra Dam and the final operating scenario[48] described in the EASR. Note that these flows are those immediately downstream from Seaham Weir and have not included for any spill contribution from Grahamstown Dam. **Figure 10** shows the percentage change from the existing situation.

The results show that over the period, reductions of the order of 80% occur on a number of occasions. As such, these results appear broadly consistent with those presented in the *UNSW Report*. However as can be seen from **Figure 10**, there will also be other months when flows increase by 80% (or more). These effects are not unexpected and are due to the regulation of streamflows by the Dam.

4.3 ANNUAL FLOW VOLUMES AT GLEN MARTIN

The 'mismatch' between the annual flow volumes at Glen Martin (which utilised the Mill Dam Falls stream gauging station) has previously been discussed in **Sections 2.2.1** and **2.3**. The UNSW modelling approach is heavily dependent on the recorded Glen Martin streamflows, whereas *SoMo* has placed higher reliance on the records from Tillegra and Chichester and has determined the residual inflows from the ungauged catchment above Glen Martin, based on the *SimHyd* rainfall runoff model. It is not surprising then that the UNSW approach produces different estimates of the average annual flows at Glen Martin when compared with *SoMo*.

In addition, there are differences because UNSW have based their annual averages on the 68 year period from 1940– 2008, whereas HWC have utilised a 77 year period from 1931 to 2007 in *SoMo*.[49]

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[47] This is contained within the '21Apr09' data set. HWC modelled this filling scenario using the standard 1931-2007 historical climate sequence with the following adjustments:

(a) Tillegra Dam level not allowed to exceed 200GL in the model, which effectively prevented simulation of any spills, but still allowed simulation of other aspects of dam operation including environmental releases. Surplus water above 200GL was simply 'taken' out of the system (i.e. preventing spills); and

(b) model was run with an urban water demand of 75GL/year on the basis that the dam will be constructed with HWC's expected demand levels over the next few years.

[48] This is the 120GL/yr 'ultimate' domestic water demand case with the 2.5GL/yr ECA and other releases described in **Sections 2.1.6** and **3.7** and also used in material presented in **Section 3.8**.

[49] Nevertheless if the *SoMo* results were worked out over the period 1940–2007, the average annual streamflow of 270.8 GL/year (shown in Table 8 on Page 56 of the *UNSW Report*) would increase by approximately 10GL/year. This leaves it still far short of the UNSW value of 341.9 GL/year.

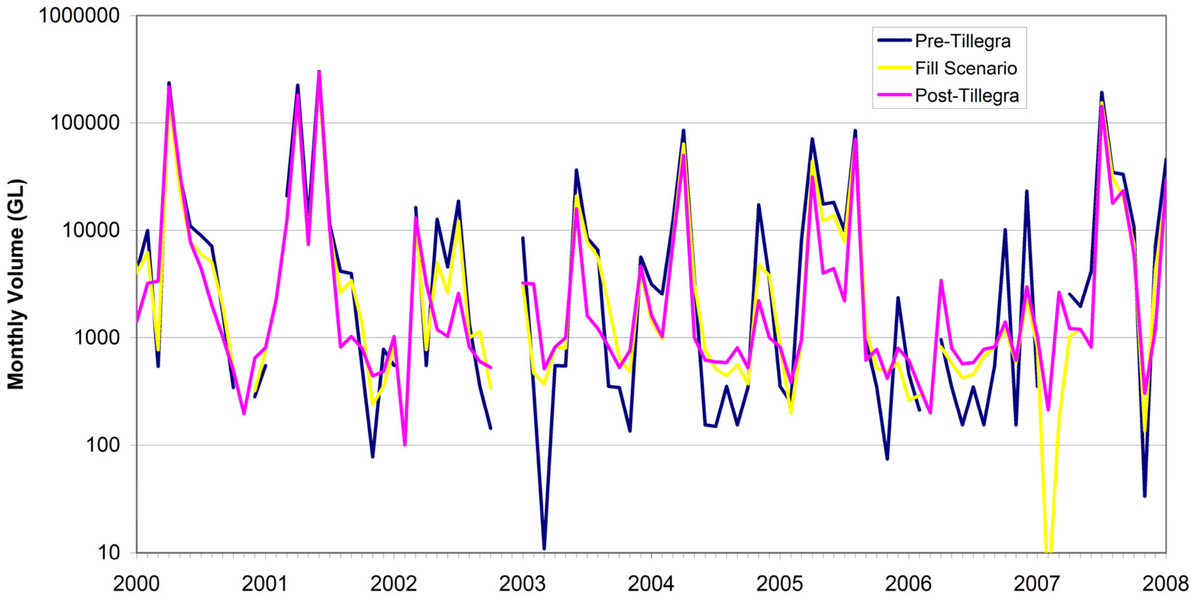

Figure 9: Monthly Flows past Seaham Weir to Estuary

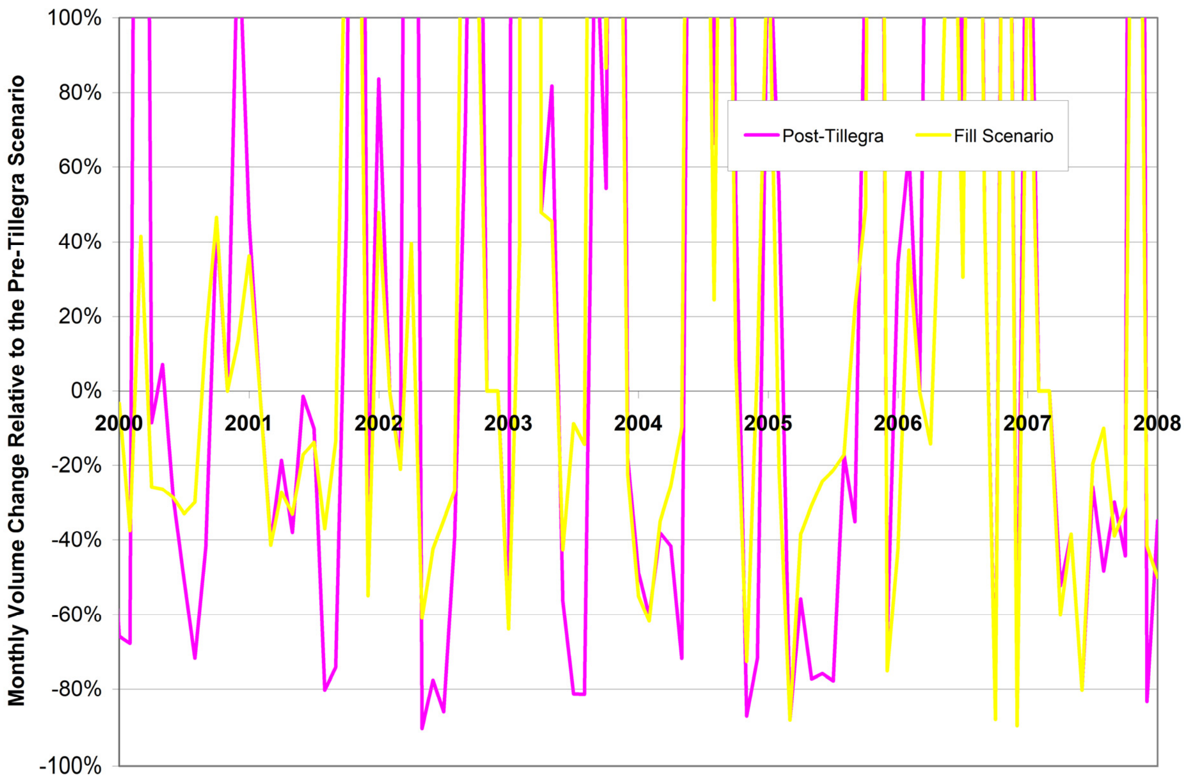

Figure 10: Change in Monthly Flows past Seaham Weir

Note that in about 10% of months, the simulated flow past Seaham Weir, pre-Tillegra, is negative (i.e. inflows into the Seaham Weir pool are predicted by *SoMo* to be less than the evaporation and other weir pool losses). Months with these negative flows have been excluded from **Figures 9** and **10**.

In reviewing the two approaches, the reviewer wishes to make the following comments:

(a) as discussed in **Sections 2.2.1** and **2.3**, the approach adopted in *SoMo* is deficient because the modellers have failed to adequately verify the model results with the observed flows at Glen Martin. Further, it may have been appropriate for HWC to have requested NOW's hydrographers to review the Glen Martin records in the same level of detail that has been undertaken for the Tillegra gauge. Without this hydrographic review, there remains some uncertainty about the accuracy of the Glen Martin records both in the period post-1963 when chart recorders were available, and in the period prior to 1963 when only daily read data was available;

(b) the approach adopted by UNSW relies heavily on the accuracy of the streamflow data at Glen Martin. In the period prior to 1963, it is less reliable than in the post-1963 period when chart recorders were available;

(c) the approach adopted by HWC in developing a *SimHyd* rainfall runoff model based on the post-1963 period has some advantages, if this *SimHyd* model was used purely for predicting streamflows in the period prior to 1963. However, HWC have undertaken the unusual step of utilising the *SimHyd* records in preference to the actual records for the post-1963 period;

(d) thus, in summary, in the post-1963 period, the approach adopted by UNSW is likely to be more accurate. In the pre-1963 period however, further analyses would be required to identify the best approach; and

(e) nevertheless in general terms, given that one of the primary outcomes of the hydrologic model is the determination of impacts caused by construction of the dam, differences in the approach used for modelling Glen Martin flows, will tend to 'cancel out', as the same flow sets have been used for both the 'pre-Tillegra' and 'post-Tillegra' scenarios. This is a generalisation however and it might not be true for some ecological and geomorphological assessments, and it might not be true over all flow ranges.

5. SUMMARY AND CONCLUSIONS

5.1 REVIEW FINDINGS

(a) The primary emphasis of this hydrology review has been on streamflows in the Williams River and the potential changes to streamflows that might occur through the construction of Tillegra Dam.

(b) HWC's Source Model (known as *'SoMo'*) simulates streamflows over a repeat of the 77 year climate from 1931 to 2007. The model has been used to examine both existing streamflows and those predicted to occur following construction of Tillegra Dam.

(c) *SoMo* has its origins as a monthly model simulating the bulk water movements in HWC's water supply network. More recently, parts of *SoMo* have been converted to a daily timestep to provide improved information on streamflows in the Williams River and to inform the environmental assessments which have been documented in the Environmental Assessment Report (EAR) and the Environmental Assessment Submissions Report (EASR).

(d) The daily streamflow simulations within *SoMo* have not been properly verified in accordance with the usual hydrologic modelling procedures. This lack of verification of *SoMo* has detracted from its credibility in assessing the impacts of the proposed Tillegra Dam on streamflows. It would appear to the reviewer that HWC have adopted some conservatism in their modelling approaches which ensures that the predicted water supply benefits of Tillegra Dam are not overstated. A consequence of this however has been a lack of rigour in the prediction of streamflows.

(e) Comparison of *SoMo's* estimates of average annual streamflows at the Mill Dam Falls gauging station at Glen Martin with the observed streamflow records at this site, suggest that *SoMo* may be under-estimating the streamflows by approximately 14%. This criticism has also been levelled at HWC by the University of NSW (UNSW) in the recent report prepared by Kingsford and Hankin. The reviewer agrees with UNSW that *SoMo* is likely to be under-predicting streamflows, particularly in the post-1963 period of the simulation, and possibly also in the pre-1963 period.

(f) If additional rigour was applied to *SoMo's* streamflow predictions at Glen Martin, there may be some changes in the environmental assessments which have been documented in the EAR and the EASR (the environmental significance of which is for others to determine). It is likely that as a result of these improved predictions, the Glen Martin average annual discharges may increase. One consequence of this would be that the impacts of Tillegra Dam on the estuary would be assessed against higher pre-Tillegra flows. In general terms, this will likely result in proportionally lower streamflow impacts[50] due to construction of the Dam.

(g) Another consequence of these more rigorous streamflow predictions would be the potential to harvest slightly more water via the Balickera pumps and marginally reduce reliance of the water supply system on Tillegra Dam.

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[50] This is general comment and may not necessarily be true over all flow ranges. To bring some clarity to this issue, further analysis of the discrepancies in the Glen Martin streamflow estimates would be necessary.

(h) UNSW have also levelled criticism at parts of the EAR and EASR for dismissing potential environmental impacts in the estuary largely on the basis of changes in average annual streamflow inputs. The documentation in the EAR and EASR supports this contention. Nevertheless the estuary consultants working for the Proponent had full access to daily streamflow predictions from *SoMo*. Therefore this appears to be an issue with the reporting rather than the modelling methodology.

(i) There have been a variety of data sets produced by *SoMo* during the last few years and used for input into parts of the EAR and EASR. HWC have provided parts of these data sets to the reviewer and have also documented the use that was made of the data sets by the authors of the EAR and EASR. The use of different data sets in different parts of the reports makes it difficult for readers. Nevertheless, the reviewer doubts whether the environmental assessments of the baseline conditions and those following construction of the dam, would alter to any significant extent if consistent data sets were used.

(j) Based on the data sets provided by HWC, the reviewer has calculated that once the dam commences to impound water, if the climate of the past 77 years was to repeat itself in the future, the dam could take almost 18 years to fill. The minimum filling time would be a little under three years and it is most likely that the dam would take around eight years to fill. Shorter estimates of the maximum filling time have been presented in the EAR. These are either in error or have been based on different dam operating policies from those proposed in the EASR.

(k) The increased system supply of 45GL/year which will be necessary to allow domestic water demands to increase from 75GL/year to 120GL/year, will be achieved by a reduction in average annual flows at Seaham Weir by 63GL/year and provision for the evaporation from Tillegra Dam of 19GL/year, in addition to other minor adjustments.

(l) The review assessed that monthly streamflow volumes passed to the estuary downstream of Seaham Weir could reduce by as much as 80% (in individual months) after construction of the dam. These predictions appear consistent with those made by UNSW. Nevertheless a large part of this change will be due to the regulation effects of the dam and will be associated with corresponding increases in other months. There will nonetheless be an overall decrease of about 22% in the volume passed to the estuary on average compared with the pre-Tillegra scenario.

(m) Under current conditions, on average 16.9% of the freshwater inflows to the estuary originate from the Williams River. This will reduce to 13.7% of the estuary inflows, post-Tillegra. One part of the EASR erroneously suggests 3% of the estuary inflows originate from the Williams River whilst other parts state that the current contribution is 23%. The latter is an overestimate caused by various simplifying assumptions.

(n) The review has determined that the ratio of the Williams River flows into the estuary compared to the total freshwater inflow to the estuary in any month, varies from about -14% to almost 50% of the estuary inflows in that month, under current conditions. The average value of this monthly relative contribution is 10.2% and this will reduce to 8.0% after construction of the Dam (and the domestic water demand increases to 120GL/yr).

(o) Under normal operation of Tillegra Dam with the 120GL/yr increased water demand, the Dam will be more than 90% full for 90% of the time, and more than 95% full for 83% of the time. Over the 77 year simulation period and under the proposed system supply of 120GL/year, the dam would not drop below 69% of its full capacity. This minimum level would occur in March 1942 and a second subsequent drop to 70% of its full capacity would occur in January 1967. In the initial years after the Dam has filled and water demands have not increased to 120GL/yr, it is likely that higher storage levels than those described, will occur.

(p) The present water supply infrastructure in the Williams River catchment has reduced average annual flows to the estuary by some 21% (relative to current conditions). With the construction of Tillegra Dam and the projected 120GL/year water use, estuary inflows will drop a further 22%, producing an overall reduction of 43% compared to the 'without-development' scenario.

(q) All the current estimates of Williams River flows entering the estuary have been based on the *SoMo* results and therefore include a lack of rigor in modelling the Glen Martin streamflows, as discussed in (e), (f) and (g) above and in **Sections 2.2.1, 2.3** and **4.3**. This includes the current ELCOM and TUFLOW-FV modelling and the reviewer's own calculations of the Williams River contributions to the estuary (which were based partly on the *SoMo* results).

5.2 RESPONSE TO TOR

5.2.1 Model Purposes for TOR 1-4

Many of the Terms of Reference (TOR) listed in **Section 1.4** relate to HWC's Source Model '*SoMo*'. In responding to the TOR, it is important to realise that models are only approximations of real world behaviour and they simulate different types of hydrologic behaviour with different levels of accuracy. Therefore the evaluation of a model cannot be carried out in isolation of the purpose to which is it to be used. In other words, any rigorous assessment of a model must consider whether a model is 'fit-for-purpose'. This is particularly relevant when considering TOR 1-4.

In responding to TOR 1-4 and assessing *SoMo*, the reviewer has focussed his attention on the following model purposes. These relate to the model's ability to inform:

Purpose (a) variability in streamflow volumes entering Tillegra and Chichester Dams, the simulation of release rules for these dams, and the prediction of the variability in storage levels;

Purpose (b) variability of streamflows in the Williams River below Tillegra and Chichester Dams at time scales of annual, monthly and daily, for the purpose of informing environmental assessments of the River and the estuary; and

Purpose (c) determining the magnitude of changes in (b) due to the construction of Tillegra Dam.

In addition, the reviewer has given cursory attention to the model's ability to simulate:

Purpose (d) bulk water demands in the HWC system beyond the Williams River, the influence of these demands on the behaviour of Grahamstown Dam and the frequency of operation of the Balickera pumps. (These matters have been previously assessed by SKM[51] and are the subject of other expert reviews);

[51] Refer Documents 6, 7 and 8 in **Table 1**.

Purpose (e) the performance of the HWC system during extended drought periods which influences the justification of Tillegra Dam (which the reviewer understands has also been the subject of other expert reviews); and

Purpose (f) estuary hydrology and hydrodynamics (which the reviewer understands have also been the subject of other expert reviews).

5.2.2 Tabulated Response to TOR

TOR 1-4 are of a general nature and relate to the capabilities of the *SoMo.* Responses to each of these TOR, having regard to the model purposes discussed above, are presented in **Table 4** below.

Responses to TOR 5-12, which relate to more specific model output issues including matters arising from the *UNSW Report*, are provided in **Table 5**.

TABLE 4: RESPONSE TO TERMS OF REFERENCE 1−4

TERMS OF REFERENCE[52]	MODEL PURPOSE[53]	RESPONSE
TOR 1. *The validity and appropriateness of the modelling undertaken.*	Purpose (a): Storage behaviours	The modelling is valid and appropriate.
	Purpose (b): Streamflow variability	The validity and appropriateness of the modelling is diminished by lack of adequate verification against recorded streamflows. Consequently some lack of precision in streamflow predictions is expected. Daily streamflows at Glen Martin and Seaham Weir likely to be under-estimated − see Note A.
	Purpose (c): Dam impacts	The proportional change in Glen Martin and Seaham Weir streamflows caused by dam construction may be slightly overstated − see Note A.
TOR 2. *The validity, accuracy and precision of the model input.*	Purpose (a): Storage behaviours	The modelling input is valid, and has an appropriate level of accuracy and precision. The consideration of spatial variability in rainfall and evaporation data has been limited, and confidence in the adopted estimates may have been improved if this had been done. Nevertheless no significant shortcomings have been identified in this review.
	Purpose (b): Streamflow variability	Glen Martin residual inflows have reduced validity, accuracy and precision because they have not been appropriately verified. Refinement of the Glen Martin streamflow records and the derivation of a time series of historical Seaham Weir outflows (subject to availability of data) would be beneficial in increasing confidence in the model's streamflow simulations. The potential change to the environmental assessments which might result from an improved model will determine whether the current model needs to be refined. In general terms, an improved model will probably result in proportionally smaller impacts to the estuary and an increased water supply from the system (i.e. marginally reducing reliance on Tillegra Dam) − see Note A.
	Purpose (c): Dam impacts	The relative accuracy of the differences between two model runs will be greater than the absolute accuracy of the results from each individual model run.
TOR 3. *The validity, accuracy and precision of interpretations based on model results.*	Purpose (a): Storage behaviours	Filling time estimates for Tillegra Dam appear sensitive to the assumed release rules. Various filling times have been reported in the EAR and EASR based on differing assumptions. Nevertheless the documents have failed to clearly portray the expected filling times for the proposed operating conditions presented in the EASR.
	Purpose (b): Streamflow variability	The validity/accuracy/precision of the interpretation of any environmental impacts drawn from the modelled streamflows is a matter for other to determine. Such interpretations may have been better informed had a 'spells' type analysis been carried out on streamflows.
	Purpose (c): Dam impacts	Conclusions (if any) concerning impacts in the estuary, which were drawn only from consideration of annual streamflow changes, are likely to be tenuous.

[52] Refer **Section 1.4** for a more complete description of these Terms of Reference.
[53] Refer **Section 5.2.1** for further details of these purposes.

TERMS OF REFERENCE[52]	MODEL PURPOSE[53]	RESPONSE
TOR 4. *Modelling improvements.*	Purpose (a): Storage behaviours	Few. There may be some benefit in obtaining a better understanding of the spatial variation in rainfall and evaporation across the catchment (for input into storage behaviour and streamflow modelling for Glen Martin and Seaham Weir residuals).
	Purpose (b): Streamflow variability	Refine the modelling of the Glen Martin and Seaham Weir residual inflows as discussed in TOR 2 above.
	Purpose (c): Dam impacts	No improvements to the process of modelling these impacts (i.e. differencing 'pre-' and 'post-Tillegra' model runs) are necessary.

TABLE 5: RESPONSE TO TERMS OF REFERENCE 5−12

TERMS OF REFERENCE	RESPONSE
TOR 5. *Accuracy and representativeness of Williams River flows entering estuary.*	Within the EAR and EASR there is a lack of analysis of the Williams River streamflow contributions to the estuary over different temporal periods. One part of the EASR erroneously quotes the average contribution as 3% whilst in other places, the contribution is generally quoted as 23%. The reviewer has determined that the average contribution of the Williams River is about 17% of the existing estuary inflow volume. This estimate is based on the existing HWC modelling with underestimated Glen Martin streamflows. If these flow predictions were improved, the relative contribution to the estuary would likely increase. Consequently, the proportional impact of construction of Tillegra Dam would likely reduce − see Note A.
TOR 6. *Use of annual average flow statistics for Williams River flows entering estuary.*	77 years of daily streamflows generated from *SoMo* were provided to the EAR and EASR consultants for their estuary assessments. Conclusions (if any) concerning impacts in the estuary, which were drawn only from consideration of annual streamflow changes, are likely to be tenuous.
TOR 7. *Tillegra Dam impacts on Williams River flows entering estuary.*	Daily streamflows passing Seaham Weir into the estuary may be overstated − see Note A. The proportional impact of changes due to construction of Tillegra Dam may consequently be also overstated − see Note A.
TOR 8. *Water balance (Figure 10.7 of EAR).*	Generally OK subject to potential improvements to residual inflows from the ungauged subcatchments upstream of Glen Martin and Seaham Weir, as discussed in TOR 2 above. Some other revisions to Figure 10.7 of the EAR have been provided in **Figure 2** of this review but these do not include the residual inflow improvements mentioned above.

TERMS OF REFERENCE	RESPONSE
TOR 9. *UNSW's comments on use of average annual statistics.*	77 years of daily streamflows generated from *SoMo* were provided to the EAR and EASR consultants. Conclusions (if any) concerning impacts in the estuary, which were drawn only from consideration of annual streamflow changes, are likely to be tenuous.
TOR 10. *UNSW's comments on dam filling times.*	UNSW have suggested the Dam could take between 8 and 15 years to fill. Based on the 'final' release strategy presented in the EASR, the reviewer has determined the filling time could range from 3 to 18 years (refer **Figure 5** of this review). Consequently UNSW have significantly over estimated the shortest filling time but have more closely estimated the longest filling time.
TOR 11. *UNSW's comments on water balance.*	There is an imbalance at Glen Martin over the 77 year simulation period particularly post-1963. The reviewer agrees that the UNSW approach of adopting streamflow records at Glen Martin for the period prior to 1963 may be appropriate, but this requires further checking (including potential improvements to the streamflow records). The UNSW approach of inferring residual inflows to the Seaham Weir catchment based on those at Glen Martin may not be appropriate as it does not allow for the spatial variation in rainfall between the two catchments. In general terms however, the reviewer agrees with UNSW's comments.
TOR 12. *UNSW's comments on Williams River flows entering estuary.*	UNSW's monthly flow reductions are of the right order and generally agree with the *SoMo* results. However due to the regulation of streamflows by Tillegra Dam, significant increases in the volumes reaching the estuary will also occur in some months. Overall Tillegra Dam reduces flows to the estuary by about 22% although much greater variations may occur in some months (or other time periods). (See also response to TOR 5).
TOR 13. *Worst case scenario for determining impacts on estuary.*	The 'worst case' cannot be defined in the absence of a description of the consequences that are under consideration (e.g. worst case for maximum salinities in the estuary, worst case for loss of pumping access by estuary irrigators, etc). In general terms, combination of relatively high flows in the Williams River with relatively low flow contributions from the Paterson and Hunter Rivers to the estuary, will likely lead to a number of worst case consequences. If not already considered, these might require consideration in order for the impacts of Tillegra Dam to be rigorously assessed. Nevertheless consideration of the estuary behaviour over the 77 year period for which *SoMo*'s daily results are available, would likely contain the principal flow combinations that would need to be considered.

Note A: This is a general statement and might not be true over all flow ranges. Further detailed analyses would be required before more definitive information can be provided.

APPENDIX A

USE OF SOMO DATA SETS WITHIN DIFFERENT SECTIONS OF THE EAR AND EASR

Table A – Assessment of Streamflow Data[54] Presented in EAR and EASR

EAR or EASR Reference[55]	Description	Hydrology Variable	Sites	Data-Set Used[56]	Comments	Reviewer's Assessment
Volume 1 Sect 10.2.2	General characterisation of flows in catchment	Daily time series (SoMo)	Tillegra GM	20 March 2008 21 April 2008 8 August 2008 17 July 2009	Last model run received on 14/8/2009 based on the 17 July 2009 model.	See Notes 1 & 2
Volume 1 Sect 10.2.4	Discusses geomorphic process discharge threshold	Daily time series (SoMo)	Tillegra GM	20 March 2008 21 April 2008 8 August 2008	Relies observations within Working Paper B completed September 2008	See Note 1 & 2
Volume 1 Table 10.4	Statistical analysis of flows to the estuary	0.5 daily (half day) time steps	Seaham		Reports figures from the HWC Seaham Weir Hydrology Report (March 2006)	See Notes 1 & 3
Volume 1 Sect 10.3 Figure 10.7	Description of water balance model including Figure 10.7 (water balance	Descriptive and average annual average	All of system	17 July 2009 (?)	Summary mass balance document emailed to EIA team on 14/8/2009 from Dr Berghout.	See Notes 1 & 4
Volume 1 Sect 10.4.3, Table 10.6, Fig 10.8	Discusses flow characterisation and historic daily flows	Characterisation of flow classes and depiction of historic flows at Tillegra Bridge		20 March 2008	Replicate figures from working paper D finalised in July 2009.	See Notes 1 & 2
Volume 1 Sect 10.5	Description of the iterative process	-	-	All	Describes the iterative process based on the evolving datasets (relevant to improvements to environmental flow release strategies)	See Note 5
Volume 1 Fig 10.10	Flow duration curves – base case with ECA (flushing events) and constant run off river transfers	Flow duration curves based on SoMo	GM and Tillegra	20 March 2008 21 April 2008	Historic time series from the March dataset – Post dam scenario from 21 April 2008 Model - Curves show the affect of adopting a blocked release strategy to the exceedance percentiles	See Note 5
Volume 1 Table 10.8	GM historic and release option stats	Exceedance statistics based on SoMo	GM	20 March 2008 21 April 2008 and 17 July 2009	Presents stats for the base case and ultimate flow regime proposed for the dam	See Note 5

[54] Much of the contents of this table have been sourced from Table 12 of the *SoMo Report*.
[55] All references relate to the EAR unless otherwise stated.
[56] For further details of these data sets, refer Table 11 of the *SoMo Report*.

EAR or EASR Reference[55]	Description	Hydrology Variable	Sites	Data-Set Used[56]	Comments	Reviewer's Assessment
Volume 1 Table 10.9	Release scenarios	-	-		Describes final release scenario	See Note 5
Volume 1 Sect 10.7 Table 10.10	Mean and peak daily floods	Annual recurrence intervals	Tillegra, Chichester and GM	Pinneena 9.0 20 March 2008 21 April 2008 8 August 2008	The EAR consultant used Pinneena 9 data and HWC modelled data to correlate mean daily and peaked instantaneous discharge. The consultant checked all aspects of his report against the 8 August 2008 record and completed his report in September 2008	See Notes 1 & 6
Volume 1 Sect 10.8	Aquatic Ecology	Seasonality, flow suppression and delivery	Variable	8 August 2008	Based on Working Paper C – The EAR ecologist used the 21 April 2008 data set (blocked releases) and made a variety of recommendations on flow release that drove new modelling scenarios including 8 August 2008 (peaked releases and freshes) pursuant to the consultants recommendations	See Notes 1 & 7
Volume 1 Table 10.11	Downstream water user impacts	CTP's (based on SoMo)	GM	20 March 2008 19 July 2009	Table presents Cease to Pump statistics for Historic Measured, Historic modelled and final env. flow and bulk water transfer regime	See Note 1
Volume 2 Appendix 6 Ramsar Wetland IA	Flood Inundation Modelling, flood frequency analysis and ELCOM modelling			21 April 2009	All work by BMT WBM relevant to the Tillegra Dam Ramsar Impact Assessment Report (Appendix 6) was based on the 21 April 2009 SoMo model where applicable.	See Note 1 and comments provided in **Section 3.6** of this Review
Vol 3, WPa Figs 2.2, 2.3 & 2.4	Daily flow distributions figures	Flow distributions	Tillegra	21 April 2008	Shows general distribution of flows and seasonality	See Note 1
Vol 3, WPa Table 2.3, 2.4 & 2.5	Flow distributions and ARI calculations	Flow distributions - tabular	GM and Tillegra	20 March 2008	Shows general distribution of flows and seasonality – the EAR consultant has used observed data in places.	See Note 1
Vol 3, WPa Table 2.6	Chichester flow distributions	Flow distributions - tabular	Chichester	20 March 2008	Shows general distribution of flows and seasonality	See Note 1
Vol 3, WPa Figure 3.2	Base flow figure	Flow characterisation	Tillegra and GM	20 March 2008		See Note 1
Vol 3, WPa S3.4.2 and Figure 3.3	Filling times		Tillegra	20 March 2008	Note the EAR consultant appears to have made an adjustment to the historic / simulated flow record to estimate dam behaviour in this figure	Refer **Section 3.4** of this Review

EAR or EASR Reference[55]	Description	Hydrology Variable	Sites	Data-Set Used[56]	Comments	Reviewer's Assessment
Vol 3, WPa Figure 3.5 to 3.9	Flow Characteristics		Tillegra	20 March 2008	These figures are almost certainly derived from the earliest data set of 20 March 2008 although the EAR consultant was asked to check all results against the 8 August 2008 model runs. The data presented relates to historic data (pre Tillegra Dam) and as historic data there should be no difference in results presented from any of the data sets	See Note 1
Vol 3, WPa Figure 5.1	Storage Capacity		Tillegra Dam	-	This data is not derived from the model. The data is compiled on a staged area graph based on Lidar data received in 18/2/2008 and denotes the relationship between topography, volume and storage	See Note 1
Vol 3, WPa Sect 5.4.1, 2 & 3 and Appendix F	Hydrodynamic model – DRESM / CAEDYM – Temperature isotherms, cyanobacteria	Inflows and outflows to proposed storage	Tillegra	20 March 2008	The EAR consultant used one year of data 1990 to 1991 which was considered representative for the model simulation and matching the input period for other model parameters	See Note 1
Vol 3, WPa Sect 5.4.3	Storage nutrient concentrations	Average daily inflow and outflow for storage	Tillegra	20 March 2008 8 August 2008	Calculated from the base case scenario - 8 August 2008 dataset provided to consultant to check validity of observations	See Note 1
Vol 3, WPa Sect 8. Figs 8.4, 8.5. Table 8.1 and 8.2	Description of Seaham Weir, including gate outflows and fishway flows		Seaham	March 2006	The EAR consultant references HWC report on Seaham Weir (2006)	See Note 1 & 3
Vol 3, WPa Appendix C	Pool / riffle bed levels and percentiles	Annual flow percentile estimates and wetted permitter estimates	Various	20 March 2008 8 August 2008	These figures are almost certainly derived from the earliest data set of 20 March 2008 although the EAR consultant was asked to check all results against the 8 August 2008 model runs. The data presented relates to historic data (pre Tillegra Dam) and as historic data there should be no difference in results presented from any of the data sets	See Note 1
Vol 3, WPb	Hydraulic modelling, discharge, channel form and material transport	Daily Time Series (SoMo)	Variable	20 March 2008 21 April 2008 8 August 2008	Paper prepared on 21 April 2008 dataset and final paper on base case checked against 8 August 2008 modelled data set for peaked 1500ML bulk water transfers programmed for the final release strategy	See Notes 1 & 8

EAR or EASR Reference[55]	Description	Hydrology Variable	Sites	Data-Set Used[56]	Comments	Reviewer's Assessment
Vol 3, WP C	Flow variability	Daily time series (SoMo)		21 April 2008	Qualitative assessment - Paper uses the 21 April 2008 "base case" to consider ecological impacts. Paper recommends inclusion of peaked discharges and minimum releases which is reflected within the new modelling of 8 August 2008.	See Note 1
Vol 3, WPd				19 July 2009	This paper culminates in the presentation of the July 2009 model runs. The paper works through all of the modelling datasets prior to its finalisation with the July 2009 results	See Notes 1 & 5
Vol 3, WPd Figs 4.1 and Table 4.4	Discusses flow characterisation and historic daily flows	Characterisation of flow classes and depiction of historic flows at Tillegra Bridge		20 March 2008	This part of the work was copied over into the main EA volume as previously noted.	See Note 1
Vol 3, WPd Table 5.2	CTPS	Daily time series transposed to exceedance probabilities	GM	20 March 2008 21 April 2008	Calculates CTPS for historic and the base case	See Notes 1 & 8
Vol 3, WPd Figure 5.2 and Table 5.4	Time to fill under three approximate representative scenarios	Daily time series (SoMo)	Tillegra	20 March 2008		See **Section 3.4**
Vol 3, WPd Table 5.8, 5.9 & Figure 5.3	Historic and modelled exceedance	Daily time series (SoMo)	Tillegra and GM	20 March 2008 21 April 2008		See Notes 1 & 8
Vol 3, WPd Figure 5.4	Median flow - Peaks	Daily Time Series (SoMo)	GM	20 March 2008		See Note 1
Vol 3, WPd Table 5.12 & Figure 5.5	CTP's – Refined Base case with peaked 1500ML flows – Tabular % exceedance and flow duration curves	Daily Time Series (SoMo)	GM	20 March 2008 21 April 2008 17 July 2009	Each curve relates back to relevant data set generated at the time	See Notes 1 & 8
Vol 3, WPd Figure 5.6	Duration curves for final flow regime of 1500ML peaked transfers, 270 ML freshes, transparent to 30th percentile Tillegra and Transparent to 95th percentile Chichester	Daily Time Series (SoMo)	GM	March 2008 17 July 2009		See Notes 1 & 9

EAR or EASR Reference[55]	Description	Hydrology Variable	Sites	Data-Set Used[56]	Comments	Reviewer's Assessment
Vol 3, WPd Table 5.13	Flow exceedances – base case, base case with translucent flows, transparent flows and towers flows	Daily Time Series (SoMo)		20 March 2008 21 April 2008 8 August 2008 17 July 2009	This table was originally based on 21 April 2008 model runs and subsequently augmented with final runs from 17 July 2009 (final release strategy with tower flows)	See Notes 1, 8 & 9
Vol 3, WPd Fig 6.1	Duration curves at Seaham Weir	Daily Time Series (SoMo)	Seaham	21 April 2009	These curves focus on flows and potential flow regimes at Seaham Weir	See Notes 1 & 9
Vol 3, WPd Appendix B – Table B1	Flow probability exceedances underlying Fig 5.2 in paper	Daily Time Series (SoMo)	Tillegra	21 April 2009	Note this is assumed by HWC and would need to be confirmed with Aurecon as a subset of daily data is used.	See Notes 1 & 8
Vol 3, WPd Appendix B, Table B2 and B3	Base Case Flow Strategy	Daily Time Series (SoMo)	Tillegra and GM	20 March 2008 21 April 2008 8 August 2008		See Note 1
Vol 3, WPd Appendix B, Table B4	All flow strategies	Daily Time Series (SoMo)	GM	20 March 2008 21 April 2008 8 August 2008 19 July 2009	Presents results of final environmental flow scenarios including historic, modelled historic (20 March 2008), base case (21 April 2008) translucent flows and peaked transfers (8 August 2008) and fully developed flows including 1500ML tower flows (19 July 2009).	See Notes 1 & 8
Vol 3, WPd Appendix B, Table B5	CTP percentages	Percentages based on daily Time Series (SoMo)	GM	20 March 2008 21 April 2008 8 August 2008 19 July 2009	Presents CTP's for irrigation supply based on all of the datasets as above	See Notes 1, 8 & 9
EASR FVM model	Tuflow 2D modelling for submissions report	Time Series (SoMo)	Seaham	21 April 2009 and 21 January 2010	The pre dam scenario data was from 21 April 2009 – Other runs from 21 January 2010.	See Notes 1 & 9

Notes:

WP= Working Paper

1. Data use is considered appropriate unless otherwise noted.
2. The streamflow data used here are for existing catchment conditions based on the 77 year simulation period from 1931-2007.
3. 2006 study relied on a monthly time step model. Weir level gauges were examined to identify periods when gates were fully opened. Behaviour at daily and sub-daily time step was inferred.
4. Water balance estimates were provided by Dr Berghout to Aurecon. Exact basis for the data set is not known but results appear very similar to July 2009 data set. Differences are minor.
5. Provides useful description of iterative process undertaken in development of alternative release strategies. However 'Final Release Strategy' now superseded by EASR (e.g. 2.5GL/yr ECA not included). Resultant changes in streamflows will likely be minor except during ECA releases.

6. Correlation of mean daily flows with daily peaks at Glen Martin appears to have been based on historical records. Given the differences between the SoMo predictions and historical records for Glen Martin streamflows, this may result in a slight underestimation of the Glen Martin peak daily flows. Such a difference is unlikely to alter the geomorphic assessment.
7. Use of a spells analysis on streamflows at key sites may have been useful to better inform aquatic ecology assessment.
8. Changes from final release strategy in EASR will be minor and will be unlikely to alter findings.
9. See discussion of differences between SoMo estimates of Glen Martin streamflows and historic records in **Sections 2.2.1**, **2.3** and **4.3**. In general terms *SoMo* will likely under-estimate these streamflows (see Note A at end of **Table 5**). A similar approach is used for Seaham Weir so inflows/outflows will also be under-estimated (see Note A at end of **Table 5**).

APPENDIX B

FREQUENCY ANALYSES OF THE RELATIVE CONTRIBUTION OF THE WILLIAMS RIVER TO THE HUNTER ESTUARY

Note:

1. *Estuary inflows considered here are those from freshwater sources only.*
2. *The 'Relative Contributions' described in the following figures are ratios of the freshwater inflow to the estuary divided by the total freshwater inflow from all sources. These ratios are calculated on either a daily, monthly or annual time period.*
3. *The daily and monthly statistics presented here are derived from time series of these ratios over the 67½ year period from January 1940 to June 2007. The period used for the annual statistics finishes in December 2006.*

Figure B1: Relative Contribution of Williams River Flows to Estuary (Daily)

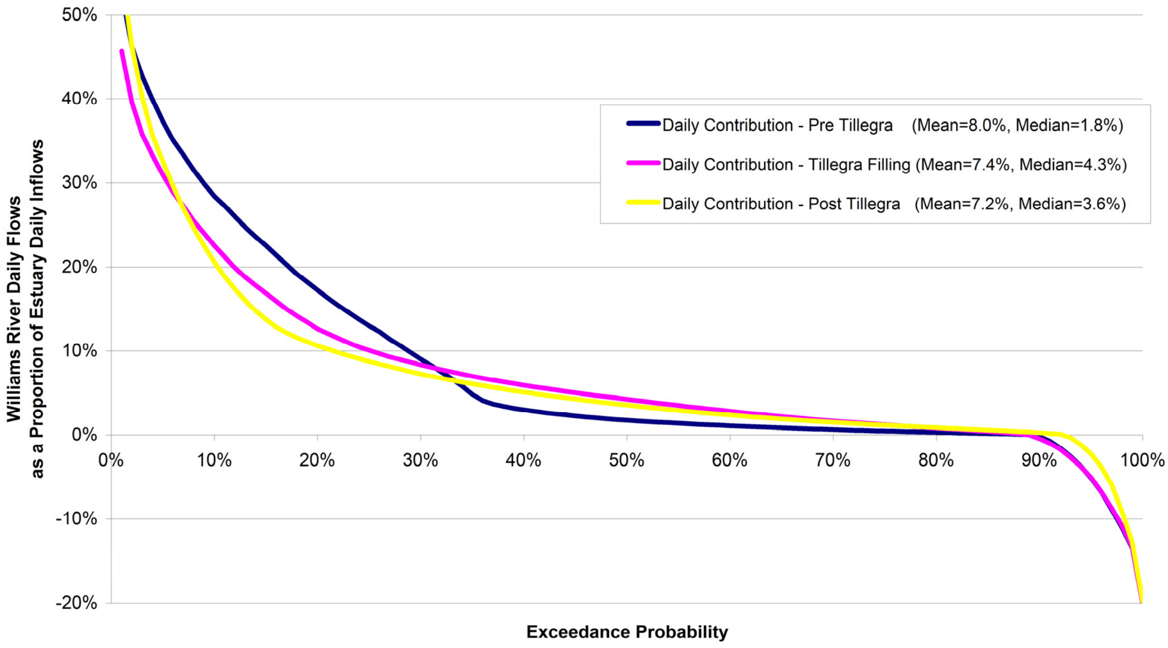

Figure B2: Relative Contribution of Monthly Williams River Flows to Estuary (All Months)

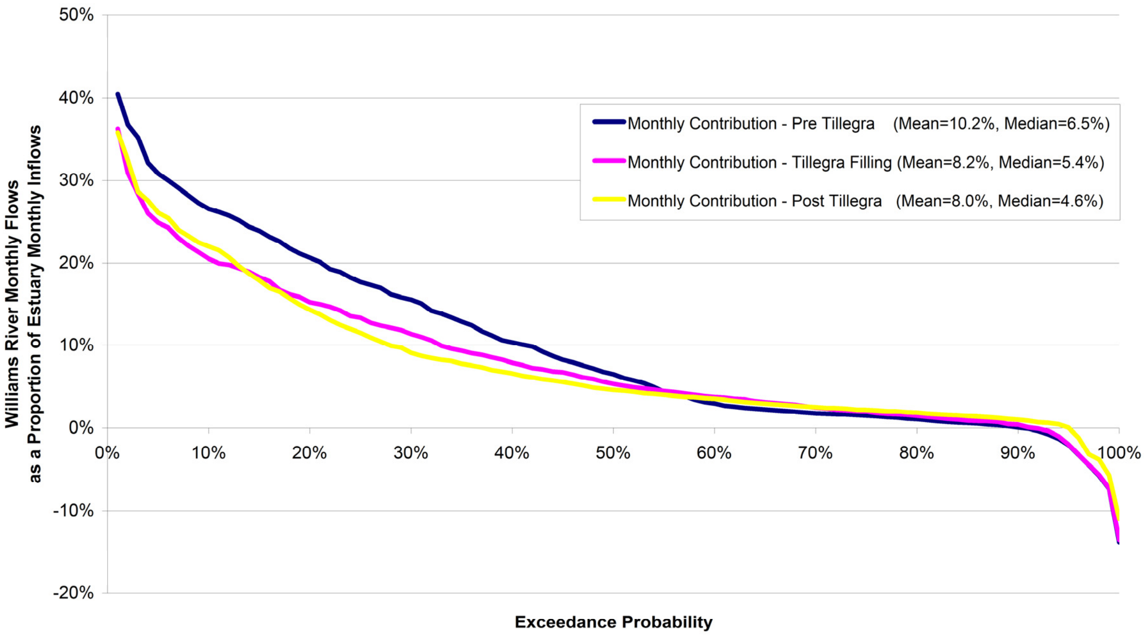

Figure B3: Relative Contribution of Monthly Williams River Flows to Estuary (Summer Months)

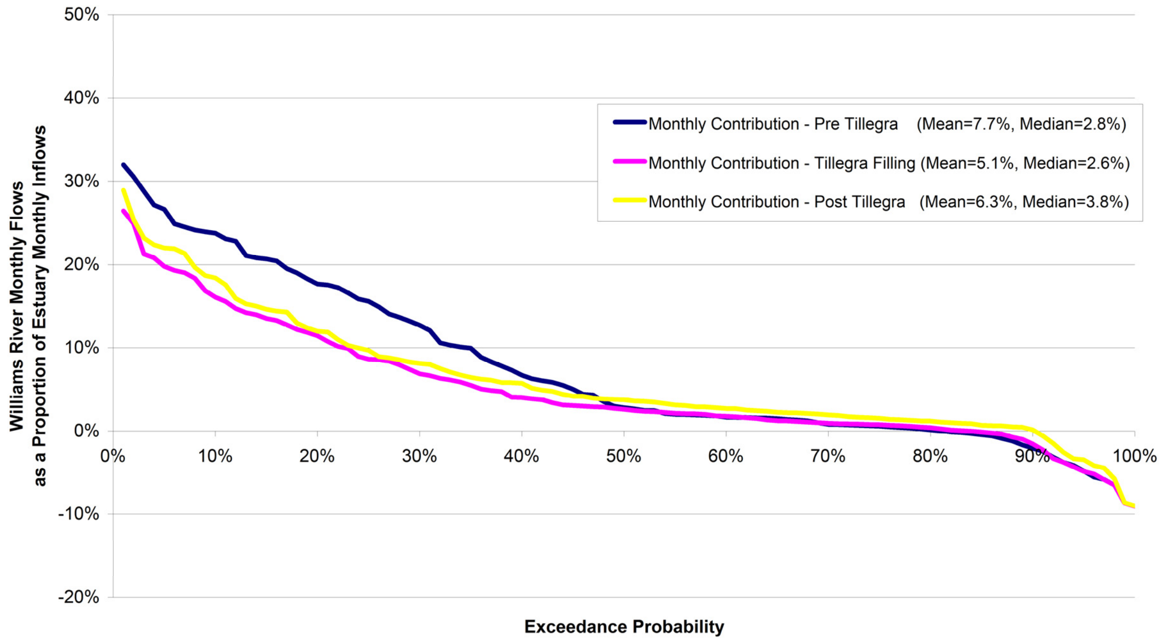

Figure B4: Relative Contribution of Monthly Williams River Flows to Estuary (Autumn Months)

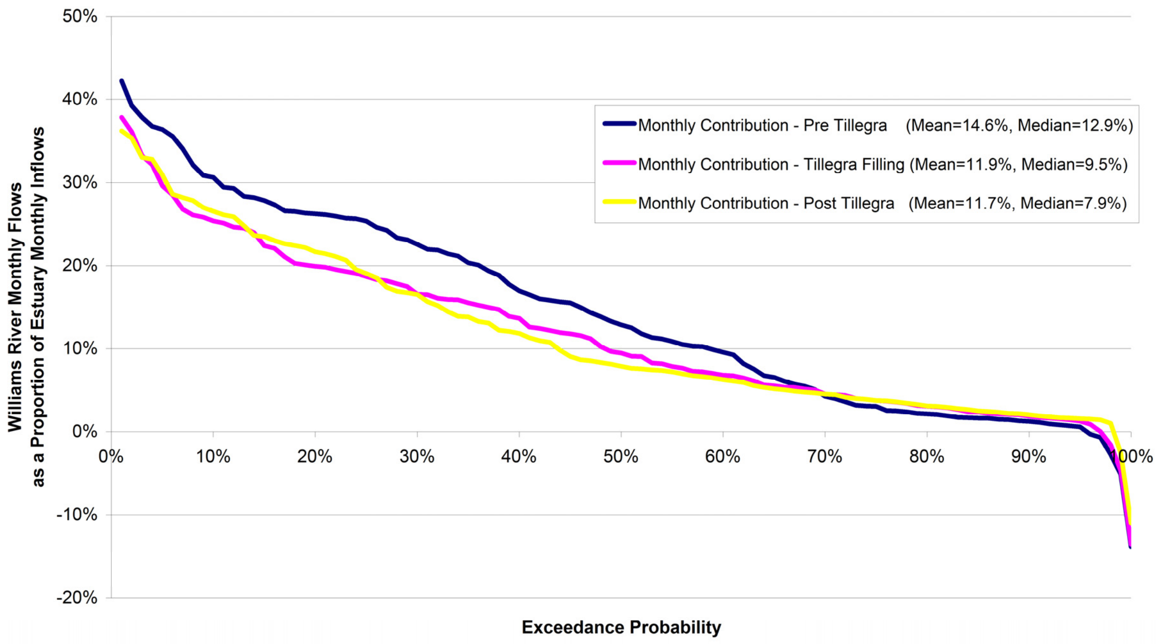

Figure B5: Relative Contribution of Monthly Williams River Flows to Estuary (Winter Months)

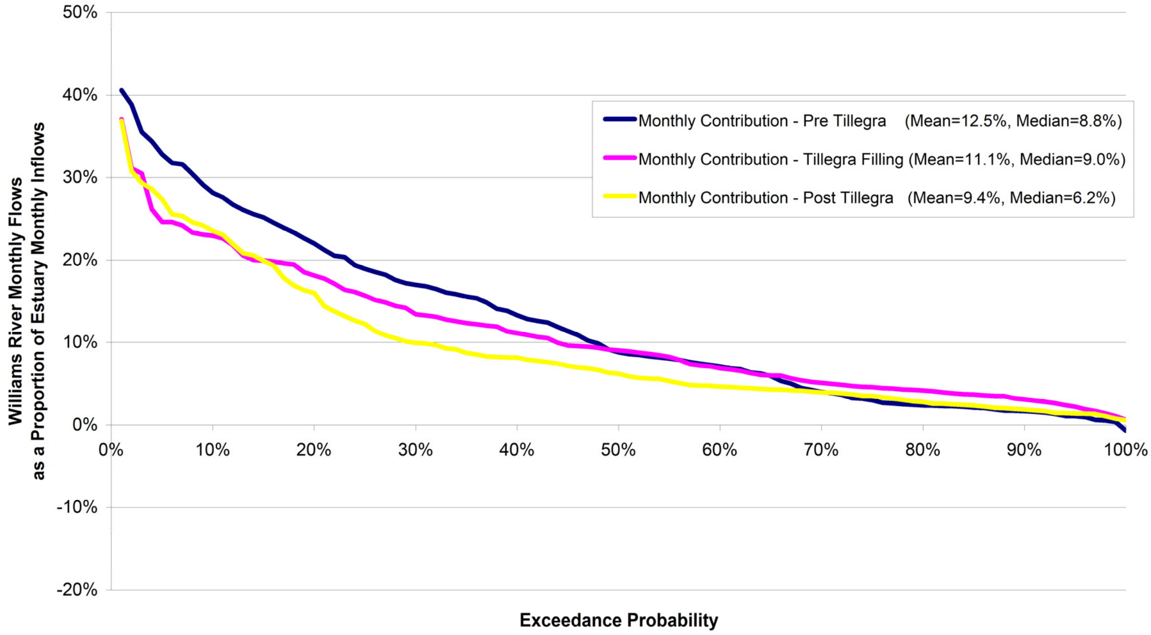

Figure B6: Relative Contribution of Monthly Williams River Flows to Estuary (Spring Months)

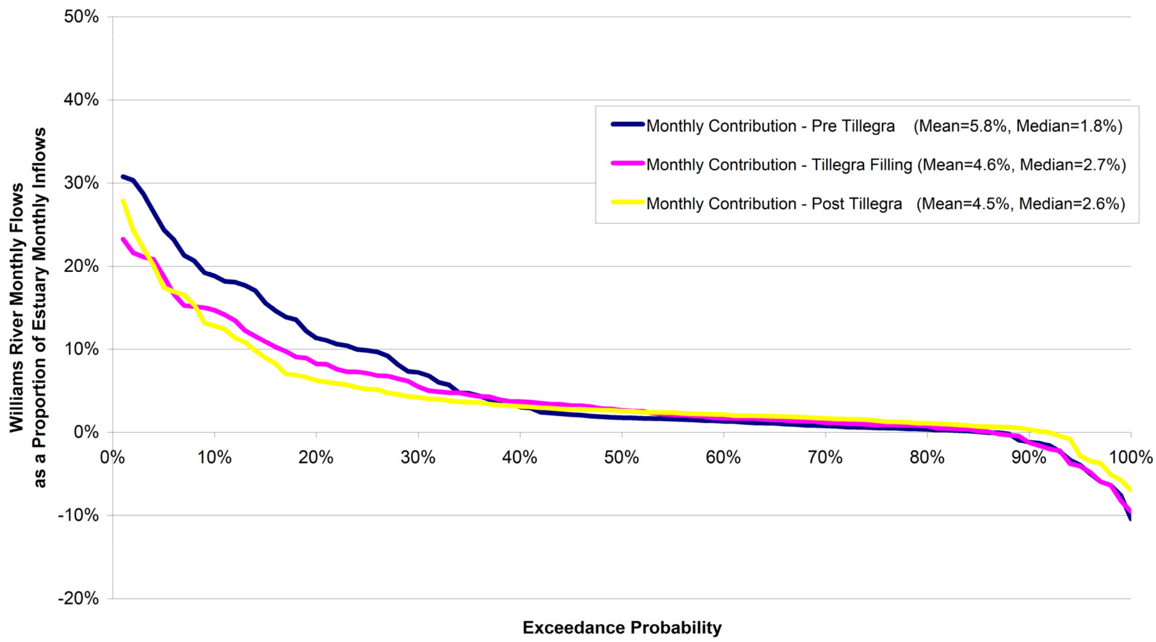

Figure B7: Relative Contribution of Annual Williams River Flows to Estuary (67 Years: Jan 1940 to Dec 2006)